THE TRAVEL ASSISTANT DEVICE: UTILIZING GPS-ENABLED MOBILE PHONES TO AID TRANSIT RIDERS WITH SPECIAL NEEDS

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ABSTRACT

Recent advancements in mobile technology allow Global Positioning System (GPS)-enabled cell phones provide a variety of real-time location-based services (LBS). This paper reports on the design, implementation, and testing of such a service, the Travel Assistant Device (TAD), that aids transit riders with special needs to use public transportation. TAD is a program that provides the rider with customized real-time audio, visual, and tactile prompts for when they should exit the transit vehicle by announcing "Get ready..." and "Pull the cord now!" Additionally, TAD provides alerts to riders, their caretakers, and travel trainers if a rider deviated from the planned route. A website allows easy access for the creation of new trip itineraries and also allows monitoring the rider's location by authorized personnel in real-time from any computer. While the TAD was designed to aid transit riders with special needs to increase their level of independence and their care-takers level of security, any rider new to a transit system can use TAD for planning and executing trips with confidence and ease.

Keywords: global positioning system, GPS, mobile phone, special needs, travel, assistance, TAD, location-based services, LBS, transit

INTRODUCTION

The public transportation environment challenges new and existing riders to make rapid, real-time decisions which are especially difficult for special needs populations. A range of techniques including advertising trip routes, online trip-planners, and travel trainers (instructors that train new riders how to travel via public transportation) are utilized by transit agencies to overcome barriers to increased ridership. A number of studies have found that current informational materials do not fully meet the riders' need for clear instructions. According to the National Center for Transit Research (NCTR), approximately half of their general population survey sample could not successfully plan an entire trip on fixed-route transit systems using the printed information materials provided *(1)*. This situation is magnified for Americans with disabilities depending on transit as their primary means to and from school, work, and doctor's appointments. For those with cognitive disabilities, approximately 16.4 million Americans, or 6.9 percent of the population, it is especially daunting to plan and execute a trip with no

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assistance from others *(2)*. Additionally, transit agencies are struggling to support expensive specialized demand responsive services (i.e., paratransit) for disabled riders who cannot use fixed-route transit. According to the American Public Transportation Association, the average cost of paratransit is $17 per trip versus an equivalent fixed route transit cost of $1.70 per trip *(3)*. It is therefore worthwhile for transit agencies to support and invest in innovative technology to shift more riders to fixed-route transit.

The use of mobile devices to assist cognitively disabled persons ride public transportation is not unprecedented as seen in publications by researchers at the University of Illinois at Chicago, the Coleman Institute for Cognitive Disabilities, and the Center for Lifelong Learning and Design, both at the University of Colorado (CU-Boulder) *(4),(5),(6),(7)*. These researchers speculated that a personal digital assistant (PDA) coupled with a GPS system could successfully assist the cognitively disabled person ride transit. In a 2003 research project, the CU-Boulder's Coleman Institute and partner software company, AgentSheets, used off-the-shelf PDAs and GPS devices to create a prototype transportation guidance device *(8)*. They concluded that "no hardware platform exists yet with all needed capabilities" for creating an all-in-one mobility assistant device *(9)*. A subsequent system created in 2004 entitled *Opportunity Knocks* showed significant promise for automatically detecting when an individual is lost based on GPS data recorded from a cell phone coupled with an external GPS unit *(10)*. However, the system provided alerts when it sensed the individual was lost but did not provide reminders to the user to exit the transit vehicle. Additionally, the system must have stored prior travel behavior to determine normal performance, and thus cannot provide alerts for new riders. Combining separate cell phone and GPS units increases total system costs and is cumbersome to carry by any individual; disabled or otherwise.

