IDEA

Innovations Deserving Exploratory Analysis Programs

Travel Assistance Device (TAD) to Help Transit Riders

Final Report for Transit IDEA Project 52

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TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

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List of Acronyms

API	Application Programming Interface
AVL	Automatic Vehicle Location
ETA	Estimated Time of Arrival
GPS	Global Positioning System
GTFS	Google Transit Feed Specification
GUI	Graphic User Interface
IT	Information Technology
ITS	Intelligent Transportation Systems
JAVA ME	Java Micro Edition
JDBC	Java Database Connectivity
NCTR	National Center for Transit Research
PDA	Personal Digital Assistant
SOAP	Simple Object Access Protocol
TCIP	Transit Communications Interface Profiles
TAD	Travel Assistance Device
UDP	User Datagram Protocol

EXECUTIVE SUMMARY

This Transit IDEA project enhanced the travel assistance device (TAD), a global positioning system (GPS)-enabled mobile phone application, by integrating communication with an Automatic Vehicle Location (AVL) system for transit vehicles into the system to aid the use of transit by the cognitively disabled and other riders.

Navigating some transit systems can be an obstacle for attracting new riders, especially for special needs populations and visitors. Many people in the general population surveyed in a 2004 study by the National Center for Transit Research at USF reported that they could not successfully plan an entire new trip on the fixed-route transit system using only printed information materials *(Cain, 2004)*. For those with cognitive disabilities (approximately 14.2 million Americans, or 6.9% of the population), it is especially daunting to plan and execute a trip without any personal assistance from travel trainers provided by the transit agency or other group, especially on their first few trips.

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 research and development of cutting-edge mobile technology for transportation applications. Previous applications were developed with funding from the Florida Department of Transportation (FDOT) through the National Center for Transit Research (NCTR) and the University Consortium for Intermodal Transportation Safety and Security, and have focused on the use of Global Positioning System (GPS)-enabled personal digital assistants (PDAs), mobile phones, and the development of location-aware artificial intelligence software systems. The knowledge gathered from these projects, along with recent advances in the last several years in mobile communications technology, led the research team to conclude that a GPS-enabled mobile phones could now serve as a personalized travel assistant device. These devices are a fraction of the cost of previous portable technology systems, and therefore more accessible to the public.

Funding from NCTR and FDOT supported the initial development of the TAD software prototype, which used commercially-available multimedia cellular phones with built-in GPS to aid new transit riders, especially those who are cognitively disabled. Informational prompts are delivered to the rider in a "just-in-time" method that triggers the phone to vibrate and deliver audio and visual messages when the rider should pull the stop cord and exit the bus. Automated alarms can be triggered and the travel trainer and/or parent/guardian remotely alerted if a rider deviates from their pre-determined path.

Potential benefits of the TAD include increased transit ridership, decreased costs to the transit agency by enabling riders to use fixed-route transit that would have otherwise used paratransit, increased independence for people with cognitive disabilities, improved quality of life for transit riders, and increased productivity of transit agencies' travel trainers whose job is to provide one-on-one instruction for new riders or existing paratransit riders on how to use fixed-route transit. While riders with cognitive disabilities are the initial target market for this application, TAD could be used by any traveler.

This Transit IDEA project developed and tested a communication application between TAD and an AVL system, to provide new services to TAD users such as estimated vehicle arrival time while they are waiting for the bus, and the display of the real-time bus locations on the TAD website map. This communication supports advanced TAD features based on the real-time location of the transit vehicle in relationship to each rider's real-time location including:

- providing personalized notices of the estimated time remaining for the bus arriving to current position;
- notifying riders when their specific bus arrives; and
- providing the rider with identifying information so that they board the correct bus if multiple buses are present

Many lessons were learned in this project during the integration process between the TAD system and Hillsborough Area Regional Transit's (HART) AVL system in the Tampa, Florida area. Some conclusions reached from these experiences in this project include:

