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# Travel assistance device: utilising global positioning system-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 to provide a variety of real-time location-based services. This study reports on the design, implementation and testing of such a service, the travel assistance device (TAD), that aids transit riders with special needs in using public transportation. TAD is a program that provides the rider with customised real-time audio, visual and tactile prompts for exiting 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 deviates from the planned route. A website allows easy access for the creation of new trip itineraries and allows authorised personnel to monitor the rider’s location 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.

## 1 Introduction

The public transportation environment challenges new and existing riders to make rapid, real-time decisions that are especially difficult for special needs populations. A range of techniques including advertising trip routes, online trip-planners (e.g. Google Transit) and travel trainers (i.e. instructors that train new riders in how to travel via public transportation) are used by transit agencies to overcome barriers to increased ridership. A number of studies have found that current informational materials do not fully meet riders’ need for clear instructions. According to the National Center for Transit Research, 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% of the population, it is especially daunting to plan and execute a trip with no assistance from others [2]. Additionally, transit agencies are struggling to support expensive specialised 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 against 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) [4–7]. These researchers speculated that a personal digital assistant (PDA) coupled with a global positioning system

(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, '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 pro-active reminders to the user to exit the transit vehicle. Additionally, the system must have stored prior travel behaviour 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 for any individual; disabled or otherwise.

Over the past 5 years, cell phone technology has continued to evolve at an astounding rate and the adoption of mobile phones has truly reached global proportions. In mid-2009, there were an estimated 4.1 billion worldwide mobile cellular telephone subscriptions, a number equivalent to over 60% of the world's estimated population, with many new subscribers being added in emerging markets such as India and China [11]. Owing to concerns regarding locating emergency callers in the US market, cellular carriers and device manufacturers have improved GPS-based positioning technologies in order to properly meet the Federal Communication Commission's e911 mandate. As a result of these developments, as well as a global demand for mobile navigation services such as real-time driving directions, high-sensitivity-assisted GPS chips have been integrated into many of the recent-generation mobile phones. The global number of GPS-enabled cell phones is expected to exponentially increase with 550 million GPS-enabled handsets expected to ship in 2012 [12]. As a result, mobile phone software applications can now take advantage of this embedded GPS technology to provide location-based services to the cell phone user, even in obstructed environments such as transit vehicles [13].

## 2 System design

The travel assistance device (TAD) system described in this paper 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 [14], 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 (Fig. 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.

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. Standard-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

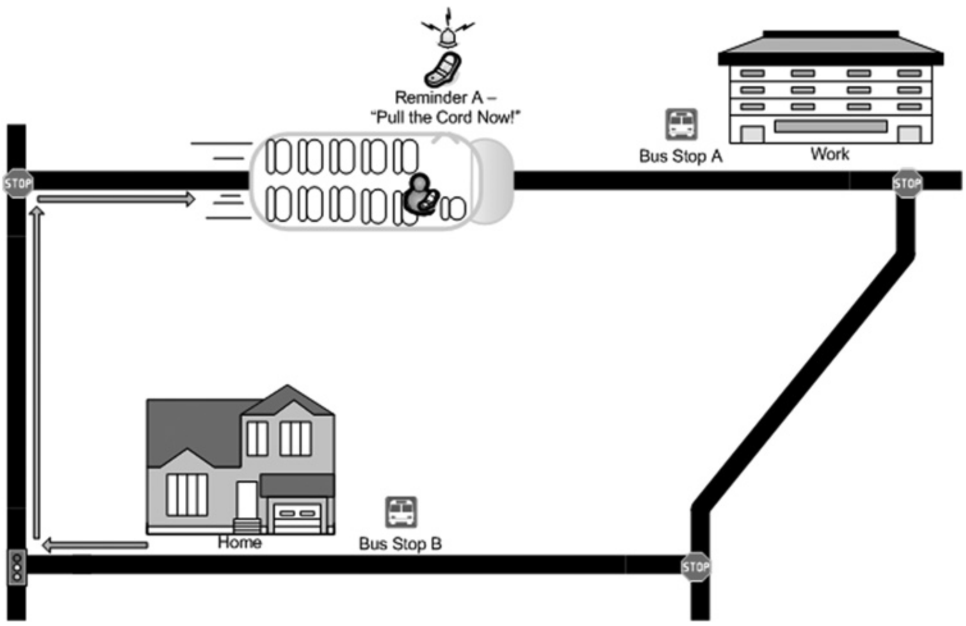


**Figure 1** *TAD software on mobile phone alerts transit riders when they are about to reach their stop*

management costs to transit agencies. Finally, the software should be forward compatible with future mobile devices to minimise 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 that allow TAD systems to operate in heterogeneous computing environments on multiple platforms and operating systems. System entities should also be encapsulated so elements (e.g. database server) may be exchanged without disrupting the entire system.

