Using Technology to Revolutionize Public Transportation

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Abstract

Using Technology to Revolutionize Public Transportation

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Public transportation could be an effective solution to providing mobility while reducing traffic congestion and the environmental impact of transportation. However, from a customer perspective, a mobility choice is only a choice if it is fast, comfortable and reliable. This research looks at the reliability of public transportation and the use of easy-to-access information to combat the inherent unreliability and other barriers to increased use that exist in the system.

The first section investigates the characteristics of transit service that are associated with on-time performance. The second and third sections discuss results of a survey and wait time assessment of OneBusAway, a real-time next bus countdown information source. The results of the survey indicate that OneBusAway users have an increased satisfaction with public transportation, as well as a perception of a decreased waiting time, increased number of transit trips per week, increased feelings of safety, and an increased distance walked compared with before they used OneBusAway. The follow-up study finds that for riders without real-time information, perceived wait time is greater than measured wait time. However, riders using real-time information do not perceive their wait time to be longer than their measured wait time. In addition, mobile real-time information reduces not only the perceived wait time, but also the actual wait time experienced by customers.

The final three sections discuss other potential transit information tools that overcome the barriers to increased public transportation use. The Explore tool, an Attractions Search Tool, is described. Explore makes use of an underlying trip planner to search online

databases of local restaurants, shopping, parks and other amenities based on transit availability from the user's origin. In the fifth and sixth sections, the Value Sensitive Design process is used to brainstorm and assess additional transit tools from the user and the bus driver perspective.

As a whole, this work gives credence to the notion that the power of improved access to information can overcome the barriers to increased transit use.

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Finally and most importantly, I would like to thank my husband and daughters for the tremendous love and support they give me every single day. I am so lucky that they have been willing to take this journey with me and their smiles and hugs have helped to smooth out any bumps in the road.

Introduction

It is imperative to improve potential riders' satisfaction with public transportation, because of its societal benefits. Transit provides mobility to those who cannot or prefer not to drive, including access to jobs, education and medical services (American Public Transit Association 2008). Transit reduces congestion, gasoline consumption and the nation's carbon footprint. 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 (Schrank and Lomax 2009). Use of public transportation reduced U.S. CO_2 emissions by 6.9 million metric tons in 2005 (Davis and Hale 2007). While hybrid and electric vehicle technologies can reduce the carbon-footprint of single-occupancy vehicles, they cannot compete with transit in reduction of traffic and promotion of compact, sustainable communities.

By helping travelers move from single-occupancy vehicles to transit systems, communities can reduce traffic congestion and the environmental impact of transportation. However, from a customer perspective, a mobility choice is only a choice if it is fast, comfortable and reliable. Improvements to transit reliability measurement can lead to better evaluation of potential transit improvements that can increase ridership and load factors (Perk et al. 2008). Therefore, the initial purpose of this research was to increase knowledge about the causes of travel time variability in transit. This initial piece of research was intended to determine which minor infrastructure improvements and small service tweaks were the most worthwhile for transit agencies in their pursuit of more reliable transit service. Only a few studies to date have compared actual arrivals and schedule data based on infrastructure and route characteristics. None have done so for an entire transit system at the stop-level, but have instead focused on only one route or have used route-level data alone. The results of this work are found in Section 1.

However, through the research in Section 1, it quickly became apparent that there is inherent unreliability in public transportation and indeed all transportation modes that would require substantial investments in infrastructure to overcome. The minor infrastructure and service improvements only accounted for a small percentage of late or early arrivals. Without substantial buffer time, a schedule cannot be met, but substantial buffer time creates long inefficient travel times. How then can this inherent unreliability be overcome? The answer is through the power of information.

The difficulty with unreliability for many transit riders is the unknown wait time they will face. Riders stand at a corner scanning the horizon for the approaching bus, wondering when it will come; or if it will come. Another day they time their arrival exactly to the scheduled minute to see that the early-running bus just passed their stop and they have another 30 minutes (or longer) to wait. By knowing when the bus is actually coming, the entire picture changes. The inherent unreliability is less of an issue if the rider knows in advance when the bus is coming, even if it is a few minutes late. If transit agencies hope to retain choice riders and increase ridership, they need to allow riders to maintain some control over their trip by providing them with real-time information.

Therein was born OneBusAway (OBA, http://onebusaway.org), a set of transit rider information tools with a current primary use to provide real-time next bus countdown information for riders of King County Metro (KCM) in greater Seattle (Ferris, Watkins, et al 2009). OneBusAway originally did this by using the underlying data feed from King County Metro's Automatic Vehicle Location (AVL) system and the prediction algorithms developed by Dr. Daniel Dailey and others from the Electrical Engineering department at the University of Washington (Maclean and Dailey 2002). OneBusAway provides a more user-friendly interface to KCM's AVL data by providing multiple means to access the data, including a website, a standard telephone number by which arrival information is read by the computer, an SMS interface for text-messaging, a website optimized for internet-enabled mobile devices, an iPhone application, and an Android application. Since the original OneBusAway program began, several additional regional transit agencies have been added.

The underlying goal of OneBusAway is to reduce the burden of using public transportation and thereby increase rider satisfaction and increase transit ridership. In order to test the success of these goals, the first study conducted was an online survey of OneBusAway users that is described in Section 2. The results of this survey indicated that OneBusAway users have an increased satisfaction with public transportation, as well as a perception of a decreased waiting time, increased number of transit trips per week, increased feelings of safety, and an increased distance walked compared with before they used OneBusAway.

This initial study of OneBusAway users relied on self-report data and had no control group for comparison. The results are useful for a broad-brush picture of real-time information impacts for riders, however more detailed quantitative study was needed. Therefore, a follow-on study was conducted to more thoroughly measure the perceived and actual wait times of transit riders based upon their usage of real-time information. The results from this study of implications of real-time information for perceived and actual wait times is found in Section 3.

Although previous studies have looked at traveler response to real-time information, few have addressed real-time information via devices other than public display signs. For this study, researchers observed riders arriving at Seattle-area bus stops to measure their wait time while asking a series of questions, including how long they perceived that they had waited. The study found that for riders without real-time information, perceived wait time is greater than measured wait time. However, riders using real-time information do not perceive their wait time to be longer than their measured wait time. This is substantiated by the typical wait times that riders report. Real-time information users say that their average wait time is 7.5 minutes versus 9.9 minutes for those using traditional arrival information, a difference of about 30%. A critical finding of the study is that mobile real-time information reduces not only the perceived wait time, but also the actual wait time experienced by customers. Real-time information users in the study wait almost 2 minutes less than those arriving using traditional schedule information. This section of the dissertation has shown that mobile real-time information has the ability to improve the experience of transit riders by making the information available to them before they reach the stop.

Although it has become the cornerstone of OneBusAway, real-time arrival information is only one type of information transit riders require. While there are significant benefits to using transit, many choice riders 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. A host of tools could be developed in order to overcome the barriers to transit use. Another area of potential improvement in transit information is trip planners. Trip planners work well if a rider has both an origin and a destination. However, sometimes the availability of transit at a location is more important than the actual destination. Using transit in such circumstances requires multiple searches on a trip planner. No tools exist to allow a search based on origin and type of trip (restaurant, doctor, etc). The Explore tool, an Attractions Search Tool described in Section 4, makes use of an underlying trip planner to search online databases of local restaurants, shopping, parks and other amenities based on transit availability from the user's origin. The ability to perform such a search by attraction type rather than specific destination can be a powerful aid to a traveler with a need or desire to use public transportation.

Real-time arrival information and the Explore trip planner are only two types of tools that transit riders need to provide better information. In order to help determine what transit rider information tools to build next, the OneBusAway team turned to the Value Sensitive Design (VSD) process from information and computer science. Through conceptual, empirical, and technical investigations, the OneBusAway team has developed a list of potential transit information tools and begun to prioritize projects based the needs of riders of all types, as well as impacts to indirect stakeholders. This process of using VSD for OneBusAway is described in Section 5. VSD has only been used in one other transportation-related application to date (UrbanSim). The introduction of a new process for looking at the implication of transportation improvements on human values could be a substantial contribution to the transportation industry. The move from processes such as context-sensitive solutions to VSD allows for a more comprehensive look at the impacts of a project and can give engineers a broader base from which to select alternatives.

Finally, although it is apparent that greater information has a positive effect on transit riders, no studies to date have investigated bus drivers' reactions to real-time arrival information and other potential rider information tools. In the final section of this dissertation, 253 bus drivers were surveyed to determine their reactions to the existing use of real-time information and to ask about future transit rider information applications. Almost all drivers (93% and 91% on two separate questions) were positive or neutral to the provision of real-time information. In addition, drivers were receptive to building other new information applications, with all applications in the survey being supported by at least 60% of the bus drivers. This research gives a better understanding of the impact of rider information tools on bus drivers, including their values, harms and benefits.

Contribution

As detailed above, this dissertation makes several contributions to the transportation industry. The initial work in Section 1 is the first to compare actual arrivals and schedule data based on infrastructure and route characteristics for an entire transit system at the stop-level. For the work in this section, I came up with the initial idea for the project; pursued and obtained funding through TransNOW; developed the database to link schedule, arrival, GIS and other data; and conducted the initial statistical analysis. I then involved Mark Wheldon, a PhD student, and Dr. Paul Sampson, a professor, from the Statistics department to further refine my analysis. The conclusions based on their contributions are my own.

The initial study of OneBusAway in Section 2 is based on the paper: Ferris, B., K. Watkins and A. Borning. "OneBusAway: Behavioral and Satisfaction Changes Resulting from Providing Real-Time Arrival Information for Public Transit" that I presented at the Transportation Research Board 2011 Annual Meeting. This paper was also presented by Brian Ferris as "OneBusAway: Results from Providing Real-Time Arrival Information for Public Transit" at the Chi2010 conference in Atlanta, GA. My contribution to the paper was portions of the original survey design and analysis and write-up of the results. The OneBusAway program is coded by Brian Ferris and substantial pieces of this first section were written by him and his advisor, Alan Borning. It is included in this dissertation mostly for background information.

The study of the implications of real-time information for perceived and actual wait times in Section 3 is based on the paper: Watkins, K., B. Ferris, A. Borning, G. S. Rutherford, and D. Layton, "Where Is My Bus? Impact of mobile real-time information on the perceived and actual wait time of transit riders", submitted to Transportation Research Part A in June 2010. Although previous studies have looked at traveler response to real-time information, few have addressed real-time information via devices other than public display signs. I designed this study to address perception of wait time via mobile devices, including envisioning the study, obtaining human subjects approval, designing the survey instrument, supervising the conduct of the surveys, conducting the analysis and all write-up. The contributions of co-authors were only in the periodic review of elements of the study.

The Explore tool, described in Section 4, is the first tool to allow a search based on origin and category of trip (restaurant, doctor, shopping, etc). I envisioned the initial tool for a course in data analysis at the University of Washington. Two other University of Washington students, Evan Siroky and Carl Langford, helped me implement the initial tool. Brian Ferris then came in to take my idea to Web 2.0 and create a more useable tool by refining the search process and linking the search to the Yelp database. The paper written about the tool is my own work, with minor edits by Brian Ferris and Scott Rutherford. The paper was published late last year as: Watkins, K., B. Ferris, G. S. Rutherford, "Explore: An Attraction Search Tool for Transit Trip Planning" Journal of Public Transportation, Vol.13, No. 4, 2010.

The process of using Value Sensitive Design for OneBusAway as described in Section 5 was conducted by Brian Ferris, Yegor Malinovskiy and myself. As discussed, VSD has only been used in one other transportation-related application to date (UrbanSim). The introduction of a new process for looking at the implication of transportation improvements on human values could make a substantial contribution to the transportation industry. The discussion of the comparison between context-sensitive solutions and VSD is my own. My contribution to the actual VSD process in Section 5 was in the design and conduct of the cultural probe, the review of the rider / non-rider surveys, and the design and conduct of the bus driver interviews. The paper itself that was written about the process was begun by Brian Ferris, Yegor Malinovskiy and myself and I refined it for submission as: Watkins, K. , B. Ferris, Y. Malinovskiy, A. Borning, "Beyond Context Sensitive Solutions: Using Value Sensitive Design to Identify Needed Transit Information Tools" submitted to ASCE Journal of Transportation Engineering in December 2010.

The study in Section 6 is the first to date to investigate bus drivers' reactions to real-time arrival information and other potential rider information tools. Again, I envisioned the study, obtained human subjects approval, designed the survey instrument, mailed out the surveys, conducted the analysis and completed all write-up. I hired an undergraduate student to help with the manual coding of the surveys. In addition, Brian Gill from Seattle Pacific University checked my statistical analysis and gave me guidance on the types of tests to conduct. The work was recently submitted as: Watkins, K., A. Borning, G. S. Rutherford, B. Ferris and B. Gill, "Impact of real-time transit information tools on bus drivers" to the journal Transportation in March 2011. The contributions of other co-authors were only in the periodic review of elements of the study.

Section 1
Measurement and evaluation of transit travel time reliability

1.1 INTRODUCTION

Transportation system customers need consistency in their daily travel times to enable them to plan their daily activities. A frequent user of a facility can become accustomed to the typical travel time, but their continuing concern is punctuality, or the deviations from the expected travel time. A journey to work travel time that takes 20 minutes one day and 40 minutes another day takes an average of 30 minutes, but the individual making this trip would either have to plan for the 40 minute trip or plan for 30 minutes and be late certain days. The consequences of being late repeatedly could mean costs anywhere from daycare fines to the loss of a job. To understand the effects such variability has on transportation customers, performance measures must take typical travel times into account as well deviation from those typical travel times. Travel time reliability on freeways has recently become the subject of much research, including investigations of the value of reliability (Bates et al. 2001; Brownstone and Small 2005) and development of reliability performance measures (Cambridge Systematics et al. 2008; Lomax et al. 2003; Lyman and Bertini 2008). The inclusion of travel time reliability in planning and operations analysis is becoming a critical element of understanding the customer perspective. Some travel behavior studies have even suggested that reliability in travel is more important than travel time (Daskalakis and Stathopoulos 2008; Rietveld et al. 2001).

Although measures of travel time reliability on freeways and arterials are receiving increased attention, transit travel time reliability often continues to be viewed by transit agencies solely on the basis of overall route-level on-time performance, if it is measured at all. Currently, the predominant performance measures collected in the transit industry are used to evaluate an agency's business. Measures collected for the National Transit Database, the largest national source for performance data, mostly include measures related to cost and utilization (Federal Transit Administration). The Transit Capacity and Quality of Service Manual (TCQSM), first produced in 1999, was an attempt by the industry to provide a guide for measurement of the quality of service provided to the passengers (Kittelson & Associates 1999). Quality of Service is defined as "the overall measurement of perceived performance of transit service from the passenger's point of view." The TCQSM breaks quality of service into two areas, availability and comfort & convenience, and further describes those areas as shown in Table 1.1 (Kittelson & Associates et al. 2003).

Table 1.1 Fixed-Route Transit Service Measures

	Transit Stop	Route Segment	System
Availability	**Frequency**	**Hours of Service**	**Service Coverage**
Comfort & Convenience	**Passenger Load**	**Reliability**	**Transit-Auto Travel Time**

Source: Transit Capacity and Quality of Service Manual, 2^{nd} Edition, Exhibit 1-1

Reliability in transit, as defined by the TCQSM, has two components, the amount of time passengers spend waiting at a stop for their transit vehicle and the consistency of their arrival time at their destination. The perceived and actual reliability of service affects passenger choices about the time they will arrive at the stop and the trip they will choose to give them buffer for their destination. Travel time reliability is influenced by a number of factors, some of which are controlled by the transit agency, such as vehicle and maintenance quality, vehicle and staff availability, schedule achievability, and operations control strategies; some of which are partially controlled by the transit agency, such as differences in operator driving skills, route length and the number of stops and transit preferential treatments; and some of which are out of the agencies control, such as background traffic conditions, road construction, weather, evenness of passenger demand, and wheelchair lift and ramp usage (Kittelson & Associates et al. 2003).

Transit travel time reliability can therefore be improved by changes and improvements that take these factors into account. Agencies frequently adopt measures such as transit signal priority, proof-of-payment fare collection, increased layover times and operations control to improve travel times and reliability. The Transportation Research Board has published an entire series of documents about the effects of such changes called TCRP 95, Traveler Response to Transportation System Changes (Transportation Research Board 2003). The documents detail experiences with various improvements a transit agency can undertake and the gives elasticities for the resulting ridership. It includes items such as parking, transit-oriented development, road pricing, transit information, scheduling and others.

The two most common measures of fixed-route service reliability that passengers can relate to are on-time performance (or schedule adherence) and headway adherence. Transit agencies also often measure missed trips and distance between mechanical breakdowns, but these measures are not as readily seen by the passenger. On-time performance is a measure of percentage of on-time vehicles and is used by agencies for service operating on schedules, which is usually service with headways more than 10 minutes. Many agencies use the measures outlines in the TCQSM to analyze on-time performance (El-Geneidy et al. 2007; Perk et al. 2001). Agencies differ, however, in their definition of on-time, with Canadian agencies typically having shorter windows for on-time performance (Benn 1995; Canadian Urban Transit Associations 2001). King County Metro defines on-time as 1 minute early to 5 minutes late. More than half of the Canadian agencies only allow 3 – 4 minutes late with no early arrivals.

Headway adherence is used for service operating headway-based, typically for headways less than 10 minutes. Headway adherence uses the coefficient of variation of headways, which is equal to the standard deviation of headway deviations (actual headway minus the scheduled headway) divided by the mean scheduled headway. Both measures are graded similar to the Highway Capacity Manual guidelines with LOS A to LOS F. Some agencies also monitor travel speeds as a measure of reliability (Jacques and Levinson 1997) and the MTA in New York uses a specific measure of passenger wait assessment (New York Metropolitan Transit Agency).

1.1.1 Automatic Vehicle Location

Automatic Vehicle Location (AVL) data is collected by many transit agencies to allow real-time tracking of transit vehicles for supervision, safety and customer information. The data is typically archived for use in planning applications such as schedule adjustment and analysis of route performance. AVL data is frequently used by agencies to track on-time performance, also referred to as schedule adherence. As described above, on-time performance is the most frequently used measure of reliability for schedule-based transit service. Headway adherence is the most frequently used measure of reliability for headway-based service.

TCRP 113, entitled "Using Archived AVL-APC Data to Improve Transit Performance and Management, details the uses of archived automatic vehicle location data for planning, scheduling and performance measurement applications (Furth et al. 2006). One major advantage of using AVL data is the ability to focus on extreme values in travel time, such as 95th percentile travel time, that are frequently used in travel time reliability analysis. Therefore, using AVL data has become a major asset in the measurement of on-time performance, schedule adherence and other travel time reliability measures for transit service.

Although many newer AVL systems are GPS based, the current King County Metro (KCM) AVL system is a sign post beacon and dead reckoning system. This older type of AVL system was implemented before the US government began unscrambling military-based GPS signals. KCM's AVL system uses radio emitters (beacons) to serve as fixed-point location devices throughout the system. When a bus passes a beacon, its Mobile Data Terminal (MDT) on-board relays the bus number, the mileage and the current time to the beacon. The Data Acquisition and Control System (DACS) records this information and relays it for use in real-time supervision of the system. Between beacons, the MDT uses the odometer-based dead reckoning to determine the location of the vehicle.

The shortcomings of this type of system stem from the route that the bus must follow in order for data to be recorded. If the bus does not follow its assigned routing, data will not be collected about the vehicle's location. Therefore, with any kind of route deviation, such as alternate routings due to special events or weather, the vehicle is lost to the system. No real-time information can be provided to transit operations or to the public and no data can be stored for performance monitoring. In addition, the system may provide inaccurate data at trip terminals, wear and tear and topography may affect the mileage, and schedule adherence can only be tracked at the scheduled timepoints. For this reason, KCM is upgrading to a GPS-based system in the next few years.

In the meantime, KCM's current AVL system can be used for analysis on a timepoint basis for routes which are running on their usual pattern. Buses that are rerouted for special events or adverse weather are removed from the data. KCM's AVL system has 319 radio emitters throughout the system. Routes pass up to 16 emitters per trip, which means data can be provided at up to 16 scheduled timepoints per trip. However, most routes pass emitters and record at 5 to 9 timepoints per trip.

1.2 LITERATURE REVIEW

Many transit agencies use AVL data to evaluate their bus operations. In most cases, routes are evaluated in their entirety in order to adjust schedules and layovers to account for variability. In both Portland and Chicago, the agencies are using AVL data to measure their performance on a system, route and even a stop level with the intent of recommending improvements to the service (Bertinit and El-Geneidy 2003; Hammerle et al. 2005). Many agencies also use AVL data to monitor their systems in real-time to respond to reliability issues (Furth et al. 2006; Pangilinan et al. 2008). Strathman and Kimpel used Portland's AVL and APC data to verify that reliability in the form of headway deviations are the primary cause of overloaded buses (Strathman et al. 2003). However, little research exists about the causes of the variability using AVL data.

A few studies have been done using AVL data to investigate the before and after effects of specific travel time and travel time reliability improvements. One study in Portland looked at the effects of bus stop consolidation using AVL and APC data, finding that combining stops had no significant effects on ridership, but running times were improved (El-Geneidy et al. 2006). Similar studies were done in both Portland and Seattle to investigate the effectiveness of transit signal priority looking at AVL data before and after implementation (Kimpel et al. 2005; King County DOT Speed & Reliability Program 2002). Both found that the improvements in travel time variability were mixed.

There are several factors widely believed to impact travel time reliability in transit and research about their impact has been undertaken for decades. In 1976, Sterman and Schofer found that the length of route had the biggest impact on reliability (Sterman and Schofer 1976). Levinson recommended minimizing the number of stops and speeding up fare collection (Levinson 1983), as well as minimizing the impact of traffic congestion (Levinson 2005). Abkowitz and Tozzi also summarized that traffic conditions and dwell time at stops were major factors in headway variation (Abkowitz and Tozzi 1987). More recently, Chen et al found a correlation between reliability and route length, headways, and exclusive bus lanes in China (Chen et al. 2009). Research conducted in the Netherlands showed the importance of taking reliability into account when planning the line length and stop spacing of a transit service (Oort and Nes 2008).

Using AVL data for travel time reliability research is ideal because of the large sample size available, which is necessary to look at extreme values (Furth and Muller 2007). However, because the widespread use of AVL is relatively new, few studies have been done to date (Okunieff 1997; Parker 2008). Strathman, et al. looked at the effects that the driver has on the reliability of the transit system in Portland (Stratman et al. 2002). They found that the operator had a significant effect on running time variation, but the only operator characteristic that was significant was years of experience. One study in Twin Cities, Minnesota, did a microscopic analysis of the reasons behind performance and reliability issues using regression models to predict run time, run time deviation, headway deviation, and coefficient of variation of run time (El-Geneidy et al. 2008). The authors used length of route, driver experience, number of stops served, and passenger activity in their multivariate regression model. The data was only for one route however and no stop-level data was used.

1.3 PROBLEM STATEMENT

With the increase in congestion on America's roadways, travel time reliability has become a more critical measure of performance in recent years. Although measures of travel time reliability on freeways and arterials are receiving increased attention, transit travel time reliability often continues to be viewed by transit agencies solely on the basis of overall on-time performance. Therefore, this research will be used to increase knowledge about the causes of travel time variability in transit by comparing the on-time performance and runtime deviation of routes and portions of routes based on specific characteristics of the service (right-of-way, stop spacing, load factors, etc).

This research strives to answer three related questions:

1. What are the characteristics of route segments where travel times (as measured by runtime) are the least variable?
2. What are the characteristics of route segments where drivers are least likely to fall behind?

3. What are the characteristics of route segments where drivers are most likely to be able to catch-up if they have fallen behind schedule?

1.4 METHODOLOGY

The basis for this study will be the King County Metro (KCM) Automatic Vehicle Location (AVL) data described in the background section. This data is archived by KCM for the use in transit planning applications. Examples of the use of this data are before and after studies of transit signal priority projects or the tracking of on-time status of the system over time. In addition, this data is used by Metro on a route by route basis to decide when additional time should be added to a schedule to improve on-time performance for a particular trip.

This analysis uses the KCM Speed and Reliability Analysis (SandRA) database currently under development. SandRA is an SQL-based data warehouse that consolidates data from multiple departments within KCM by linking the data and matching it to a common framework. The initial implementation of SandRA includes data from the AVL system, the Transit Enterprise Database (TED, which includes KCM scheduling data output from HASTUS) and TNET (the King County regional GIS system). In addition, KCM has made the Automatic Passenger Counting (APC) system data available for the project. Approximately 15 percent of the vehicles in KCM's fleet are equipped with APC and these vehicles are rotated throughout the system on random basis.

Using the AVL data and schedule data, the deviation from schedule can be determined for every route in the system for every trip that route makes and for every timepoint within that trip. This data on deviation from scheduled timepoints has been linked to the other data available through the links in SandRA to determine the impact that various characteristics of the routes and stops have on the travel time variability.
In addition to the AVL, APC, schedule and GIS data, KCM provided data on the characteristics of coaches and a listing of through-routed buses, both of which were imported into an Access database to connect with SandRA data. Local Climatological Data was obtained from the National Oceanic and Atmospheric Admistration (NOAA) National Data Centers and imported into the Access database as well.

Specific characteristics to be included on the route level include:

1. Through-routing and length of route pattern – Initial analysis at KCM has shown that buses which travel through the center of the city and begin another trip without laying over (waiting for the driver to take a break and get back on schedule) typically have worse on-time performance. In is unclear if it is the absence of a layover or simply the length of route that causes this variability in travel time.
2. Ride Free Area – The lack of the fare collection in the ride free area may cause transit service arrival times to be less variable, because greater numbers of boarding passengers would not slow the service down to the same degree.
3. Coach type (articulated vs. standard, low vs. high floor, trolley vs. diesel) – The type of transit vehicle can impact reliability based on the difficulty in boarding for low or high floor vehicles, the number of passengers versus doors for articulated (longer length) or standard vehicles or the type of propulsion and frequency with which buses are disabled for trolley-wire or diesel buses.
4. Express vs. local route – Express routing (buses which go longer sections without stopping) versus local routing impacts the stop spacing on portions of a route. Although this is accounted for in other variables below, this will be tested as a route characteristic as well.
5. Weather – Severe weather can impact both the underlying vehicular traffic and the transit service. During snow storms or flooding, many routes are rerouting and lose their ability to be tracked via KCM AVL. However, moderate amounts of rain or wind may impact transit travel time reliability and can be tested with the existing system.

Characteristics to be included on the stop level include:

6. Passenger counts and passenger loads (passenger count vs number of seats) – Using the APC data for the routes and runs available, passenger counts will be taken into account. In addition, an analysis of the passenger count compared to the number of seats on the bus will be taken into account to determine the impact that an overloaded bus has on travel time variability.
7. Stop spacing and number of stops along route – Transit agencies commonly consolidate stops to improve travel time on routes because each stop along a route

can take several seconds for acceleration, deceleration and opening and closing of doors regardless of the number of people boarding and alighting the bus. The impact of this stop spacing on reliability is unclear. The distance between stops and the number of stops along a route will both be considered as potential variables.

8. Stop location (near side vs. far side) – The location of stops before an intersection or after an intersection is a major factor in transit signal priority. However, it is unknown what the effect of near or far side stop locations will be on travel time variability.
9. Type of right-of-way (tunnel, HOV, BAT lane) – Giving buses exclusive right-of-way allows them to travel unimpeded by traffic congestion. Several forms of transit right-of-way exist within King County, including business-access and transit (BAT) lanes, high-occupancy vehicle (HOV) lanes and the downtown transit tunnel. The impact of these varying levels of exclusive right-of-way will be included as a variable.
10. Presence of transit signal priority – The presence of transit signal priority has been shown to improve travel time and the variability of travel time along severely congested routes in some cases, however little research has been done to quantify this impact. In addition, lanes at intersections that allow buses to jump the queue (move ahead of waiting traffic) can impact reliability. Frequently these measures are part of a larger bus rapid transit implementation project which includes multiple travel time improvements which cannot be separated.

The analysis uses data for weekdays during the summer 2008, fall/winter 2008 and winter/spring 2009 service changes to account for one year worth of transit service. In addition to variables listed above, the analysis uses control variables for the month, the time-of-day, and the direction of travel (inbound vs. outbound).

The analysis uses ordinary least squares (OLS) regression models of the form:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

The explanatory variables, X, are those in the list above. The explained variable, Y, will be two measures that look at on-time performance: the difference between actual and scheduled arrival at a timepoint and the difference between actual and scheduled runtime on a route-level. The error term, ε, accounts for variation in the data that cannot be accounted for using the explanatory variables, including the three sources of variability for which data cannot be obtained (driver, fare payment, and underlying vehicular traffic).

1.5 RESULTS

1.5.1 Analysis of Segment-level data

Due to the nature of the AVL system in King County, data is not available on the stop level. For many purposes, such as vehicle arrival predictions, data is interpolated to the stop level. However, we only know where the bus is when it passes a timepoint. For this reason, the finest level of analysis was conducted on the route segment, the distance from one timepoint to another timepoint. For all of the following analysis, the data was filtered to remove nighttime time periods, boarding and alightings greater than 50, stops per mile greater than 10 and travel times along a segment less than 1 minute to remove anomalies in the data that may indicate errors from the AVL tracking or extremely unusual conditions.

The first series of statistical tests are t-tests for each of the categorical variables comparing the on-time deviation of the bus at the timepoint. The on-time deviation is measured as:

On-time deviation = Actual Arrival Time – Scheduled Arrival Time

As shown in Table 1.2, although all of the t-tests show significant differences between the means, the magnitude of these differences is substantial. For articulated versus standard buses and minor weather, little difference in the mean values is observed. High floor buses and trolley buses have a slight negative impact on the mean on-time deviation. Having a bus run express improves the mean on-time deviation. Severe weather also has an impact on the mean on-time deviation. The greatest impact from items under a transit agency's control are the improvement from not thru-routing and from running enough service that buses are not substantially overloaded. Having some sort of service problem, although a rare occurrence, has the greatest impact of all the variables shown.