- Using common values of data attributes (e.g., direction) is very important when exposing transit information as part of multiple datasets (e.g., Google Transit Feed Specification (GTFS), estimated time of arrival web services).
- Real-time dynamic transit information such as real-time bus position and estimated time of arrival should be exposed to external systems via Representational State Transfer (RESTful) web services for maximum mobile device efficiency and compatibility.
- Use of cell phone software emulators are valuable to test new software in the development process before deploying to the field, but ultimately the performance of location-based mobile software needs to be evaluated through actual field tests in the real-world environment.
- The lack of timely transit vehicle location data can restrict some potentially innovative mobile applications, such as the ability to use the vehicle GPS as a backup when the phone's GPS is interrupted. Future transit systems should consider providing timely (i.e., less than 10 second delay) updates as part of AVL system design.
- The transit industry should consider an effort to standardize the format of lightweight web services exposing dynamic transit information. American Public Transportation Association's (APTA's) Transit Communications Interface Profiles (TCIP) standard should be considered as part of this process to determine if it fulfills the needs of transit information access for mobile devices. Existing web services implemented by transit agencies such as Tri-County Metropolitan Transit District of Oregon (TriMet) in Portland and HART in Tampa also should be reviewed to learn the pros and cons of using TCIP into their current design. If TCIP does not meet these needs, then TCIP should be modified to accommodate mobile devices or a new simple lightweight standard should be developed. For transit systems that are using TCIP standards, a TCIP-interpreter will need to be developed that will allow fluid interaction of the TAD system with TCIP-compliant systems.
- Cellular carriers must be consulted in order to test TAD on their networks. TAD has been tested on Sprint-Nextel, but was designed to be platform-neutral. Permission from other carriers (e.g., AT&T, Verizon Wireless) must be obtained before testing is permitted. At the time of this report AT&T has provided access to the research team and the team plans to begin testing on this network soon.

For transit agencies to utilize TAD at their agency, they should:

- Format their bus stop, route, and schedule information in the GTFS format.
- Coordinate with the TAD research team for data import to the TAD system and an initial test evaluation at the transit agency.

If transit agencies want to feature information from their AVL system in the TAD system, they should:

- Coordinate with the TAD research team to determine the best design for a web service to expose transit information.
- Implement a RESTful web service to expose both real-time vehicle location and estimated time of arrival information to the TAD system.

Efforts to commercialize the TAD system are ongoing. In order to properly support and maintain the TAD system for TAD users, USF's Division of Patents and Licensing (DPL) is seeking a commercial partner to assist in the operation and further development of TAD. DPL has identified a potential partner and is actively negotiating a license with this company. Through this partnership, USF hopes to obtain matching funds and seek other funding sources to begin to offer TAD as a national commercial service. The project research team at USF obtained follow-on funding from other sources for demonstration and testing in 5 other cities of the device that was developed and tested in one city in this Transit IDEA project.

IDEA PRODUCT

The product of this IDEA project is an AVL-enhanced travel assistive device that uses multimedia cell phones with built-in GPS to overcome the challenges facing new transit riders or tourists, especially those who are cognitively disabled. Informational prompts are delivered to the rider in a "just-in-time" method that triggers the phone to vibrate and deliver audio and visual messages when the rider should pull the stop cord and exit the bus. Automated alarms can be triggered and the travel trainer and/or parent/guardian remotely alerted if a rider deviates from their predetermined path.

CONCEPT AND INNOVATION

The initial TAD prototype triggers the phone to vibrate and deliver audio and visual messages when the rider should pull the stop cord and exit the bus. This Transit IDEA project implemented communication between the TAD and an AVL system to increase accuracy and build redundancy, thus increasing reliability. This communication supports advanced TAD features, based on the real-time location of the transit vehicle in relationship to each rider's real-time location, including providing personalized notices estimating when the bus will reach their current position via the rider's mobile phone, notifying riders when their specific bus arrives, providing the rider with identifying information so that they board the correct bus if multiple buses are present, and alerting the rider and officials if the rider boards the incorrect bus.

TAD consists of several components with this project adding new modules that interact with the HART system to provide real-time vehicle location and estimated time of arrival information as shown in Figure 1.

TAD is a software system compromised of four individual software components:

- TAD mobile phone software
- TAD web application that interacts with the mobile phone software
- TAD Web Page with which the end user interacts
- TAD Toolkit application that handles the import, export, and processing of transit data

The TAD system interacts with two HART components: the database server containing HART AVL data and a HART web service that provides estimated time of arrival (ETA) information for a particular bus, stop, and route.