3. *Provide a reliable service tailored to transit riders with special needs*: 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 and display a visual alert to prompt the rider to request a stop.

## 2.1 Server–client model

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 that implements a webpage. The TAD system architecture is shown in Fig. 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. Utilising the Java programming on all platforms reduces development time since code can be reused. Java Micro Edition (Java ME) is deployed on billons of devices, and is currently the best platform for reaching as many mobile devices as possible [15].

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 often 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) because of the widespread 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 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' [16]. 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. If a cell phone does not support JSR172,

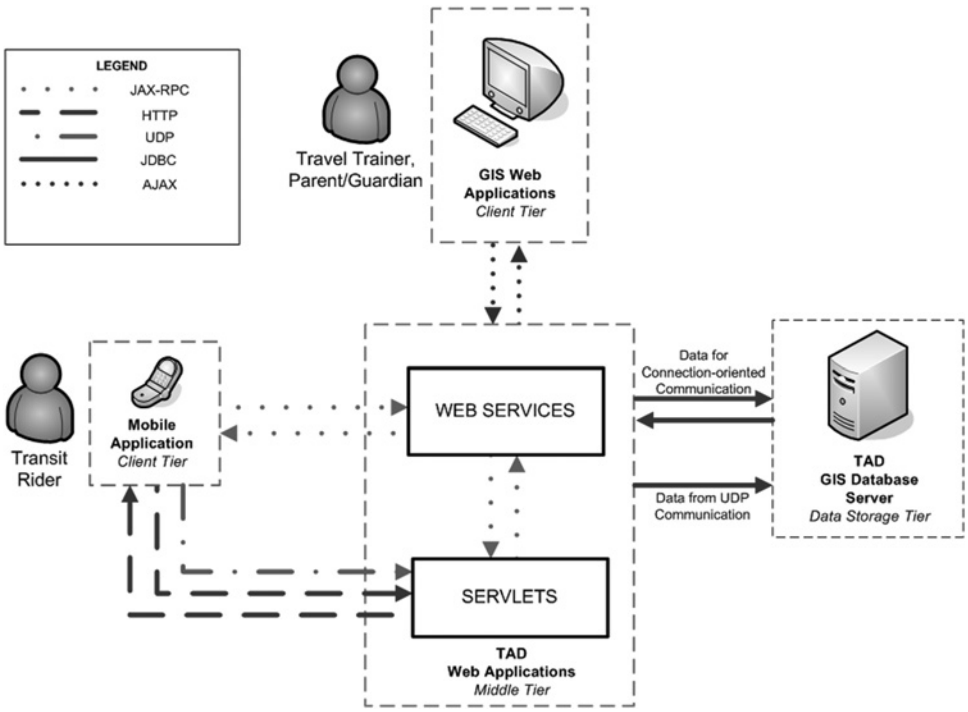


**Figure 2** *TAD system architecture*



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it can access the web services via a servlet proxy, as shown in Fig. 2. In this scenario, the cell phone communicates with the servlet proxy using the HTTP protocol, which is 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 an 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. REST-ful web services can actually be significantly more energy efficient than JAX-RPC because of the additional XML overhead that comes with the use of SOAP, and therefore mobile developers should seriously consider the use of REST-ful web services when possible to maximise mobile device battery life. The TAD system is currently implemented using REST-ful web services.

## 2.2 TAD webpage

The TAD webpage allows the travel trainer or caretaker/parent to create new trips for the transit rider, and 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 traveller'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, the bus stops on that route are shown on the webpage map. The web user can then specify the boarding and exiting bus stops by clicking on the appropriate location markers that represent the 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 immediately access and select the trip using his or her cell phone to automatically receive the 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 [17]. 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 webpage functionality, the learning curve for developing advanced AJAX applications is steep because of the multiple technologies involved. The Google Web Toolkit reduces the associated learning curve by allowing the use of Java Integrated Development Environments 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.