The Center for Urban Transportation Research (CUTR) and the Department of Computer Science and Engineering (CSE) at the University of South Florida (USF) have established an ongoing partnership over the past several years that focuses on the development of cutting-edge projects using mobile technology for transportation applications. Funded by the Florida Department of Transportation (FDOT) through the National Center for Transit Research (NCTR), this work has focused on the use of GPS-enabled PDAs and mobile phones in the development of location-aware artificial intelligence software systems. These projects evolved into the creation of the Location-Aware Information System Laboratory (LAISL) at USF. When confronted with the challenges faced by transit riders with cognitive disabilities, LAISL researchers envisioned that GPS-enabled mobile phones had sufficiently matured to serve as personalized travel assistance devices *(11)*. In an effort to apply this technology to aid transit riders, LAISL formed a relationship with Gigi Gonzalez, a special education instructor and director of the Successful Transition After Graduation for Exceptional Students (STAGES) college-experience program at USF and Mark Sheppard, a travel trainer for Hillsborough Area Regional Transit (HART) in Tampa, Florida.

SYSTEM DESIGN

The TAD system is a software communication architecture that enables GPS-enabled mobile phones to provide travel services to the person carrying the phone. For the initial phase of TAD development *(12)*, three main services were targeted for implementation: the delivery of real-time auditory prompts to the transit rider via the cell phone informing them when they should request a stop (Figure 1), the delivery of an alert to the rider, caretaker, and travel trainer when the rider deviates from their expected route, and a webpage that allows travel trainers and caretakers to create new itineraries for transit riders, as well as monitor real-time rider location.

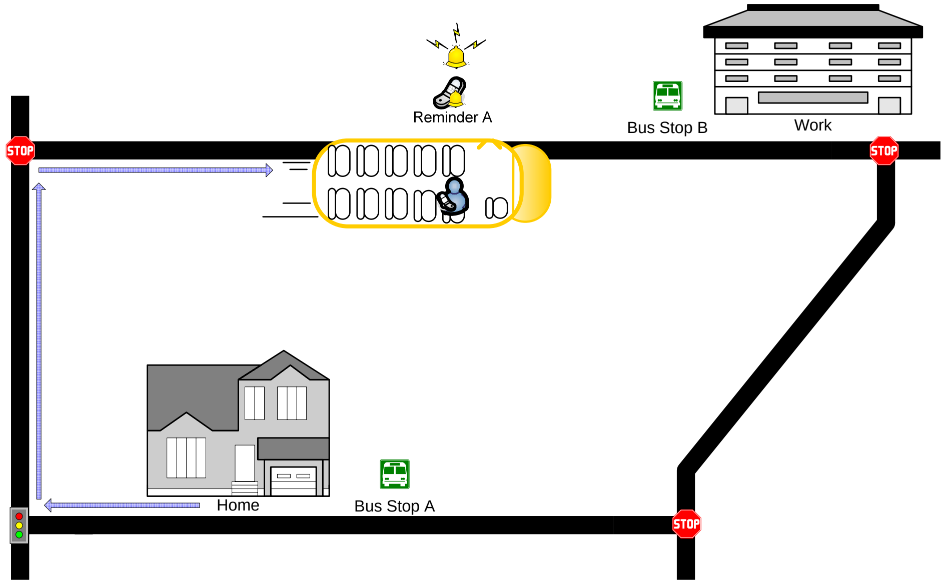

Figure 1 – Travel Assistant Device (TAD) software on mobile phone alerts transit riders when they are about to reach their stop.

In the TAD system design, there were three primary goals:

1) *Make the system low-cost and widely accessible:*
   This involves using off-the-shelf, consumer-grade GPS-enabled cell phones for a compact, inexpensive, all-in-one solution. Standards-based solutions should also be used to allow interoperability on multiple platforms (i.e., different cell phones and cellular carriers). Open-source solutions should be used when possible to reduce implementation and management costs to transit agencies. Finally, the software should be forward-compatible with future mobile devices to minimize future development costs.
2) *Make the architecture modular so that system components can be reused, and new features can be easily added in future versions.*
   Web services should be used which allow TAD systems to operate in heterogeneous computing environments on multiple platforms and operating systems. System entities should also be encapsulated so elements (i.e., database server) may be exchanged without disrupting the entire system
3) *Provide a reliable service tailored to transit riders with special needs.*

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A simple, uncluttered user interface should be shown to the user. Only two auditory announcements ("Get ready", and "Pull the cord now") should be given to avoid confusion. The phone should also vibrate to prompt the rider to request a stop.