Table 1.2 Difference of Means Tests by Service Characteristic for On-time Deviation (in minutes)

	Mean	Std Dev	Observations	T (p-value)
Standard	2.21	4.15	390,875	3.69 (0.002)
Articulated	2.18	4.52	393,906	
Low Floor	2.09	4.41	283,604	-15.88 (0.000)
High Floor	2.25	4.30	501,177	
Diesel / Hybrid	2.15	4.43	672,425	-22.43 (0.000)
Trolley	2.46	3.78	112,356	
Local	2.43	4.31	598,074	84.28 (0.000)
Express	1.46	4.37	186,707	
Layover	1.86	4.09	666,193	-170 (0.000)
Thru Routed	4.08	5.17	118,588	
Few or No Standees	2.15	4.31	766,397	-66.18 (0.000)
Standees > 5	4.29	5.09	18,384	
No Service Alert	2.18	4.32	783,110	-51.15 (0.000)
Service Alert	7.62	8.99	1,671	
No Weather	2.20	4.34	646,774	2.58 (0.010)
Minor Weather	2.17	4.38	138,007	
No or Minor Weather	2.19	4.31	773,750	-12.35 (0.000)
Severe Weather	2.70	6.25	11,031	

Tables 1.3 and 1.4 show the mean on-time deviations by time of day and day of week. Clearly, PM peak into the evening has the worst on-time deviation, as well as days later in the week.

Table 1.3 Mean On-time Deviations (in minutes) by Time of Day

	Mean	Standard Error	Observations
AM	1.45	0.008	229,398
Midday	2.24	0.007	326,926
PM	2.88	0.011	229,036
Evening	3.07	0.011	175,481
Night	1.47	0.012	94,387

Table 1.4 Mean On-time Deviations (in minutes) by Day of Week

	Mean	Standard Error	Observations
Monday	1.93	0.011	150,618
Tuesday	2.10	0.010	167,509
Wednesday	2.18	0.010	163,812
Thursday	2.33	0.011	151,054
Friday	2.45	0.012	152,367

Figures 1.1 to 1.6 show the correlations between the continuous variables and the mean on-time deviations. As shown in Figure 1.1, as the stops per mile increase, the mean on-time status worsens. The relationship between the percentage of HOV and Business Access Transit (BAT) lanes is not as obvious, with a slight decline in mean on-time deviation with greater exclusive lanes along a corridor (Figure 1.2). The relationship with transit signal priority is even worse, although TSP is not widely implemented in KCM's service area, so this could be a function of the limited number of TSP corridors (Figure 1.3).

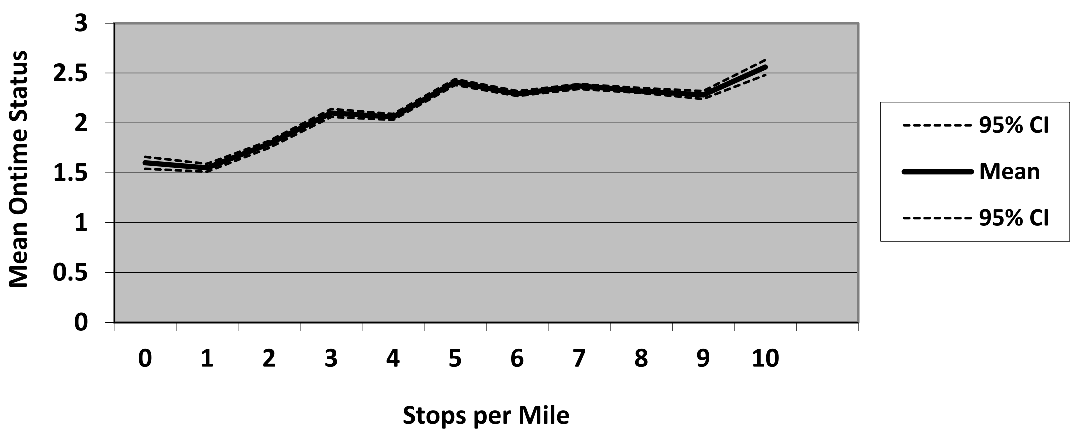

Figure 1.1 Change in Mean On-time Deviations by Stops per Mile

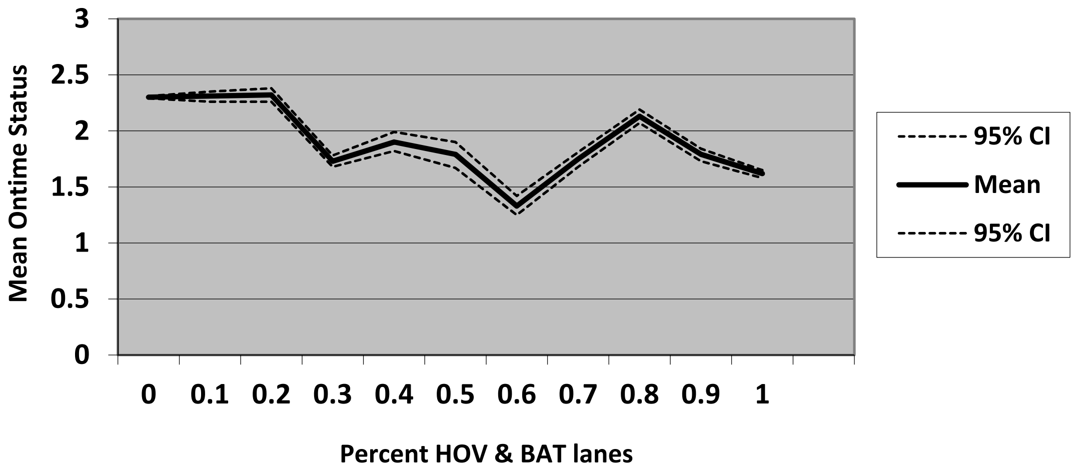

Figure 1.2 Change in Mean On-time Deviations by Percent HOV & BAT lanes

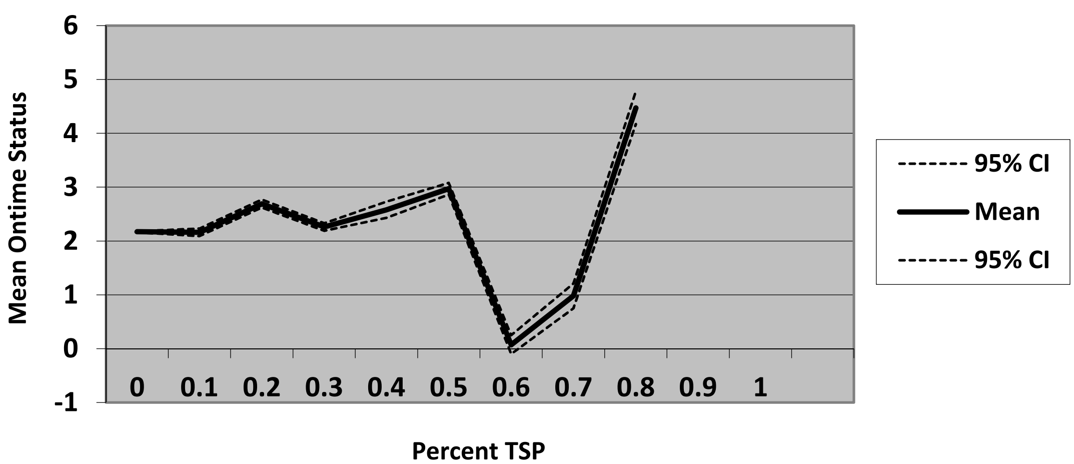

Figure 1.3 Change in Mean On-time Deviations by Percent TSP

In Figure 1.4, the percentage of farside (versus nearside or mid-block stops) seems to make no difference in the mean deviation at all. The number of boarding passengers (ons) does not seem to have a substantial impact until the number is above 40 (Figure 1.5), at which point the on-time deviation worsens. However, relatively few observations occur beyond 70 ons, as shown by the very large confidence interval. Similarly, in Figure 1.6, as the passenger loads reach numbers above 90, the confidence interval widens due to the relatively few observations. Prior to this, however, there is a clear relationship between on-time deviation and passenger load.

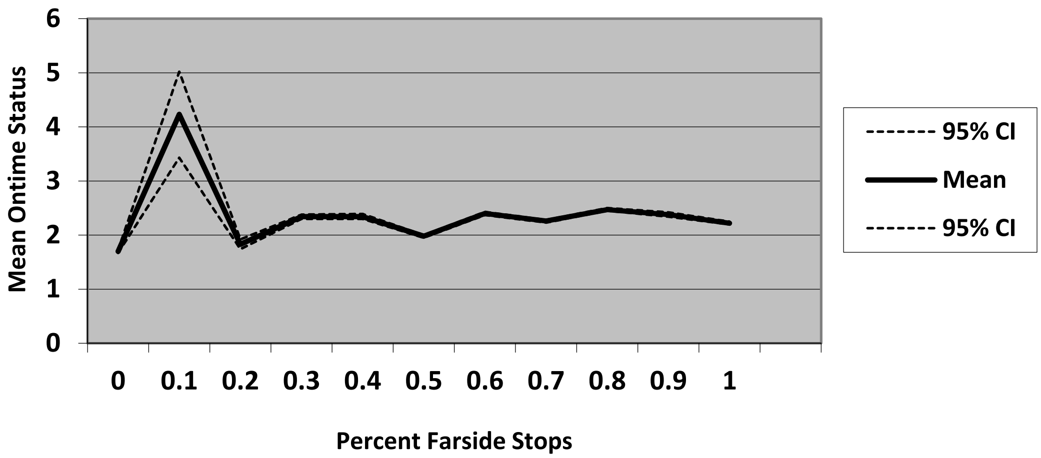

Figure 1.4 Change in Mean On-time Deviations by Percent Farside Stops

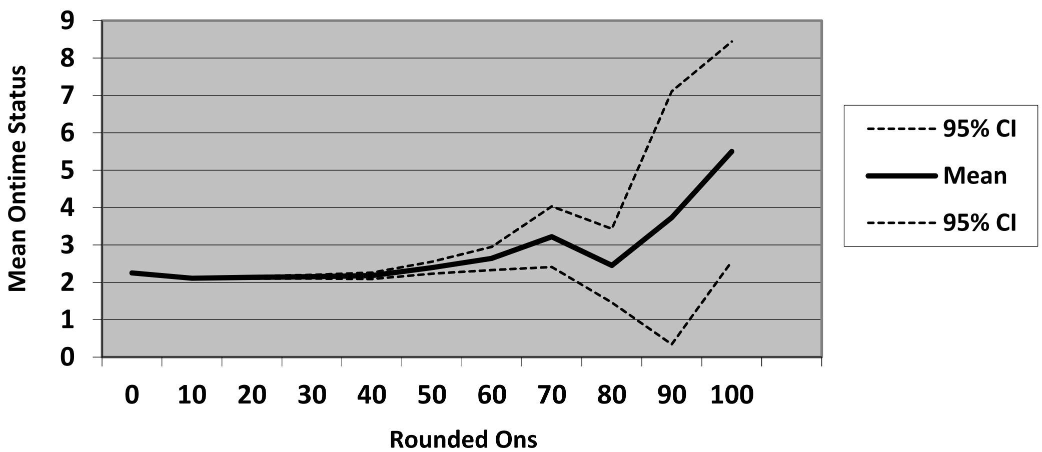

Figure 1.5 Change in Mean On-time Deviations by Rounded Ons

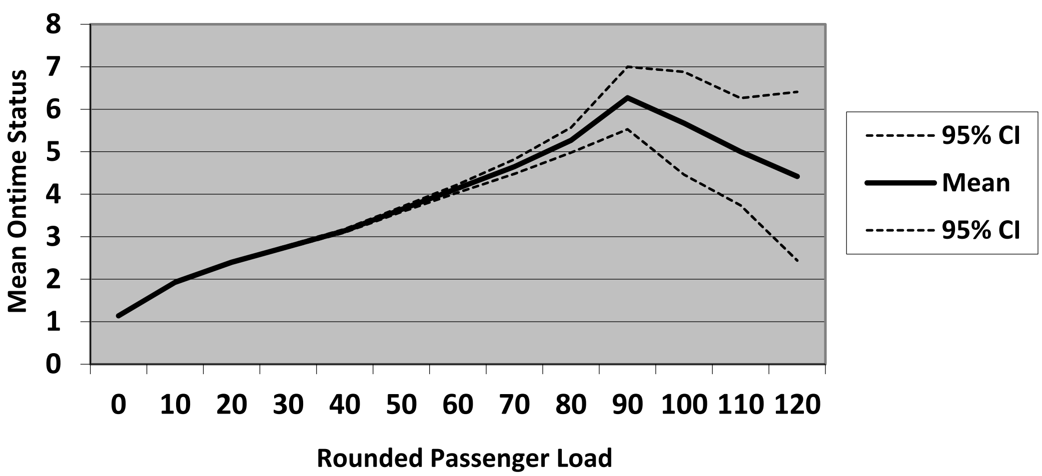

Figure 1.6 Change in Mean On-time Deviations by Rounded Passenger Load

In order to determine the interaction between these variables and their overall affect on on-time deviation, an ordinary least squares regression analysis was performed using on-time deviation as the explained variable. Based on Table 1.2 to 1.4 and Figures 1.1 to 1.6, highfloor, express, through routing, standees, service alert, severe weather, percent HOV and BAT lanes, ons, passenger loads, AM peak period, PM peak period and month and day fixed effects were used as explanatory variables. Stops per mile and express were very highly correlated and therefore only express was used, because it was a better predictor. Table 1.5 shows the results from the OLS regression on on-time deviations with significant explanatory variables. It is of note that December and Thursday were the default values and are therefore not included.

Table 1.5 OLS Regression on On-time Deviations

	Coefficient	Standard Err	t	P>t	95% Conf. Interval	
On-time Lag	0.910	0.001	1280.4	0.000	0.909	0.912
Highfloor	0.097	0.006	16.5	0.000	0.086	0.109
Express	-0.161	0.007	-23.5	0.000	-0.174	-0.147
Thru Route	0.186	0.008	22.0	0.000	0.170	0.203
Standees	0.276	0.020	14.0	0.000	0.238	0.315
Service Alert	1.492	0.062	24.0	0.000	1.371	1.614
Severe Weather	0.206	0.024	8.5	0.000	0.159	0.253
% HOV/BAT	-0.166	0.009	-17.5	0.000	-0.185	-0.148
Ons	0.019	0.000	53.9	0.000	0.019	0.020
Passenger Load	0.008	0.000	36.6	0.000	0.008	0.009
AM	-0.017	0.007	-2.5	0.011	-0.030	-0.004
PM	0.269	0.007	39.9	0.000	0.256	0.282
January	-0.265	0.015	-18.2	0.000	-0.294	-0.237
February	-0.322	0.014	-22.5	0.000	-0.350	-0.294
March	-0.364	0.014	-25.9	0.000	-0.392	-0.337
April	-0.361	0.015	-24.7	0.000	-0.390	-0.332
May	-0.209	0.015	-14.0	0.000	-0.238	-0.180
June	-0.194	0.014	-14.0	0.000	-0.221	-0.167
July	-0.175	0.015	-12.1	0.000	-0.204	-0.147
August	-0.201	0.014	-14.2	0.000	-0.229	-0.173
September	-0.121	0.014	-8.5	0.000	-0.149	-0.093
October	-0.176	0.014	-12.3	0.000	-0.205	-0.148
November	-0.172	0.015	-11.8	0.000	-0.200	-0.143
Monday	-0.132	0.009	-14.6	0.000	-0.149	-0.114

Tuesday	-0.072	0.009	-8.2	0.000	-0.089	-0.055
Wednesday	-0.048	0.009	-5.5	0.000	-0.065	-0.031
Friday	0.021	0.009	2.3	0.021	0.003	0.038
Constant	0.465	0.014	32.3	0.000	0.436	0.493
						F (29, 623840) = 69032 (Prob > F = 0.0000) **R-squared = 0.7492**

As shown in the table, the R-squared indicates that about 75% of the variation in on-time deviation is being explained by the model. The most significant explanatory variable is by far the lagged on-time deviation. In other words, if a bus is already late at one timepoint, it tends to be late by a similar amount at the next timepoint. However, in addition to this, all of the other variables are significant and explain additional deviation in the on-time status. Highfloor buses, through-routed buses, those with standees, and those operating in severe weather tend to be delayed more, each accounting for about 6 to 17 seconds of delay per segment. As expected, express buses and those with HOV or BAT lanes tend to be delayed less, with each variable accounting for about 10 seconds less delay per segment. Service alerts also increase the delay, accounting for 1.5 minutes per segment when significant problems occur. The number of boarding passengers and passengers already on the bus both increase delay, accounting for about 1 second per boarding and 0.5 seconds per passenger already aboard.

1.5.2 Analysis of Route-level data

In addition to analyzing the data on the timepoint level, a route level analysis may give additional information about the effect of each characteristic of service. For this analysis, we have collapsed the data by trip to obtain a travel time for the entire distance of the trip for each time a bus makes a trip along a route. Table 1.6 shows the prediction of the actual travel time or runtime along the route based on the scheduled travel time (ie. runtime) and the same characteristics as the previous analysis using OLS regression. It is again of note that May and Friday were the default values and are therefore not included.

As shown in the table, the scheduled runtime is predicting much of the actual runtime, as should be the case. In addition, high-floor buses add a small amount of runtime at 17 seconds for the entire trip. Express buses add runtime, about 43 seconds per run, as opposed to the previous analysis. Through-routed buses add runtime at almost 1 minute per run.

Having standees and severe weather also add runtime, both about 48 seconds per run. In contrast, articulated buses reduce runtime at about 23 seconds per run. Service alerts are again among the most influential, adding almost 4 minutes per run. The total number of boardings along the route added a small amount per boarding at about 1.5 seconds per boarding. Finally, having the run occur in the PM peak period accounted for another 1 minute of additional runtime. The percentage of HOV / BAT lanes, passenger loads, and AM peak period were not significant predictors in this analysis.

Table 1.6 OLS Regression on Actual Travel Time

	Coefficient	Standard Err	t	P>t	95% Conf. Interval	
Scheduled TT	1.076	0.001	959.1	0.000	1.074	1.078
Highfloor	0.278	0.035	8.0	0.000	0.210	0.346
Express	0.721	0.040	17.9	0.000	0.642	0.800
Thru Route	0.923	0.043	21.6	0.000	0.839	1.007
Articulated	-0.381	0.035	-10.9	0.000	-0.450	-0.313
Standees	0.788	0.075	10.5	0.000	0.641	0.935
Service Alert	3.730	0.243	15.3	0.000	3.253	4.207
Severe Weather	0.805	0.121	6.7	0.000	0.568	1.042
Ons	0.026	0.001	33.3	0.000	0.025	0.028
PM	1.026	0.034	30.3	0.000	0.959	1.092
January	-0.159	0.081	-2.0	0.051	-0.319	0.000
February	-0.461	0.080	-5.8	0.000	-0.618	-0.304
March	-0.661	0.078	-8.4	0.000	-0.815	-0.507
April	-0.784	0.079	-9.9	0.000	-0.939	-0.628
June	-0.183	0.077	-2.4	0.017	-0.334	-0.032
July	-0.194	0.080	-2.4	0.015	-0.350	-0.038
August	-0.149	0.079	-1.9	0.059	-0.303	0.006
September	-0.033	0.079	-0.4	0.674	-0.188	0.122
October	-0.204	0.079	-2.6	0.009	-0.358	-0.050
November	-0.076	0.081	-0.9	0.349	-0.234	0.083
December	0.874	0.084	10.5	0.000	0.710	1.037
Monday	-0.561	0.050	-11.2	0.000	-0.659	-0.463
Tuesday	-0.358	0.049	-7.4	0.000	-0.454	-0.262
Wednesday	-0.330	0.049	-6.8	0.000	-0.425	-0.234
Thursday	-0.187	0.050	-3.8	0.000	-0.284	-0.090
Constant	-0.040	0.083	-0.5	0.631	-0.203	0.123
F(25,139021) =53255 (Prob > F = 0.0000) R-squared = 0.9055						

1.6 INITIAL CONCLUSIONS AND RECOMMENDATIONS

The underlying goal of this research is to help transit agencies improve the usability of public transportation by focusing on an aspect of travel that is a key element to the customer, reliability. This research has taken into account a number of variables that impact reliability in transit, as measured by on-time performance and runtime.

Based on this analysis, the characteristic of service that has the highest impact on on-time status and additional runtime beyond scheduled is the presence of some kind of issue with service that would cause a service alert to be issued within the agency. This shows the importance of getting information about service alerts out to customers via a variety of means to ensure riders know that their bus is likely to be delayed.

In terms of policy decisions that agencies can make, the presence of high-floor buses increased the delays by several seconds per trip segment. Through-routing buses had an even greater impact, adding almost a minute to the actual runtime beyond that scheduled. Standees on a bus had a similar negative impact on both on-time status and overall runtime, indicating that agencies should pay attention to their passenger loads and work to add service along lines that become severely overloaded to avoid delays.

Interestingly, express buses and the percentage of exclusive lanes in the form of HOV lanes or Business-Access Transit (BAT) lanes had inconsistent impact on reliability. Although both had a negative impact on the on-time deviation on the segment level, they were either insignificant or positive on the runtime level. These substantial investments can significantly impact the scheduled runtime however, even if they do not substantially impact the difference between scheduled and actual runtime. By including exclusive lanes, the runtime will be less, which means transit planners can schedule a shorter travel time for the route. However, the impact on the variability of the actual runtime was found to be inconsistent in this research. Likewise, other variables which are not included in the regression because they were not significant, including percentage of TSP or far-side stops may greatly impact the scheduled travel time even if they do not impact reliability.

Three obvious sources of travel time variability have not been used in this analysis, including driver, fare payment (routes with more monthly passes versus those with cash), and underlying vehicular traffic. These variables either cannot be included for legal reasons or have no reliable data source to date. Although data about the driver is available, because of union agreements, it cannot be used for analysis by researchers outside of KCM. The data on fare payment will improve with time as the ORCA card is phased into service, however at present the method of fare payment is not accounted for accurately enough to use it in this analysis. Finally, although researchers are making progress in obtaining underlying traffic data, there are no robust sources of general traffic volume or speed data on arterials in Seattle available for this project.

The initial results presented for this analysis have two major caveats. First, there are a large number of observations in this analysis due to the large number of bus runs which are made throughout the county on a yearly basis. This large number of observations can have an impact on the t-tests and f-tests used, making everything seem significant. This makes it important to look at statistical significance only within the context of practical significance. Therefore, the complex nature of the data requires more than simple comparisons of means or ordinary linear regression. In addition, the variables in this analysis represent several levels of variation, those on a route level, those on a trip level and those on a stop or segment level. For both of these reasons, early consultation with the statistics department at the University of Washington has indicated that a hierarchical random effects model that moves beyond ordinary least squares regression is a better approach for this analysis. Therefore, upon completion of this analysis, the statistics department at the University of Washington was added as a partner to improve upon and verify the results reported here.

1.7 FURTHER ANALYSIS

The initial results presented above were discussed with the statistics department and further analysis was pursued in conjunction with their researchers. Based on the difficulty of analyzing at the segment level, it was decided that analysis at the route level would be pursued, but a new measure reflective of on-time performance would be created. The new response variable, which describes the difference in lateness from one timepoint to the next, accumulated over the route-level, became:

$$Y_{j,k} = \sum_{i=1}^{I_j} Y_{i,j,k} \, I\left\{Y_{i,j,k} > 0\right\}$$

Where Y_i= (Scheduled Arrival – Actual Arrival)$_i$ - (Scheduled Arrival – Actual Arrival)$_{i-1}$

k = 1,…,K is an index of service routes

j = 1,…,J_k is an index of trips for the service route k

i = 1,…,$I_{j,k}$ is an index of segments of trip j on service route k

I is an indicator function to restrict the calculation to only segments that are behind schedule.

Covariates used were similar to those in the previous analysis, including:

- Coach type (combinations of propulsion, low or high floor, seats and trolley wire)
- Express vs. local route
- Inbound vs. outbound
- Minor Weather
- Severe Weather
- Documented Service Issue
- Through-routing
- Timeperiod
- Month
- Day of week
- Percentage of miles in BAT or HOV lanes
- Percentage of nearside stops
- Number of ride free area links
- Boardings per stop (log-transformed)
- Percentage of transit signal priority equipped signals
- Trip length
- Traffic signals per mile
- Percentage of stops made
- Bus stops per mile

The data were cleaned prior to use by discarding the first and last segments of a trip, because many trips were found to be missing this information due to different driver routing at the beginning and end of a trip. In addition, data from December 16 to 31, 2008 was excluded due to the lingering impact of unusual weather conditions that would not be fully reflected in the severe weather variable. At the recommendation of King County Metro, trips were also excluded if they made no stops, if the route pattern occurred only once in a day, if the bus was more than 10 minutes early or more than 60 minutes late, or if the bus had boardings or alightings greater than 250 passengers. All of these exclusions were made because they were seen as indicators of errors in the dataset or as data that was not representative of typical operations.

Five types of models were pursued, shown in Table 1.7. For each type, due to the positive response variable, a natural logarithm was taken to improve normality of the residuals. The first model assumes that observations on the same service route are independent. However, trips on the same service route follow the same path and therefore experience similar traffic congestion, ridership and often the same bus drivers. Correlation among the observations on the same service route is accounted for in the second and third models by using service route as a fixed effect. For Model 5, the fixed effect of the service route is replaced with random intercepts for service route, with the model taking the form:

$$Y_{i,j} = \alpha + \beta X_{i,j} + b_i Z_{i,j} + \varepsilon_{i,j}$$

Where the variation in the model includes both the error term, $\varepsilon_{i,j,}$ and an additional term, $Z_{i,j}$, that varies by service route. Using Model 5 as a base, interaction effects were then added in additional models.

Table 1.7 Statistical Models Fitted

Model	Type	Description
1	Log linear, fixed effects	log Y regressed on all covariates, no interactions
2	Log linear, fixed effects	log Y regressed on service route, no interactions
3	Log linear, fixed effects	log Y regressed on all covariates and service route, no interactions
5	Log linear, mixed effects	log Y regressed on all covariates, no interactions, service route fitted as a random intercept
5.1 – 5.8	Log linear, mixed effects	log Y regressed on all covariates, service route fitted as a random intercept, various interactions

As shown in Table 1.8, the resulting fixed effects models explained little of the variation in the response variable, with R^2 in the range of 0.14 to 0.26. Using mixed effects improved the models, but not substantially, as shown by the AIC (Akaike 1974) changing only from 194413 to 193754. All interaction models improved slightly upon Model 5, with the best being Model 5.7, which included an interaction term for coach-type with percentage stops made and an interaction term for timeperiod with percentage of business-access-transit and HOV lanes signals. The AIC for Model 5.7 was only a minor improvement over Model 5 however, with an AIC of 193326.

Table 1.8 Adjusted R^2 and AIC Statistics for Fitted Models

Model	Adjusted R^2	AIC
1	0.21	199509
2	0.14	207856
3	0.26	194413
5	-	193754
5.7	-	193326

Because the models are only explaining a small portion of the variation, the results of individual parameter estimates should not be interpreted in detail, however broader statements about the direction of the estimates (positive or negative) could still be applicable. The resulting parameters in Model 5.7 that were positively associated with excess travel time were ride-free links, boardings per stop, length of trip and percentage of stops used. In addition the presence of a service alert and a through-routed bus were also associated with excess travel time. The excess travel time for express buses was smaller than that for local service, inbound buses was smaller than outbound, and low-floor buses was smaller than for high-floor buses. These results are consistent with the initial conclusions presented above.

1.8 FINAL CONCLUSIONS

The goal of this research was to investigate the causes of unreliability in transit to give agencies the ability to prioritize improvements to the service. A few conclusions can be drawn and should be emphasized here. The practice of through-routing buses is consistently negative for on-time service and should be minimized. Similarly, overcrowding has a negative effect on reliability and passenger loads should be monitored to minimize significant standee situations. High-floor buses negatively impact on-time performance and should be replaced with low-floor easier-to-board models. Other substantial infrastructure improvements such as business-access transit and HOV lanes and transit-signal priority gave inconsistent results, likely due to the limited presence of such facilities in King County Metro's service area.

The major conclusion that should be drawn from this analysis, however, is that thoroughly measuring the impact of infrastructure improvements on reliability is prohibitively difficult. Even with a dataset containing dozens of aspects of service and conditions, some elements that may predict on-time performance are missing. More importantly, even with substantial infrastructure improvements, inherent unreliability will still be present. Thus, it is critical that tools be developed to provide transit riders with better information about the status of their bus. This should come in the form of real-time information about next bus arrivals as well as service alert to ensure customers know that their bus is likely to be delayed.

Section 2

Behavioral and Satisfaction Changes Resulting from Providing Real-Time Arrival Information for Public Transit

2.1 INTRODUCTION

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. It has been shown that transit traveler information can result in a mode-shift to public transportation (Multisystems 2003). 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 (Dziekan and Kottenhoff 2007). In addition, it has been found that providing real-time information significantly increases passenger feelings of safety (Zhang, Shen, et al 2008).

These issues are definitely relevant for users of the Seattle-area regional transit agency, King County Metro (KCM). A 2006 survey of KCM riders (Elmore-Yalch 2007) identified key areas of dissatisfaction, 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, 42% of riders said they had experienced problems with on-time bus performance in the past 3 months. OneBusAway was created to address some of these issues and to expand upon existing transit tools in the region.

This section presents results from a web-based survey of 488 OneBusAway users. It also presents results from a follow-up survey focused 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, this evaluation of the results of providing real-time transit information demonstrates the value of such tools and suggests a number of interesting avenues for future research. Finally, the results make a strong case for transit agencies to provide similar systems for their own riders.