## 2.3 TAD cell phone application

The mobile application is the primary user interface for the transit rider and is also responsible for determining when to alert the rider to request a stop based on the GPS technology embedded in the cell phone. Existing literature on navigation skills for those with cognitive impairments was consulted as part of the TAD cell phone software design process. The prompting method that the cell phone uses to alert the rider was the primary focus of a literature review conducted. Some studies report that checklists and step-by-step written instructions are the most effective means to guide an individual with a cognitive disability through a series of tasks that are not related to navigation [18, 19]. Other studies have shown success using a recorded voice as a means of prompting an individual, also for non-navigation-related tasks [20–22]. Recent research suggests that the task of real-time navigation is most successful when guided by auditory prompts. One study found that auditory alerts were not only the most effective type of prompts for real-time navigation for cognitively impaired individuals but also the most preferred by participants [23]. The authors attributed these findings to the cognitive process of navigation that occupies the visual processing components of the brain. Prompts that require visual attention such as maps, images or written directions can conflict with the visual element of navigation itself. Since the auditory processing of directives does not conflict with the visual information that the individual is receiving during navigation, it therefore allows the individual to successfully manage both tasks simultaneously. These findings are similar to other studies examining individuals without cognitive disabilities, which conclude that audio prompts are preferred for multi-tasking where the visual attention of the participant is required for real-time navigation [24–26].

Based on findings from literature consulted, TAD was designed to primarily use an auditory prompt to alert the individual to exit the bus. Secondary prompting methods that are visual and tactile (i.e. vibration) were implemented as well.

To develop a design for TAD that was appropriate for the target population, the Travel Trainer for Hillsborough Area Regional Transit (HART), and a Transition Facilitator for

Exceptional Student Education for the Successful Transition After Graduation for Exceptional Students (STAGES) program at the University of South Florida, were included as members of the research team. In addition, an advisory group was convened to obtain input from those involved in travel training or special education. This group included experts from the Louis de la Parte Florida Mental Health Institute at USF, the Florida Department of Transportation, MacDonald Training Center and the Hillsborough County School District. Additional travel instructors were also consulted through a presentation and dialogue at the 2005 National Conference for the Association for Travel Instruction.

When the user starts the TAD cell phone application, the application logs the user into the TAD system using web services, and displays all trips that have been previously planned for the user via the TAD website. For ease of use, the user is required to log into the system only the first time the mobile application is used (screen A in Fig. 3). The user name and password can be saved on the cell phone, and the user will automatically be logged in and shown screen B of Fig. 3 the next time the application is started. Once the user chooses a trip from the list (Fig. 3, screen B), the phone retrieves all relevant information (e.g. bus stops, routes etc.) for the segments travelled as part of that trip. Next, the cell phone displays a screen with a globe as a GPS signal indicator along with the distance to the next stopping point (screen C in Fig. 3) that continuously counts down while the user is travelling. The cell phone will reliably provide services to the rider and the rider will receive the exit notification when appropriate as long as the GPS signal remains visible. If, however, the GPS signal fades due to obstructions such as overpasses or nearby tall buildings, a red circle and cross will appear over the globe and a warning beep announces that he or she will not receive a notification when they near the stop.

After discussions with several travel trainers, two stop reminders were chosen to alert the transit rider. As the rider is approximately 150 m from their goal stop, TAD announces 'Get ready...' twice. When the rider reaches 75 m, TAD plays an audio alert, 'Pull the cord now!' and the cell phone vibrates and displays the same message as text (screen D in Fig. 3). This announcement repeats until the rider confirms they have exited the vehicle by pressing a cell phone button. If another trip segment exists, the cell phone will display screen C again and repeat the process for subsequent segments. Once the traveller has completed the last segment, the phone will display screen B again, and the traveller can shut off the phone or exit the program.

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 utilises the JSR179 Location API to request location information from the mobile phone [27]. TAD software 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 areas surrounding the position of the destination bus stop (Fig. 5). This design allows the cell phone to work autonomously from the server if 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 [13].