Server-Client Model

In order to accomplish these goals, a flexible, modular, and easily portable software architecture must be established, including software that executes on the cell phone, a server, and a web client which implements a webpage. The TAD system architecture is shown in Figure 2. The Java platform, chosen for this project, allows Java applications to execute on multiple operating systems, including servers and mobile phones, without requiring major changes to code or recompilation of software, therefore providing a high-degree of platform independence. Utilizing the Java programming on all platforms reduces development time since code can be reused. Java ME is deployed on billons of devices, and is currently the best platform for reaching as many mobile devices as possible *(13)*.

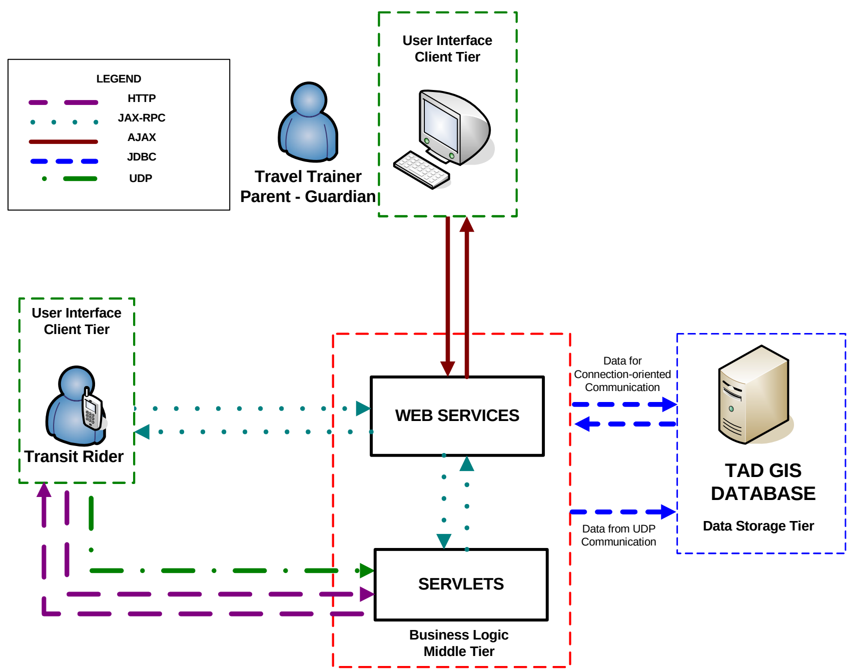

Figure 2 - Travel Assistant Device System Architecture

To support a modular design, web services were used as the interface between client and server-side software. Web services provide a well-defined interface by which a client application can request a service that is executed server-side and a result returned to the client application. Extensible Markup Language (XML) is used to format the data passed to and from the server via the SOAP protocol. SOAP can be implemented using any networking protocol, but it is most often used on top of the Hypertext Transfer Protocol (HTTP) due to the wide use of HTTP in the Internet. Since HTTP, SOAP, and XML are independent of any programming language, web services allow the exchange of data in heterogeneous environments where the communicating entities may be implemented in completely different languages or running on different computing platforms or operating systems. Additionally, the implementation of a web service is

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completely independent of the client making the request, so changes to the TAD server system are transparent to the client as long as the client-server interface remains the same.

Cell phone access to web services is implemented via Java API for XML-Based Remote Procedure Calls (JAX-RPC), defined for Java ME in "Java Specification Request (JSR) 172: J2ME Web Services Specification," *(14)*. If a cell phone's Java ME environment supports JSR172, it can directly access the same web services as a web or desktop client via SOAP and XML. If a cell phone does not support JSR172, it can access the web services via a servlet proxy, as shown in Figure 2. In this scenario, the cell phone communicates with the servlet proxy using the HTTP protocol, which must be supported in all Connected Limited Device Configuration (CLDC) 1.1 Java ME devices. The servlet can, in turn, translate these requests to JAX-RPC or a similar web services access method to invoke the web service, or the servlet can implement the same functionality as the web service if it is located in the same application server instance. This second configuration is commonly referred to as a Representative State Transfer (REST)-ful web service. In both scenarios, the servlet then returns a HTTP response to the phone. Since JAX-RPC is not yet widely supported by Java ME devices, this method guarantees that any CLDC 1.1 Java ME device will be able to access the web service.