2.2 LITERATURE REVIEW

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 rail stations, transit centers, and major bus stops. However, it is prohibitively expensive to provide and maintain such displays at every bus stop. 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 usually cheaper to deploy than fixed real-time arrival displays at a large number of stops. Further, these systems, especially on 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 (Maclean and Dailey 2002). Although not real-time information, more recently, Google Transit began providing transit trip planning for more than 400 cities around the world (Google 2009). It addition to providing information to transit riders around the world, Google Transit is also significant for establishing a de facto standard for exchanging transit schedule data: the General Transit Feed Specification (GTFS). 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, creating development ecosystems 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 (Trimet 2009) 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. 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 transit, both for the general rider (Multisystems 2003; Dziekan and Kottenhoff 2007; Zhang, Shen, et al 2008; Kjeldskov, Howard, et al 2003), and for targeted groups such as those with cognitive impairments (Carmien, Dawe, et al 2005; Barbeau, Winters, et al 2006, Repenning and Ioannidou 2006; Patterson, Liao, et al, 2004). The OneBusAway tool suite aims for general usability by providing a broad set of interface options, with particular focus on ease of access to information. OneBusAway does this via open-source code and the project team is simultaneously working to promote open access to transit data.

2.3 DESIGN PROCESS

Initial work on OneBusAway was started to improve the usability of existing tools. The regional transit agency has had real-time tracking capabilities for its buses since the 90s and provides web and SMS access to arrival information. The MyBus program at the University of Washington also provides similar tools (Maclean and Dailey 2002). However, both these tool sets were difficult to use when riders were waiting at a stop, primarily due to providing no way to use posted stop IDs to quickly access information and the resulting complexity of information lookup. OneBusAway is financially supported by grants through the University of Washington and access to data is supported by the Seattle-area transit agencies (King County Metro, Sound Transit, Pierce Transit, Community Transit, City of Seattle, Washington State Ferries) and Dr. Daniel Dailey's AVL data stream.

The new set of tools provided by OneBusAway improved on 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 (http://onebusaway.org), an interactive-voice-response (IVR) phone interface, an SMS interface, an iPhone-optimized web interface, and a 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, as well as a wide range of users, there was an appropriate interface available. There are even deaf-blind users of OneBusAway who access the information using SMS and a Braille display. Additionally, in September 2009 and February 2010 respectively, a native iPhone application and native Android application were released that include automatic localization of the information presented using the phone's GPS capabilities.

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 2.1. 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.

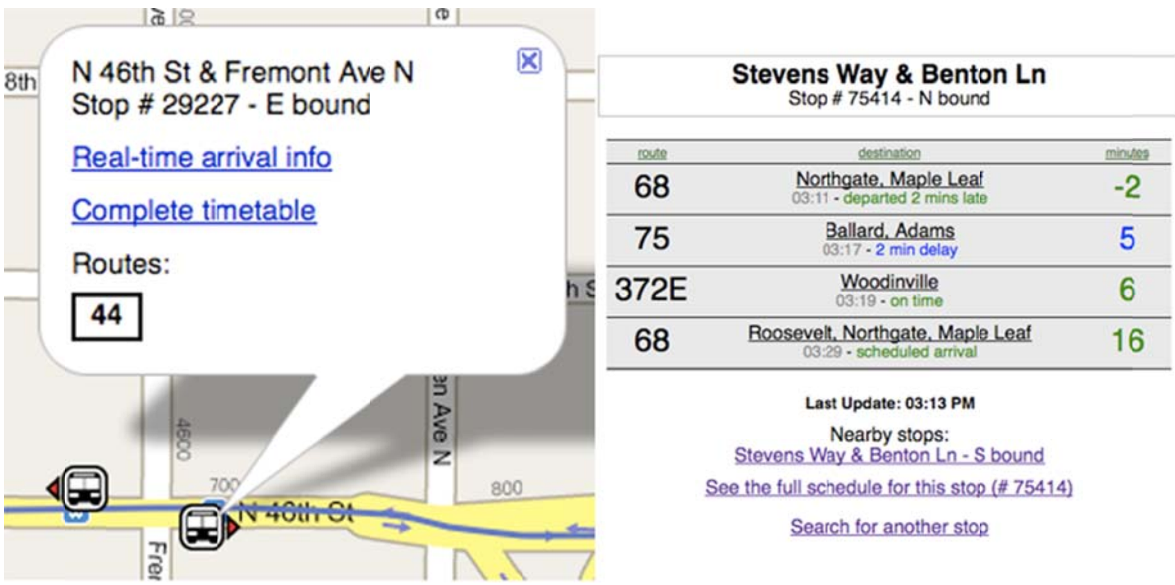

FIGURE 2.1 Example of the map-based interface (left) along with real-time arrival information for a single stop (right).

The text-only-optimized web interface and IVR phone system offer similar functionality to the web interface. 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 without the stop ID. The IVR phone system works via a touch-tone phone interface with text-to-speech. Users can 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.

These interfaces were informally evaluated in summer 2008 with several 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. OneBusAway provides several feedback mechanisms (email, Twitter, blog, bug tracker) that allow users to make comments or suggestions about the tools. Because OneBusAway is open-source software, users have also submitted improvements of their own. An additional survey of OneBusAway users was performed specific to usage of OneBusAway on the iPhone platform (Ferris, Watkins, et al 2010a).

The implementation of OneBusAway is further described in the Chi conference paper in which this work was originally presented (Ferris, Watkins, et al 2010b). OneBusAway is open source and more information can be found at the code project site on the web, http://code.google.com/p/onebusaway/.

2.4 METHODOLOGY

To evaluate the effects of using OneBusAway, two web-based user surveys were developed. The primary survey queried users about their usage of OneBusAway and how OneBusAway had changed their overall perception of 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 Seattle-area blogs where OneBusAway had been mentioned in the past. The goal was to reach both regular and infrequent users of OneBusAway. The survey was anonymous, but users were invited to notify a special email address on completion of the survey to be entered in two $25 gift certificate drawings. A copy of the survey can be found at http://onebusaway.org/research.

A total of 488 respondents completed the survey during five days in August 2009. Basic demographic information about survey respondents was gathered, 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. In comparison to typical transit users in the region (Elmore-Yalch 2007), the survey respondents are more predominantly male and younger, while income levels are comparable. The 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 were nearly 10% of the daily OneBusAway user base of August 2009. At the time, the OneBusAway user base represented less than 2% of Metro's weekday ridership.

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, this issue was pursued in more depth. To do so, a shorter second survey was developed asking 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 email contact information. The follow-up survey was advertised to those respondents, who were again optionally entered in a second gift certificate drawing. A total of 139 respondents took the follow-up walking survey during five days in August of 2009, a response rate of 72%.

2.5 RESULTS

2.5.1 Usage of Transit and OneBusAway

Survey respondents were asked general questions about how often they rode the bus on a weekly basis and for what purpose. The results, in Figure 2.2, show that the majority of respondents (more than 60%) could be classified as daily riders, making 9 or more bus trips each week. For trip purpose, 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 which OneBusAway tools respondents used, if any. The relative percentage of total respondents for each individual interface is shown in Figure 2.3, with the iPhone-optimized and standard web interfaces dominating the usage. The relative ratios of users of the various tools in the survey show a reasonably close match with actual usage statistics from the server logs.

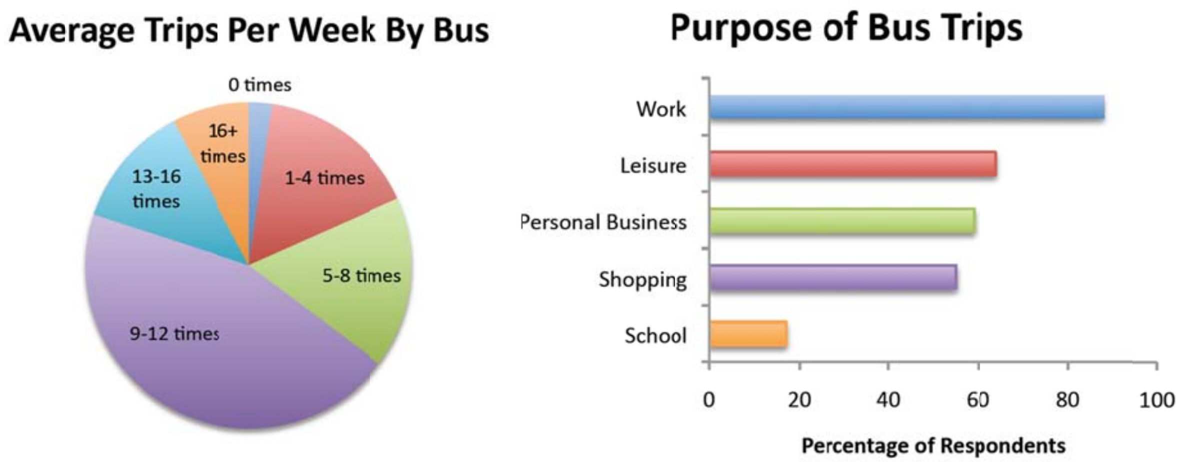

FIGURE 2.2 Average number of trips per week by bus and purpose of bus trips as percentage of total respondents.

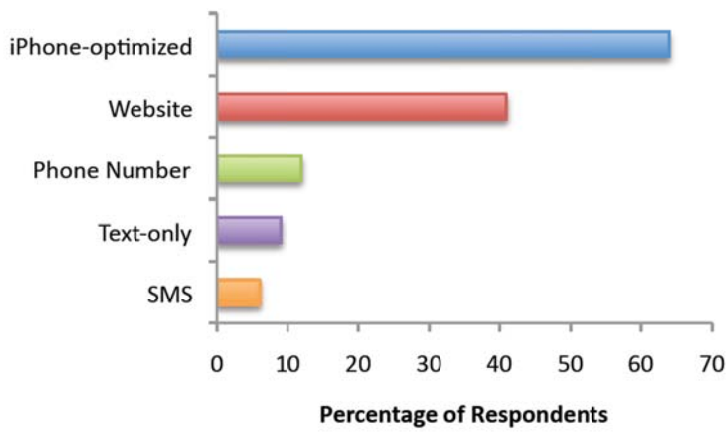

FIGURE 2.3 Percentage of respondents who frequently use each specified OneBusAway tool.

2.5.2 OneBusAway and Changing Behavior

2.5.2.1 Satisfaction With Public Transit

Survey respondents were asked whether their overall satisfaction with transit had changed as a result of using OneBusAway. The results (Figure 2.4) 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 transit. This is a remarkably strong effect from adding a relatively inexpensive technology to public transit.

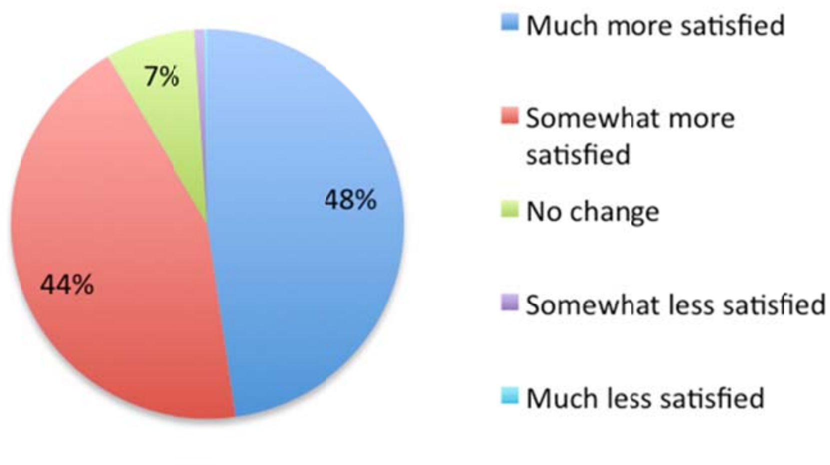

FIGURE 2.4 Change in overall satisfaction with transit as a result of using OneBusAway.

To get a better picture of user satisfaction with transit with regards to OneBusAway, respondents were asked to describe how their satisfaction had changed in a free-form comment. The 418 responses 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. Typical comments:

> "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."

> "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 transit, including which bus to take or when to catch it. Typical comments:

> "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."

"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%) in comparison to existing tools.

In addition to the comments describing changes in satisfaction with transit, it was also found that satisfaction was significantly negatively correlated with age among respondents (χ^2=24.615, p=0.017). The younger the rider, the more satisfaction they have with transit from using OneBusAway.

2.5.2.2 Time Spent Waiting

Survey respondents were asked 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 1% reported an increase in wait times. Regarding the relationship between satisfaction and wait time, overall satisfaction with public transport was found to be highly correlated with decreased wait time amongst survey respondents (χ^2=40.467, $p < 10^{-5}$). These results are confirmed by the user comments, noted in the previous section, that list time savings as a major reason for increases in overall satisfaction.

2.5.2.3 Number of Transit Trips Per Week

In addition to changes in satisfaction and wait time, users were asked how their average number of weekly commute and non-commute trips has changed as result of using OneBusAway. The results, presented in Figure 2.5, show an increase in the number of trips taken by OneBusAway users, with more gains in non-commute trips.

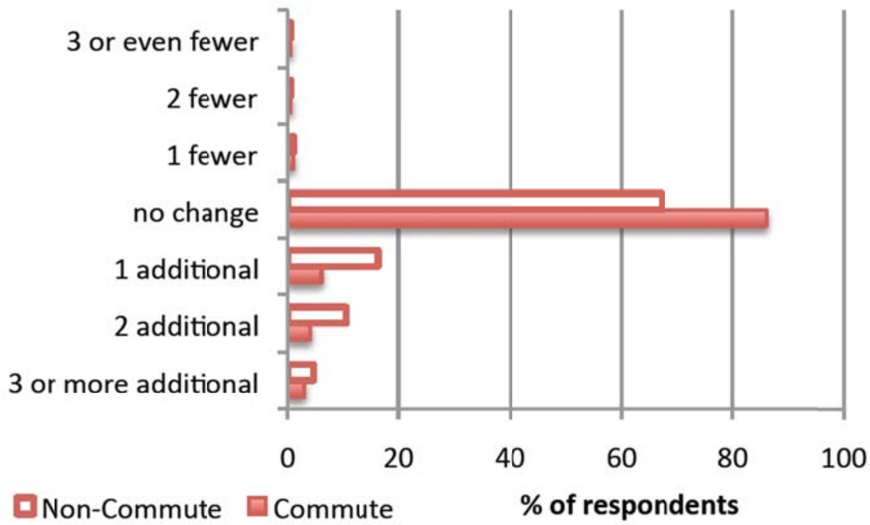

FIGURE 2.5 Change in the average number of trips per week among users of OneBusAway.

2.5.2.4 Access to Schedule Information

Respondents were asked how they typically find bus departure time information. While 16% of respondents reported using the published schedule provided by the transit agency either on paper or online, 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 later.

2.5.2.5 Perception of Personal Safety

Users were asked 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 (χ^2=98.05, p < 10^-15). Additionally, safety was correlated with gender (χ^2=19.458, p=0.001), with greater increases for women.

Furthermore, respondents whose feeling of safety had changed were asked 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. Representative comments:

> "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."

> "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 (Elmore-Yalch 2007).

2.5.2.6 Walking to a Different Stop

Survey respondents were asked how likely they are to walk to a different bus stop based on information from OneBusAway. While 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. This substantial response regarding increased walking was not expected in the original survey, which lead to a second survey to provide more detail about how and why walking habits had changed.

In the follow-up survey, respondents were again asked how likely they are to walk to a different bus stop based on OneBusAway information, and had an almost identical response (79% more, 19% no change, 2% less). They were next asked where they walk when they walk to a different bus stop. The results (Figure 2.6) show that the most popular choice was to a stop on a different route, while stops further along or ahead on the current route were picked less frequently. Respondents were also asked to classify why they walked to a different stop. Responses indicate that finding a faster route to their destination is the most popular reason. On average, respondents estimated 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 suggest that this survey may capture multiple walking populations with different motivations to walk.

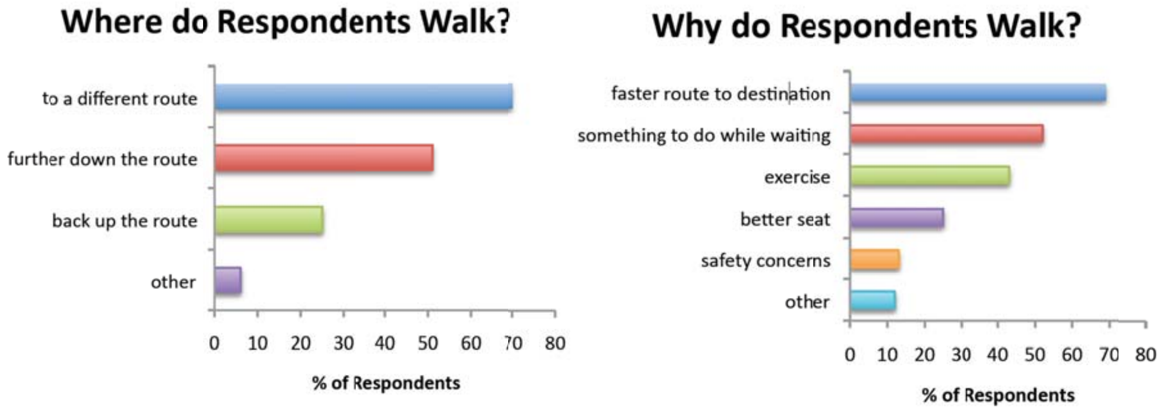

FIGURE 2.6 Where and why do respondents walk when they choose to walk to a different stop?

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.

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 walked less due to OneBusAway than they otherwise would. In the follow-up survey, it was found that this result is due to respondents (26%) 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.

2.6 DISCUSSION

A few important caveats should be noted before discussion of the results. First, the survey results are self-report, which can call into question the reliability of responses and limits the potential strength of claims to be made using response data. Second, there was no 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 to be made regarding changes in behavior resulting from the OneBusAway tool. Despite these limitations, the results from the survey, bolstered by qualitative comments from survey respondents, make a strong case for the value of systems such as OneBusAway. Survey respondents indicated a number of positive outcomes as a result of their usage of OneBusAway: increases in overall satisfaction with 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.

The reduction in wait time is especially interesting. This reduction is believed to be 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 (Dziekan and Kottenhoff 2007). In a follow-up study to the one described here, the difference between actual and perceived wait time was measured with and without mobile real-time information (Watkins, Ferris, et al 2011). The provision of mobile real-time information reduced both the inflated wait time perceived by waiting transit riders and the actual wait time they experience. 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 transit.

The increase in number of trips per week is a potentially important finding for policy makers looking to boost usage of transit. Again, the exact increase is hard to quantify with only these 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."

The survey results also indicated that for some of the users, feelings of personal safety play an important role in using transit, and that OneBusAway can help address concerns in this area. Despite the improvements brought by OneBusAway, there are some real opportunities for addressing this issue further in a value sensitive way (Friedman, Kahn, et al 2006) 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 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.

People are also using OneBusAway in other unexpected ways. One user commented:"OBA makes [it] much easier to avoid standing room only busses by letting me know there's a follow up bus right behind the current full bus." Like predicted arrival time, the number of available seats on a bus is another important piece of information to make more visible in transit systems. The OneBusAway team has 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.

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 not 100% accurate, and 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 include providing users with targeted feedback tools, allowing transit agencies to crowd-source the correction of their data.

2.6.1 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 (Parker 2008). 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 is 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 (Parker 2008), thereby needing a schedule. However, with the introduction of real time information such as OneBusAway, users more frequently refer to real time information than to schedules to determine when to wait at the bus stop. This is important because a significant amount of time is lost in attempting to maintain reliability for scheduled service due to the slack time planners must build into the schedule (Fan and Machemehl 2009). 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 (Zhao, Dessouky, et al 2006). 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 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 (Cham, Darido, et al 2006). 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.

Finally, the OneBusAway 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, other transit agencies should be encouraged to include real-time arrival information in their transit systems and to publish this data, along with static schedule data, through public APIs so that applications like the OneBusAway toolset can help make transit work better for the riders who use it every day.

2.7 CONCLUSIONS

This section presents the results from a survey evaluation of OneBusAway, a set of tools specifically providing access to real-time arrival information for transit and improving the usability of transit in general. The results of this survey are that respondents have an overall increase in satisfaction with 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. Further research is needed to quantify the impacts of mobile real-time information systems. However, the results of this survey show that the provision of mobile real-time bus arrival information has a positive impact on riders and is worth further implementation by transit agencies. Transit agencies should be encouraged to continue the growing trend of opening up their data to third-party developers to support innovation applications such as OneBusAway.

Section 3

Impact of mobile real-time information on the perceived and actual wait time of transit riders

3.1 INTRODUCTION

Increasing the competitiveness of non-auto modes is one key to reducing environmental impact (Poudenx, 2008). Transit agencies continuously work to improve transit travel time and on-time performance, but such efforts often come at a substantial cost. One inexpensive way to combat unreliability from the user perspective is real-time transit information. Real-time information can help riders to feel more in control of their trip, including their time spent waiting and their perception of safety. Recent advances in mobile device technology are enhancing opportunities for more productive use of travel time (Lyons and Urry, 2005). Now, the introduction of these more powerful personal mobile devices is also changing the wait time portion of the transit trip as well.

As described in Section 2, the initial study of OneBusAway users relied on self-report data and had no control group for comparison. Therefore, a follow-on study was conducted to more thoroughly measure the perceived and actual wait times of transit riders based upon their usage of real-time information. Several studies have looked at traveler response to real-time information; however few have addressed real-time information via devices other than public display signs. Public display signs are expensive, both for the initial purchase and the ongoing maintenance, thereby limiting the number of stops at which real-time information could be available (Schweiger 2003). For this reason, it is becoming increasingly popular to provide real-time arrival information via website and handheld devices. Information via mobile devices and the internet has the added benefit of intercepting a rider before they are waiting at the station or stop, allowing them to maximize their time and wait for a shorter period of time. Although many at-stop real-time arrival information displays have been tested, little work has been done with the perceived and actual wait time using phone-based real-time information, including internet-enabled ("smart") phones.

3.2 LITERATURE REVIEW

There are two principal reasons that OneBusAway is interested in providing better transit traveler information: to increase satisfaction among current riders; and to increase ridership, especially among new or infrequent transit users and for nonpeak hour trips, two key markets for many agencies. Although higher transit ridership is explained mostly by regional geography, economy, population, and transportation system characteristics (Taylor et al. 2009), it has been shown that real-time transit traveler information can result in a mode-shift to public transportation (Multisystems 2003). This stems from the riders' ability to feel more in control of their trip, including their time spent waiting and their perception of safety. Reducing wait time is important for transit riders, because it occurs at the critical preprocess phase of service delivery, in which delays carry more weight with customers (Dube et al. 1991).

Several studies have looked at traveler response to real-time information. However, the use of AVL only began in the last decade and the provision of actual real-time information to riders is an even more recent development. Before many transit agencies even had real-time bus tracking capabilities, Reed conducted a conjoint analysis of the response to real-time information using ratings of hypothetical situations. He found that real-time information was expected to reduce the burden of the wait as the degree of certainty increased (Reed 1995).

As of 2003, when the Transit Cooperative Research Program (TCRP) synthesis document on Real-time Bus Arrival Information Systems was written, only three US and five international agencies had measured the rider reaction to real-time arrival information. According to the synthesis, London Transport's Countdown program, which used at-stop real-time arrival signage, found that the perceived wait time dropped from 11.9 to 8.6 minutes. In addition, passengers felt less stress and felt reliability had improved since implementation (although it had actually decreased) (Schweiger 2003). Transit Watch, a program implemented with real-time information via video monitors in Seattle, was found to be useful, but not to increase overall satisfaction with transit. One major finding was that customers wanted the information via internet websites and at malls or office buildings close to transit (Mehndiratta et al. 2000). A study of Portland's Transit Tracker, another at-stop real-time arrival system, did not find a change in the perceived wait time, nor did it find a change in overall satisfaction with transit (Science Applications International Corporation 2003).

In order to determine the possible benefit of real-time information, Mishalani, et al (2006) looked at the difference between perceived and actual waiting times at a bus stop. The study was conducted at campus bus service stops on the Ohio State University campus in Columbus by lurking at bus stops and observing the arrival time, then asking riders how long they had been waiting when the bus approached. There was a statistically significant difference in the perceived versus actual waiting time. However, this difference was small and no actual real-time arrival information was tested.

Katrin Dziekan has also done significant work with rider reactions to real-time arrival information via at-stop displays. In one paper, she summarizes that real-time arrival displays increase feelings of security, reduce uncertainty, increase ease-of-use, adjust travel behavior and improve customer satisfaction. Most importantly to this investigation, permanent real-time arrival signage at transit stations showed 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 (Dziekan and Kottenhoff 2007).

Dziekan also conducted a before and after study of the perception of wait time after the installation of real-time arrival information signage on a tramline in The Hague, Netherlands. The study was conducted via survey mailed to the same respondents before the installation, 3 months after the installation and again 16 months after the installation. The perceived wait time decreased from 6.22 to 5.00 to 4.81 minutes, a difference of 20 percent over 3 months and 23 percent over 16 months (Dziekan and Vermeulen 2006).

In a before and after study of the ShuttleTrac system on University of Maryland College Park campus, seven models were estimated using panel data to determine behavioral and psychological response (Zhang et al. 2008). The real-time information for ShuttleTrac is provided via terminals at selected stops, a large display at an activity center, telephone and website. The results indicated that real-time information increased rider's feelings of security after dark and boosted their overall level of satisfaction, however it was not found to significantly increase trip frequency, nor was it found to reduce waiting anxiety or the perception of on-time performance.

3.3 METHODOLOGY

To begin to overcome the limitations of the earlier self-report survey, this study more thoroughly looks at rider perceptions of wait time versus actual wait time. The earlier self-report survey showed that 91% of OneBusAway users indicate that they spend less time waiting for the bus than they did before using OneBusAway (see Section 2)(Ferris et al., 2010). The study reported in this section will quantify how varying forms of real-time transit information, including OneBusAway via the basic voice interface, via the custom iPhone application, via the website and via text-messaging changes the actual and perceived time waiting for transit riders.

For the purposes of this study, eight researchers worked in pairs at fourteen bus stops in the vicinity of the University of Washington in February 2010. Both members of the survey pair attempted to remain inconspicuous, with the first surveyor (the recorder) standing in a location away from the stop for easy observation and the second surveyor (the questioner) attempting to appear as a typical bus rider waiting at the stop. Using a spreadsheet, the recorder noted the arrival times, gender and age group (college-age or older) of all riders who approached the bus stop. In addition, they recorded any distinguishing characteristics (purple hat, leather jacket, beard, etc) to help them identify this rider throughout the survey. The questioner chose respondents randomly for a series of questions about waiting. Upon the beginning of the questioning, the recorder noted the time and survey ID from the back of the survey form. After the survey was complete and the rider boarded a bus, the recorder noted the bus number the respondent had boarded for verification of that answer on the survey form.

The questioner surveyed as many riders as possible at the stop, aiming to begin surveying a rider after an average of approximately 5 minutes wait time and attempting to avoid influencing the answers of the next person by speaking in a quiet voice, alternating ends of the stop to choose respondents and waiting between respondents. The first two questions inquired about the respondent's willingness to participate and whether or not they had been surveyed previously. In all, 856 riders were approached for the survey. 804 were willing to participate, equating to a response rate of 94%. It is of note that many of those not willing to participate indicated that they saw their bus approaching and therefore did not have enough time. Of those who were willing and able to begin the survey, 13 had previously been approached by the survey team at another stop or on another day; another 20 respondents had a missing arrival time due to the recorders inability to catch all arrivals at busy stops; 54 were missing a critical piece of information due to the rider boarding a bus before the survey was complete; and 62 were transferring at the time of the survey. Therefore, in all there were 655 usable surveys in the analysis.

The first question asked of all respondents was “As precisely as possible, how long have you been waiting for the bus?” If a respondent answered in a 5- minute increment, they were asked if they could be more precise and answer in a 1-minute increment. The second question asked of all respondents was “On a scale of 1 to 10, 1 being relaxed and 10 being aggravated, how do you feel about waiting for the bus?” If asked for clarification, they were told that the question referred to their general impression about waiting and not just this specific instance. At the end of the survey, all respondents were asked “As precisely as possible, how long do typically wait for this bus?” Again, they were asked to attempt to answer in a 1-minute increment. In the middle of the survey, respondents were asked what they use to find out when the next bus is arriving, what type of device they use to access this information, the bus route, their destination, and how frequently they take this particular bus.

Of those surveyed, the breakdown of next bus arrival information was as follows:

- 88 were OneBusAway users
  - 55 of those primarily used the smart phone application
  - 10 primarily used their cell phone
  - 8 primarily used text-message
  - 12 primarily used the website
- 544 arrived without real-time information (used schedules, trip planners, maps, etc), which are referred to below as “Traditional Methods”.
- 23 used other programs for real-time information, including KCM Tracker (http://trackerloc.kingcounty.gov/), BusView (http://busview.org), MyBus (http://www.mybus.org/)

The data collected in the survey allows for the testing of three hypotheses:

1. Bus riders perceive that they are waiting longer for a bus than they actually are waiting.

2. Real-time bus arrival information will reduce the perceived wait time of a bus rider to bring it in line with the measured wait time.
3. Real-time bus arrival information will reduce the aggravation level experienced by a bus rider.

In addition, for 156 surveys, the recorder noted the actual arrival times of the buses. This aspect of the survey was added later as it became apparent that we would not be able to do this automatically using KCM data. By comparing this to the arrival times and the bus boarded, a 4th hypothesis can be tested:

4. Real-time bus arrival information will reduce the actual wait time of a bus rider.

Each of these hypotheses can be tested using difference of means tests. In the case of the first hypothesis (#1), a series of Paired Differences of Means T-tests can be used to find the difference between the mean measured wait time and the mean perceived wait time:

$$H_0 : \mu_{\text{Perceived wait}} - \mu_{\text{Measured wait}} = 0$$

The other three hypotheses (#2 - #4) can all be tested using an Independent Difference of Means T-test by taking the difference between the mean wait time or aggravation level for those riders with traditional information (schedules, trip planners) versus those with real-time information:

$$H_0 : \mu_{\text{Real-time}} - \mu_{\text{Traditional}} = 0$$

In the case of the wait times specifically (#2), this hypothesis can be expanded to:

$$H_0 : (\mu_{\text{Real-time measured}} - \mu_{\text{Real-time perceived}}) - (\mu_{\text{Traditional measured}} - \mu_{\text{Traditional perceived}}) = 0$$

In addition to these hypotheses, a regression model for the prediction of perceived wait time can be developed based on the actual wait time, the use of real-time information, and other factors about the rider or the bus. Based on the data available from the collection effort, several variables can be tested for inclusion in the prediction model, including:

- real-time information categorical variables (OneBusAway user, other real-time user, traditional arrival information)
- rider categorical variables for gender and age (college or older)
- user frequency variables for the frequency that the rider uses that particular bus (4+ times per week, 2-3 times per week, about 1 time per week, about monthly, infrequent, first time)
- rider aggravation level (scale of 1 to 10, 1 being relaxed and 10 being aggravated)
- distance variable corresponding to the approximate distance the rider was about to travel
- environmental categorical variables for weather (sunny, rainy, cloudy)
- time of day categorical variables for PM, midday, evening
- bus route-related variables for bus frequency / headway and percent of late buses

3.4 RESULTS

3.4.1 Effect of Real-time on Perceived Wait Time

For riders who arrived at the bus stop having used traditional methods, such as a schedule, map, trip planner or other static data source or simply showed up at the stop, Table 3.1 shows the hypothesis that their perceived wait time is equal to their measured wait time is rejected. On average, these riders perceive that they are waiting 0.83 minutes (15%) longer than they are. This is consistent with previous findings in both the transportation literature discussed previously and service industry literature (Jones and Peppiatt 1996).