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 are more important than its reliability [28]. UDP allows the mobile phone to efficiently transmit location data up to one GPS location per second without the

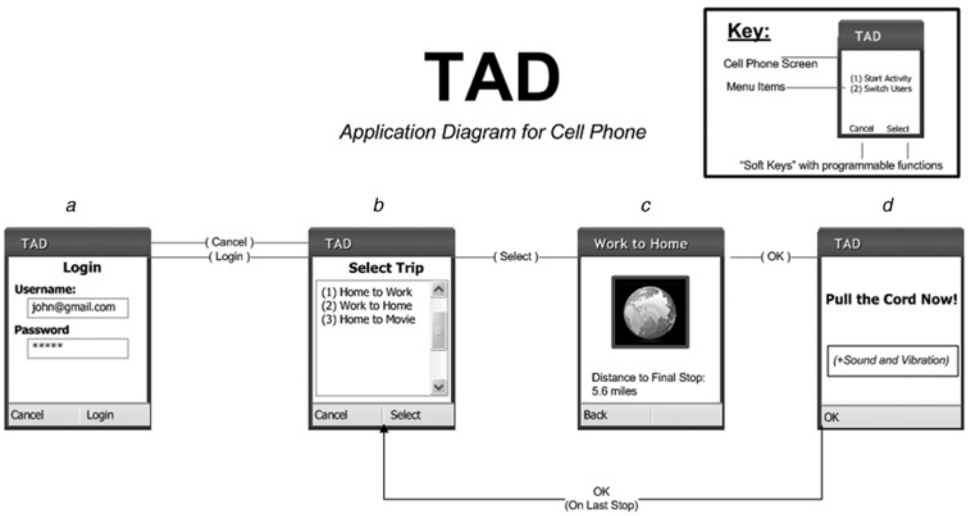


**Figure 3** *TAD cell phone software user interface*



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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, whereas 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 [29].

## 2.4 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 travelling on a route, the user's 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 geo-fence 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, and if the rider's position deviates from this route an alert is sent to the travel trainer assigned to the transit rider. Therefore the automated monitoring system is fully programmable based on input from the website, and the trip chosen by the rider's cell phone.

A critical server-side software module is the TAD Database Toolkit, which includes a transit data update tool. 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 utilises data formatted via the Google Transit Feed Specification (GTFS), posted by each transit agency on its respective websites [30]. Google Transit is a free trip planner that transit agencies may provide to their customers, provided the transit agency format its data in a specific format and keeps an updated copy of these data on their website for Google to periodically download. The TAD system utilises 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 additional incentive for the agency to keep its data current. As of mid-2009, over 425 agencies world-wide have placed their data in the GTFS format, with over 110 transit agencies participating in the US. Owing to the widespread popularity of Google Transit and the GTFS format and the capability of the TAD system to easily import and update its database using datasets in the GTFS format, the TAD service can be adopted by many transit agencies on an international scale without requiring significant effort by the TAD system operator or each participating transit agency.

# 3 Field tests

TAD was field-tested by the research team, including the travel trainer from HART, 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 [31]. After the initial TAD software development phase was complete, 38 trips were performed by the research team to evaluate the reliability of the TAD prototype system. TAD was also tested by participants from the STAGES program (a post-high school curriculum for special education students), on an additional 12 trips to identify human interface issues. Since TAD was a proof-of-concept system, the focus of all testing was the performance of the technology as a reliable application given the current capabilities of commercially available GPS-enabled cell phones. These field tests provide the groundwork to establish TAD as a viable technology in preparation for future tests, which will focus on the impact of TAD on human behaviour, as discussed later in this paper. The following sections present the results from the technology proof-of-concept tests, as well as a discussion of the lessons learned.

## 3.1 Results

Each of the 50 trips evaluated as part of the field tests are 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 Tables 1 and 2. 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 as soon as the prompt is given. Late prompts are those given after the stop prior to the destination stop but require fast reaction time by the user to avoid missing

**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 stop | 1 |
| Number of times no prompt given | |
| HART service change | 1 |
| incorrectly Geocoded bus stop | 1 |
| total number of trips | 38 |

**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 drifts | 1 |
| user did not hear alert when it was first issued | 1 |
| Number of times no prompt given | |
| owing to lack of connection to wireless carrier location server | 1 |
| owing to incorrectly Geocoded bus stop | 1 |
| total number of trips | 12 |

the stop. Early prompts are those given to the user before they reach the stop prior to the destination stop. It should be noted that while Early and Late prompts may still be useful to the user, these prompts are strictly differentiated from prompts being delivered to the user in the precise Ideal location to facilitate the evaluation of the TAD system and identify areas of future improvement.

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 utilising the TAD software. One research team member accompanied the students on each trip, but remained distant from the student on the bus. The observed TAD behaviour during testing is shown in Table 2. Two additional trips were started with STAGES students but were prematurely aborted because of miscommunication by the research team before the response of TAD could be observed, and therefore are omitted from Table 2.