Using the additional HART systems, new features in the TAD application become possible. TAD mobile phone application can display real-time ETA information to the user waiting for their bus at the bus stop. Additionally, the TAD web page can show the real-time bus locations for all buses relative to the active user. Using the ETA, TAD alerts the user when a set number of minutes remain before the bus is to arrive, and then notifies the user as the bus is actually arriving at the stop.
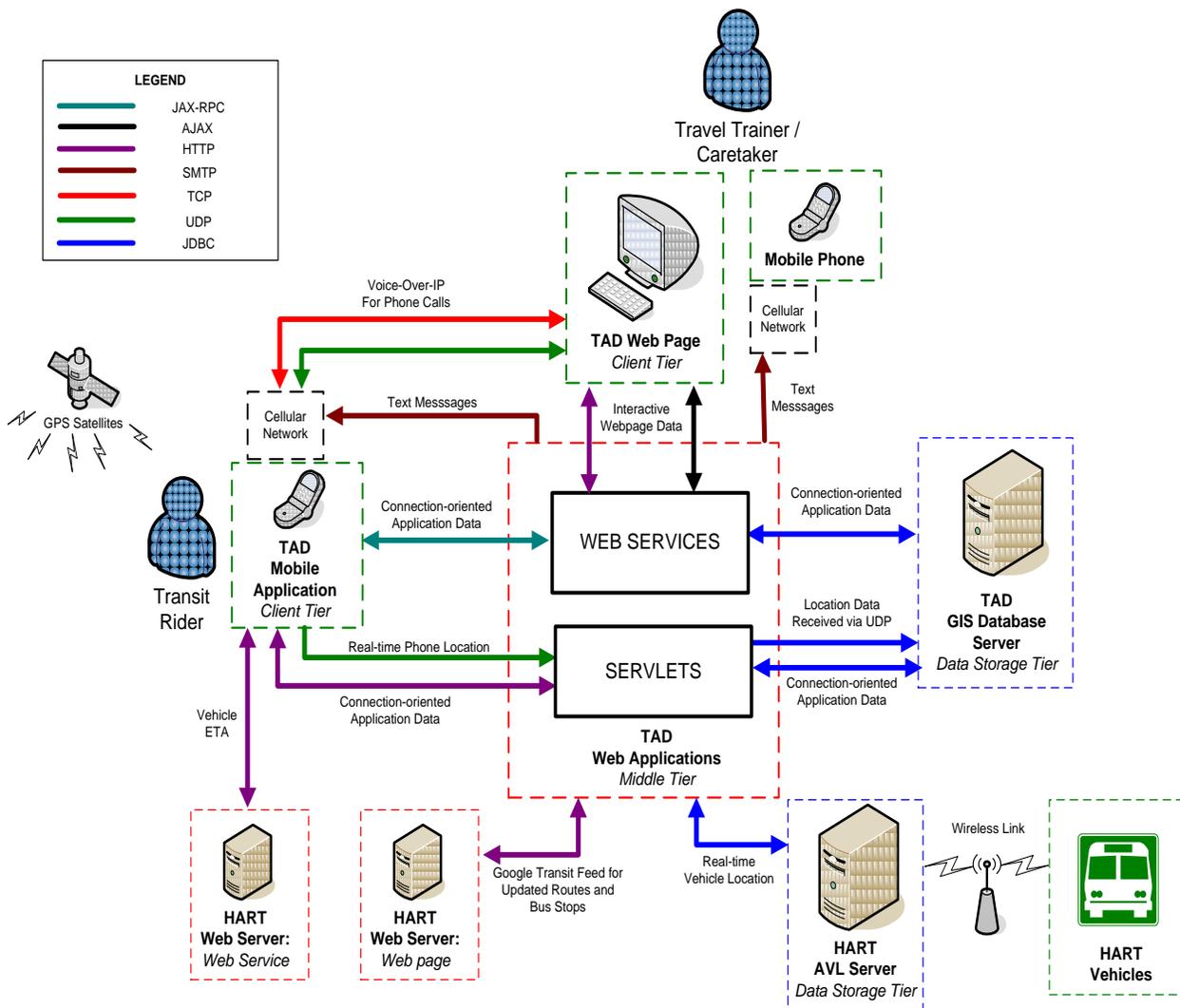
FIGURE 1 TAD complete architecture

INVESTIGATION

The following describes the steps taken in the project to develop the integration between TAD and HART's AVL system. Subsequent subsections of this report will highlight interesting or unexpected results that significantly affected the investigation, either positively or negatively.