TAD Webpage

The TAD webpage allows the travel trainer or caretaker/parent to create new trips for the transit rider, and also allows for monitoring the location of the rider in real-time. Through the webpage, the user can communicate either by text or multimedia message by clicking a Text Message balloon over the marker designating the traveler's position, or by calling them directly by clicking the Call icon which launches a Voice-Over-IP client such as Skype™.

Upon specifying the route that the transit rider will travel on, the bus stops on that route are shown on the web page map. The web user can then specify the boarding and exiting bus stops. If a trip requires several transfers, multiple segments can then be created that each contains a boarding and exiting bus stop. A trip can be given a custom name (e.g., Home to Work) that is relevant to the transit rider. Once this trip is saved on the website, the transit rider can access the trip from the server database using his or her cell phone and automatically receive real-time audio prompts such as "Get ready…" and "Pull the cord now . . ." for each trip segment. Other web features include user management, trip editing, and user permissions assignment for restricted functionality (e.g., viewing real-time rider location).

The TAD webpage was developed using the Google Web Toolkit, which allows the development of Asynchronous JavaScript and XML (AJAX)-based web applications using Java as the programming language *(15)*. AJAX uses JavaScript to exchange small pieces of information between a client and server instead of reloading the entire webpage every time new information is presented in order to provide an enhanced web application experience that is more responsive and interactive. While AJAX provides unique web page functionality, the learning curve for developing advanced AJAX applications is steep due to the multiple technologies involved. The Google Web Toolkit reduces the associated learning curve by allowing the use of Java Integrated Development Environments (IDEs) to develop web applications in Java using the traditional client-server model and remote procedure calls. It then translates the client-side code into JavaScript so that AJAX may be used when the webpage is viewed in a web browser.

TAD Cell Phone Application

The TAD cell phone application is the primary system interface for the transit rider, as well as the entity responsible for real-time navigation. Using web services, the cell phone application logs the user into the TAD system, and requests information on the transit route being traveled. For ease of use, the user is required to log into the system only the first time the application is used (Screen A in Figure 3). The user name and password can be saved on the cell phone, and on the user will automatically be logged in and shown screen B of Figure 3 where he or she can choose a previously created trip. Once the user chooses the trip, the phone retrieves all relevant information for the segments included (i.e., bus stops, routes). Next, the cell phone displays a screen with a green or red square along with the distance to the next stopping point (Screen C in Figure 3). If the square remains green, the cell phone will reliably provide services to the rider, and they will receive the exit notification when appropriate. If, however, the GPS signal fades due to obstructions such as overpasses or nearby tall buildings, the square will turn red and a warning beep announces that he or she will not receive a notification when they near the stop. If the cell phone maintains connectivity and continues to calculate an accurate GPS position, a countdown to the next stop along with the green square will be displayed, illustrating that TAD is working properly.

Through discussions with Mark Sheppard, HART travel trainer, it was determined that approximately 80 percent of HART's travel trainees have some kind of cognitive disability. It was decided that two stop reminders are ideal for individuals with cognitive disabilities; as the rider is approximately 150 meters from their goal stop, TAD announces "Get ready…" twice. When the rider reaches 75 meters, TAD announces "Pull the cord now!" and the cell phone vibrates and displays the same message (Screen D in Figure 3). This announcement continues until the rider confirms they have exited the vehicle by pressing a cell phone key. If another trip segment exists, the cell phone will display screen C again and repeat the process for subsequent segments. Once the traveler has completed the last segment, the phone will display Screen B again, and the traveler can shut off the phone or exit the program.