For 38 out of the 50 trips, TAD gave the prompt to the rider at the ideal place and time. Of the remaining 12 trips, TAD either provided the alert slightly early or slightly late eight times, and failed to provide an alert to the rider four times. The specific reasons for the select late or missing prompts are given in Tables 1 and 2, which could be addressed through improvements to the system as discussed in the following section.

## 3.2 Discussion

The proof-of-concept testing of the TAD software successfully demonstrated that a GPS-enabled cell phone with the proper software could successfully alert a transit rider to their upcoming stop. As a result of the testing, several observations were made, which revealed important challenges regarding the operation of TAD in a real-world transit environment. Several examples of challenging conditions follow, which resulted in prompts being delivered either early or late to the user. Lessons learned from these experiments and resulting future TAD improvements that can increase the accuracy and reliability of the system further are discussed in the subsequent section.

*3.2.1 Sample challenging condition A:* TAD did not successfully detect the starting bus stop of the trip because of erroneous bus stop location information stored in the TAD database. The actual bus stop location is indicated by the balloon-shaped marker in Fig. 4, while the nearby light grey bus square indicates the location stored in the bus stop inventory. Although preliminary testing was previously conducted on the same route with success, it did not uncover the error only because TAD approached the bus stop from the south close enough to the database stop location to detect it. However, during the actual field test, the bus stop was approached from the north and TAD did not come close enough to the database stop location for it

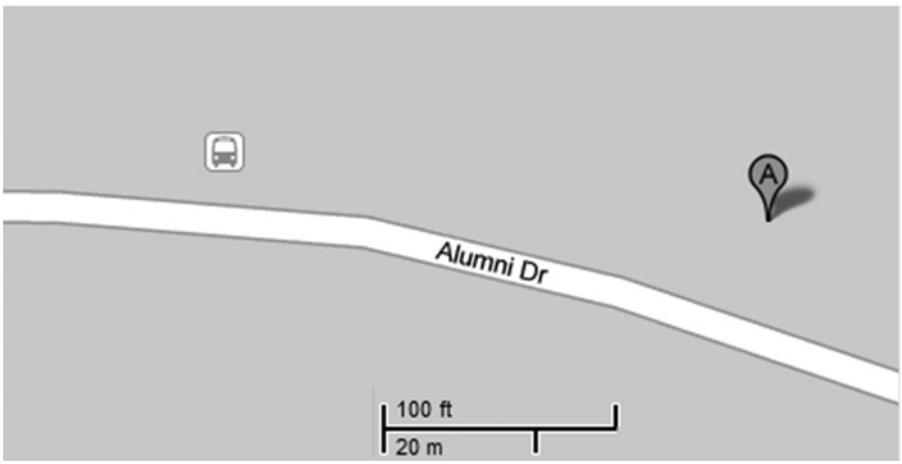


**Figure 4** *Bus stop inventory inaccuracies (difference between bus stop icon and balloon)*




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to be detected. This issue has been resolved by correcting the bus stop location in the TAD database.

Ongoing work by HART should also help in addressing any other bus stop inventory inaccuracies in the database. Additionally, future versions of TAD will not require proximity detection of the boarding bus stop location in order to detect the destination stop. TAD will only rely on the accuracy of one bus stop (i.e. the stop prior to the destination stop) instead of three stops, which will improve the reliability of the system.

*3.2.2 Sample challenging condition B:* Ideally, TAD would alert the user immediately after the bus departs the second-to-last stop. However, on the first segment of the trip the user received the alert slightly early while the bus was stopped at the bus stop prior to the destination stop. This was caused by two factors: the small distance of approximately 135 m between destination stop and the stop prior to it and the fact that the bus came to a halt to allow riders to board or alight at the second-to-last stop. The TAD application was set to alert the user at approximately 165 m prior to the final destination; thus, the alert sounded prior to passing the second-to-last bus stop. If the bus did not stop at the stop, the alert likely would have been executed in an ideal position. These problems result from the desire to maximise the radius of the geo-fence to provide the user with early warning along with the restriction of the radius size being at most the minimum possible distance between bus stops (to avoid giving the prompt too early). Future TAD versions should examine potential improvements to the current bus stop detection and alert algorithm, which would take into account the second-to-last bus stop location and the velocity of the bus on the approach to the final stop to make a more accurate alert.