1. Define the functional requirements for integrating transit AVL data into the TAD system to support new features (e.g., provide user with an estimated arrival time of a bus while they are waiting at their bus stop, providing information about real-time vehicle position via the TAD website).

2. Review existing literature: current standards as they relate to TAD-AVL system integration (e.g., TCIP, Google Transit Feed Specification, GTFS), and research related to the experience of individuals with cognitive disabilities using public transportation *(Winters, Barbeau, Georggi, 2009)*.

3. Develop and assign tasks to meet those functional requirements, based on the outcome of steps 1 and 2.

4. Hire and train computer science and engineering graduate and undergraduate students to carry out supporting tasks in parallel.

5. Obtain real-time remote access to HART's AVL system that was being installed during the course of this project.

6. Review/modify functional requirements based on HART AVL system functionality.

7. Finalize system design and architecture based on functional requirements and HART AVL system functionality.

8. Develop new features for TAD

   a. Displaying the remaining wait time for the transit rider while he or she is waiting for his or her bus to arrive at the stop.

   b. Alerting the transit rider when the correct bus is approaching his or her bus stop location.

   c. Showing the bus locations in real-time on a publicly accessible web page.

   d. Developing a notification algorithm for TAD mobile application to benefit the rider, overcoming the limitation of the previous algorithm for providing the notification at the correct time when bus stops are close together.

   e. Exporting cell phone GPS trip data in a format that can be re-played through a phone emulator to simulate TAD trips, allowing preliminary mobile phone software testing without actually boarding the transit vehicle.

9. Test the prototype with representative end-users of the product and refine.

The following subsections discuss the functional requirements (Table 1) and the detailed design of each component in the high-level architecture shown in Figure 1.

Identifying and Meeting the Functional Requirements

Table 1 summarizes the functional requirements and how the new TAD system architecture fulfills those requirements. The following system components are used within the TAD architecture shown in Figure 2 to provide services to the TAD end-user based on AVL data. Components 4 and 5 below are new to the architecture and provide AVL-based information to the TAD system.

1. TAD Mobile Phone Application
2. TAD Web Server Application
3. TAD Web Page
4. HART Web Service to provide vehicle estimated time of arrival information
5. HART database containing vehicle location

Reviewing Relationships to Existing Standards

As part of the design and implementation process, the research team examined the APTA standards on TCIP to determine applicability to this particular software implementation. Since this project made use of existing data sources that do not implement the TCIP standard as part of this system prototype (e.g., AVL web service and database, GTFS *(Google, Inc. 2009),* making TAD TCIP-compliant would not result in a working prototype. However, it is planned that, in future TAD software implementations that will interface with TCIP-compliant systems (e.g., different AVL systems), a TCIP-interpreter will need to be developed that will allow fluid interaction of the TAD system with TCIP-compliant systems.

TABLE 1 TAD Functional Requirements

Requirement	TAD's Functionality
Display the remaining wait time for the transit rider while they are waiting for their proper bus to arrive at the stop.	Utilizing the information from HART's web service and knowledge of the user's planned route, the TAD system will query HART's web service for the estimated time of arrival for the correct stop and route and display the information on the phone's screen.
Alert the transit rider when the correct bus is approaching his or her bus stop location	Utilizing the information from HART's web service and knowledge of the user's planned route, the TAD system will query HART's web service for the estimated time of arrival for the correct stop and route and alert the transit rider when the estimated time until arrival is less than a threshold value.
TAD Web page shows real-time bus locations	By combining current active service information stored in TAD database and bus location data stored in HART AVL data source, the webpage will display locations of the buses on the TAD Web Page.
New notification algorithm for TAD mobile application to benefit the rider	By using the current speed of the bus and several circles of different radii around the second-to-last bus stop, the TAD phone software will determine the earliest appropriate time it can trigger the alert to the user to pull the cord. The goal is to sound the alert right after passing the second-to-last bus stop so that there is less confusion for the rider. The previous notification algorithm worked well when stops were a significant distance apart, but had challenges providing the notification at the correct time when bus stops were close together. The new algorithm attempts to overcome this limitation.