TABLE 3.1 Perceived versus Measured Wait Times (in minutes) of Bus Riders using Traditional Arrival Information

Variable	Mean	Std. Dev.	95% CI
Perceived Wait	6.19	3.51	5.90 – 6.49
Measured Wait	5.36	2.97	5.11 – 5.61
Difference	0.83	2.85	0.59 – 1.07
No. observations = 544		**t = 6.8169**	**Pr (T > t) = 0.0000**

However, as shown in Table 3.2, for riders using real-time information from OneBusAway, the hypothesis that the perceived wait time is equal to the measured wait time cannot be rejected. The 0.32 minute difference in perceived and measured wait time is not significant (p-value 0.1884).

TABLE 3.2 Perceived versus Measured Wait Times (in minutes) of Bus Riders using OneBusAway Real-time Arrival Information

Variable	Mean	Std. Dev.	95% CI
Perceived Wait	4.98	2.76	4.39 – 5.56
Measured Wait	4.66	2.43	4.14 – 5.17
Difference	0.32	2.25	-0.16 – 0.80
No. observations = 88		**t = 1.3256**	**Pr (T > t) = 0.1884**

Similarly, for the users of real-time information from other mobile sources, the hypothesis that their perceived wait time is equal to their measured wait time cannot be rejected. As shown in Table 3.3, the 0.30 minute difference in perceived and measured wait time is not significant (p-value 0.4940). The sources of information for these other real-time users include King County Metro's own Tracker, the predecessor to OneBusAway called MyBus, and other smart phone or website-based programs developed by independent developers.

TABLE 3.3 Perceived versus Measured Wait Times (in minutes) of Bus Riders using Other Real-time Arrival Information

Variable	Mean	Std. Dev.	95% CI
Perceived Wait	4.96	3.15	3.59 – 6.32
Measured Wait	4.65	2.17	3.72 – 5.59
Difference	0.30	2.10	-0.60 – 1.21
No. observations = 23		**t = 0.6956**	**Pr (T > t) = 0.4940**

After combing the two groups of real-time information users, the hypothesis that real-time information is reducing the perceived wait time to bring it in line with the actual wait time can be tested with an Independent Difference of Means T-test.

The results, shown in Table 3.4, indicate that the hypothesis that the two ways of obtaining information about arriving differ from each other cannot be rejected.

TABLE 3.4 Difference of Means test for Perceived Wait Time (in minutes) comparing Traditional Arrivals versus Real-time Arrivals

Group	Observations	Mean	Std. Dev.	95% CI
Real-time	111	0.32	2.21	-0.10 – 0.73
Traditional	544	0.83	2.85	0.59 – 1.07
Difference		-0.52		-1.00 – -0.04
			t = -2.1305	**Pr(T > t) = 0.0344**

3.4.2 Regression Model for the prediction of Perceived Wait Time

In order to expand upon these results, a regression model for the prediction of perceived wait time based on the measured wait time, presence of mobile real-time information, and other bus and rider factors was developed. Possible variables included an indicator variable for gender, an indicator variable for college-age, a categorical variable for frequency of rider use as well as indicator variables for the categories of rider frequency, a discrete variable for the rider aggravation level, a continuous variable of the approximate distance the rider was about to travel, environmental categorical variables for weather, time of day categorical variables, a discrete variable for bus frequency / headway, and a continuous variable for the percent of late buses on the route.

After testing these variables for their significance, the final model was determined to be:

$$PW = \beta_0 + \beta_1 MW + \beta_2 RT + \beta_3 PM + \beta_4 BF + \beta_5 FL$$

Where: PW = perceived wait time

MW = measured wait time

RT = categorical variable for Real-time Information

(RT = 1 if real-time is available, RT = 0 if traditional arrival)

PM = categorical variable for PM peak period

BF = bus route frequency in buses per hour

FL = typical frustration level as experienced on a scale of 1 to 10

As shown in Table 3.5, all variables are significant and the overall R^2 was 0.43. The Breusch-Pagan test for heteroskedasticity indicated that the regression model is heteroskedastic (chi^2 = 97.33, p-value = 0.0000), therefore robust standard errors have been used. On average, riders perceived that they are waiting 1.9 minutes plus 0.72 minutes for every minute they actually wait with an additional 0.59 minutes if they are waiting in the PM peak and 0.19 minutes for every integer increase in the level of aggravation. For every additional bus per hour, the perceived wait decreases by 0.14. The addition of real-time information decreases the perceived wait time by 0.73 minutes.

TABLE 3.5 Estimation Results for Perceived Wait Time (PW) Model

Variable	Coefficient	Robust Standard Error	t-statistic (p-value)
Intercept	1.9	0.40	4.82 (0.000)
Measured Wait (MW)	0.72	0.049	14.63 (0.000)
Real-time Info (RT)	-0.73	0.24	-3.08 (0.002)
PM Peak Period	0.59	0.22	2.73 (0.006)
Buses per Hour (BF)	-0.14	0.064	-2.24 (0.025)
Aggravation level (AL)	0.19	0.054	3.53 (0.000)
No. observations = 646 R2 = 0.43 F(2,652) = 56.10 (P = 0.0000)			

Accepting our model as a linear approximation in the vicinity of wait times actually experienced, the model suggests several conclusions. The insignificance of the percentage of late buses and significance of real-time information shows that riders do not care as much about buses being late as they do about knowing that buses are late. Personal rider variables such as gender, college-age, the distance they expected to travel or the frequency with which they used the bus did not impact the perception of wait time. However, the aggravation level, which could be considered a personal measure of many other factors from their trip (Is someone waiting? Are they late for a meeting? What is their personality type?) was significant – frustrated users perceive that they wait longer. The insignificance of environmental variables may be unique to Seattle and the weather patterns experienced here. Many riders are accustomed to waiting in rainy weather in February, so the presence of rain does not impact their stated perception of wait.

One interesting point is the balance between providing additional service (increasing buses per hour) and providing real-time information. It is not until the route reaches a level of 6 buses per hour (10 minute headway) that the bus per hour coefficient (-0.84) is greater than the coefficient for the provision of real-time information. By using cost estimates for providing real-time predictions and for adding frequency on routes, a transit agency could use these estimates to determine which is more cost effective.

In summary, real-time information significantly reduced perceived wait time. Rider characteristics do not significantly impact the perception of wait time except for the typical aggravation level waiting for the bus. Real-time could be a very cost-effective means for reducing perceived wait time.

3.4.3 Effect of Real-time Information on Perceptions of Typical Wait Time

In addition to their perceived wait time for the one particular instance in which they were waiting, riders were also asked about their typical wait time if they took the bus more than once per month. The difference between real-time information users (OneBusAway or other real-time programs) versus those using traditional arrival information (schedules, trip planners, etc) can again be tested using an Independent Difference of Means T-test.

As shown in Table 3.6, real-time information users say that their average wait time is 7.54 minutes versus 9.86 minutes for those using traditional bus arrival information, a difference of 31%. The t-test is significant with a p-value of 0.000. Clearly, real-time information makes a significant difference in the typical bus wait time, indicating that riders use the information to arrive closer to the actual arrival of the bus.

TABLE 3.6 Difference of Means test for Typical Perceived Wait Time (in minutes) comparing Traditional Arrivals versus Real-time Arrivals

Group	Observations	Mean	Std. Dev.	95% CI
Real-time	103	7.54	3.56	6.85 – 8.24
Traditional	497	9.86	5.19	9.40 – 10.32
Difference		2.32		1.49 – 3.15
		t =	**5.5022**	**Pr(T > t) = 0.0000**

After the survey was complete, if respondents answered that they use OneBusAway to access real-time arrival information, they were asked to comment about their use of OneBusAway. Their comments were specifically directed toward how OneBusAway has changed their trip making patterns, wait time or frustration with waiting. Of those asked about OneBusAway, 25 respondents commented specifically about its effect on their wait time, with 16 (64%) stating that OneBusAway has reduced their wait time and 9 (36%) stating that their wait time has not changed. No one indicated that their wait time was longer as a result of OneBusAway. Some of the comments received include:

> "I absolutely do use it to do other things or go back to my desk. It has changed my morning routine – I wait no time at all in the morning."

> "OneBusAway is valuable, especially when coming in the morning. In the afternoon, I have two buses to choose from and it tells me which one to try to catch. It has probably changed my wait time."

3.4.4 Effect of Real-time Information on Aggravation Level

In addition to questions about perceived wait time, riders were asked how they felt about waiting for the bus. This aggravation level was measured on a scale of 1 to 10, with 1 being relaxed and 10 being aggravated. The model for the prediction of perceived wait time includes the aggravation level as a significant variable, indicating that riders who are less aggravated predict their wait time more accurately while those who are more aggravated tend to perceive their wait times as being longer, other things being equal. It is also worth investigating if real-time information is leading these riders to be less aggravated. Conceivably, if a rider knows when the bus is coming, they will be more relaxed as they wait for the bus.

However, as shown in Table 3.7, this is not the case. There was no significant difference between the real-time information users self-reported aggravation level and the self-reported aggravation level of those without real-time information.

TABLE 3.7 Difference of Means test for Aggravation Level (scale 1 to 10) comparing Traditional Arrivals versus Real-time Arrivals

Group	Observations	Mean	Std. Dev.	95% CI
Real-time	110	3.35	1.96	2.98 – 3.72
Traditional	540	3.29	2.17	3.11 – 3.48
Difference		-0.05		-0.46 – 0.36
		t =	**-0.2442**	**Pr(T > t) = 0.8074**

Of those who indicated they use OneBusAway, their comments were also directed toward their aggravation level since using OneBusAway. Of the 25 who commented about their aggravation, 19 (76%) indicated that they are less frustrated and 5 (20%) indicated that they are equally frustrated as before using OneBusAway. One person responded that they are more frustrated when OneBusAway shows that the bus was late and less frustrated when it shows the bus is on time. Other comments received include:

> "Before OneBusAway, my average aggravation would have been a 9. I definitely use the bus more often. I can plan around the bus with OneBusAway."

> "OneBusAway improves the fluidity of moving. I have less anger and I manage my time better as a result. I am more relaxed on the bus."

3.4.5 Effect of Real-time Information on Actual Wait Time

In Table 3.1 and 3.2, the mean measured wait of riders using traditional arrival information was reported as 5.36 minutes and the mean measured wait of riders using real-time information was reported as 4.66 minutes. The difference between these mean measured waits could indicate that real-time information users not only perceive their wait to be shorter, but their actual wait time is shorter as well. However there is one caveat to this claim. Although the surveyors attempted to be random in their selection of riders to respond to the survey, they may have inadvertently influenced the measurement of actual wait time because the surveyors knew this was a study for OneBusAway. In particular, iPhone users are obvious to spot at the stop and their desire to make sure they got enough OneBusAway users may have lead them to ask about wait time sooner than for other riders. Therefore, in order to supplement this information, for some of the survey periods, the arrival time of the buses was recorded to see the entire wait time of the survey respondents. In all, 156 respondents were surveyed when the exact bus arrivals were being recorded.

The results of these actual wait times are shown in Table 3.8. Based on the independent difference of means t-test, real-time information users wait almost 2 minutes less than those arriving using traditional information, a result which is significant at a p-value of 0.0357. This is perhaps the most important finding of the study. By using mobile real-time information, users are not only perceiving that their wait is shorter, but they are actually arriving at the stop closer to the actual arrival of the bus.

TABLE 3.8 Difference of Means test for Actual Wait Time (in minutes) comparing Traditional Arrivals versus Real-time Arrivals

Group	Observations	Mean	Std. Dev.	95% CI
Real-time	26	9.23	4.05	7.59 – 10.87
Traditional	130	11.21	5.08	10.33 – 12.09
Difference		1.98		0.14 – 3.82
			t = 2.1695	**Pr(T > t) = 0.0357**

3.5 CONCLUSIONS

The underlying goal of this research is to help transit agencies improve the ridership and satisfaction with public transportation. Giving passengers real-time information about the arrival of the next bus helps minimize waiting time, improves the perception of the wait and alleviates the stress of wondering when the bus is coming. Although bringing the perception of wait time in line with the actual wait time will not improve the reliability of transit, it can improve the perceptions that relate to reliability by giving riders more control.

Many of the hypotheses tested in this study relate to perceptions of wait time. It was found that on average, transit riders perceive that they are waiting 0.83 minutes longer than they are. However, for riders using real-time information, the hypothesis that the perceived wait time is equal to the actual wait time cannot be rejected. The difference between the perceived and measured wait times for those with real-time information and those without real-time information is significant and large. This is substantiated again by the typical wait times riders report. Real-time information users say that their average wait time is 7.54 minutes versus 9.86 minutes for those using traditional arrival information, a difference of 31%.

A model to predict the perceived wait time of bus riders was developed, with significant variables that include the measured wait time, an indicator variable for real-time information, an indicator variable for PM peak period, the bus frequency in buses per hour, and a self-reported typical frustration level. The addition of real-time information decreases the perceived wait time by 0.73 minutes. The model results show that the percentage of late buses was not as significant as the provision of real-time information, indicating that riders do not care as much about buses being late as they do about knowing that buses are late. Real-time information is also more important than bus frequency, with the coefficient on real-time information exceeding the coefficient for frequency until the route reaches a level of 6 buses per hour (10 minute headway).

Although real-time information effects the perceived wait time of riders, real-time information makes no difference in the self-reported aggravation level experienced by riders in this study. However, comments received from OneBusAway users indicate that they feel a reduced level of aggravation as a result of using OneBusAway. It could be that real-time information users are a self-selecting group, which has a naturally higher level of aggravation with waiting for the bus and real-time information brings their aggravation down to the level of a typical rider. This can only be tested with a before and after study of OneBusAway users. Therefore, the next phase of this project will be a longitudinal study of riders before and after they begin using OneBusAway. This future study will recruit non-OneBusAway users and introduce them to real-time information to investigate changes in number of transit trips, wait time, and perceptions such as level of aggravation with waiting for the bus.

Finally, a critical finding of this study is that mobile real-time information reduces the actual wait time experienced by customers. Real-time information users wait almost 2 minutes less than those arriving using traditional information. Although previous studies about perceived wait time have been done using real-time information signage, the advantage of mobile real-time information is that it can change the actual wait time of riders. OneBusAway users routinely comment about their ability to grab a cup of coffee because they know there is a 10-minute delay one particular day or that they should literally run to the stop because their bus is on time and they are running late.

With the introduction of more powerful, easier to use and less expensive personal mobile devices, mobile transit information has the ability to become more prevalent for riders. OneBusAway provides applications for real-time information via internet-enabled "smart" phones, devices which cost more than $200 to purchase in addition to monthly data plans. However, in addition to these applications, the data is available via text-message, website and a regular phone line, allowing use by a substantial portion of the transit-riding population. By opening up the data via multiple media, the likelihood of riders being able to access real-time information increases. Regardless of these multiple media, a small percentage of riders are still not able to access the real-time data because they cannot afford cell phones. One possible way to overcome this is to implement a free-511 program similar to the free-911 program in which inactive cell phones can still make emergency calls. Such a program could distribute older cell phones and chargers to the transit-dependent population to enable access to real-time information at every stop in a system without the use of expensive real-time arrival signage.

In summary, mobile real-time information via devices such as websites, cell phones, text-messaging and smart phones changes the perceived wait time of transit riders to be insignificantly different from their actual wait time. Additionally, mobile real-time information changes the actual wait time of transit riders by allowing them arrive at the stop when the bus is actually approaching, rather than leaving for the stop according to the schedule data. Not only does mobile real-time information save a transit agency money by avoiding the installation of real-time signage, it actually improves the experience of transit riders by making the information available to them before they reach the stop.

Section 4
Explore: An Attraction Search Tool for Transit Trip Planning

4.1 INTRODUCTION

Publishing information about a transit agency's stops, routes, schedules, and status in a variety of formats and delivery methods is an essential part of improving the ease of use of a transit system and the satisfaction of a system's riders. No longer the domain of just simple printed schedules, transit traveler information systems have grown to include route maps and timetables, trip planners, real-time trackers, service alerts, and others tools made available across cell phones, web browsers, and new internet devices as driven by rider demand (Multisystems 2003).

The primary reason for providing better traveler information as a service to customers is to increase ridership by making transit service easier to use and more convenient. This can be especially true for infrequent transit users and non-peak hour trips, two key markets for improving load factors for many agencies. Transit information appeals most to choice riders and can result in a mode-shift to public transportation (Multisystems 2003). Providing automated user information through trip planners can also reduce the need for call-center representatives to address schedule questions over the phone (Radin, Jackson, et al 2002).

One of the key staples of most transit traveler information systems is the trip planner. Trip planners use an origin address and destination address to search for a transit vehicle that travels between the two according to the desired time-frame of the traveler. Most trip planners begin with assumptions about walking distance, transfers and time-frame, requiring a user to enter only two addresses to perform a search. The next step can involve refinements to the initial information provided to narrow or enhance the search for a particular transit trip.

Trip planners have existed for decades, but were primarily used by agencies for in-house call center staff. The first internet-based transit journey planners were introduced by transit agencies in the 1990’s. As of 2002, there were 30 web-based trip planners in the US (Radin, Jackson, et al 2002). At the time, transit agencies had significant interest in developing online trip planners, with new ones being added at a rate of about 1 per month. Trip planners were seen as a way to save money, provide better service and increase ridership, but the agencies lacked the money to implement them and knowledge about GIS, ITS, trip planning vendor terminology and maintenance of websites (Radin, Jackson, et al 2002).

Online transit trip planning took a leap forward with the release of Google's transit trip planning lab product in December 2005 and subsequent integration into their Google Maps site in June 2006 as Google Transit. Since the launch of this product, transit agencies of various sizes in 256 cities in 29 countries have provided their data to Google for integration into their system (Google 2009).

4.2 TRANSIT AGENCY TRIP PLANNERS TODAY

Today, the most useful source for pre-trip information is the internet (Eriksson, Friman, et al 2007), especially for younger riders (Farag and Lyons 2008). People typically consult information for a new trip unless their trip has no time constraints, service is frequent, or journey is local (Farag and Lyons 2008). Among other pre-trip queries asked by transit customers for occasional trips is the question, "What routes are near my home, work and other key locations, and what destinations can I reach by transit from these points?" (Multisystems 2003) Table 4.1 shows the results of our investigation of the trip planners for the 50 transit agencies with the highest unlinked passenger trips in the United States. Trip planners are found on the websites of most of these agencies, either in their own version or through a link to Google. The few agencies without trip planners have provided schedule data to a larger agency in their area.

TABLE 4.1 Trip Planner capabilities for the 50 largest transit agencies in the United States

	Transit Agency	City	State	2007 UPT	Trip Planner on Website	Google Transit
1	MTA New York City Transit	New York	NY	3,256,977,960	Yes	Yes
2	Chicago Transit Authority	Chicago	IL	499,544,307	Link to Google	Yes
3	Los Angeles Co. MTA	Los Angeles	CA	495,362,403	Yes	Yes*
4	Washington MATA	Washington	DC	411,598,592	Yes	No
5	Massachusetts Bay TA	Boston	MA	357,578,991	Yes	Yes
6	Southeastern Pennsylvania TA	Philadelphia	PA	321,839,783	Yes	Yes*
7	New Jersey Transit Corp.	Newark	NJ	268,289,345	Yes	Yes
8	San Francisco Municipal Rail	San Francisco	CA	206,458,675	Yes	Yes
9	Metro. Atlanta Rapid TA	Atlanta	GA	147,523,544	Yes	Yes
10	King County Metro	Seattle	WA	113,928,156	Yes	Yes

11	Miami-Dade Transit	Miami	FL	111,263,859	Link to Google	Yes
12	MTA Bus Company	New York	NY	110,269,609	MTA NYC	Yes
13	San Francisco Bay Area RTD	Oakland	CA	109,219,470	Yes	Yes
14	Maryland Transit Admin.	Baltimore	MD	108,831,451	Link to Google	Yes
15	MTA Long Island Rail Road	Jamaica	NY	102,143,717	MTA NYC	Yes
16	MTA of Harris County	Houston	TX	100,868,417	Yes	Yes
17	Tri-County MTD	Portland	OR	100,638,004	Yes	Yes
18	Denver RTD	Denver	CO	94,196,136	Yes	Yes
19	Port Authority Trans-Hudson	Jersey City	NJ	82,406,648	NJ Transit	Yes
20	San Diego MTS	San Diego	CA	82,333,186	Yes	Yes
21	MTA Metro-North Railroad	New York	NY	80,324,201	MTA NYC	Yes
22	Metro Transit	Minneapolis	MN	76,966,724	Yes	Yes
23	METRA	Chicago	IL	74,550,584	Link to Google	Yes
24	Dallas Area Rapid Transit	Dallas	TX	73,949,618	Yes	Yes
25	City and Co. of Honolulu DOT	Honolulu	HI	72,557,307	Link to Google	Yes
26	Orange County TA	Orange	CA	70,266,572	Yes	Yes
27	Port Authority of Allegheny	Pittsburgh	PA	68,525,198	Yes	Yes
28	Alameda-Contra Costa TD	Oakland	CA	67,414,737	511 SF Bay	Yes
29	RTC of Southern Nevada	Las Vegas	NV	63,733,694	Link to Google	Yes
30	The Greater Cleveland RTA	Cleveland	OH	60,187,823	Yes	Yes
31	Bi-State Development Agency	St. Louis	MO	53,990,802	Yes	Yes*
32	Valley Metro	Phoenix	AZ	50,590,609	Yes	No
33	Milwaukee County Transit	Milwaukee	WI	46,599,318	Link to Google	Yes
34	Santa Clara Valley TA	San Jose	CA	43,434,199	Link to Google	Yes
35	Broward County Office Trans	Pompano Beach	FL	42,442,268	Link to Google	Yes
36	VIA Metropolitan Transit	San Antonio	TX	41,717,688	Yes	Yes*
37	Utah Transit Authority	Salt Lake City	UT	41,349,702	Yes	Yes*
38	Pace - Suburban Bus Division	Arlington Hts	IL	36,590,058	Link to RTA	No
39	City of Detroit DOT	Detroit	MI	35,402,314	Link to Google	Yes
40	Capital MTA	Austin	TX	34,039,638	Yes	Yes
41	MTA Long Island Bus	Garden City	NY	32,440,169	MTA NYC	Yes
42	Sacramento RTD	Sacramento	CA	32,261,658	Yes	Yes
43	Westchester County Bee-Line	Mount Vernon	NY	31,079,433	Link Trips123	No
44	DOT and Public Works	San Juan	PR	30,491,313	No	No
45	City of Los Angeles DOT	Los Angeles	CA	30,205,735	On LA Metro	No
46	Ride-On Montgomery Co.	Rockville	MD	28,302,019	On WMATA	Yes**
47	Long Beach Transit	Long Beach	CA	26,636,190	Link LA Metro	Yes**
48	Southwest Ohio RTA	Cincinnati	OH	26,146,916	Yes	No
49	Central Florida RTA	Orlando	FL	26,078,255	Yes	No
50	Niagara Frontier TA	Buffalo	NY	24,145,786	Yes	Yes

* = Added between April 2009 (research initially conducted) and July 2009 (paper submission)
** = Added since July 2009

Although online trip planning has come a long way in the past decade, the current information provided is still considered poor to average in many cases and there is a desire for higher quality information (Caulfield and Mahony 2007). Efficiency, the ease and speed of accessing and using the site, is the most critical contributor to users' perceptions of a website (Eriksson, Friman, et al 2007). In one rating of nine cities based on website performance, static information performance and journey planner performance, Melbourne and London performed the best, but US cities Portland and Washington DC performed well (Currie and Gook 2009).

4.3 RECENT ENHANCEMENTS TO TRIP PLANNERS

The state-of-the-art in trip planning has changed rapidly over the past decade. Beyond the typical trip planner, several transit agencies and third-party developers have added more advanced tools to their trip planners. Recent enhancements include added input capabilities, output capabilities, mapping capabilities and multi-modal integration.

In addition to the minimal input of an origin address, destination address, date and time of trip, many trip planners frequently add inputs such as maximum walk distance, maximum number of transfers, need of ADA accessible service, and preferred mode of travel. Rather than just inputting origin and destination by address, some trip planners allow input by intersection, stop or station, landmark or even by clicking on a map (SEPTA 2009, UTA 2009, Metlink 2009). Cherry, Hickman, et al have implemented an ArcIMS GIS-based itinerary planner for Sun Tran in Tucson that allows users to select origin and destination on a map in addition to traditional manual address entry or pull down landmark menus. As they point out, the difficulty in implementing such a feature is in the slow speed of calculation due to the necessity of redrawing the map (Cherry, Hickman, et al 2006).

Using this input, trip planners output at least one potential route in response to the input constraints. These output routes typically include detailed walk, transit and transfer directions with times of trips, as well the potential to investigate earlier or later trips, fare information, links to schedules, and route maps. This information appears on the screen, but more recent enhancements allow results to be printed, e-mailed or downloaded to a PDA (Dadnab 2009, MTA 2009). Many agencies now include a button to quickly plan the return trip as well. In addition to mobile tools, BART in San Francisco has one of the best website trip planners in terms of output, with maps of walk and transit components and information such as detailed station information, carbon saved by using public transportation, fare information, and station advisories all on one output screen (BART 2009).

A critical component of the future of transit trip planning is the ability to integrate trip planners across agencies and across modes. Regional trip planners such as Goroo, the trip planner found on the Chicago area RTA website, typically work through obtaining a feed from all agencies involved in the trip planner (RTA 2009). Regularity of feed data through standards such as the General Transit Feed Specification and the JourneyWeb protocol allow integration of multiple trip planners (Fingerle and Lock 1999). Others have attempted the integration of two completely independent trip planners using a broker that divides the trip between the two systems and assembles the answer for the user. One system was developed and tested for the trip planners in greater Waukesha and Milwaukee, Wisconsin (Peng and Kim 2008).

In addition to integration across agencies, integration across modes is a critical future direction for trip planning. The Google transit trip planner began as an enhancement to their online roadway directions. Multi-modal trip planners have been developed by others prior to Google's work (Chen, Kitamura, et al 1999). More recently, several regions, including greater Chicago, Atlanta, London, and Athens have developed multimodal trip planners. The Regional Transportation Authority's Goroo trip planner includes the option to obtain directions for train, bus, driving and drive to bus, comparing the distance, time, cost and carbon output of the trip for the modes queried (RTA 2009). The A-Train in Atlanta and Transport for London already include cycling and walking routes in their transit trip planners, however driving is not an option (Citizens for Progressive Transit 2009, Transport for London 2009). In Athens, an urban trip planner has been combined with country-wide coach, air and ferry service (Zografos 2008).

4.4 BEYOND THE SINGLE TRIP ORIGIN / DESTINATION PLANNER

To aid commuters in their individual transit planning, several agencies have added trip planner tools that go beyond a single origin to destination trip. MTA in New York, MUNI in San Francisco, Seattle's King County Metro and Minneapolis all have added Point to Point schedules to their websites to allow users to obtain personalized schedules over a range of times between any two locations on the same route.

Many agencies have added "service in area" searches to allow a user to search for routes in the area of a landmark or address. This type of search appeals to someone who is new to a location or new to transit and trying to investigate routes available to one location. However, without consulting maps for each of the routes, these "service in area" tools cannot provide information about potential destinations along the reachable routes.

In addition to these agency trip planners, Google Maps has implemented a Search Nearby tool that allows users to enter an address and then search for attractions nearby by entering a category (doctor, park, etc). Although users could then click on any of the resulting nearby attractions to find transit directions, it may require several tries before an easily reachable destination is found.

4.5 ONEBUSAWAY EXPLORE TOOL

Typical online trip planners work well if the destination is known. However, sometimes the availability of transit at a location is more important than the actual destination. Here are a few examples:

1. A transit-dependent elderly woman needs to find a new doctor's office for regular visits. Although the quality of the care is important, several doctors would be acceptable for her situation. The ability to search for a doctor that is easily reachable via transit can help make her routine trip to the doctor easier on her.
2. A group of college roommates wants to go out drinking and are concerned about getting home without needing to drive. Although some bars are more popular, many would be welcome choices. By having the ability to search a website for easily reachable bars, the group finds using transit preferable to driving intoxicated.
3. A new mom with a desire to limit her carbon output is looking for activities to entertain her toddler. She is willing to go to any number of local parks or community centers, but would enjoy traveling without her car. Using an reachable attractions search tool allows her to pick a location for their daytrip and travel car-free.

For those looking for a new destination, infrequent riders or those new to an area, these can be difficult questions to answer. Such a search would require looking up and typing in multiple destinations into a trip planner and would not be worth the effort. Given this premise, we developed the Explore Attractions Search Tool to make use of an underlying trip planner to search online databases of local restaurants, shopping, and other amenities.

In the first iteration of the Explore tool, a website was created that searched a four table Microsoft SQL Server database. The user would input a route number and an attraction type (doctor, bar, park, etc). The program would then search an ordered pattern stop table to translate the route to a list of stops along the route. Using the longitude and latitude of the stops, the program would search a destinations table for the particular category and output a list of possible destinations. The main problem with this approach was that all the data was static GIS data stored locally on a computer and would have had to be maintained by the authors. Therefore, it was decided that the next iteration should rely entirely on data updated by other parties, such as King County Metro, Google or Yahoo. As the process of redoing the Explore tool began, the authors brainstormed features and interviewed users from different demographic categories to gain input for format and features.