*3.2.3 Sample challenging condition C:* On the first segment, the user reported that TAD provided the alert too close to the final stop, approximately 60 m before the intended bus stop. Upon the review of the GPS log, it appears that TAD should have been triggered by several GPS fixes at approximately 165, 145, and 130 m distance from the bus stop. Further testing was not able to replicate this observation. Based on the available information, it is believed that the user did not hear or feel the alert until very close to the stop. Future versions of TAD should be enhanced to automatically indicate in the GPS log exactly where the notification was given to the rider to better aid in the troubleshooting process. Additionally, future versions should examine delivering the alert through a Bluetooth™ wireless headset to increase the chance that the rider will hear the alert as soon as it is issued.

*3.2.4 Sample challenging condition D:* On the second segment of this trip, TAD delivered the alert to the user when approaching the destination stop. The 'Pull the cord now!' alert sounded as the trainer and student were preparing to exit the bus, which was too late for the rider to have requested a stop when the bus was moving at full speed. As previously mentioned, future TAD versions should examine potential improvements to the stop detection algorithm that would alert the user as soon as the bus passes the second-to-last stop, thus avoiding these late alert occurrences.

*3.2.5 Sample challenging condition E:* For the first segment, TAD delivered the alert in an ideal location. For the second segment, the user reported that TAD delivered the alert too close to the destination stop. After the review of the GPS data logs from the phone, this anomaly was likely because of a temporary loss of GPS accuracy (i.e. GPS drift). The research team could not replicate this behaviour by travelling this route multiple times before and after the STAGES testing.

A temporary loss of GPS accuracy can be attributed to many causes, including weather, position of the phone in the bus, wireless interference and incorrect assistance information from a location server. The research team is working with the wireless carrier to utilise a different location server to ensure that reliable assistance data are available during future TAD testing. Future mobile phone models should show a further increase in GPS sensitivity that should also provide better positioning information, therefore reducing the chance of GPS drift. The research team will also look to enhance the stop detection algorithm to provide the user with alerts earlier in order to give the rider more notice before they must pull the stop request cord. As this was the only occurrence of GPS drift observed during system testing, GPS drift does not seem to be a significant problem for the TAD system. Future work will examine integration of TAD with transit automatic vehicle location (AVL) systems to determine whether 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 arrival time of the transit vehicle to the user's location, could also be provided using live AVL data.

# 4 Lessons learned

The TAD field tests successfully demonstrated the proof-of-concept of the TAD software for GPS-enabled cell phones to alert transit riders as they near their bus stop. Many valuable observations were made during these tests, which can be used to improve the system's usability and reliability. The following subsections discuss lessons learned.

## 4.1 Importance of bus stop accuracy

One of the most significant problems encountered during testing has been the inaccuracies in geo-coded bus stop locations. The bus route and stop information are obtained from the transit agency and formatted according to the GFTS. Since TAD relies on this information to properly