Transit Agency System

Wireless Link

Transit Vehicles

Transit AVL Server
Database

Transit Web Server
Web Service

LEGEND
— HTTP
— AJAX
— Database Connectivity

TAD Server Requests Vehicle Positions, Vehicle Positions are Returned

Phone Requests Estimated Time to Vehicle Arrival, Estimated Time to Vehicle Arrival is Returned

TAD System

Vehicle Position Updated on Website Map View

TAD Web Page
Client Tier

TAD Web Server
Web Application Server

TAD Mobile Application
Client Tier

Website User

Work to Home

5 DOWNTOWN
Next Bus:
4:58 minutes

Back

Transit Rider

FIGURE 2 TAD interaction with HART AVL system components

Providing Transit Riders With Vehicle Estimated Time of Arrival Information:

TAD utilizes an existing web service hosted on HART's server to retrieve an estimate of bus time arrival based on HART's real-time AVL system. As seen in Figure 3, when the TAD cell phone application starts, it prompts the user to select a trip to travel. Trips are previously planned on the TAD website by the travel trainer, parent/guardian, or if capable, the transit rider.

FIGURE 3 TAD cell phone software prompts user to select a previously planned trip to travel

Using the existing knowledge of the user's planned route (including both bus stop IDs and route IDs), once a trip is selected, the TAD mobile application communicates with HART's web service and displays the ETA to the user (Figure 4). The user does not have to enter any further information about their bus stop or route to see this information. To make this display easy to read, the number shown counts down in real-time second-by-second to illustrate the constant change in remaining time <u>until</u> the vehicle arrives. This display differs from other formats of display in which the estimated time that the bus will arrive is shown to the rider, and the rider is responsible for subtracting the estimated time <u>of</u> arrival from the current time to determine the actual amount of time remaining until the vehicle arrives at the stop. If there is a change in the actual arrival time based on unscheduled delays, the TAD phone application retrieves this information from HART's web service and updates the display to the transit rider. The phone will vibrate to remind the user when five minutes remain until the bus is estimated to arrive. Once the vehicle is within two minutes of arrival, the phone will display a "Now Arriving . . ." message to the user to indicate that they should be ready to board the bus (Figure 5).