In the current version of Explore, the user specifies their starting point along with what they are interested in searching for. Optionally, they may specify a start time and date, a maximum trip length, a maximum number of transfers, and a maximum walking distance. A screen shot of the introductory data entry screen is shown in Figure 4.1.

When the search is submitted, the program executes the search in two steps, described below. The first step involves computing the total area reachable by transit given a starting point and any constraints supplied by the user. The second step involves doing a local search within the reachable transit area for the amenities specified by the user.

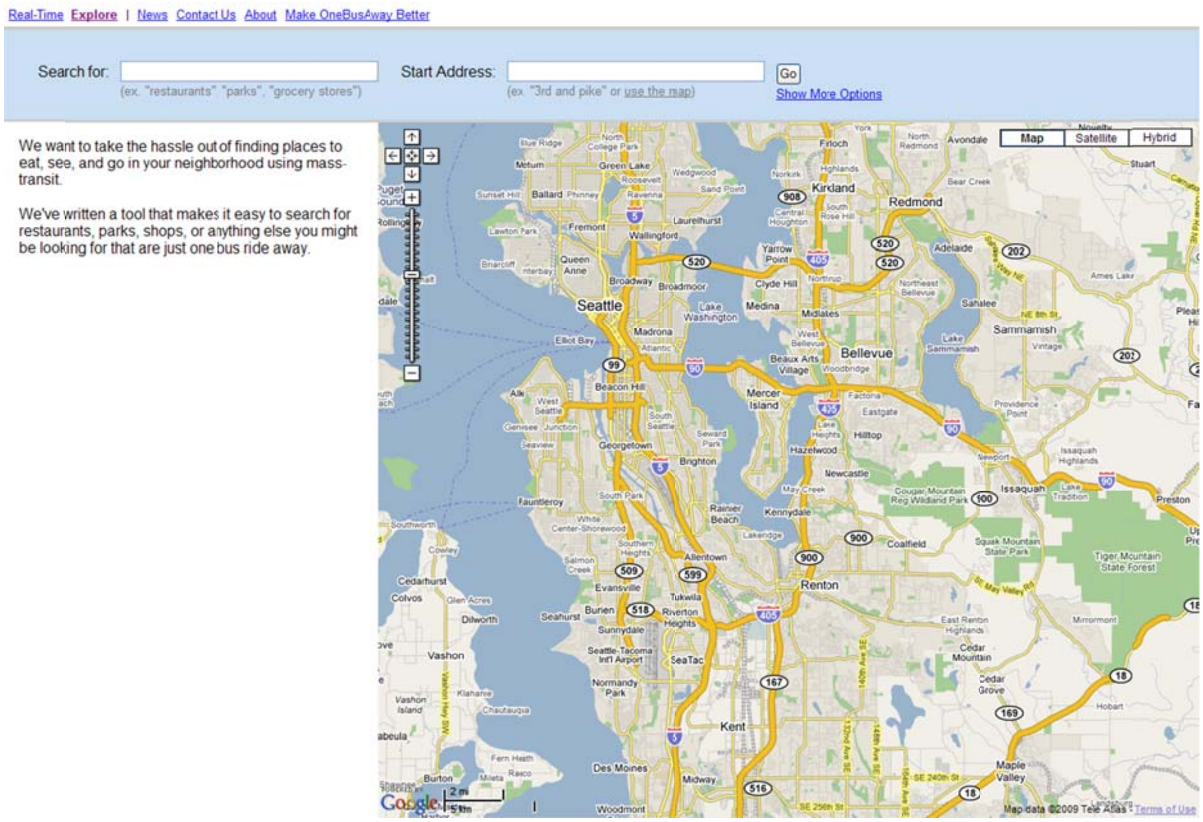

FIGURE 4.1 Explore Introductory Data Entry Screen

4.5.1 Finding the Area Reachable by Transit

To find the total area reachable by transit, we specifically search for the set of all transit stops reachable from the user-specified starting location in the specified amount of time along with any additional constraints, such as the number of transfers or max walking distance. This search problem is fundamentally different than the search task undertaken by a typical trip planner. In the typical case, the search is between a known source and destination, so directed search algorithms such as A-Star search can be leveraged to efficiently find paths between the two points. In our case, we have no fixed destination. Instead, we are looking for efficient paths to ALL potential stops and destinations reachable within the constraints specified by the user.

To compute this set of stops, we employ what is essentially Dijkstra's graph search algorithm on a memory-resident street/sidewalk and transit network graph, with a number of optimizations to limit the search space. Effectively, we simulate all potential trips taken by a rider from the starting location, advancing each trip in parallel through time. As each trip reaches a new stop, we note if it was the first trip to reach the stop. If so, we continue modeling the trip. If not, we prune the trip from further consideration, since any travel from this stop going forward would be made using the first trip that had already reached the stop. We stop searching when the length of the longest trips in the current search reach the time window specified by the user.

As an optimization, we pre-compute offline the full set of potential transit transfer points in the transit network graph. Since we are computing the fastest times to reachable stops, as opposed to the set of all points on the street/sidewalk network, our graph search can avoid having to search the street/sidewalk network for potential destinations and transfers and can instead only consider transfer points between stops in the pre-computed set. This optimization dramatically reduces the search space of potential trip itineraries.

4.5.2 Finding Amenities Within in the Area Reachable By Transit

Once the set of reachable stops is computed, the second step of the search begins as we discretize the reachable area into a half-mile grid, including a grid cell if it contains one of the reachable stops. We then start searching for local businesses and amenities as specified by the user within the activated grid cells of the reachable area. The beta version of One Bus Away Explore utilizes the Yelp (http://yelp.com) online database of reviews, but we could just as easily integrate another local search database such as Google Local or Yahoo Local. Once results have been returned, we check them against our street/sidewalk network to ensure that there is a path from a nearby stop to the search result and that the total travel time is still under the specified limit. We wish to avoid search results that are close to a reachable stop, but that are separated by non-walkable barrier such as a major highway or a body of water.

Figure 4.2 shows the resulting screen from the initial search. In this example, the user has searched for nearby parks within 30 minutes by transit from their home with no transfers. The display of results includes the name of the park, the average rating for that park, and the minimum travel time to that park, along with a display of all the results on a map. Once a user has settled on a particular park, they can select it for more information, including location and up to three transit trip plans that will get them to their destination at the selected time frame, as shown in Figure 4.3. By clicking on the individual trip number, the walk and transit paths are explained and shown on the map.

A second example search is shown in Figure 4.4 and Figure 4.5. In this example, the user has searched for a chiropractor from a local retirement community. The user does not wish to walk very far, so they have opted for a maximum of ¼ mile walk, but are allowing one transfer during the trip. Several choices are available and they choose a chiropractor close to the university.

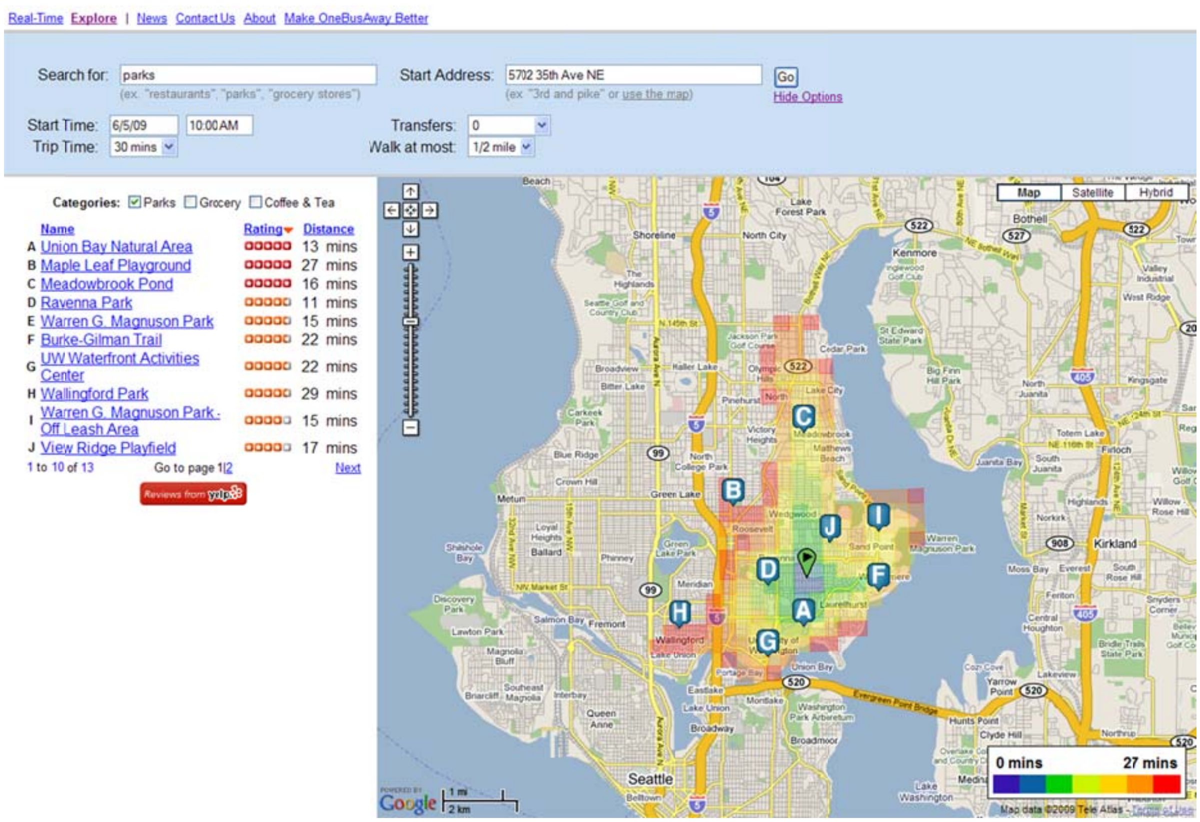

FIGURE 4.2 Parks that are less than 30 minutes away by bus from a Seattle residence

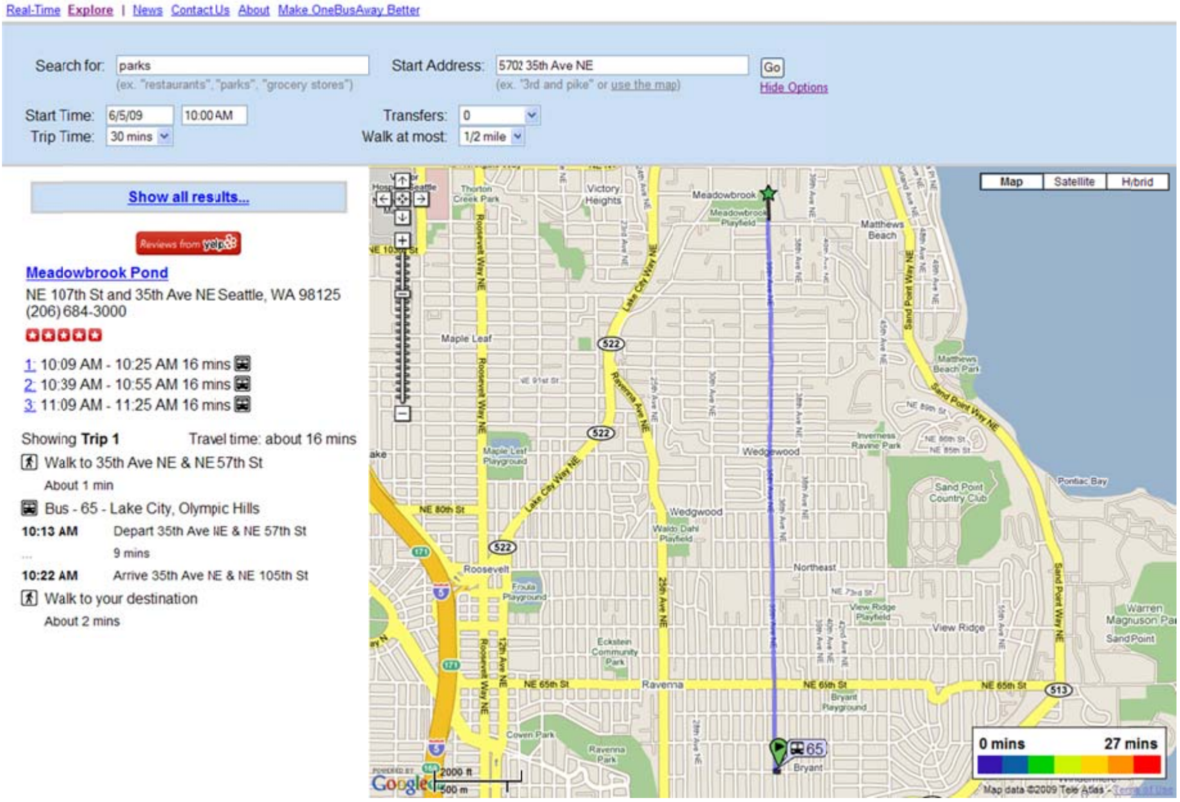

FIGURE 4.3 Trip plan results for a specific park using Explore

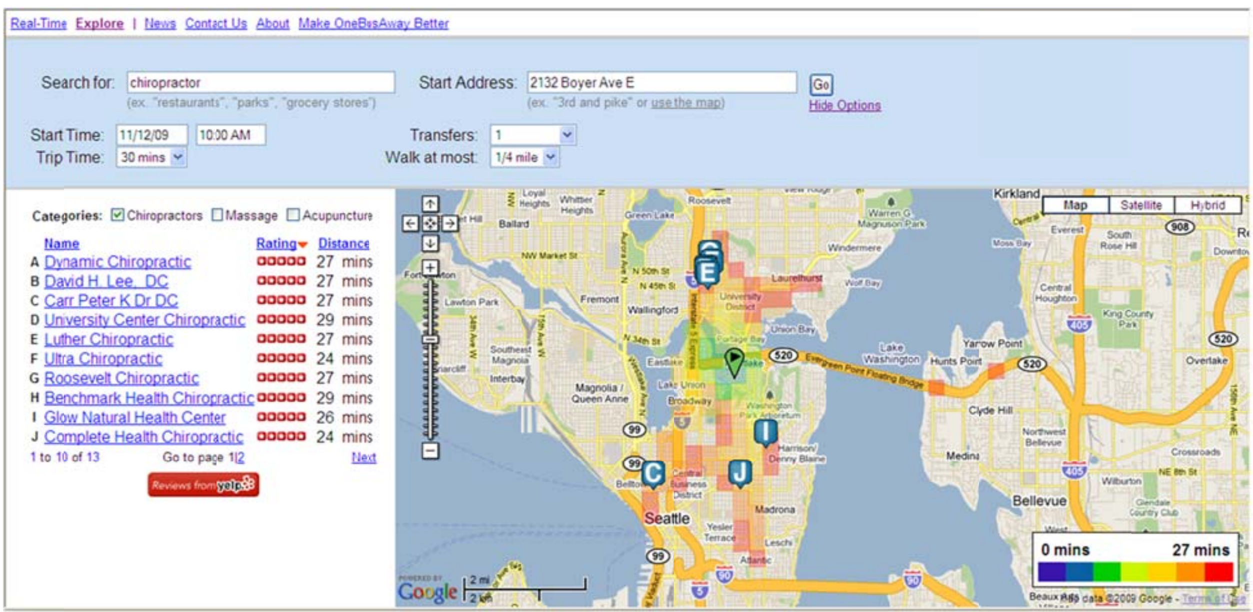

FIGURE 4.4 Chiropractors that are less than 30 minutes away by bus from a retirement community

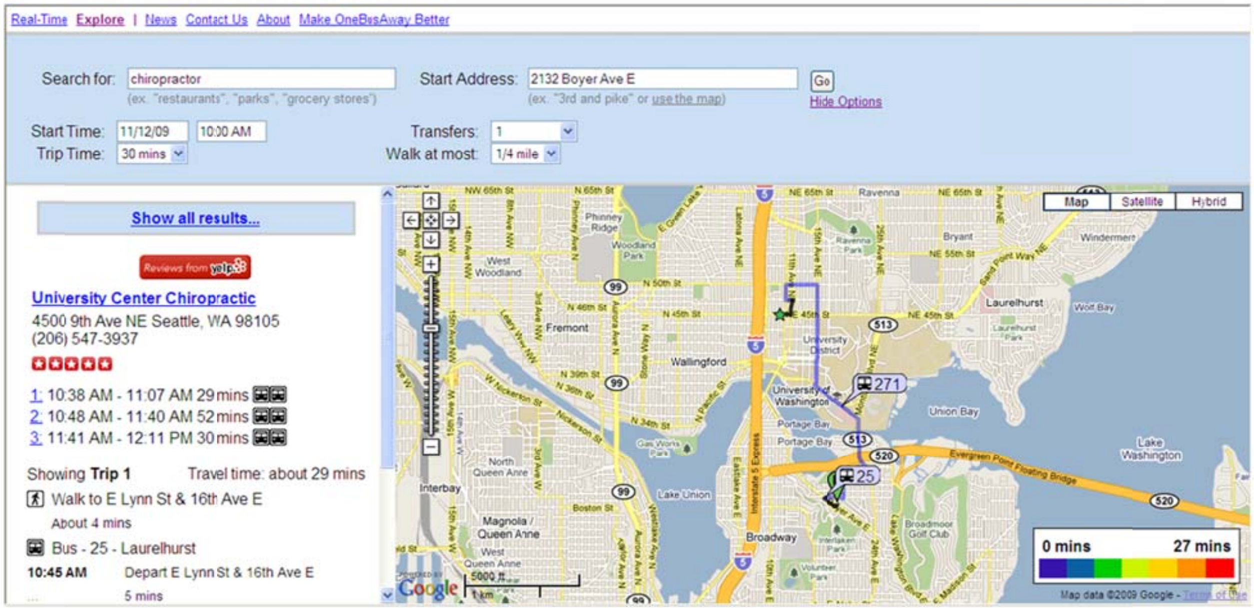

FIGURE 4.5 Trip plan results for a specific chiropractor using Explore

This beta version of Explore has been implemented on the OneBusAway website at http://onebusaway.org/explore/onebusaway/ using data from King County Metro, an underlying OpenStreetMap transportation network (www.openstreetmap.org) and the Yelp online database of reviews (www.yelp.com) for a comprehensive list of attractions. Although Yelp is fairly thorough and offers user ratings for their listing, the site is predominantly used by a younger demographic. Future versions may explore the use of another local search database such as Google Local or Yahoo Local to overcome this barrier. All of these local search databases are provided free of use and are updated by companies other than transit agencies, thus ensuring minimal cost and effort for a program such as Explore. The addition of more transit agencies to the Explore program requires only agency schedule data in the format of the General Transit Feed Spec (GTFS), about one day worth of programming on the part of the developer and adequate server resources.

4.6 NEXT STEPS FOR EXPLORE

The Explore tool is still under development by the OneBusAway project team. We have a list of enhancements and smaller bugs that have to be addressed. One bug that must be addressed is the ability to stop a search once an acceptable destination has been shown. One enhancement would add details about the bus frequency and return trip frequency and exceptions (weekdays only or only until 10 pm), so that a user does not get stuck at their destination. As mentioned previously, there are some drawbacks to the use of Yelp, especially with the searching of categories in which the word must only appear somewhere in the write-up. Therefore a restaurant near a park may get listed with a “park” category search. We would therefore like to add support for Yahoo and Google Search as well. We would like to add features such as a print button to make it easier to print and take all the needed information with the user. In addition, the user should have the ability to store a search to repeat it or alter it slightly from the last time the site was used. Finally, we think the user should be able to have an option to connect a trip to the original one searched. With this ability to add a second destination, a user could plan an evening including dinner and then a movie, all with the stipulation that the locations would be easily reachable via transit.

In addition to these Explore enhancements, another missing element of the Explore tool is a link to the real-time information that is the cornerstone of OneBusAway (Ferris, Watkins, et al 2010, Ferris, Watkins, et al 2009). One goal of OneBusAway is to develop many rider information tools, including more tools that build on underlying trip planners and to add more transit agencies to the system so that the tools can be used outside the metro Seattle area. Our hope is to integrate an open-source trip planner with real-time arrival information and real-time service alerts to create a network of linked transit rider tools. To this nature, we are currently working with Tri-Met’s Open Trip Planner project as well as undergoing a value sensitive design process to identify the most needed rider tools and enhancements to the existing OneBusAway tools.

4.7 CONCLUSIONS

The ability to perform such a search by attraction type rather than specific destination can be a powerful aid to a traveler with a need or desire to use public transportation. Explore allows riders to choose their destinations based on transit availability, which can encourage transit use. The only other existing attraction search tool has been implemented by Google Maps. Although their Search Nearby tool allows users to enter an address and then search for attractions nearby by entering a category (doctor, park, etc), users interested in determining the transit availability at the destinations may have to try clicking several results before an easily reachable destination is found.

The Explore tool is one of many possible online search tools to make transit more easily reachable to current and potential riders. In addition to our work at OneBusAway, the WalkScore developers are currently implementing a TransitScore algorithm to inform potential homebuyers and renters about which locations are the most transit-friendly. Their initial efforts are found at http://www.walkscore.com/transit-map.php. By helping riders to choose transit-friendly properties in the first place, programs such as TransitScore can complement tools such as Explore, which allow riders to choose destinations based on the easiest journey from their home location.

The goal of the One Bus Away project is to implement tools that will make transit easier to use and better able to compete with non-public modes. One Bus Away is being developed as an open-source transit traveler information system to allow transit agencies to access the code and use it themselves. In addition, the open-source model allows other developers to make use of the code or the data to create further transit traveler information tools such as those described. The source code for the deployment is available at http://code.google.com/p/onebusaway/ under an open-source license.

The development of this type of program is only possible with the aid of transit agencies that are willing to make their data available for free. The leader in this type of data exchange between a transit agency and transit software developers for the past two years has been the Bay Area Rapid Transit agency. BART has partnered with the developer community and makes their schedule data, real time data and service alert data all easily available for other websites and tools. Tri-met and MBTA have more recently implemented similar programs and other agencies are following suit. King County Metro in greater Seattle has graciously partnered with One Bus Away to provide the data for this project.

Section 5
Using Value Sensitive Design to Identify Needed Transit Information Tools

5.1 INTRODUCTION

Since the National Environmental Policy Act of 1969, the transportation industry has made significant advances in involving the public in transportation decision-making. With the advent of Context Sensitive Design or Context Sensitive Solutions (CSS), this public involvement was taken a step further by encouraging a collaborative approach to design (Newman et al. 2002). As stated in the core principles of CSS, engineers should "Strive towards a shared stakeholder vision to provide a basis for decisions" and "Foster continuing communication and collaboration to achieve consensus" (FHWA 2010).

CSS has been proven to integrate community input while ultimately saving time and money on many projects (Olszak et al. 2008). Although CSS instructs the designer to respect "community values" such as "safety, mobility, and the preservation of scenic, aesthetic, historic, [and] environmental" resources (MSHA 1998), the focus is typically on the context, or more so the surroundings, of the project. Value Engineering has been combined with CSS (Osman et al. 2007, Venner et al. 2007) by integrating the monetary value of costs and benefits of the project into the context-sensitive process. However, monetary values only scratch the surface of what matters to a community and the individual members within. Similarly, within CSS, the broad community values as identified by the designer and public processes typically focus only on specific projects. They do not go far enough to integrate the public's values into design.

Therefore, when identifying and designing new transit rider tools for OneBusAway, a transit information system developed for greater Seattle, we employed an approach from information and computer science disciplines called Value Sensitive Design (VSD). In VSD, a designer begins a project by looking at the human values the community possesses, allowing the designer and the public to envision a fuller range of possibilities.

5.2 DEFINITION OF VALUE SENSITIVE DESIGN (VSD) AND APPLICATION IN THE TRANSPORTATION INDUSTRY

Value Sensitive Design (VSD) is a principled approach for examining the set of values implicated in an information technology system (Friedman et al. 2006). The "values" in VSD refer to "what a person or group of people consider important in life" – things like freedom, community, or clean air. In order to investigate the impact on people's values, VSD integrates three types of investigations - conceptual, empirical and technical – in an iterative process. In the conceptual investigation, direct and indirect stakeholders, their values and the tensions among their values are identified. Direct stakeholders are those who interact directly with the final product. Indirect stakeholders are impacted by the product, but do not interact with it. Empirical investigations involve observations, interviews, surveys, literature reviews and measurements of user behavior, all to enhance the designers' understanding of the values implicated. Finally, technical investigations focus on the technology itself, ideally proactively during the design process.

OneBusAway is not the first application of VSD in the transportation sector. The design of UrbanSim, a simulation package for predicting patterns of urban development developed by Paul Waddell, Alan Borning and their colleagues, has been substantially influenced by the VSD methodology (Borning et al. 2008, Borning et al. 2005, Friedman et al. 2008). This is of particular relevance for this work, because the UrbanSim project faced a similar challenge with respect to prioritizing urban transportation and land use indicators and models.

5.3 APPLICATION OF VSD TO ONEBUSAWAY

Although the more than 40,000 unique weekly users of OneBusAway suggest it has been a success as a transit information system, the aspirations of the OneBusAway team are much bigger. We hope to develop an information system that can be relied on by transit riders in the many situations they face while using public transportation throughout the region and beyond.

The underlying goal of OneBusAway is to make it easier for riders to use public transportation and thereby increase rider satisfaction and increase transit ridership (Sinha 2003). Although we have developed applications beyond real-time arrivals (Watkins, et al. 2010), to date, the tools offered are based almost completely on our own experiences as riders, rather than on a comprehensive look at the potential user base. Because the developers of OneBusAway represent only a few types of riders on the transit system, we must expand our knowledge of riders' and other stakeholders' values and information needs in order to achieve our goal.

Rather than using VSD to evaluate a specific technological system, we are taking a more open-ended approach. When attempting to answer the question, "What do we build next?" we are faced with a lengthy list of potential applications. Which should we implement? Which would be most valuable to our community? Are we missing an important class of applications? We hope to use the VSD process to help inform these questions.

The general outline of the process undertaken to date can be broken into three major steps:

1) Identify the range of important stakeholders, both direct and indirect.

2) Map the set of benefits, harms, and pertinent values for the different stakeholders in the area of public transit through conceptual and empirical investigations.

3) Generate a list of potential transit applications as guided by the benefits, harms, and values identified in our initial investigations.

The remainder of this section describes in further detail the process outlined above as well as future work.

5.4 INITIAL CONCEPTUAL INVESTIGATION

Using the principles of VSD, the OneBusAway team first conducted a conceptual investigation listing groups of direct and indirect stakeholders. The direct stakeholders included various categories of riders, such as riders of different age groups, genders, and socio-economic groups, commuters and non-commuters, choice and captive riders, riders with access issues (blind, deaf, cognitive, wheelchair) and riders with accessories (bike, suitcase, stroller, packages). The indirect stakeholders included non-riders on various other modes, transit employees (bus drivers, general manager, transit planners / schedulers, GIS / data-source employees, field supervisors and dispatchers), and other members of the community (businesses, employers, advocates, citizens, elected officials). A preliminary list of the benefits, harms, and pertinent values for each of these groups was developed. The result of the conceptual investigation was a detailed description of the value trade-offs implicated by transit rider information tools, summarized below.

Many of the tools for OneBusAway, both existing and potential, aim at improving the efficiency and lowering the uncertainty of a rider's interaction with public transit. However, in the process of supporting the values of individual riders, we find these values can be in tension with a variety of other values. Rider **privacy** is an important value that is a source of tension for many of the current and future OneBusAway tools. These tools, from a basic text-message interface to a powerful location-aware smart-phone application, all leave bread-crumbs of personal location data as users interact with the system. Requesting real-time arrival information or planning a trip gives detailed information about the user's current location and travel patterns and raises questions about how OneBusAway is using and/or protecting that information.

Rider **accessibility**, **economic cost**, and **fairness** can be in tension with providing more efficient OneBusAway tools, as many of these potential tools could require increasingly advanced (and expensive) smart-phones. While the set of applications enabled by such devices are exciting, they leave out those riders who either cannot afford these devices or have trouble using them because of visual or other impairments. There is a larger question of fairness if we are developing tools that make public transit easier to use for only a subset of the total transit-using population. This tension can be mitigated by providing tools for a range of platforms (as we do already), but the experience of a user with a simple cell phone is nevertheless probably not as satisfying as that for a user with a smart phone. Further, we need to consider riders without access to the technology at all.

There are a number of values that are implicated by system accuracy, including **safety**, **comfort**, and **calmness**. For many of the tools, the end result is a more efficient transit experience *when the tools work correctly.* When the tools do not work correctly, it can make riders' trips take much longer and be more stressful, especially if they miss a bus. As the transit tools push the limits of the available real-time data, we also push the limits of how much confidence each rider can have in the results of the tools. Beyond simple data errors, there is the potential for users to game the system as well. For example, a tool that allows riders to crowd-source information concerning the status of bike racks or available wheelchair spaces on the bus could be gamed by riders who claim that both are full, when they are in fact empty, in order to discourage other riders with bikes or wheelchairs from taking a particular bus and slowing down the route.

Values of transit drivers can sometimes also be in tension with those of riders. Driver **safety** may be an issue for systems that require the driver to manually input vital stats about the bus, such as when the bus is full, when the bike rack is full, or when wheelchair spaces are taken. While such information could prove useful to riders in any number of tools, it requires an additional task of the driver, potentially involving input data into his or her management console and diverting attention from the road.

The **privacy** of transit drivers and transit agency **reputation** may also be in tension with rider efficiency. Many of the tools that share information about the on-time status of a particular bus or on-time statistics for an entire route may be useful to riders, but they also potentially make more transparent each driver's on-time performance along with the on-time performance of the agency overall. Drivers and the agency might not want this information made public. This trade-off is part of the overall tension between rider **trust** and **transparency** in OneBusAway tools and transit agency **accountability**, as building tools that are transparent for riders with regard to underlying transit information might require exposure of more information from the transit agency and hold them to a higher standard of accountability.