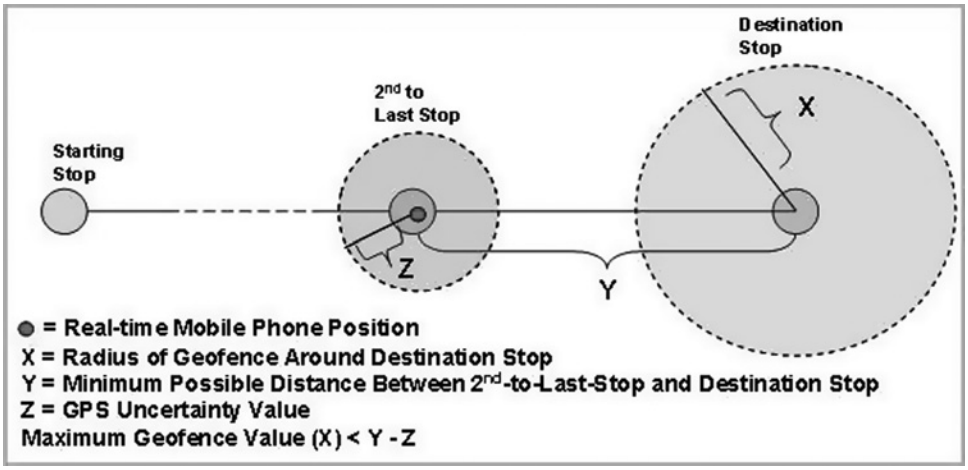


**Figure 5** *Bus stop detection and rider alert algorithm*

announce the alerts to request a stop, TAD will not perform well if the bus stop location data are highly inaccurate. 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 geo-coded without sufficient accuracy for TAD, which requires GPS-level resolution (i.e. 10–25 m). Although the majority of bus stops in HART's inventory were geo-coded near their actual location, in several instances incorrectly geo-coded locations caused TAD to fail to issue the 'Pull the cord now!' prompt to the user at an ideal time. While HART has recently completed a newly geo-coded bus stop inventory using GPS devices, thus improving on what was available at the times of TAD testing, some inaccuracies still remain. A bus stop editing tool should be developed for the TAD website to allow travel trainers and system administrators to directly reposition stops that are incorrectly geo-coded. Once repositioned, the bus stop location would be corrected in the TAD and TAD would perform properly for all future trips which visit that bus stop for all TAD users.

It should be noted that some bus stop inaccuracies do not negatively affect TAD's performance. For example, if the bus first encountered the geo-coded stop position before passing the actual physical location of the stop, TAD would prompt the rider to get off at the proper stop. The stop request alert would be triggered sooner than intended; however, the rider would still be able to exit the vehicle at the correct stop.

## *4.2 Bus stop detection and alert trigger algorithm*

The stop detection algorithm on the mobile phone must be extremely efficient because of the limitations of computing resources on the phone that prevents advanced spatial queries and the lack of complex spatial data from the Google Transit Feed that would define the actual path the bus travels. For the TAD project, a simple geo-fencing algorithm was implemented that detected when the device comes within a certain distance of the destination bus stop while the user is travelling on the bus (Fig. 5).

It is desired that the geo-fence radius from the destination stop be maximised to give the alert to the user as soon as possible to allow him/her to prepare to exit the bus. However, to prevent the 'Pull the cord now!' notification from being triggered too soon, the radius of the geo-fence (Fig. 5 – X value) cannot exceed the distance between the second-to-last stop and the destination stop. Since the actual travel distance between the stops is not necessarily known from the transit agency's Google Transit Feed data, the minimum possible distance between bus stops must be assumed when using this algorithm (Fig. 5 – Y value). Considering that there is an uncertainty value associated with the GPS position calculated by the mobile phone (Fig. 5 – Z value), to use this algorithm in the real world, the radius of the geo-fence must actually be at least several meters less than the GPS uncertainty value subtracted from the distance between the second-to-last stop and the destination stop.

While TAD generally gave the 'Pull the cord now!' notification appropriately between the second-to-last stop and the destination stop, the current algorithm design creates some challenges related to proper alert timing when bus stops are very close together. A very early alert is not possible for bus stops that are far apart since the algorithm is constrained by the minimum possible distance between the second-to-last stop and destination stop. During the evaluation of TAD by STAGES students, a few early and late prompts were observed in several locations where bus stops are positioned very close together. Continuous field testing conducted by research team members on random bus stops, usually well spaced apart, resulted in more prompt alerts by the TAD application.

Several of the occasions where TAD gave the notification to the rider too close to the destination stop could potentially be improved by a more advanced stop detection algorithm based on the knowledge of the location of the second-to-last bus stop



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in coordination with other measurements. This advanced algorithm could also potentially give riders alerts while they are travelling on the bus much earlier while avoiding the problem of giving the alert too early.

A new stop-detection algorithm should also eliminate the dependency of detecting the rider's proximity to the boarding bus stop. In one situation, the rider was not given the alert because the beginning bus stop was incorrectly geo-coded, thus breaking the chain of events that would lead to the eventual prompt. By removing this dependency, the reliability of the algorithm will improve since the 'Pull the Cord Now!' prompt depends only on the second-to-last stop location.

Future versions of TAD could also examine direct support to the transit rider in case they miss their bus stop and exit the vehicle at an incorrect stop. Currently, the server-side route deviation algorithm should detect when the rider is outside the area of the route they are travelling. In this case, a text-message and email alert would be sent to the caretaker and travel trainer. Future integration with AVL systems could potentially be able to detect situation where the rider is still near the route but their real-time location no longer matches the bus real-time location and they have not arrived at the correct stop. In other words, the rider would have exited the vehicle at the incorrect location but is still in proximity to the bus route.