FIGURE 4 After selecting a trip, the user is shown a real-time countdown until their bus will arrive, and the headsign of the bus they should board, while they are waiting at the bus stop
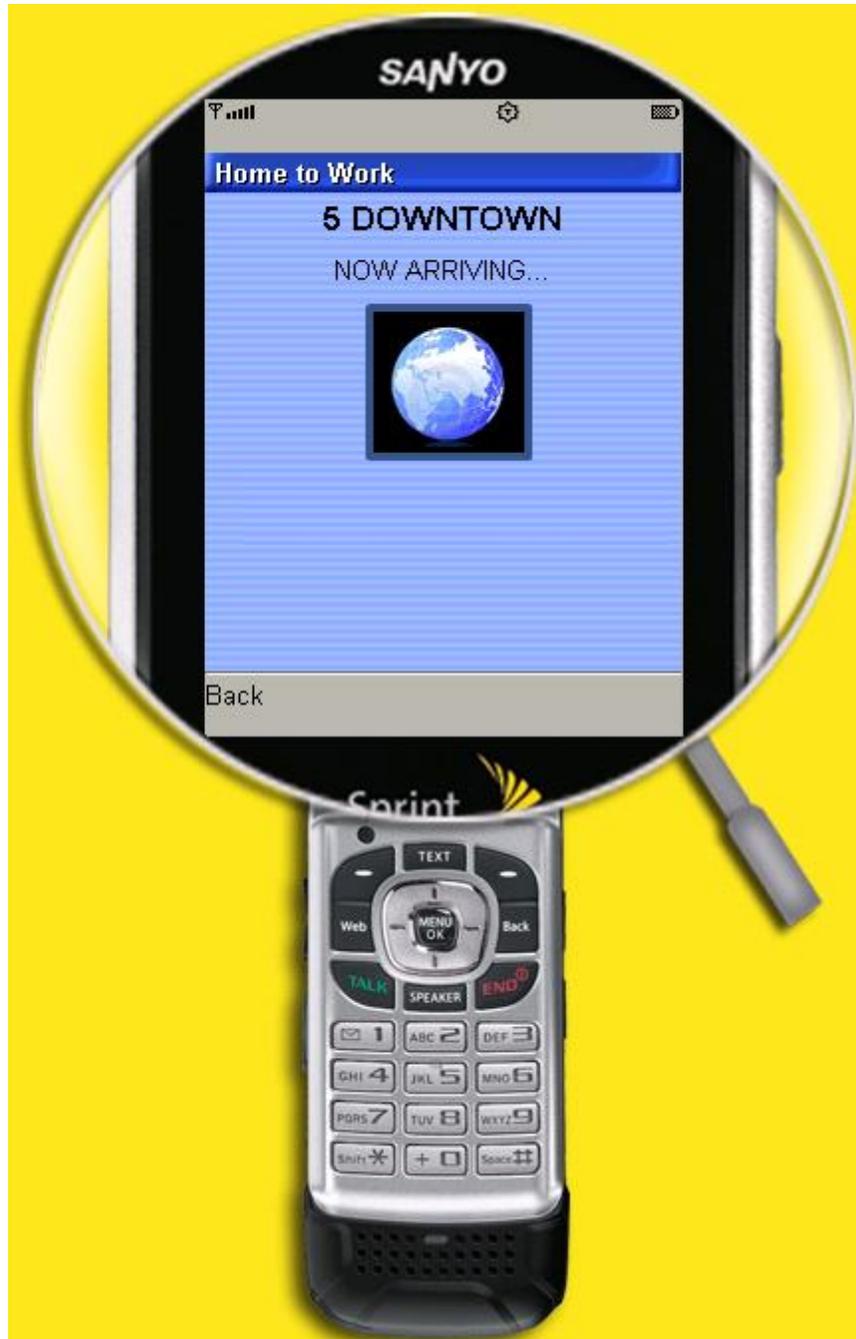
FIGURE 5 When the vehicle is approximately 2 minutes away from the rider, the phone vibrates and displays the "NOW ARRIVING..." message which alerts the rider to prepare to board the bus.

The main screen also includes information regarding the user's selected trip and route. In the top title bar, the trip name is shown, e.g. "Home to Work." Immediately below, the route information appears, making the transit rider aware of which bus he or she should board (e.g. "5 DOWNTOWN" in the case of Figure 6). After the rider boards the bus and the bus begins moving along the route, the distance to the destination stop decreases as the user approaches their destination (Figure 6). The user will receive the