Agency **economic** interests may be in tension with rider tools that promote efficiency. These tools may be great for riders, but they can be costly to maintain for transit agencies. Even when third parties, such as the OneBusAway developers, are providing the tools, time and money must be spent preparing and maintaining the transit data feeds that power these tools. In fact, **economic** interests are often in tension with many of the values listed in our analysis, as one of the main road-blocks to potential solutions is often a financial barrier.

OneBusAway already supports the rider value of personal **safety** by providing tools that give real-time arrival information so a rider doesn't have to wait any longer than necessary for a bus. We could go further by providing information about the relative security of particular stops or even broader neighborhoods. While these tools directly address riders' value of **safety**, they may be in tension with rider **trust** and **accountability**, especially when the tools provide information that is incorrect. Furthermore, these tools might be in tension with the values of **community** and **privacy** if they give riders the ability to label stops, other bus-riders, particular drivers, or even entire neighborhoods as “sketchy” or “unsafe”, when in fact they may be relatively safe.

The value of **sustainability** is a motivating value to provide tools that increase the usability, and as result the overall use, of public transit. However, these values are often in tension with the values of **independence**, **self-respect**, and **self-image**. Many members of the community find a personal car to be more flexible and socially validating than the public transit alternative. A personal car may be easier to use for a broader range of trips. Car ownership might also be seen as a symbol of status when compared with riding the bus.

We have considered developing tools that work to build a social network around transit usage to increase the sense of **community** and **self-image** for transit-riders. However, such social network tools are often in conflict with the value of rider **privacy**, as these tools can potentially share considerable private information about individuals across their social networks.

5.5 EMPIRICAL INVESTIGATION

In order to better understand the human values implicated, the second portion of the project was an empirical investigation that built on the conceptual investigation described above. The process included a literature search and review of transit agency rider / non-rider surveys, a group forum and cultural probe with the King County Metro Transit Advisory Committee, and interviews with transit agency personnel. The focus of this empirical investigation was to refine the list of harms, benefits and values, as well as determine the types of transit rider tools that would increase satisfaction and the potential to ride.

5.5.1 Value Analysis of Rider / Non-rider Surveys

The first stage of the empirical investigation was to pull together a wealth of information on the reasons why people do and do not ride transit from reports produced by transit agencies across the US through on-board surveys and telephone surveys (Northwest Research Group 2001, Corey, Canapary & Galanis 2008, California DOT 2003, CUTR 2002, WestGroup Research 2004, Northwest Research Group 2007). The detailed notes from these surveys are summarized below.

These transit rider / non-rider surveys indicated that customers were concerned with the following improvements:

- On-time performance
- Frequency of service, especially at night
- Wait time when transferring
- Cleanliness of shelters
- Personal safety on bus after dark
- Travel time by bus
- Ability to get parking at park-n-ride lots
- Availability of seating / overcrowding
- Where routes go
- Inside cleanliness
- Driver operates safe / competent
- Personal safety waiting after dark
- Driver courtesy
- Number of stops bus makes
- Number of transfers to make
- Ability to get info from routes / schedules
- Driver helpfulness with route / stop
- Availability / difficulty with luggage, bikes

In addition to these, non-riders faced additional barriers to public transportation use. These were characteristics that they not only would like to see improved, such as those listed above, but things that were preventing them from choosing public transportation. This list included:

- I like my car
- Planning around bus schedules
- Have to transfer
- Need car for emergency / daytime travel / errands / kids

- Need to transport stuff
- No stop near work / home
- Not knowing how to use the system

5.5.2 Transit Advisory Committee: Bus Riders

The first stakeholder group in the study was the King County Metro (KCM) Transit Advisory Committee (TAC), a volunteer group of 15 diverse transit-riding citizens who advise KCM about future developments and changes to service. The TAC meets monthly in the evening at KCM headquarters. This interaction took place during the second half of their December 2009 meeting, which 10 members of the committee attended. The attendees ranged greatly in age (twenties to sixties) and transit usage (some commuter, some leisure, some transit dependent) with an approximately equal gender split.

5.5.2.1 Methodology

The interaction with the KCM TAC took the form of a modified futures workshop and cultural probe. In a futures workshop, participants are asked to critique an existing system, then to fantasize about how it could work and finally to think through steps to implementation (Kensing and Madsen 1991). Due to the limited amount of time, the typical futures workshop technique was modified to focus on evaluation of transit with less time devoted to fantasizing and implementation. Instead, more detailed questions leading to improvements were added to the cultural probe. A cultural probe is a kit that is taken home by participants, allowing them to record in some way their experiences related to the system being studied (Gaver et al. 1999). The cultural probe in this case consisted of lists, postcards and a map, described further below.

In the group forum we conducted, participants were asked to list their critiques and suggestions for the transit system aloud while these were recorded on a whiteboard. Questions included:

- What do you like about public transit?
- What do you hate about public transit?
- What is unique about how you use transit?
- What information do you need to ride the bus?

After this brainstorming session, each participant was left with a packet containing a series of fill-in-the-blank lists, a group of postcards and a map with sticky dots. The lists expanded on the questions asked in the group forum, instructing respondents to fill in 5 things for each question, including the 4 questions from the group forum listed above, as well as these 6 questions:

- What about public transit would you change?
- What about public transit would you keep the same?
- What are your tips and tricks for using transit?
- What frustrations do you have finding that information?
- What are your favorite websites and why?
- Which websites do you find easiest to use?

The preaddressed stamped postcards showed faces with various emotions (smart, disappointed, exhausted, resourceful, confused, annoyed, helpful, calm or peaceful, scared, happy, angry) with the phrase "Today, transit made me feel…" on one side and left space to tell us why on the other side. Examples of the postcards are shown in Figure 5.1.

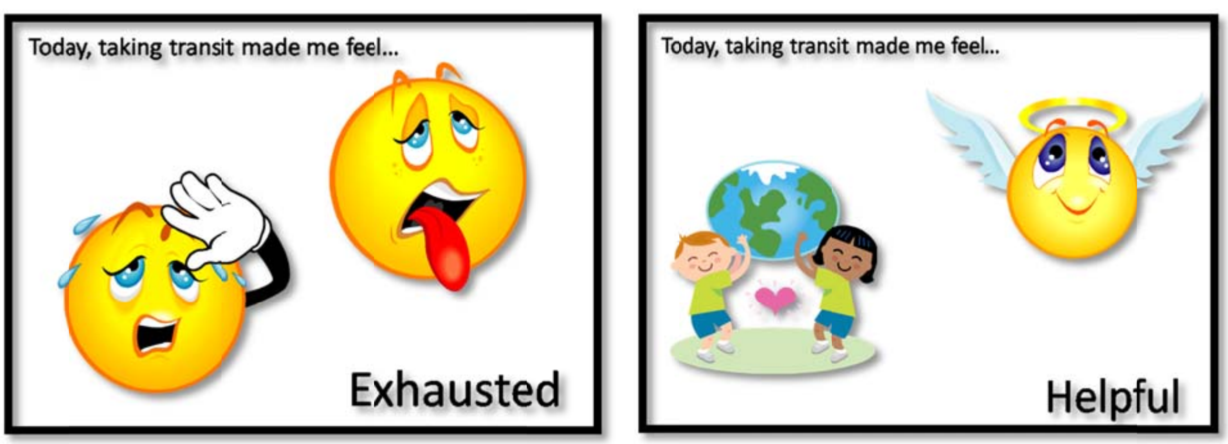

FIGURE 5.1 Example Postcards from the Transit Advisory Committee Cultural Probe

On the map of the KCM service area, respondents were asked to place different colored dots near:

- Where you live

- Where you go by bus to work or school
- Where you go by bus for shopping or entertainment
- Where you'd like to go by bus, but can't

In addition, they were given a crayon to draw areas of King County that are inaccessible by bus from where they lived. The map is shown in Figure 5.2.

Participants were asked to complete the materials in the packet over the course of the following month.

5.5.2.2 Results

Responses during the group forum tended to focus on the communal and economic benefits and harms of transit. For benefits, over half of the benefits listed involved community improvement or exploration. The remainder focused on the lower costs associated with transit and its environmentally positive aspects. Concerns regarding transit also focused on community issues, but lack of control dominated the list. Participants expressed concern about the unpredictability and unreliability of buses, as well as the limited possibilities inherent to a fixed route/schedule system. When questioned about what the participants felt was unique about the way they use transit, responses included multi-modal variants, complete dependence on transit and riding with additional accessories or children. In response to the information they needed to ride the bus, real-time information and routing were of primary interest. Further suggestions mentioned way-finding via common landmarks, as well as touch-screen capability.

Within a week of the meeting, responses to the cultural probe began arriving. In total, 8 surveys, 21 postcards and 6 maps were returned from the 10 participants who were present at the KCM TAC meeting. Responses ranged from being exceptionally verbose and detailed to single word descriptions.

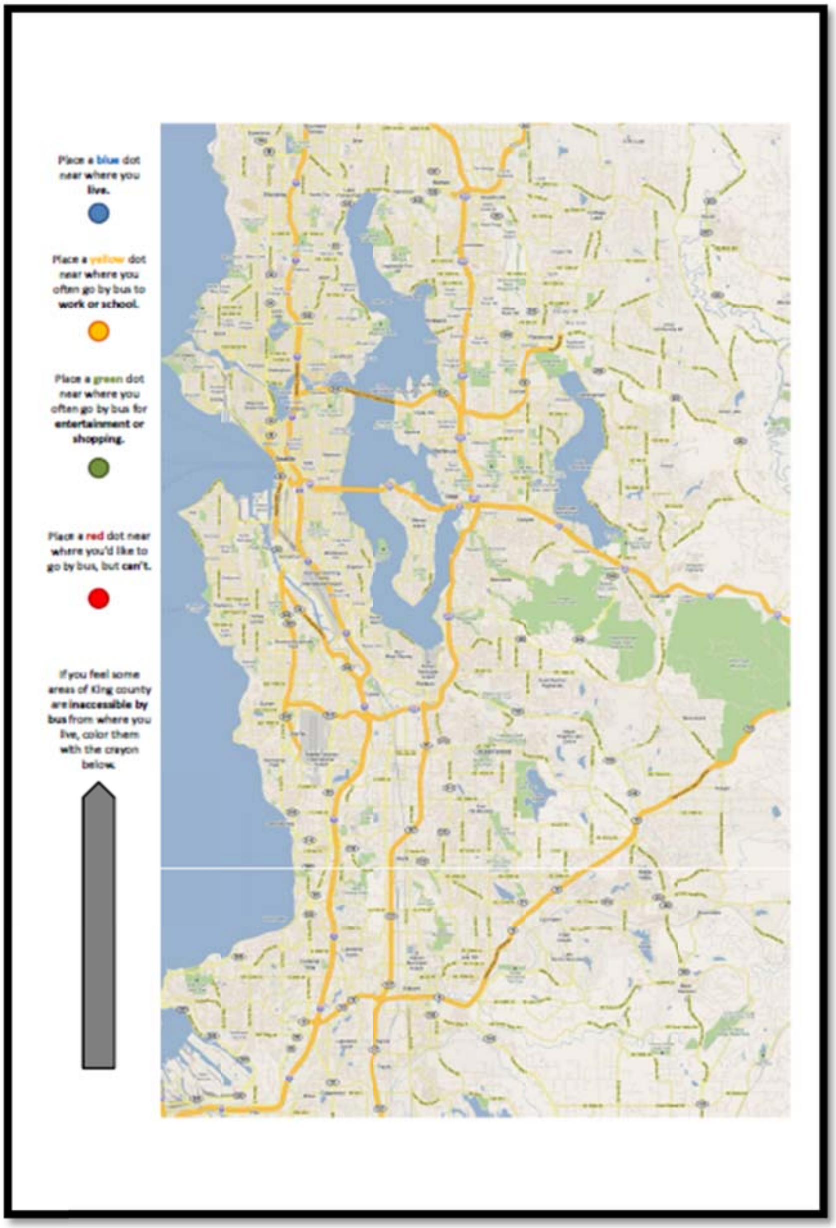

FIGURE 5.2 Map from the Transit Advisory Committee Cultural Probe

Participants were most diligent in filling out the surveys, providing detailed responses to each of the questions. These responses were perhaps easiest to convert into user needs and desires, as the participants were directly solicited for the benefits and harms associated with their transit riding experience. The benefits expressed were similar to those elicited in the futures workshop, save for an additional benefit of overall system efficiency. Harms were listed in greater detail than those obtained from the group session; however the overall trends remained the same. An additional component was the importance of bus drivers to the overall transit experience. Responses regarding useful information for transit use included communication forms that do not require a smart phone and information regarding the current conditions of an upcoming bus. Relatively few additional insights were obtained from questions that asked for tips and tricks and usable websites, in part due to a lower response rate.

Postcards returned as part of the cultural probe were harder to interpret, but reinforced certain issues that have been brought up in list form. Responses were sometimes detailed: "Today transit made me feel Angry. Surly driver (Rt 66) did not respond to 'Good Morning' and did not call out stops - did not apologize when sudden jerk made passenger almost fall" to brief – "Today transit made me feel WET!". To interpret these postcards, our group attempted to understand the deeper issue behind the feelings expressed by the participants. For example, the "Angry" card suggested that there should be some better means of allowing for communication between riders and drivers (perhaps at times other than in the heat of the moment). However, other cards ("WET!") were simply taken at face value.

Given the small number of responses (N=6), the maps were challenging to interpret and were therefore set aside. That said, we found the maps as a data collection method intriguing and we intend to use this method again with a larger group in future studies. Despite the lack of information from specific colorings and dots on the map, the notes found on some of the more detailed maps gave some additional hints to potential improvements. These notes were considered, along with the harms and benefits obtained from the probes and forums, during the technical brainstorming session described later.

5.5.3 Bus Driver Interviews

In addition to the direct stakeholder group forum and cultural probe, we interviewed several key indirect stakeholders in the transit rider tool building process. The intent of these interviews was to obtain information about how rider tools may affect indirect stakeholders, such as bus drivers or other transit employees. In addition to some informal interviews with planning and engineering staff, 6 semi-structured interviews were conducted with bus drivers recruited through the Amalgamated Transit Union for KCM. The interviews were scheduled in advance over the phone and took place in local restaurants or on the bus during a layover. All interviewees were male in their thirties to fifties.

5.5.3.1 Methodology

At the beginning of the interview, the bus drivers were asked several warmup questions, including:

- What are the 5 best things about driving a bus?
- What are the 5 worst things about driving a bus?
- What would you change about driving a bus given the chance?
- What would you leave the same about driving a bus?

They were then asked a series of rider information needs questions, including:

- What kinds of information do riders typically ask you for?
- How frequently do you get these types of questions?
- What kind of information should KCM provide to riders?

The follow-up included several questions pertaining to their values of safety and privacy.

They were first asked to detail the types of things they currently have to do while operating a bus and their ability to add an additional task. They were then asked their opinions about real-time information, including the value to passengers and the potential violation of their privacy by providing the information as countdown to arrival as well as a historic on-time status for that particular bus. The interview also included a series of questions about running "hot" (i.e., ahead of schedule), and the impact that real-time information might have on this.

The interview concluded by giving the bus drivers an opportunity to share other benefits or harms that they could foresee from providing greater rider information.

5.5.3.2 Results

The themes regarding the best aspects of driving a bus revolved around social interaction and independence. Drivers enjoyed "meeting people you wouldn't normally meet" and being able to "leave their job at work". However, this independence was countered by what was considered the worst aspect – management and policy's interference with their ability to do their job well. Things like "draconian rules" and "a 180 page contract" made their job stressful. Aspects of the job they would want to change touched on this same theme, with reduced political interference and improved interaction with other parts of KCM topping the list.

The drivers thought KCM should be providing basic and advanced trip planning components and next bus information. However, the drivers also specifically mentioned providing ways the public can impact the service, fare payment information, and effective rider alerts. One driver commented that "rider alerts should be more effective", including an "interactive system to get the word out about known closures". They made specific suggestions about interior stop announcement signs including alerts and materials to encourage transit access to attractions.

There were a range of views regarding drivers needing to push a button to provide greater information about a full bus, full racks, etc. – some felt they would remember and others did not think they would always remember – or that some drivers at least would not remember. Most importantly, unless drivers felt strongly about the benefits of information the extra effort produced, they wouldn't even try to remember. Drivers considered the idea of providing the information good, but they weren't sure it would make a difference to most riders. Drivers guessed that if a rider sits at their desk an extra minute because of a full bus, then that would help the entire system, but if a rider was already at the corner, most of them would still climb on despite knowing that another, emptier bus is coming in just a minute. Drivers also felt that this information needed to be 100% accurate, otherwise no one would use it.

For both early and late buses, drivers alter how they drive to match the schedule. There was some discrepancy about how accurately drivers know that they are on-schedule. If they are significantly early, they will sometimes pull over and sit, but this is psychologically painful for them and the riders, so they try not to. Instead they drive very slowly and follow guidelines painstakingly, such as allowing all passengers to sit before they start to drive.

Some participants thought drivers would adhere to the schedule more if people were more aware of on-time status, but others thought that this might actually make on-time status worse. Currently, drivers will purposefully run late or early at the beginning of a route because they know what will happen further down the line. They attempt to drive so that most of the route is on-time using their knowledge of historic traffic and the day's events.

Early running may stop completely, but late running might increase. Likewise, the practice of leaving late might stop, but drivers would end up sitting at a stop, which riders do not like. If drivers are given pressure to stay on-time at all the stops, this may put more pressure on the schedulers as well.

The current vehicle location technology was considered not accurate enough, but providing next bus information was considered highly important to riders, especially in the city where "people have options for their wait time". However, caution in the use of real-time information was emphasized because drivers can get back on schedule after a rider has looked at the information. So, riders always need to plan for a couple of minutes before the anticipated arrival time. None of the drivers saw real-time arrivals as a violation of their privacy and indicated that "it is part of my job to perform in the public eye". However, information about the percent of on-time arrivals historically for a route was seen as a violation of their privacy. Many worried that this would lead to disciplinary action over something the driver is unable to control. It could also increase public confrontation with drivers, such as an in-your-face passenger asking them "Why are you always late?"

Feelings on the "rate my stop/route/driver" were mixed. Drivers felt that any ratings would have to be anonymous and not considered in any disciplinary action by the agency. One driver felt it wouldn't be a bad thing to "let drivers know they were considered grumpy", but another was worried that the public might not use it in the right way. In general, they were worried about discipline coming out of tools and possible physical or mental harm from rowdy passengers. This ties to stress on the job being listed as another worst aspect of the job during the warm-up section of the interview.

The bus drivers really wanted to have OBA type tools on their console, so they could help passengers. Indeed, another aspect listed to change during the warm-up questions was to provide more information to the drivers to enable them to answer passenger questions. Or, they would like to have OBA type tools in an on-bus kiosk, so passengers could help themselves get information about where to get off or the timing of their transfer.

5.6 TECHNICAL BRAINSTORMING

Through our conceptual and empirical analyses, we have identified a number of harms and benefits arising from various aspects of public transit that affect the different stakeholders in our study. We are taking a broad look at the set of all potential technical solutions, so that we might make an informed decision about which solution to implement given our limited resources. This is in contrast to a typical method that might focus the study on one specific technical solution that might address one of the identified harms or benefits.

Part of that informed decision process involved constructing an extensive list of potential technical solutions. We generated the list through a brainstorming process guided by the results of our conceptual and empirical investigations. Some of the results of our empirical investigations are directly translatable into technical solutions. For example, the "Information Tools" sections of our cultural probes study solicited feedback such as "Trip planning for primary and return trip", which is a direct deliverable in terms of a technical solution we could implement.

However, not all the results from our conceptual and empirical investigations were immediately translatable to technical solutions. For example, in a list of positive aspects of public transit, a user listed "More social activity - can talk with fellow passengers, children." Here, there is nothing wrong with public transit that needs fixing. Instead, we can imagine a class of applications that supports the existing positive activity. That led us to suggest an application to support transit social networking, allowing riders with similar interests (mothers with children, a book club) to coordinate their riding.

Of course, users also listed a number of negative aspects of public transit: –"Get rid of rude, surly drivers", "Violence / disturbances on the bus", and "Loud, rowdy passengers" are a couple of examples. These issues could be addressed through a "Rate My Route" application that allows users to provide feedback on various aspects of their transit experience and make decisions about which trips they take based on that feedback. However, such an application is subject to many value tensions discussed previously. Although it would benefit some riders, the problems may increase for remaining riders on a route. Therefore, if such an application was pursued, it would have to be with careful and continuing value sensitive design process input.

Some problems listed by riders are not ones we can fix directly. Some riders asked for more dedicated right-of-way (ROW) for transit vehicles and more frequent buses, especially during evenings and weekends. Though we can't provide more ROW or more buses ourselves, we can turn the problem around, and provide applications that highlight where service is available. This might be a commute calculator application that suggests the level of transit service at various places in the area, or a last call app that notifies you when the last bus of the night is about to depart.

When our brainstorming process was complete, we had collected a list of over 75 potential applications. We will not discuss the full list of potential applications here. Instead, the list of potential technical applications can be roughly grouped into 7 categories. We discuss those categories below, along with a few examples for each category.

5.6.1 Social Engagement

A number of applications would support increased social interaction and engagement amongst users of public transit. Example applications might encourage and enable riders to organize book clubs for riders of a particular route, or allow mothers with children who ride the bus to match their schedules so they might ride together, creating an ad-hoc social network for this group.

Another major application that fell in this category was the set of "Rate my Route" tools. This application would allow riders to rate various aspects of their transit experience: ride quality, the driver, the route, the area, and stops. Feedback would be shared amongst all riders to allow them to make better decisions about using public transit.

5.6.2 Transit-use Incentives

A number of applications worked to encourage riders to use public transit more often or to be more community-minded through various incentive systems. A typical example was an interactive game where riders were awarded points based on how often they used transit. Special "merit badges" would be awarded for completing specific tasks such as "visiting all the light rail stops" or "giving up your seat on a crowded bus to another rider". This category of applications uses a variety of incentives such as games or perhaps rewards from sponsoring retailers to encourage transit usage.

5.6.3 Trip Planning Tools

A number of applications were suggested to improve the capabilities of trip planners, including over-all usability improvements, and adding new data sources such as historical and real-time performance data.

5.6.4 General Planning Tools

This category of applications supports high-level planning of the use of public transit and, more generally, the impact of transportation in general on the wider community. These applications are distinct from trip planning applications, because they focus less on planning a specific trip using public transit and more on the class of trips enabled by public transit in general. These applications include various calculator applications that allow one to easily visualize the various financial, environmental, social, and traffic congestion impacts of various transportation modes. Such tools might help riders plan a better commute based on various impacts or pick a new place to live entirely.

5.6.5 Maps and Information Tools

Many of the suggested applications focused on improving maps and other information display systems used in public transit. Changes were suggested for route maps to support better local context through detailed street names. A customizable map-maker application was suggested to create maps targeted to certain neighborhoods, tasks, or class of users. Applications in this category generally focused on providing general information about basic transit service through maps and other formats.

5.6.6 Notifications

This category of applications focused on notification capabilities. Being able to automatically notify riders when their stop is coming up or when their bus is running late were all frequently-request example notification applications. In addition to notifying riders, a number of applications in this category would offer the ability for riders to notify the transit agency of problems such as buses or stops that needed cleaning.

5.6.7 Accessibility

Many of the applications in our list directly address the issue of improving the accessibility of public transit. They included issues of general accessibility, such as providing features across a variety of mobile devices instead of just smart-phones. They also included specific issues of accessibility, such as providing tools for blind and deaf-blind riders, and improving the functionality of the paratransit system.

5.7 RESULTING APPLICATIONS

The results of the initial round of investigations have left us with both a lengthy list of potential tools to develop and a beginning list of how those tools might impact direct and indirect stakeholder values. Recognizing that we do not have the time or resources to develop *all* the specified applications, we have to decide about the prioritization of the various potential applications. While a developer might typically just pursue the application that "seems cool", we would like to follow a more principled prioritization strategy.

Looking to the work of Friedman et al. (2006) for inspiration, our prioritization is using a triangulation of three aspects when making a decision about the relative merits of a particular application:

1) Stakeholder concerns and values impacted
2) Stakeholder dependence on transit (ranging from occasional choice riders to those completely reliant on transit for basic mobility)
3) Technical feasibility and availability of resources for development

Stakeholder concerns and values encompass all the harms, benefits, and values we have identified in our conceptual and empirical analysis and how they are served by a particular application. To continue to assess these, our follow-up work will focus more on the relative importance of various concerns and values amongst our stakeholders. We are evaluating the relative importance in a number of ways. For riders, we are gathering comparative information using an online feedback page at http://onebusaway.ideascale.com/. In addition, as the primary indirect stakeholder group that both strongly impacts the rider experience and is also affected by these new tools, we sent out a survey to 500 bus drivers in

July 2010, drawing on the interview results described previously. The results from this survey are forthcoming.

Following these surveys, we have begun a value dams and flows analysis (Miller et al. 2007) to conduct the first leg of our triangle - stakeholder concerns and values. In this analysis, value dams would be potential rider information tools or components of those tools that are strongly opposed by a set of stakeholders, even if that group is small. Value flows are potential rider information tools or components of tools that a large percentage of stakeholders would like to see included.

The relative dependence upon transit by the stakeholders implicated in a particular transit application is also an important element in our prioritization. All other things being equal, a solution that benefits a large population of riders will generally be preferred to an application that benefits just a few riders. However, some riders are more dependent on transit than others, and we would like to reflect that in our prioritization. For example, an application that benefits a smaller population of blind riders who are totally reliant on public transit might be prioritized over an application targeted at a larger population of choice riders who are not dependent on public transit at all.

Finally, we consider the technical pragmatics of each solution, including technical feasibility, funding, and availability of software developers. For example, some solutions are more technically difficult to implement, others more expensive. These technical pragmatics are a third factor in our prioritization scheme.

The elements described above do not give a straightforward formula for defining a prioritization of the various transit applications we have proposed. Rather, the prioritization will be a judgment call on the part of the implementers. However, we hope that by calling out the different elements to consider when prioritizing, we can come to a more principled prioritization that does not miss any major aspects of the issues at hand.

As a result of the VSD analysis, the two projects that have been pursued immediately are integration of trip planning with real time arrival information and the integration of service alerts with all transit rider information. In order to pursue the first project, the developer of OneBusAway has partnered with the OpenTripPlanner project to work on an open-source coded trip planner that is capable of integrating real time arrivals. For the second project, the OneBusAway team is working with transit agencies in greater Seattle-

Tacoma to improve notification of service alerts and availability of service alert information, including integration into real time arrival information. Both of these projects have been emphasized by bus drivers and riders alike as critical to the transit experience. Neither project is believed to have critical value dams. Finally, both touch on improving the experience for blind riders, who are particularly reliant on receiving accurate and timely information when a bus trip is at all delayed or detoured.

In addition, OneBusAway has renewed a commitment to providing real time arrivals via website, cell phone and text-message, the media which are less expensive and more widely available for riders of lower economic means.

5.8 CONCLUSIONS

Invoking the VSD approach for the design of OneBusAway has significantly changed the overarching goals of the project. Before using the VSD approach, our focus was on developing new tools and many of these tools were for high-end smart phones. We had also considered applications which rate drivers or neighborhoods or provide historical arrival information. These applications were found to have severe value dams because of their potential negative impact on bus drivers and some groups of transit riders. Instead, our emphasis has been placed on providing integrated tools on all media, especially service alert notification and integration.

The consideration of indirect stakeholders has revealed the full spectrum of impact that OneBusAway may potentially have. One of the most significant impacts is the consideration of transit drivers in the design. Through bus driver interviews and value tension analyses, it became apparent that the successes of OneBusAway improvements are strongly affected by their acceptance by drivers, who are the primary interface between riders and the transit system. Further, basic questions of fairness dictate that we should consider the views and values of drivers in any case, as a group strongly affected by such technology. Finally, VSD has allowed for a more systematic design process that scrutinized the original plans for the potential improvements to OneBusAway, allowing for a more comprehensive solution approach.

Although VSD has to date been used primarily in the design of information technology, there are many other applications within the world of transportation where it could be useful. At the core of VSD is the idea that we should systematically identify the values of stakeholders and take time to envision the value tensions that may be created by any design, whether technological or otherwise. OneBusAway, as an application of technology to solve transportation problems, was a natural use of VSD. However, the principles of VSD can be applied throughout the transportation industry, especially when considering broader transportation planning goals.

Context Sensitive Solutions has greatly improved the integration of community values into transportation design, yet its primary focus remains the context or surroundings of a corridor. Moreover, even with the name change to context sensitive "solutions" rather than "design", the focus of the process is still typically on specific projects rather than on overall mobility and access solutions. CSS has allowed us, as transportation engineers and planners, to think beyond the books, but not yet to step outside our box. As we strive for livability, it is imperative that we consider the human values of both the users of the transportation system and the other indirect stakeholders impacted by transportation.

Section 6
Impact of real-time transit information tools on bus drivers

6.1 INTRODUCTION

As discussed in the previous sections, transit users value knowing how long their wait is or whether they have just missed the last bus. However, although it is obvious that greater information has a positive effect on transit riders, no studies to date have focused on bus drivers' impressions of real-time information or other potential information tools. Through the earlier VSD process described in Section 5, it became apparent that there was one major group of indirect stakeholders that should have a larger stake in the process - the bus drivers.

The overall goal of the VSD process within OneBusAway is to investigate and rank potential rider information tools based on many factors, such as how often they would be used by riders, how big of a difference they would make in gaining new transit riders or in improving the experience for existing riders, and how they would affect the job of bus drivers and other transit employees. Often such tools are implemented without the input of the bus drivers who have day-to-day contact with the riders and know them the best. Therefore, in order to learn about bus driver's views and values regarding potential rider information tools, a set of semi-structured interviews and a survey were conducted. While the primary intent of the survey was to ask about future transit rider applications, drivers' reactions to the existing use of real-time information were probed as well.