Additional prompts could be given to the transit rider to help guide them back to their planned destination stop. However, these prompts would have to be designed with consultation from travel trainers and special education professionals to be practically appropriate to each transit rider. For example, it may be preferable to simply have the travel trainer contact the transit rider via the cell phone and give verbal directions based on the rider's location, local environment, the rider's abilities and the travel trainer's professional judgement. Navigation software will not be able to take all of these issues into account, and therefore may inadvertently direct the user to perform an action (e.g. crossing a street), which could be dangerous to that particular user.

### 4.3 Challenge of working with special populations

Getting TAD into the hands of the targeted population for simple field tests was very challenging. There were significant hurdles to overcome regarding the paperwork and process required by the Hillsborough County School System and USF's IRB that oversees the integrity of research conducted with human subjects. Because the students are considered minors by the school system but consenting adults by USF standards, several different consent forms were modified to satisfy both entities. Modifying these forms and all survey documents and obtaining approval was a time-consuming task, which included fingerprinting members of the research team before they could interact with the students.

The many delays introduced because of having a special population use TAD proved to be challenging not only from the project management perspective, but also for the technical management of the TAD system. To minimise the possibility of errors during actual STAGES trips, the research team travelled on each route planned for use by the STAGES students to ensure that TAD worked properly for these areas. In each of these tests, TAD alerted the user at an ideal location. Once these tests were performed and validated, the TAD system was frozen in that state (i.e. no further automatic updates that could cause unexpected changes to the bus stops or routes) in preparation for the trips with the STAGES students. However, as time passed from these initial tests, HART made transit service changes and construction at several locations resulted in bus stops relocation. Ordinarily, these changes would have been automatically integrated into the TAD system via the update from the Google Transit Feed as HART posts updated bus stop and route data to their website and TAD is able to automatically download and integrate these changes into the TAD database.

However, in an attempt to minimise changes to the system between the preliminary TAD testing and STAGES evaluation, the research team chose to manually update only the stops and routes that were related to the planned STAGES trips and re-test those trips. This service change, manual update and re-test process happened several times before the actual STAGES trips were performed. Since the system was not initially designed with manual updates in mind, some additional errors in bus stop placement may have resulted from manual adjustments within the database, which requires direct editing of latitude and longitude values through a database record interface. Since TAD was proven very reliable when utilised in a live state with system updates happening regularly from the Google Transit Feed, it is recommended that the TAD system be kept in a live state for any future field tests. Additionally, the creation of a tool for the TAD system, which allows visual editing of stop information through a map interface, would be very useful and would help avoid any potential data entry errors. Ideally, these corrections could then be provided in a list form back to the transit agency to improve the quality of their own bus stop inventory.

### 4.4 User preferences

When interviewed, several of the STAGES students expressed preference of having the phone's vibration feature as the primary alert format over a voice alert so as not to draw unnecessary attention to themselves. Many of the parents expressed preference for an audio alert to assure gaining the rider's attention if he or she was distracted. 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 TAD was still able to gain their attention and 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 in the noisy bus environment 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 development should examine the use of Bluetooth™ wireless headsets in conjunction with the TAD mobile phone software. By utilising the Bluetooth headset, TAD can continue to deliver the prompt via the audio method found most effective for navigation directions while respecting the user's privacy [23]. Additionally, the Bluetooth headset should help the transit rider hear TAD announcements over the noisy bus environment.

### *4.5 Future work on human behaviour analysis*

Future analysis related to the impact of TAD on human behaviour should be conducted. The field tests described in this paper focused on the evaluation of the TAD technology, as the initial TAD design project was a proof-of-concept to determine if today's cell phones could accurately and reliably provide alerts to transit riders. The tests reported in this paper helped to identify problems with the TAD prototype system and ensure that TAD could provide a reliable service before more extensive research in the human behaviour area was initiated. Future work could also examine the impact of different types of voices (e.g. travel trainer's voice, parent's voice, user's own voice) on the behaviour of the transit rider in order to determine whether the type of audio announcement affects the user.

## 5 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 that is also used to create new trip itineraries. Alerts can be automatically issued if the rider deviates from his or her planned route. TAD has been field-tested in the Tampa, Florida area on the HART transit bus routes for over a 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 from AVL systems. 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 recommended to assess the impacts of integrating TAD into travel training curriculums. While TAD was designed to aid transit riders with special needs to increase their level of independence, any new transit rider or tourist can benefit from its service.

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