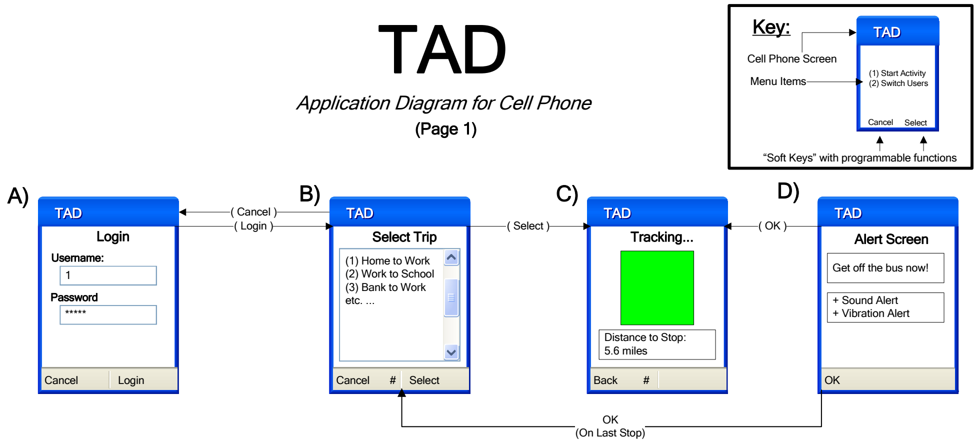

Figure 3 - TAD Cell Phone Software User Interface

Since real-time user position is of vital importance to the system, the check for device proximity to the upcoming bus stop position must be performed in real-time on the cell phone. The TAD Java ME application utilizes the JSR179 Location API, to request location information from the mobile phone *(16)*. TAD bases its real-time navigation decisions on assisted GPS data provided by the embedded GPS chip in the cell phone. In phase 1 of TAD implementation, proximity detection was implemented on-board the mobile phone as a geo-fencing operation based on the location of the destination bus stop. This design allows the cell phone to work autonomously from the server in the event communication is lost while the rider is on the bus. One of the unknown variables in the initial TAD design was the GPS signal quality to be expected inside a moving transit vehicle. Through early field testing of the TAD software, it was determined that the accuracy was sufficient to provide the services for which TAD was created *(11)*.

The User Datagram Protocol (UDP) is used for transmitting real-time cell phone location data to the server to enable real-time tracking. UDP is a connection-less protocol that is useful for communications when timeliness of data is more important than its reliability *(17)*. UDP allows the mobile phone to rapidly transmit location data up to one GPS location per second without the overhead of the handshake as required by the TCP protocol, therefore reducing the impact on device and server resources.

Various algorithms are also implemented in the TAD software to enable efficient operations on-board the mobile device by reducing the frequency of GPS position calculations, as well as the number of wireless transmissions in order to save device battery energy. A Critical Point algorithm can be used to transmit only GPS fixes required to reconstruct the user's path, while a location-aware state machine is able to reduce the frequency of GPS position calculations when the mobile phone is detected at a far distance from the next stop position *(18)*.

TAD Server Applications

The server-side software consists of several applications that work together in order to provide the storage of transit, trip, and user information, as well as detect when the user unexpectedly deviates from the planned route. A Post-GIS database server is used to store the spatial information associated with the transit routes, and a Microsoft SQL Server is used to store all other information. Once the transit rider is traveling on a route, the position is reported to the server in real-time by the mobile phone. When the travel trainer initially creates the rider's trip on the webpage, a custom geofence is automatically defined around the planned route. The rider's position is checked in real-time against the sequence of routes the rider has chosen. Therefore, the system is fully programmable based on input from the website, and the trip chosen by the rider's cell phone.

An important server-side software module is the transit data update application. Since changes to bus schedules, routes, and bus stops can be frequent, it is important for an automatic update procedure to be in place if TAD is to be deployed to multiple transit agencies. The TAD server update application utilizes data formatted via the Google Transit Feed specification, posted by transit agencies on their respective websites *(19)*. Google Transit is a free trip planner that transit agencies may provide to their customers, provided the transit agency formats their data in a specific format and keeps an updated copy of this format on their website. The TAD system utilizes these same postings to update its own database, which enables TAD to add new transit agencies to its database, or update existing transit agency data with one click. Since Google Transit is a free resource for transit agencies, this provides an incentive for the agency to keep its data current.