6.2 LITERATURE REVIEW

The health and psychology literature has done a fairly thorough job of establishing the links between characteristics of the work environment and the health of transit operators (Cunradi et al., 2005; Ragland et al., 1998; Rydstedt et al., 1998). In addition, multiple studies have been conducted to investigate the ties between bus driver performance and safety while riding public transportation (Blower et al., 2008; Chen et al., 2008; Palacio et al., 2009; Rey et al., 2002; Wahlberg, 2008; Wahlberg and Dorn, 2009). Research has even combined the two, looking at the impact of health and wellness among commercial drivers as related to traffic safety (Krueger et al., 2007). However, little research has been done related to bus drivers outside the areas of health effects and traffic safety.

In their review of literature related to bus driver well-being, Tse, Flin and Mearns conclude that the burden from traffic, violent passengers and tight running schedules affect drivers severely and that these job stressors cannot simply be written-off as part of the job of an urban transit driver (Tse et al., 2006). It seems critical then that drivers' values and the potential harms and benefits to them should be considered as part of any new implementation of technology.

The one study that looked at the effects of real-time vehicle location information on transit operators was done by Lee, Chon, et al using data from MTA in Baltimore, Maryland. Their investigation showed that schedule adherence was improved after implementation of intervention from an automatic vehicle location system (Lee et al., 2001). A self-report survey conducted as part of the study showed that 29 of 40 drivers always or almost always check their schedule at each time point; 30 of 40 drivers drag the line to get back on schedule if they are running ahead; and 31 of 40 drivers try to adjust speed to get back on schedule if they are running late.

6.3 METHODOLOGY

The semi-structured interviews have provided an expanded understanding of the values, harms and benefits from rider information tools. However, understanding how widely held these beliefs are requires a statistically robust survey of bus drivers. The information from this survey allows the OneBusAway team to use a value dams and flows analysis (Miller et al., 2007) to help determine which riders information tools should be pursued and in what order. In this analysis, value dams would be potential rider information tools or components of those tools that are strongly opposed by a set of stakeholders, even if that group is small. A small group of strongly opposed stakeholders can cause a project to fail. Value flows are potential rider information tools or components of tools that a large percentage of stakeholders would like to see included. As the primary indirect stakeholder group that impacts the rider experience, the bus operators' opinions are critical to the analysis.

In June and July of 2010, a survey of bus drivers was conducted. The paper survey instrument was mailed out to 500 drivers randomly selected from the Amalgamated Transit Union (ATU) Local 587's database of 2,769 drivers who work for King County Metro in greater Seattle, Washington. Because of the sensitivity of the driver's personal information, the randomly selected addresses were given to a mailing services company that routinely works with the union rather than the study researchers. Responses were completely confidential with no return address or identification of any type.

Prior to survey distribution, the survey was mentioned in the monthly ATU newsletter. Several days before the survey instrument was mailed out, a pre-letter was mailed to all survey recipients giving them notice that a survey was coming in the mail. The survey instrument included a letter of explanation and a $2 bill as a small incentive and thank you for their response. A week after the survey was mailed out, a follow-up postcard was mailed to the recipients to remind them about the survey. A few months after the survey, another notice was posted in the ATU monthly newsletter thanking the participants and asking if any non-respondents needed another copy of the survey.

All of these techniques, including repeated contact through pre-letter, survey and follow-up postcard and the small monetary incentive, were included in order to increase the response rate to have a representative sample, as suggested by the Tailored Design Method (Dillman, Smyth, et al 2009) In total, there were 255 surveys returned, 2 of which were returned completely blank. The remaining 253 surveys were substantially complete, equating to a response ratio of over 50%. 127 surveys were returned in the first few days of the survey before the follow-up postcard was mailed out. Another 85 surveys were returned in the week after the follow-up postcard. The remainder were returned in the second half of July (33 surveys), August (7 surveys), September (1 survey), October (1 survey) and November (1 survey).

As shown in Table 6.1, of the drivers who responded to the survey, 75% were male. The number of years of experience was roughly broken into quarters with approximately a quarter (26%) that had worked as a bus driver for 20 or more years, 23% that had worked 10 to 19 years, 25% that had worked 5 to 9 years and 25% that had worked less than 5 years. The median age of drivers fell in the range of 50 to 59 years, with 43% of the respondents in this category. As shown by the Chi-Square Goodness of Fit Tests, the survey responses were a representative sample of the actual bus driver population.

TABLE 6.1 Survey Response and Driver Population by Category

	All Bus Drivers (N=2687)		Survey Respondents (N=252)		Chi-Square Goodness of Fit Test
Gender	**N**	**%**	**N**	**%**	$\chi^2 = 0.640$, 1 d.f. $p = 0.424$
Female	607	23%	62	25%	
Male	2080	77%	189	75%	
Years of Experience	**N**	**%**	**N**	**%**	$\chi^2 = 6.168$, 4 d.f. $p = 0.187$
Less than 5	780	29%	63	25%	
5 to 9	598	22%	62	25%	
10 to 14	458	17%	34	13%	
15 to 19	249	9%	26	10%	
More than 20	602	22%	67	27%	
Age	**N**	**%**	**N**	**%**	$\chi^2 = 5.704$, 4 d.f. $p = 0.222$
Less than 30	69	3%	6	2%	
30 to 39	306	11%	20	8%	
40 to 49	693	26%	56	22%	
50 to 59	1052	39%	108	43%	
60 or more	567	21%	60	24%	

All questions in the survey were tested for differences in responses based on years of experience, age of the bus driver, gender of the bus driver and frequent PM peak or night drivers, and results were corrected for multiple comparisons using Holm's sequential Bonferroni method (Holm 1979). All significant results are discussed along with each question in the results section below.

6.4 RESULTS

The survey began by asking bus drivers about the questions they are asked by riders and how they feel about being asked such questions. For the first, drivers ranked each type of rider question as being asked several times per hour, about once per hour, several times per day, about once per day, at least once per week, not very often or almost never. Questions were grouped as those about how to get to a certain location, those about bus arrivals, those about schedules, and those about safety. Table 6.2 shows the responses to the frequency that drivers are asked questions about trip planning, bus arrivals, schedules and safety. Most drivers felt trip planning type questions (How do I get downtown? Does this bus go to the University District?) were the most predominant, with 90% responding that they are asked trip planning questions at least once per day. Questions about bus arrival

(Where is the #65 bus? How long until the #71 bus?) and schedules (When will we get to Northgate Mall?) were the next most frequent with 74% indicating they are asked bus arrival questions at least once per day and 69% indicating they are asked schedule questions at least once per day. Safety questions (Is this a safe stop at which to wait?) are substantially less frequent with only 3% being asked such questions on a daily basis. However, bus drivers who drive frequently at night (10 PM to 6 AM) were more likely to indicate that they are asked questions (Kruskal-Wallis, χ^2=16.56 to 18.52, 1 d.f., p=0.0001 for all), including questions about safety. 12% of Night drivers indicated that they are asked questions about safety at least once per day compared to 0% of non-Night drivers.

Table 6.2 Frequency of which bus drivers are asked questions about trip planning, bus arrivals, schedules and safety

	Trip planning questions such as “How do I get to XXX?” or “Does this bus go to XXX?”		Bus arrivals such as “Where is the ### bus?” or “How long until the ### bus?”		Schedules such as “When will I get to YYY?” where YYY is a certain location such as the downtown?		Safety of bus stops or areas of town such as “Is this a safe stop to wait for the next bus?” or “Is route ### safe?”	
Several times per hour	58	23%	29	11%	19	8%	0	0%
About once per hour	34	13%	25	10%	26	10%	0	0%
Several times per day	112	44%	90	36%	68	27%	3	1%
About once per day	25	10%	44	17%	62	25%	6	2%
At least once per week	14	6%	35	14%	33	13%	19	8%
Not very often	7	3%	25	10%	35	14%	77	30%
Almost never	1	0%	3	1%	7	3%	146	58%
No answer	2	1%	2	1%	3	1%	2	1%
Total	**253**	**100%**	**253**	**100%**	**253**	**100%**	**253**	**100%**

In a related free-form question, drivers stated what other types of questions they are frequently asked. Many indicated they received fare-related questions (71 drivers) such as “What is the cost of the trip?” or “Where does the ride-free zone end?” Others (23 drivers) expanded on the schedule question above to point out related questions about the arrival of the last bus, frequencies of buses or weekend or holiday service. Drivers also expanded on trip planning type questions that were related to specific local information, such as local destinations (16 drivers), stop locations (11 drivers) or transfers (14 drivers). Questions about the current time were mentioned by 18 drivers. Another 21 drivers indicated that they are asked about service alert type questions such as "Why are you late?" or "Why has the ### bus not shown up?" Destination alerts were listed by 4 drivers ("Can you tell me when we get to XXX?"). Finally, a few drivers mentioned questions about future service changes, service planning or routing. Of course, some questions will always remain a part of driving the bus, such as personal questions ("How do you like driving? Where is your accent from?") or question related to passenger comfort ("Can you turn down the heat? Do you have a paper towel?")

As a follow-up question to set the stage for the rest of the survey, drivers were asked how they felt about being asked questions. They were given three ideas, with Idea 1 representing a more negative response toward being asked questions, Idea 2 representing a more positive response, and Idea 3 being more neutral toward being asked questions. Prior experience with VSD methods (Kahn 1999) has shown that presenting multiple ideas that participants can select among, rather than just presenting one idea and asking for a reaction to it, leads to richer and more accurate interview data. As shown in Table 6.3, most drivers (66%) are neutral about questions, stating it is a part of their job. Few drivers (8%) said they would miss being asked questions. Based on Kruskal-Wallis tests of equality, these feelings about being asked questions were not associated with the frequency of which questions were asked by riders.

TABLE 6.3 Drivers feelings about being asked questions

IDEA 1: Some drivers say it would be great if riders asked fewer questions because they could spend more time focusing on other parts of their job and may be able to speed up bus service.	63	25%
IDEA 2: Other drivers say they enjoy interacting with passengers and would miss the chance to answer questions about taking the bus if people got their information elsewhere.	21	8%
IDEA 3: Other drivers say that answering questions is part of their job and even with new information sources, people will always ask them a lot of questions.	168	66%
No answer	1	0%
Total	253	100%

6.4.1 Existing Rider Information Applications

The next set of questions related to the existing applications that give real-time information in greater Seattle, applications such as OneBusAway, King County Metro's own

Tracker application and related programs such as MyBus. In response to being aware of existing applications that are available to provide real-time arrival information, most drivers were at least aware that such information is available to the public (82%). Of the 253 respondents, nearly half (46%) of the drivers in the survey had seen the tools being used, had spoken with riders who use them or (as indicated in the comments to the question) had used the tools themselves. Results are shown in Figure 6.1.

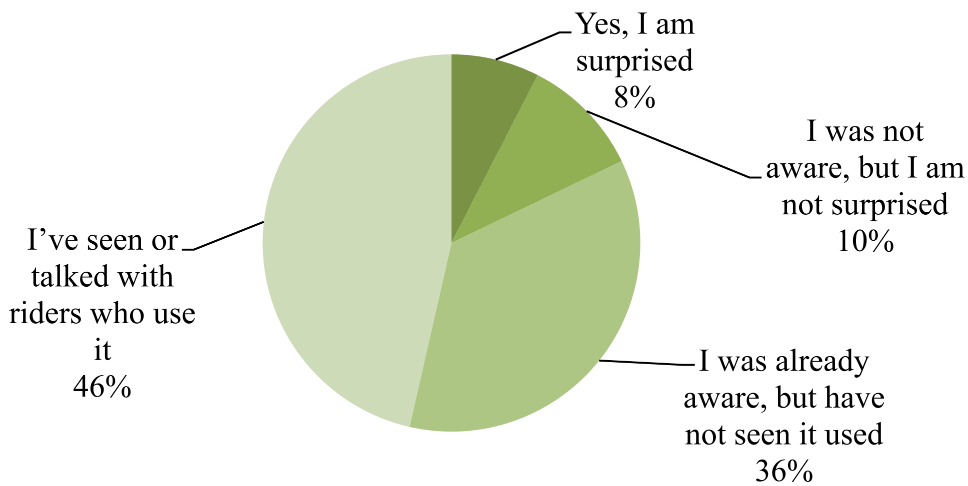

FIGURE 6.1 Response to question "Are you surprised to learn that [real-time arrival] information is available to the public?"

In terms of how the drivers feel about such information being provided, the response was mostly positive. To gauge this response, drivers were asked two questions, one which inquired about their feelings and one which asked them to choose one of three ideas. For the emotion question, drivers were asked to check off how they feel from a list of 9 possible feelings, 3 of which were positive ("That's cool", "Relieved" and "Excited"), 3 of which were neutral ("So what?" "Doesn't hurt anyone" and "Uninterested") and 3 of which were negative ("Shocked", "Worried" and "Invades my privacy"). Almost all drivers (93%) selected only positive or neutral responses to the information being provided. Only positive emotions were chosen by 67% of the drivers. The second question asked drivers to choose between three ideas, 1 of which was positive, 1 of which was neutral and 1 of which was negative:

IDEA 1: Some drivers say it's OK that next bus arrival information is available to the public because trying to keep the schedule is part of their job, and riders already know whether or not their bus is on time. (Neutral)

IDEA 2: Other drivers find it troubling that this information is available to the public, because it reflects on how well they do their job and may cause issues with riders or management. (Negative)

IDEA 3: Still other drivers really like having this information available, because it improves the experience for riders, and happier riders make their job easier. (Positive)

Almost all drivers (91%) were positive or neutral. The positive idea was chosen by 57% of the drivers. Results for responses to both questions are shown in Figure 6.2. For each feeling (positive, neutral, negative), the first bar shows respondents who chose only that feeling in the emotion question (i.e., only "Cool", "Relieved" or "Excited" if shown as positive), the second bar shows respondents who chose any emotion associated with that feeling (i.e., "Cool", "Relieved" and / or "Excited" and possibly also another emotion) and the third bar shows the results from the idea questions. For both questions related to drivers' feelings about real-time information, the response was overwhelmingly positive.

Responses to the two questions about existing real-time information were highly related. For example, among those who selected the positive option (Idea 3) on the idea question, 91% also selected at least one positive response on the emotion question, while among those who selected the negative option (Idea 2) on the idea question, only 40% selected at least one positive emotion. Drivers who selected the positive or neutral options (Idea 1 or 3) on the idea question very rarely selected any negative emotions (3%), while 33% of drivers who selected the negative idea (Idea 2) also selected at least one negative emotion.

Treating responses to the idea question as an ordinal variable (from negative to positive), responses were positively associated with the number of positive emotions selected (Kendall's tau-b = 0.211, $p<0.0005$), negatively associated with the number of neutral emotions (tau-b = -0.133, p = 0.031), and negatively associated with the number of negative emotions selected (tau-b = -0.172, p = 0.005)

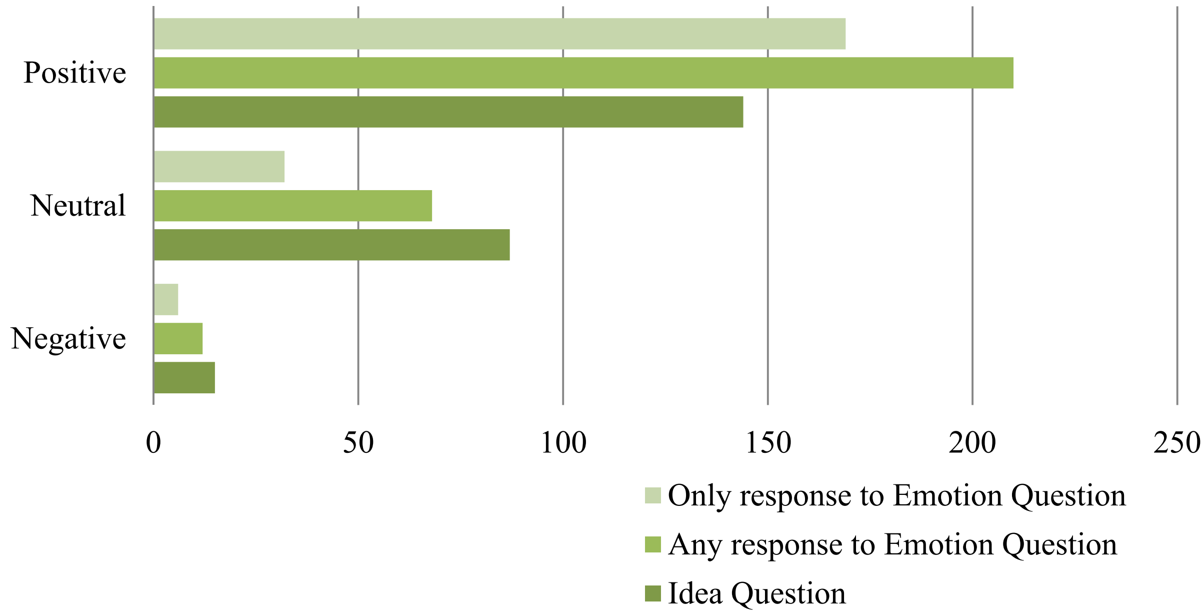

FIGURE 6.2 Responses to questions about how drivers feel about real time information

Drivers who were not aware that real-time arrival information was available to the public were more likely to select the negative response to the idea question than drivers who were aware (18% vs. 3%, respectively, p=0.002, Fisher's exact test). Similarly, drivers who were not aware were more likely to select at least one negative response to the emotion question (13% vs. 3%, p=0.010, Fisher's exact test). The drivers who had a negative opinion of providing real-time arrivals were more likely to be the ones who were not aware of the existence of real-time information, especially those who were neither aware of it and were also surprised that it existed.

6.4.2 Future Rider Information Applications

The next set of questions revolved around driver's opinions about types of future applications that could be built. Six general applications were asked throughout the remainder of the survey. Five were in this section and a sixth was in the final section on blind and deaf-blind riders. Although these six applications are far from the bulk of potential applications that could be built to inform transit riders, they were chosen because they represent the six areas that are most likely to affect bus drivers.

Each of the applications was investigated to see if drivers thought the application should be built or not. The first two applications related to data that the public would input, including physical issues at stops, shelters, or on buses, and opinions about social aspects of bus-riding. These applications could be created so that only the transit agency would see the results, or they could be created so that results would be seen by both the public and the agency. Drivers were therefore given two choices within "build it", data open to the public or data seen by the agency only. Driver responses are shown in Tables 6.4 and 6.5. In addition, for each question, drivers were given the ability to comment as to why they thought an application should or should not be built. These free-form answers allowed further investigation of their responses. This was particularly important in determining if the respondent had any barriers (known in value sensitive design as value dams) that could be identified in opposition to an application. Many comments revolved around the expense of building rider applications in tough economic times. The OneBusAway program is funded independently from the transit agency and so financial matters are not currently relevant as a barrier.

TABLE 6.4 Driver responses to public input applications: "Should an application be developed to...?"

	To identify physical issues at stops, shelters or on buses (graffiti, broken parts, the need for lights, etc)		To give opinions about social things related to stops or bus routes (routes in pretty area, friendly people, stops with vagrants, or unsafe at night)	
Build it and open it to the PUBLIC	157	62%	154	61%
Built it to be seen by agency ONLY	66	26%	40	16%
Should NOT be built	24	9%	51	20%
No answer	6	2%	8	3%
Total	**253**	**100%**	**253**	**100%**

The first application, identifying physical stop, shelter and bus issues (graffiti, broken parts, need for lights, etc), was supported by 88% of the drivers, with 62% saying it should be seen not only by the agency, but also by the public. Regarding the 9% of drivers that thought this was not a good idea, most were concerned with the financial cost of creating such an application, especially if drivers and riders already have the ability to report these issues. Only 6 drivers responded with comments that could be possible barriers. They were concerned with false reports, the agency's ability to follow-up on reports, or the creation of potential conflicts between drivers and riders or drivers and management. The comments were overwhelmingly positive, showing support for easier identification of issues and the likelihood that this would create a fairer system through which issues get addressed.

The second application would allow riders to give opinions about social things (routes in prettiest parts of town, routes with the friendliest people, stops with many vagrants or drug dealers or routes that feel unsafe at night). This application was supported by a similar number of drivers (61%), but far more drivers were opposed (20%). Furthermore, the comments identified many possible barriers, such as the possibility that such as application would encourage stereotypes, would be subject to differing and changing opinions and circumstances, would be misused, or would possibly even proliferate negative issues on certain routes.

The next four applications were based on data either currently available at the agency or data that could be available given basic technological advances. All would report information to the public to make transit use easier in their particular situation. These four applications were to see past performance data (on-time performance based on time of day, how full buses typically are, or the likelihood of finding park and ride spots), to be notified about the on-time status, to be notified about capacity aspects of the bus (seats full, bike racks full, wheelchair spaces full) or to allow blind and deaf-blind riders easier access. Results are shown in Table 6.5.

TABLE 6.5 Driver responses to question: "Should an application be developed to…?"

	To see past performance data (historic on-time, full).		To allow notification about the on-time status of the bus > 10 minutes late.		To allow notification about how full the bus is.		Aid blind and deaf-blind riders.	
Build it	167	66%	191	76%	154	61%	224	89%
Should NOT be built	74	29%	46	18%	90	36%	15	6%
No answer	12	5%	16	6%	9	4%	14	5%
Total	**253**	**100%**	**253**	**100%**	**253**	**100%**	**253**	**100%**

The first application shown in Table 6.5 would be used to display past performance data to the public. Rather than just real-time information, this application would allow riders to see how frequently buses were early or late, how full buses typically were or the likelihood of finding a park and ride spot, all by the time of day and route for their personal situation. Here, 66% of the bus drivers were in favor of such an application and 29% were against it. The reasons for being against such applications mostly revolved around a lack of funds, the variability in the information, or a lack of need on the part of riders. Some drivers felt that frequent riders already have this information and infrequent riders could obtain it by asking fellow passengers. One driver was concerned that it might discourage ridership rather than encourage ridership. In addition, many drivers were not opposed to the general idea of past performance data, but were concerned about the ramifications. The on-time status in particular brought about concerns with drivers being responsible for things that were outside their control (such as traffic or improper scheduling). This concern about the impact of such information on the rider or management opinion of job performance could be considered a barrier for such an application.

The next application in Table 6.5, which would send e-mail or text-message notification to riders if a bus was unusually late (greater than 10 minutes as an example), was supported by many more drivers (76%). Of the 18% who thought the application should not be built, most were concerned about the cost or about the need when existing applications already give the information. Although many potential concerns were identified for future investigation, no barriers to implementation were identified in the responses. In the comments, many drivers indicated that a better use of such a notification application would be to provide information about service alerts, indicating why a bus is unusually late (weather, traffic, breakdown, etc). Although the regional transit agencies currently have this service, it is not specifically tailored to individual trips, but is instead sent out for an entire route.

An application notifying riders of a full bus (no standing room), a bus with full bike racks, or a bus with full wheelchair spaces was the least favored application. Only 61% of drivers were in favor of such an application. Most drivers were concerned that the stop-to-stop rapidly changing conditions would negate the usefulness of such an application. In addition, drivers indicated that in their experience, riders would use the full bus anyway because they are more concerned with arrival time than room to sit or stand.

As follow-up to the question about capacity notifications, one way to design this application would be to use passenger counting equipment or sensors for the bike racks or wheelchair spaces. Another way would be to have the drivers push a button on their consoles to allow a message to be sent to riders. This could be an inexpensive means to acquire the information, but would be highly dependent on drivers themselves. Therefore, drivers were asked their reactions to pushing a button for such items. Only 32% of drivers felt this was a safe and reasonable task. A full 20% felt it was unsafe and 29% felt it would be safe but unreasonable given the other necessary tasks of driving. Of the remaining, 14% thought that pushing a button could be possible, but only if other elements of driving could be made easier.

In addition, drivers were asked how often they would remember to push a button if information was acquired in this fashion. In anticipation of drivers believing that they are more likely to remember than most drivers, a second question about how often they think a typical driver would remember to push a button was asked. As shown in Table 6.6, a full quarter (27%) of the drivers readily admitted that they would remember less than half of the time and 42% indicated that a typical driver would remember less than half of the time. Less than 5% felt that a typical driver would remember more than 95% of the time, a level of accuracy that could be desired for many applications of this nature.

TABLE 6.6 Percentage of time that drivers thought they would remember to push a button to indicate something about the bus

	Themselves		Typical driver	
<50% of the time	67	26.5%	105	41.5%
50 – 75% of the time	60	23.7%	77	30.4%
75 – 95% of the time	54	21.3%	40	15.8%
>95% of the time	54	21.3%	12	4.7%
No answer	18	7.1%	19	7.5%

The most widely supported potential application in the survey was additional tools to help blind and deaf-blind riders. The application was described as allowing "blind and deaf-blind riders to better get around by giving them next bus arrival information and alerting them that their stop was approaching once they were on the bus." 89% of drivers supported such an application, commenting that such tools would not only make bus drivers work easier, but would empower blind riders by allowing them to get around without as much assistance from other people. The major concern identified by the 6% of drivers who were opposed to the application were that blind riders make up a small portion of the general ridership, making such a tool prohibitively expensive for development. Although this should be considered, it does not represent a barrier for such an application.

In summary, the applications were all well supported by the bus drivers. Every one of the applications was supported by more than 60% of the respondents. Drivers were most supportive of building apps to aid blind & deaf-blind (89%) and identify physical stop, shelter, & bus issues (88%). Drivers were least supportive of building apps to notify about full buses (61%) and see past performance (66%). McNemar tests show that the first two are significantly more popular than the other 4 among drivers ($p<.002$ for all tests), and the last 2 are significantly less popular than the other 4 ($p<.006$ for all tests). Male drivers tended to be more likely to favor the new applications, however with correction for multiple comparisons, only the physical issues at stops application was significant (Chi-squared, $\chi^2=16.31$, 2 d.f., $p<0.0005$), with men being 11% more likely to favor the application. There was no association between favoring new applications and the number of years of experience or the age of the driver.

In addition to these questions about potential OBA applications, drivers were asked what other types of information that should be provided to riders. Most of their answers revolved around service alerts and interruptions, such as informing riders about breakdowns, event reroutes, adverse weather reroutes, severe tie-ups that delay the service, etc. Many other comments were about improvements to the trip planner, either by redoing the existing trip planner, making trip planning tools more widely available or by tying trip planning into real-time information. The third piece of information mentioned was improved and more widely available mapping, including better maps of downtown service, detailed bus stop location maps for high transfer or unusually-located stops, points of interest maps with bus routes, and easier to read route maps. Drivers also indicated that automatic stop announcements and clocks on the bus would help riders en-route. One commented about hold notification between buses in to aid transfers. Another commented about providing information about the last scheduled trip on a route. Similar to the responses about questions they received from riders, better information about fare rules and payment details was listed by a few drivers. Finally, drivers saw the benefit of a modified version of some of the suggested applications, such as public-access to reports about safety security ("use facts rather than opinions") or a website that gives riders tips, rules, etiquette, and safe-use principles.

6.4.3 On-time Status on the bus

The next section of the survey related to real time on-time status of the bus. In the first question, drivers were asked how often they think the bus they drive is more than 1 minute early or more than 5 minutes late per week. The results, shown in Table 6.7, indicate that drivers feel they are infrequently early, as should be the case, because there are relatively few reasons to be early. Many more drivers indicated that they are frequently more than 5 minutes late, with 70% indicating they are more than 5 minutes late at least once per day. This was particularly true for PM peak hour drivers who were significantly more likely to say they are behind schedule (Kruskal-Wallis, χ^2=14.71, 1 d.f., p=0.0001).

As suggested by some drivers in the earlier interviews, another important class of tool would be for drivers rather than riders. For example, a simple gadget that gave the on-time status of their bus (x minutes early or late) could be placed on the console and give information based on the bus location and schedule. To determine if drivers agreed with this suggestion, they were asked how hard or easy it is to know if they were on schedule. Most drivers (84%) indicate that it is easy to know if they are ahead of or behind schedule and another 12% said that sometimes it is easy and sometimes it is hard. No drivers indicated that is hard to know if they are on schedule.

TABLE 6.7 Frequency of time that drivers indicate their bus is running early or late

	> 1 minute early		> 5 minutes late	
At least once per run	12	4.7%	33	13.0%
Several times per day	14	5.5%	102	40.3%
About once per day	19	7.5%	42	16.6%
A couple times per week	21	8.3%	27	10.7%
About once per week	14	5.5%	20	7.9%
Almost never	164	64.8%	24	9.5%
No answer	9	3.6%	5	2.0%
Total	253	100%	253	100%

As a follow-up, drivers were asked if there was better information for drivers about running ahead or behind schedule via such a device, would they be ahead or behind less often. Only 12% thought that such a device would make a difference. Of the 79% that said it would not improve on-time performance, most commented that when they were late, they already are doing everything they can to get back on schedule. Knowing if they are early is simply a matter of looking at their runcard frequently enough.

6.5 CONCLUSIONS

Although bus drivers are key to the transit rider experience, they are infrequently consulted when planning and implementing new transit initiatives. Improved transit rider information has been identified as a critical component to building ridership, and with the opening of more transit data to developers, more applications are being developed for rider use. However, to date, bus driver perspectives about real-time information and other transit information tools have never been gathered. In this study, driver views and values about the implications of existing real-time arrival data and possible future rider information tools were investigated through interviews and surveys. Surveying drivers about such tools allows for tools that drivers believe in to be prioritized over those they are concerned about. This process of identifying the barriers and support for implementation (called value dams and flows in Value Sensitive Design) has been successful in multiple information technology applications.

In the survey, bus drivers indicated that they are asked a lot of questions, including trip planning, bus arrivals, schedule, fare-related and service alert type questions. Most drivers (66%) are neutral about being asked questions, stating it is a part of their job.

Bus drivers in greater Seattle were for the most part at least aware that real-time information is available to the public (82%). Nearly half (46%) of the drivers in the survey had seen the tools being used, had spoken with riders who use them or (as indicated in the comments to the question) had used the tools themselves. In terms of how the drivers feel about such information being provided, the response was mostly positive. Almost all drivers (94% and 91% on two separate questions) were positive or neutral to the information being provided. The drivers who had a negative opinion of providing real-time arrivals were more likely to be the ones who were not aware of the existence of real-time information, especially those who were neither aware of it and were also surprised that it existed. This gives some indication that drivers may at first be opposed to the notion of providing real-time information to riders, but over time may see that more benefit than harm comes from doing so.