FIELD TESTS

TAD was continuously evaluated during the development process by project staff and by Mark Sheppard using Motorola iDEN i870 and Motorola iDEN i580 cell phones on the Sprint-Nextel iDEN network, and Sanyo 7050 phones on the Sprint-Nextel CDMA network *(20)*. To observe the interaction between a transit rider with special needs and the TAD software on the mobile phone, TAD was also evaluated by students from the STAGES program at the USF. The following sections present the results from these tests, as well as a discussion of the lessons learned.

Results

Results of TAD testing on 38 trips was documented by the research team, where each trip is defined by a starting and ending bus stop that requires TAD to issue one "Pull the cord now" notification. The results of these trips are shown in Table 1. Ideal prompts are those given between the stop prior to the destination stop and the destination stop, while giving the user enough time to comfortably react and pull the stop request cord. Late prompts are those given after the stop prior to the destination stop but require fast reaction time by the user to avoid missing the stop. Early prompts are those given to the user before they reach the stop prior to the destination stop.

Table 1 – Results of TAD Testing on Random Bus Stops

TAD Testing Conducted on Random Stops	
Number of Ideal Prompts	34
Number of Late Prompts	
Incorrectly Geocoded Bus Stop	1
Close Proximity of Bus Stops	1
Number of Times No Prompt Given	
HART Service Change	1
Incorrectly Geocoded Bus Stop	1
Total Number of Trips	**38**

After following USF Institutional Review Board (IRB) procedures required when involving humans of potentially vulnerable populations, 12 one-way trips were completely navigated by six students from STAGES utilizing the TAD software on a Sanyo 7050 mobile phone on the Sprint-Nextel CDMA network. One research team member accompanied the students on each trip, but remained distant from the student on the bus to observe their behavior. The observed TAD behavior during testing is shown in Table 2. Two additional trips were started with

Table 2 – Results of TAD Evaluation with STAGES Students

Evaluation of TAD with STAGES Students	
Number of Ideal Prompts	5
Number of Early Prompts	
Received prompt while bus was stopped at 2nd-to-last bus stop	1
Number of Late Prompts	
Close Proximity of Bus Stops	2
GPS drift	1
User did not hear alert when it was first issued	1
Number of Times No Prompt Given	
Due to Lack of Connection to Wireless Carrier Location Server	1
Due to Incorrectly Geocoded Bus Stop	1
Total Number of Trips	**12**

STAGES students but were prematurely aborted as a result of miscommunication by the research team before the response of TAD could be observed and therefore are omitted from Table 2.

Discussion

In both the random stop testing and the evaluation with the STAGES students, a number of important observations about TAD were made. First, the accuracy of the bus stop inventory made available through the transit agency's Google Transit Feed is critical to the successful operation of the TAD. The accuracy requirements of the transit agency for bus stop locations for their scheduling software (i.e., block-level resolution) may result in some stops being geocoded without sufficient accuracy for TAD, which requires GPS-level resolution (i.e., 10-15 meters). While the majority of bus stops in HART's inventory were geocoded near their actual location, in several instances incorrectly geocoded locations caused TAD to fail to issue the "Pull the cord now!" prompt to the user at an ideal time. While HART has completed a newly geocoded bus stop inventory using GPS devices since these tests, since some inaccuracies remain an editing tool should be created on the TAD website to allow travel trainers and system administrators to directly reposition stops that are known to be incorrectly geocoded.

Figure 4 – Bus stop inventory inaccuracies (difference between bus stop icon and balloon).

Second, updates from the transit agency's Google Transit Feed should be immediately applied to the TAD system. During software testing by the research team, an update of the TAD system from a newly posted feed was delayed for one week which prevented TAD from delivering the notification for one trip.