Six potential transit information applications were chosen as a range of applications that would be most likely to affect bus drivers. Each of the applications was tested to see if drivers thought the application should be built or not. In addition, driver comments allowed for the association of negative opinions with any potential barriers to implementation (also called value dams). All applications were supported by the majority of drivers who responded to the survey, with at least 60% of the bus drivers favoring each of the applications.

The two most widely supported potential applications in the survey were additional tools to help blind and deaf-blind riders (89% of bus drivers favored) and an application would aid riders in identifying physical stop, shelter and bus issues such as graffiti, broken parts or a need for lights (88% of bus drivers). Drivers stated that the blind rider tool would not only make their work easier, but would empower blind riders by allowing them to get around without as much assistance from other people. The second would allow agencies to more easily account for issues in the system and help them be more responsive to riders' needs. Both of these applications had relatively few potential barriers for the bus drivers.

Bus drivers also supported (76%) an application to send e-mail or text-message notification to riders if a bus was unusually late (greater than 10 minutes as an example). In the related comments, drivers indicated that service alert notifications, showing why a bus is unusually late (weather, traffic, breakdown, etc) would be a critical component of such an application. Although many transit agencies currently have this service, it is not specifically tailored to individual trips, but is instead sent out for an entire route or service. This application had no major barriers. Another application that would allow riders to give opinions about social things (routes in prettiest parts of town, routes with the friendliest people, stops with many vagrants or drug dealers or routes that feel unsafe at night) was supported by a similar percentage of drivers (77%). However, this application had more potential barriers, with valid concerns about the negative impact on routes and ridership.

Two additional applications were received with less support and more potential barriers. An application that would display past performance data, such as typical on-time status could have negative implications for the bus driver's relationship with riders or management even if performance was outside their control. Finally, an application identifying a full bus (no standing room), a bus with full bike racks or a bus with full wheelchair spaces was the least favored application (61% in favor). This lack of enthusiasm amongst the drivers pairs with the difficulty of implementing such an application. One possible means of implementation involving having drivers push a button to indicate something about the bus was not considered reliable enough, let alone safe. Only 32% of drivers felt pushing a button was a safe and reasonable task. Less than 5% of the bus drivers felt that a typical driver would remember more to complete the task more than 95% of the time, a level of accuracy that would be necessary for most applications of this nature.

This research gives a better understanding of the impact of rider information tools on bus drivers, including their values, harms and benefits. This study was performed to aid the OneBusAway team in deciding the next transit tools to develop and identify barriers (or value dams) which the team should be cognizant of in future design. The results have pointed to the importance of information tools for blind transit riders currently being pursued by researchers tied to OneBusAway (Azenkot, Prasain, et al 2011). Through survey results and driver comments, further evidence has been given to the importance of notification about service alerts and interruptions. As such, the OneBusAway team has begun work in this area funded in part by a grant from the Bullitt Foundation.

At the conclusion of the survey, drivers were given the opportunity to comment about the survey and OneBusAway program in general. The overwhelming response was to thank us for giving them the opportunity to take the survey. Drivers appreciated the chance to have their voices heard on these issues. Relatively few surveys have been conducted to ask drivers how they feel about transit rider information. The results have already served to inform the OneBusAway team about driver values. Hopefully the results can also be used by other transit agencies and developers looking to work on innovative tools to help increase transit rider satisfaction and transit ridership.

Conclusions

We live in a changing society - a society that is becoming more aware of the complex world in which we reside. As engineers, we have changed too. We have come to understand that the design of civil engineering facilities must be approached from a more holistic perspective. The larger context of infrastructure decisions now includes people's behavior, as well as land use, the environment, the economy, social welfare, health, and safety. It is clear that we cannot build infrastructure without considering the larger impact of our designs.

Our individual transportation decisions are based on many system and personal characteristics. As professionals, we have an obligation to minimize the negative societal impacts of infrastructure, but the users of our services require accessibility and user-friendliness. Decades of design that did not reflect a systems perspective now has to be overcome. However, by making more sustainable choices easier, we can encourage proper use of the system.

The underlying goal of this research is to help transit agencies improve ridership and satisfaction with public transportation. This dissertation research began with a desire to increase knowledge about the causes of travel time variability in transit. The first objective of this research was to compare the on-time performance of routes based on specific characteristics of the service, such as the type of right-of-way (exclusive or shared), through-routing, stop-spacing, transit signal priority and passenger load factors. The investigation used automated vehicle location data from King County Metro, combined with a database of route characteristics. The database allowed the investigation of the variability in on-time performance for routes throughout the transit system, using a regression analysis to determine which route characteristics have the greatest impact on transit reliability.

However, it quickly became apparent that understanding transit unreliability is not as important as overcoming transit unreliability. Therein was born the open-source transit traveler information system called OneBusAway (OBA). The purpose of OBA is to develop information tools for rider use, as well as undertake research as to the influence of these tools on ridership and rider perceptions. The OBA system combines a number of integrated tools and exposes them across multiple interfaces, including the web, standard cell phones, smart phones, and text-messaging.

One of the first steps for OneBusAway research was to survey OneBusAway users to determine the impact of real-time information. Although many cities have real-time next bus arrival information, few places have done detailed studies about the impacts on riders. Survey respondents indicated a number of positive outcomes as a result of their usage of OneBusAway: increases in overall satisfaction with 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. The survey results also showed a strong correlation between reported reductions in wait time and an increase in overall satisfaction with transit.

Giving passengers real-time information about the arrival of the next bus helps minimize waiting time, improves the perception of the wait and alleviates the stress of wondering when the bus is coming. Although bringing the perception of wait time in line with the actual wait time will not improve the reliability of transit, it can improve the perceptions that relate to reliability by giving riders more control.

Building on the correlation between satisfaction and reduced wait time found in the first OneBusAway study, a follow-up study was done to test several hypotheses related to perceptions of wait time. It was found that on average, transit riders perceive that they are waiting 0.83 minutes longer than they are. However, for riders using real-time information, the hypothesis that the perceived wait time is equal to the actual wait time cannot be rejected. The difference between the perceived and measured wait times for those with real-time information and those without real-time information is significant and large. This is substantiated again by the typical wait times riders report. Real-time information users say that their average wait time is 7.54 minutes versus 9.86 minutes for those using traditional arrival information, a difference of 31%. Through a regression model to predict the perceived wait time of bus riders based on the measured wait time, it was found that real-time information is more important than bus frequency, with the coefficient on real-time information exceeding the coefficient for frequency until the route reaches a level of 6 buses per hour (10 minute headway).

A critical finding of this wait time study is that mobile real-time information reduces the actual wait time experienced by customers. Real-time information users wait almost 2 minutes less than those arriving using traditional information. Although previous studies about perceived wait time have been done using real-time information signage, the advantage of mobile real-time information is that it can change the actual wait time of riders. OneBusAway users routinely comment about their ability to grab a cup of coffee because they know there is a 10-minute delay one particular day or that they should literally run to the stop because their bus is on time and they are running late.

Real-time arrival information may address the unreliability of transit, but it is only one tool needed to overcome the barriers to transit use. Another improved tool transit users require is improved trip planners. Although trip planners function well if both an origin and destination are known, the ability to perform a search by attraction type rather than specific destination can be a powerful aid to a traveler with a need or desire to use public transportation. The Explore tool was created as an attraction search trip planner to improve upon existing trip planner searches in some specific transit-use situations. Explore allows riders to choose their destinations based on transit availability, which can encourage transit use.

In addition to real-time information and trip planning tools, there are many other tools that could be envisioned to use information to overcome the barriers to transit use. By invoking the Value Sensitive Design approach for the future design of OneBusAway, the overarching goals of the project changed substantially. Before using the VSD approach, the focus was on developing new tools and many of these tools were for high-end smart phones. The new emphasis has been placed on providing integrated tools on all media, especially service alert notification and integration.

A key piece of the VSD process is the consideration of indirect stakeholders, especially transit bus drivers. Through bus driver interviews and value tension analyses, it became apparent that the successes of OneBusAway improvements are strongly affected by their acceptance by drivers, who are the primary interface between riders and the transit system. Although bus drivers are key to the transit rider experience, they are infrequently consulted when planning and implementing new transit initiatives. Improved transit rider information has been identified as a critical component to building ridership, and with the opening of more transit data to developers, more applications are being developed for rider use. However, to date, bus driver perspectives about real-time information and other transit information tools have never been gathered. In the final study of this dissertation, driver views and values about the implications of existing real-time arrival data and possible future rider information tools were investigated through interviews and surveys. Surveying drivers about such tools allows for tools that drivers believe in to be prioritized over those they are concerned about.

Bus drivers in greater Seattle were for the most part at least aware that real-time information is available to the public (82%). In terms of how the drivers feel about such information being provided, the response was mostly positive. Almost all drivers (94% and 91% on two separate questions) were positive or neutral to the information being provided. The drivers who had a negative opinion of providing real-time arrivals were more likely to be the ones who were not aware of the existence of real-time information, especially those who were neither aware of it and were also surprised that it existed. This gives some indication that drivers may at first be opposed to the notion of providing real-time information to riders, but over time may see that more benefit than harm comes from doing so.

Six potential transit information applications were chosen as a range of applications that would be most likely to affect bus drivers. Each of the applications was tested to see if drivers thought the application should be built or not. In addition, driver comments allowed for the association of negative opinions with any potential barriers to implementation (also called value dams). All applications were supported by the majority of drivers who responded to the survey, with at least 60% of the bus drivers favoring each of the applications.

Implications and Future Work

"Scientia potentia est" - knowledge is power. Knowledge allows you to better succeed in your endeavors. This is true for immense endeavors such as the value of education to your career (this is certainly the case for the pursuit of a doctorate in engineering). But the power of knowledge in the form of better information can help in even the smallest of endeavors, such as a simple trip from Point A to Point B. Although increased transit use could have substantial positive impacts for society, users face many barriers when making the transit choice. Choosing to rely on another for your transportation has inherent risks. Will the bus come? Will it come in time to make my appointment? Where does the bus run? Where do I stand to catch it? How do I board and pay and tell the driver I need to get off? Where should I get off? These simple issues can be overwhelming when attempting to make a decision to try a new mode. However, many of the inherent difficulties in transit use can be overcome through better information. If high-ridership transit service is a more sustainable means for transportation, then through the power of better information, we can change the face of transportation for the better.

Imagine a day when you could wake up and simply type into your phone your first destination for the day and your arrival time required. The phone would tell you based on your location and the current conditions of the system, where you should go to catch the bus at what time. If conditions change en-route, the phone would warn you to change your path. Once work or school was done for the day, you could type in "thai for dinner" and the phone would give a suggested list of places that were easy to access from your location based again on the current conditions. After dinner, it would automatically direct you how to get home. With some additional enhancements to existing tools and integration of components already introduced through OneBusAway and similar applications, we are not far from this situation.

There are several issues however that must be addressed as transit agencies and developers pursue the next steps in increasing access to transit rider information. These include open data, rider equity, and performance measurement. Finally, although increased access to information is critical, further investments in transit infrastructure are critical to a successful system in the future.

OPEN DATA

The development of this type of ubiquitous information will require additional information gathering (underlying traffic data, GPS on all buses) as well as increased dissemination of the information. OneBusAway and other innovative transit applications are only possible with the aid of forward-thinking transit agencies that have made their routes, schedules, and real-time arrival data open and available via data feeds and public application programming interfaces (APIs). For these reasons, other transit agencies should be encouraged to include real-time arrival information in their transit systems and to publish this data, along with static schedule data, through public feeds and APIs so that applications like the OneBusAway toolset can help make transit work better for the riders who use it every day. OneBusAway in particular is being developed as an open-source transit traveler information system to allow transit agencies to access the code and use it themselves. In addition, the open-source model allows other developers to make use of the code or the data to create further transit traveler information tools such as those described.

The primary issue with opening up the data from agencies is the fear of accountability. Just as the bus drivers feared being held accountable for situations they cannot help, agencies too can have a valid fear that their citizens will expect perfect schedule adherence and speedy travel times despite their operations on congested shared right-of-way with other weather and rider-related factors. The public can be very demanding, sometimes unreasonably so. However, as the bus drivers found in the OneBusAway VSD study, the additional power that riders derive from having better information actually improves their satisfaction. Further studies are needed to quantify the benefits and harms of transit information to better inform agencies about their decision to support improved access to transit information.

RIDER EQUITY

With the introduction of more powerful, easier to use and less expensive personal mobile devices, mobile transit information has the ability to become more prevalent for riders. OneBusAway provides applications for real-time information via internet-enabled “smart” phones, devices which cost more than $200 to purchase in addition to monthly data plans. In addition to these applications, the data is available via text-message, website and a regular phone line, allowing use by a substantial portion of the transit-riding population. By opening up the data via multiple media, the likelihood of riders being able to access real-time information increases. However, in many locations, the information is available via smart phones only. Furthermore, regardless of these multiple media, a small percentage of riders are still not able to access the real-time data because they cannot afford cell phones.

One program that overcomes this limited access to cell phones is the Safelink Wireless program, which distributes free cell phones along with limited monthly call plans to low-income households. With such a program in place, access to transportation information can be improved for all demographic groups. These plans do have limited minutes, however, and typically unlimited text plans can be included. Therefore, text-message based transit information is a key piece of equity in available information. One possible way to overcome this is to implement a free-511 program similar to the free-911 program in which inactive cell phones can still make emergency calls. Such a program could distribute older cell phones and chargers to the transit-dependent population to enable access to real-time information at every stop in a system without the use of expensive real-time arrival signage.

PERFORMANCE MEASUREMENT

In the transit service planning industry, 10 minutes is 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 (Parker 2008), thereby needing a schedule. However, with the introduction of real time information such as OneBusAway, users more frequently refer to real time information than to schedules to determine when to wait at the bus stop. This is important because a significant amount of time is lost in attempting to maintain reliability for scheduled service due to the slack time planners must build into the schedule (Fan and Machemehl 2009). 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 (Zhao, Dessouky, et al 2006). This savings in running time can reduce agency costs to provide the same level of service on a transit route. Further studies must be conducted to determine the new threshold between schedule-based and headway-based service with the increased use of real-time information. In addition, the savings in slack time and agency costs should be further verified.

In addition, beyond the issue of headway versus scheduled service is a bigger service planning issue. If on-time performance has been the traditional measure of reliability, what matters now if on-time does not? The few agencies that have headway-based service look at headway deviation measures to determine the consistency in the wait time. These types of measures will become more critical into the future. Headway deviations can be paired with running time deviations or speed deviations to ensure that buses are spaced a fare distance apart and provide decent end to end travel time. Essentially, with real-time information, riders only care about two things: How long will I have to wait? And how long will my trip take me?

To date, travel time measurement has been based on the vehicles themselves rather than the riders in them. For suburban or rural auto-based modes, this may be an acceptable practice. But with multimodal travel in urban areas, travel time measurement must occur at the person-level to get an idea of the end to end travel time. We do not have a good idea of how long it takes a typical bus rider to get to their initial stop, how long their wait is, how many times they transfer, how long each transfer is, and how long it takes to access their final destination. Further work should be undertaken in measuring travel times using personal handheld devices such as smart phones that sense if a person is walking, biking or riding a bus.

In the meantime, directly measuring the wait at stops is one way to get a better handle on the averages and distributions of the wait times riders face during their trip. These wait times are a key element of mode choice and must be better measured and understood. As such, I am working with another researcher at the University of Washington to determine if Bluetooth devices can be used to accurately measure waits at transit stops.

Finally, as explained above, riders want to know how long they will have to wait and how long the trip will take. This information must not only be available to riders, but must also be accurate. To date, little work has been done on the accuracy of real-time predictions and the relationship between their accuracy and trust in the data. Further work in this area is critical to the further development of usable real-time information systems.

INFRASTRUCTURE INVESTMENTS

Auto-oriented infrastructure has been the predominant transportation infrastructure investment for almost a century. The resulting system shows a clear bias toward single-occupant vehicles. Although VSD has to date been used primarily in the design of information technology, there are many other applications within the world of transportation where it could be useful. At the core of VSD is the idea that we should systematically identify the values of stakeholders and take time to envision the value tensions that may be created by any design, whether technological or otherwise. OneBusAway, as an application of technology to solve transportation problems, was a natural use of VSD. However, the principles of VSD can be applied throughout the transportation industry, especially when considering broader transportation planning goals. Many transportation planning applications involve looking at a specific corridor and a roadway-based solution is implied from the beginning. By starting the process uncovering the inherent human values of the traveling public, the focus would shift to overall mobility and access solutions. As we strive for livability, it is imperative that we consider the human values of both the users of the transportation system and the other indirect stakeholders impacted by transportation.

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Curriculum Vitae

Education:

Doctor of Philosophy in Civil Engineering, University of Washington, June 2011
Dissertation Topic: Using Technology to Revolutionize Public Transportation

Master of Science in Civil Engineering, University of Connecticut, 2003
Thesis Topic: "A Comparison of Bus Rapid Transit and Light Rail Transit in Ten North American Cities".

Bachelor of Civil Engineering, Georgia Institute of Technology, 1997
Graduated with highest honors, Cooperative Student at Georgia Department of Transportation

Awards and Honors:

University of Washington Valle Fellowship – 2010-2011
Women's Transportation Seminar Puget Sound Chapter Helene Overly Scholarship - 2011
USDOT Eisenhower Fellowship – 2007-2010
University of Washington ARCS Fellowship – 2007-2010
UTC Student of the Year for TransNOW – 2009
ENO Foundation Leadership Conference – 2008
Women's Transportation Seminar Puget Sound Chapter Helene Overly Scholarship - 2008
WSA Outstanding Contribution Award – 2000 & 2002
Georgia Tech Goodloe Yancy Scholarship - 1996 & 1997
Georgia Tech H & H Smitha Scholarship – 1996 & 1997
Georgia Tech Society of Women Engineers Scholarship - 1995
Gamma Beta Phi & Chi Epsilon Honor Societies
Congress-Bundestag Scholarship – Exchange Student – 1990

Professional Registrations:

Professional Engineer - Connecticut #23100

Peer-reviewed Publications:

Watkins, Kari, Brian Ferris, and G. Scott Rutherford. "Explore: An Attraction Search Tool for Transit Trip Planning." *Journal of Public Transportation,* Vol. 13, No. 4, pp. 111-128, 2010.

Schramm, LisaRene, **Kari Watkins**, and G. Scott Rutherford. "Amenities That Effect Variability of Travel Time on BRT Systems." *Transportation Research Record #2143,* pp. 77-84, 2010.

Ferris, Brian, **Kari Watkins**, and Alan Borning. "Location-Aware Tools for Improving Public Transit Usability." _*IEEE Pervasive Computing*, Vol. 9, No. 1, pp. 13-19, Jan-Mar 2010.

Watkins, Kari, Timothy Sorenson, and Norman Garrick. "Platform Layout for the New Britain – Hartford Busway." *Transportation Research Record # 1791*, Transportation Research Board, 2002.

Pending Peer-reviewed Publications:

Wu, Yao-Jan, Mark Hallenbeck, Yinhai Wang and **Kari Watkins**. "Evaluation of Arterial and Freeway Interaction for determining the feasibility of Traffic Diversion under Recurrent Congestion." *Accepted for future publication in the Journal of Transportation Engineering, American Society of Civil Engineers.*

Watkins, Kari, Brian Ferris, Alan Borning, G. Scott Rutherford and David Layton. "Where Is My Bus? Impact of mobile real-time information on the perceived and actual wait time of transit riders." *Submitted for publication in Transportation Research Part A.*

Watkins, Kari, Brian Ferris, Yegor Malinovskiy and Alan Borning. "Beyond Context Sensitive Solutions: Using Value Sensitive Design to Identify Needed Transit Information Tools." *Submitted for publication in the Journal of Transportation Engineering, American Society of Civil Engineers.*

Watkins, Kari, Alan Borning, G. Scott Rutherford, Brian Ferris and Brian Gill. "Impact of Real-time Transit Information Tools on Bus Drivers." *Submitted for publication in Transportation.*

Peer-reviewed Conference Papers:

Ferris, Brian, **Kari Watkins** and Alan Borning. "OneBusAway: Behavioral and Satisfaction Changes Resulting from Providing Real-Time Arrival Information for Public Transit". *Presented by **Kari Watkins** at Transportation Research Board 2011 Annual Meeting.*

Watkins, Kari and Brian Ferris. "Explore: An Attraction Search Tool for Transit Trip Planning." *Transportation Research Board 2010 Annual Meeting.*

Watkins, Kari and Mark Hallenbeck. "Impact of Weather on Freeway Travel Times in the Rain City." *Transportation Research Board 2010 Annual Meeting.*

Ferris, Brian, **Kari Watkins**, and Alan Borning. "OneBusAway: Results from providing real-time arrival information for public transit." *Association for Computing Machinery Conference on Human Factors in Computing Systems (CHI) 2010 (Best paper nominee).*

Ferris, Brian, **Kari Watkins**, and Alan Borning. "OneBusAway: A Transit Traveller Information System." *International Conference on Mobile Computing, Applications and Services (MobiCase)*, 2009.

Watkins, Kari and Mark Hallenbeck, "Reliability Measures - Which Statistics Will Actually Help Manage Our Roadways?" *Transportation Research Forum 50th Annual Forum*, 2009.

Watkins, Kari, Peter Plumeau, and Michael Munson. "A New Tool for Assessing Developments: The Land Use Transportation Index." *Transportation Research Board Annual Meeting*, 2003.

Watkins, Kari, "How the stigma of a Bus Rapid Transit system was overcome – The New Britain to Hartford Bus Rapid Transit Experience." *American Public Transportation Association (APTA) Rail Transit Conference*, 2002.

Significant Published Reports:

Muench, S.T., Anderson, J.L., Hatfield, J.P., Koester, J.R., & Söderlund, M. et al. *Greenroads Rating System v1.0.* (J.L. Anderson and S.T. Muench, Eds.). Seattle, WA: University of Washington. 2010. **Author of the Transit Access Credit**

Schimek, Paul, **Kari Watkins**, David Chase, Karl Smith and Stephen Gazillo. *Silver Line Waterfront Bus Rapid Transit Project 2007 Evaluation.* Federal Transit Administration, 2007.

Schimek, Paul, **Kari Watkins**, David Chase, Karl Smith, Stephen Gazillo and Bethany Whitaker. *Las Vegas Metropolitan Area Express (MAX) Bus Rapid Transit Project 2006 Evaluation.* Federal Transit Administration, 2006.

Wilbur Smith Associates. *New Haven-Hartford-Springfield Commuter Rail Implementation Study: Final Report.* Connecticut Department of Transportation, 2005, http://ct.gov/dot/cwp/view.asp?a=3535&q=425110.

Wilbur Smith Associates. *Strategies Evaluation Report: Regional Transit Development Strategies Study: Final Report.* South Central Regional Council of Governments, 2005.

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Wilbur Smith Associates. *Griffin Busway Feasibility Study: Final Report.* Capitol Region Council of Governments, 2004.

Wilbur Smith Associates. *Congestion Mitigation Systems Plan Vision 2020.* South Western Regional Planning Agency, 2003.

Wilbur Smith Associates. *Final Environmental Impact Statement and Section 4(f) Evaluation, New Britain-Hartford Busway.* Federal Transit Administration, 2001.

Wilbur Smith Associates. *I-84 West Side Access Study.* Connecticut Department of Transportation, 2001.

Wilbur Smith Associates. *I-84 West of Waterbury Needs and Deficiencies Study.* Connecticut Department of Transportation, 2001.

Presentations and Posters:

Watkins, Kari. *OneBusAway*. USDOT University Research Technology Transfer Day, Washington, DC, April 2011.

Watkins, Kari. *Using Technology to Revolutionize Public Transportation*. University of Virginia, March 14, 2011.

Watkins, Kari. *Using Technology to Revolutionize Public Transportation*. Western Michigan University, February 21, 2011.

Watkins, Kari. *OneBusAway: A Suite of Transit Traveler Information Tools.* ITS World Congress, Busan, Korea, October 2010.

Watkins, Kari. *OneBusAway: Using Technology to Revolutionize Public Transportation*. ARCS Foundation, April 12, 2010.

Watkins, Kari. *Using Technology to Revolutionize Public Transportation*. University of British Columbia, March 11, 2010.

Watkins, Kari. *Using Technology to Revolutionize Public Transportation*. Georgia Institute of Technology, March 1, 2010.

Watkins, Kari. *A Real-world Process for Transportation Senior Design.* Transportation Education Conference, June 22, 2009.

Watkins, Kari. *Transit Travel Information.* ITE Washington Section Annual Meeting, June 8, 2009.

Watkins, Kari and Brian Ferris. *One Bus Away: An Open-source Transit Traveler Information System.* American Public Transportation Association (APTA) Bus & Paratransit Conference, May 6, 2009.

Watkins, Kari. *Reliability Measures - Which Statistics Will Actually Help Manage Our Roadways?* TransNOW Student Conference (won 2nd prize for best presentation), November 7, 2008.

Watkins, Kari. *What's New in Bus Rapid Transit?* Guest speaker, University of Connecticut, February 6, 2007.

Watkins, Kari and Justin Fox. *New Haven, Hartford, Springfield Commuter Rail – Operations Simulation*. American Public Transportation Association (APTA) Rail Transit Conference, 2006.

Panels:

Panelist, *From Here to There Community Forum*, Seattle City Council, March 29, 2011

Moderator, *BRT, Land Use and Ridership*, American Public Transportation Association Bus & Paratransit Conference, May 6, 2009.

Panelist, *University of Washington Women in Science and Engineering 2009 Conference*, February 2009.

Transportation Panelist, *World Usability Day 2008*, Usability Professional Association of Puget Sound, November 13, 2008.

Moderator, *ITS Moving People*, ITS Connecticut 8th annual meeting, September 19, 2005.

Teaching Experience:

Seattle University, Senior Design Faculty Advisor, entire academic year 2010 - 2011
Sustainable Transportation certificate program, University of Washington, Environmental Analysis and Assessment, anticipated 2012
Guest Lecture, University of British Columbia, Discrete Choice Modelling, March 10, 2010
Guest Lecture, University of Washington, Presentation Skills 101, January 2010 and January 2011
Guest Lecture, University of Washington, New Methods in Transportation Planning, December 2, 2009
University of Washington, Transportation Capstone, Spring 2009
University of Washington, Transportation Capstone (Teaching Assistant), Spring 2008
University of Washington, Transit Planning, Spring 2007
Wilbur Smith Associates, Presentation Skills Training, monthly from Oct 2006 – Aug 2007
University of Connecticut, Transportation Planning, Spring 2005
University of Connecticut, Transportation Design, Fall 2004
University of Connecticut, Transportation Design, Spring 2003

Recent Professional Activities:

Member, Transit Capacity and Quality of Service, Transportation Research Board, 2010.
Member, Bus Transit Committee, Transportation Research Board, 2008 – 2010.
Chair, Research Subcommittee of Bus Transit Committee, Transportation Research Board, 2009-2010.
Student Representative, Department of Civil and Environmental Engineering, Transportation Faculty Hiring Committee, 2009.
Speaker Chair, Region 10 Student Conference, 2008.

Professional Experience:

August 1998 to September 2007:

Wilbur Smith Associates, Seattle, Washington and New Haven, Connecticut, Senior Transportation Engineer

Selected Experience:

Branding and Facilities Design for King County Metro RapidRide – Served as project manager for this introduction of bus rapid transit service on five corridors in the Seattle, Washington area. Responsibilities included coordination of staff and subconsultants in brand application to transit vehicle design, signage, and passenger facilities, architectural schematic design services, cost estimation for passenger facilities, and a significant public and jurisdictional involvement process.

Washington Department of Transportation Statewide Pedestrian and Bicycle Plan – Served as GIS coordinator for this modal program and policy document.

Capital District Transportation Authority NY5 Bus Rapid Transit Operations Plan – Served as WSA project manager, responsible for conducting a peer review of six agencies to determine current BRT practices for management and operations to aid CDTA's development of a new BRT service in Albany, New York.

Federal Transit Administration Bus Rapid Transit Initiative Evaluation, Technical and Programmatic Support – Served as WSA project manager as part of a team to support FTA's Bus Rapid Transit Initiative. Responsibilities include the evaluation of BRT systems in Boston and Las Vegas and other technical assistance to FTA as an expert in BRT.

New Haven, Hartford, Springfield Commuter Rail Implementation Plan, Connecticut – Served as Project Manager for this high-profile plan to implement commuter rail service. Coordinated development and evaluation of alternatives with varying levels of service, track configurations and station locations; modeling efforts with Connecticut DOT to determine ridership for various alternatives; lead public involvement effort

San Diego Association of Governments (SANDAG) Independent Transit Planning Review – Responsible for quantifying existing socio-economic conditions and preparation of bus rapid transit, light rail transit and commuter rail option definitions for this assessment of transit plans.

Griffin Line Busway Feasibility Study, Connecticut – Deputy Project Manager for this study of Bus Rapid Transit in the northwestern Hartford area. Completed an update to CRCOG's model for use in evaluation of alternatives, including analysis using FTA SUMMIT for New Starts.

New Britain-Hartford Busway, Connecticut – Responsible for preliminary horizontal alignment, station area layout, and cost estimates for the busway. Also responsible for graphics preparation and GIS for the Environmental Impact Statement. Aided in the public involvement process and completion of an FTA New Starts Application, including cost estimates and analysis of socio-economic data within a ½ mile radius of stations.

Southwestern Connecticut Congestion Mitigation System Plan – Completed existing conditions evaluation and alternative strategy development for this study of alternatives to address congestion along I-95 and Merritt Parkway. Developed a GIS method to utilize GPS data to represent current congestion on the freeways.

Williston Comprehensive Transportation Study, Vermont – Lead the development of an alternative development impact assessment method called the Land Use Transportation Index for this Vermont town.

Northern Arc EIS, Atlanta, Georgia – Evaluated secondary impacts using the EPA Smart Growth Index

Route 303 Sustainable Development Study, Rockland County, New York – Performed trip generation, distribution and assignment for differing land use scenarios, as well as accident analysis and projections, GIS, and alternatives analysis for this sustainable development study along a busy corridor.

January 1998 - July 1998: URS Greiner, Rocky Hill, CT, Transportation Engineer

January 1994 – September 1997: Georgia Department of Transportation, Atlanta, GA, Transportation Co-op