Several technical issues were also observed that prevented TAD from delivering several alerts in ideal locations. The bus stop detection algorithm, a simple circular geofence around the destination stop implemented in the TAD Java ME software, has difficulties providing alerts to transit riders at the appropriate time when bus stops are very close in proximity *(12)*. In several situations, most of them occurring in the STAGES evaluation in neighborhoods with very close bus stops, the alert was either given to the rider too soon (Table 2), or too late (Table 1 and Table 2). These problems result from the desire to maximize the radius of the geofence and provide the user with early warning, while the radius size must be restricted to the minimum possible distance between bus stops to avoid giving the prompt too early. Therefore, future TAD work will examine more advanced stop detection methods that can be implemented on board a mobile phone to give riders timely notifications without delivering the prompt too early. Another technical issue encountered was a transient connection problem between the mobile phone and the wireless carrier location server which prevented the phone from determining its location using GPS at the beginning of a trip. While under normal operation, a mobile phone should be able to calculate a GPS fix without requiring wireless communication, the particular model utilized in these tests requires communication with a location server when a GPS fix is first requested. This problem is not of great concern for the general operation of TAD, since it should only be encountered in development environments.

GPS drift, shown in Figure 5, also caused one late TAD prompt. Due to increasing mobile phone GPS accuracy and sensitivity, GPS drift is not a significant problem for TAD, as this was the only such observation of GPS drift. Future work will examine integration of TAD with Automatic Vehicle Location (AVL) systems to determine if the bus location can be used as a redundant positioning system when the mobile phone is unable to get a GPS fix. Additional services, such as the estimated time until the transit vehicle arrival to the user's location, could also be provided using live AVL data.

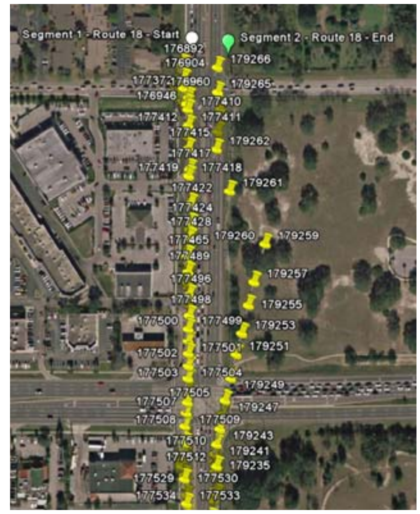

Figure 5 – GPS drift caused one late TAD alert.

Several important observations related to human interaction were observed during the STAGES evaluation. During most of the testing, the transit rider was able to go about different tasks, such as listening to a portable music player or reading, while riding the bus and the TAD was still able to gain their attention to prompt them at the appropriate time. However, during one trip, the user pulled the stop request cord late since they did not hear the initial auditory prompts until they were near the destination stop. Currently, the audio prompts are announced through the phone's external speaker while the phone vibrates and displays a visual message. Future TAD work will examine directing the auditory prompt through a Bluetooth™ wireless headset to make it easier for the rider to hear the notification. Several transit riders also expressed a preference for prompt methods that could be issued without drawing attention (e.g., vibration) while several parents of the transit riders indicated that they would prefer the auditory prompt because it would be more likely to command the rider's attention. The Bluetooth wireless headset is a good compromise between these two sets of preferences, since the rider will maintain their privacy by receiving an audio alert that only they can hear.

CONCLUSION

The design, implementation, and field testing of TAD, a software application for commercially-available GPS-enabled mobile phones that announces a transit rider's upcoming bus stop, has been successful. The rider's real-time location can be viewed on a website, which is also used to create new trip itineraries. Alerts can be automatically issued in case the rider has deviated from his or her planned route. TAD has been field- tested in the Tampa, Florida area on the HART transit bus routes for over one year, including an evaluation with special needs transit riders from USF's STAGES program. These tests successfully demonstrated the proof-of-concept of TAD and inspired areas of future TAD research. The accuracy of bus stop inventories provided by transit agencies is a critical requirement for TAD to work properly on a transit system. Future work will focus on improving the bus detection algorithm to increase the general system reliability and adding new services through the integration of TAD with live bus location data. The capability to receive the "Get ready…" and "Pull the cord now!" prompts through a Bluetooth™ wireless headset will reduce the risk of the auditory alert being lost in a noisy transit environment, and will protect the user's privacy. Future research is also needed in integrating TAD into travel training curriculums. While the TAD was designed to aid transit riders with special needs to increase their level of independence, any new transit rider can benefit from its service.

ACKNOWLEDGEMENTS

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