"Get Ready…" audible notification with vibration when they are a few bus stops away from their destination. When it is time for the user to request a stop (i.e., the bus has passed the bus stop prior to the rider's destination stop) the phone vibrates and announces "Pull the Cord Now!" via visual and auditory messages so he or she can signal the driver that he or she wishes to disembark the transit vehicle (Figure 7).
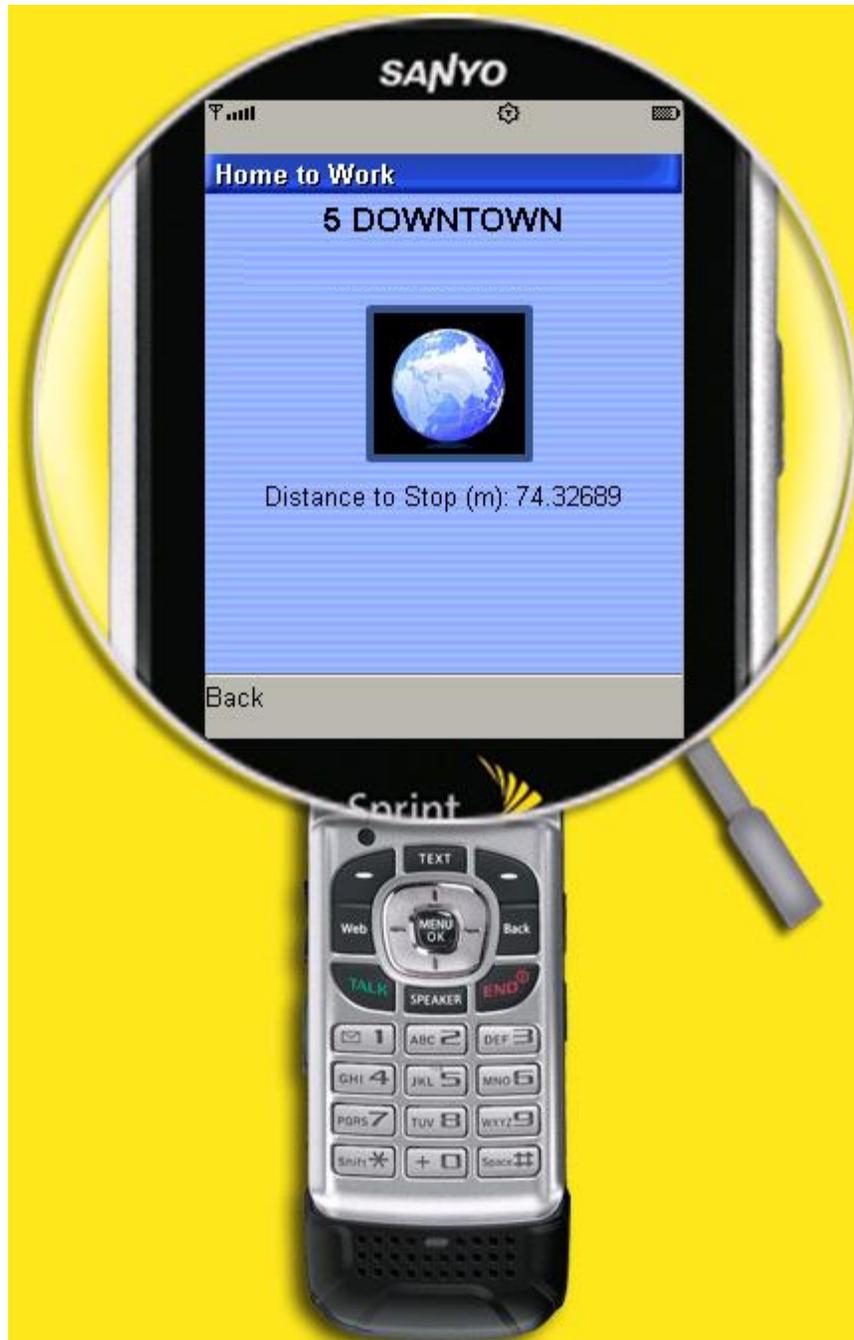
FIGURE 6 While the rider is traveling on the bus, they are shown a real-time distance measurement that decreases as they near their destination stop

Figure 7 - TAD announces "Pull the Cord Now!"
vibrates phone, and shows written notification to user when s/he should request a stop.

The design of the main TAD cell phone interface (i.e., the portions not related to AVL information) was based on literature reviewed under the first phase of the TAD project which identifies audio prompts as the most effective and preferred type of prompts for real-time navigation which interferes least with the cognitive process of navigation *(Sohlberg et al. 2007, Lee et al. 2001, McCallum et al. 2004, and Parush*

et al. 2005). For more information on this topic, the reader is directed to the TAD Phase 1 Final Report *(Barbeau et al 2008).*

Web Page Showing Real-Time Buses Location

The near real-time locations of buses are retrieved from a SQL Server database maintained at HART. One of the challenges uncovered during this project was the actual delay between the location of the bus and the transmittal of that location. There is an estimated delay of approximately 90 seconds between when a vehicle position is calculated on-board using GPS to when the information is made available to the TAD system through HART's database. HART vehicles are scheduled to report location to the AVL system at a minimum of once per minute and propagation delays account for the additional time before the new information is visible to the TAD system. A basic algorithm that pulls new vehicle locations to the TAD system is shown in Figure 8. The Graphic User Interface (GUI) of the TAD Web Page features new icons to better differentiate markers indicating the position of TAD mobile users and the real-time location of buses.
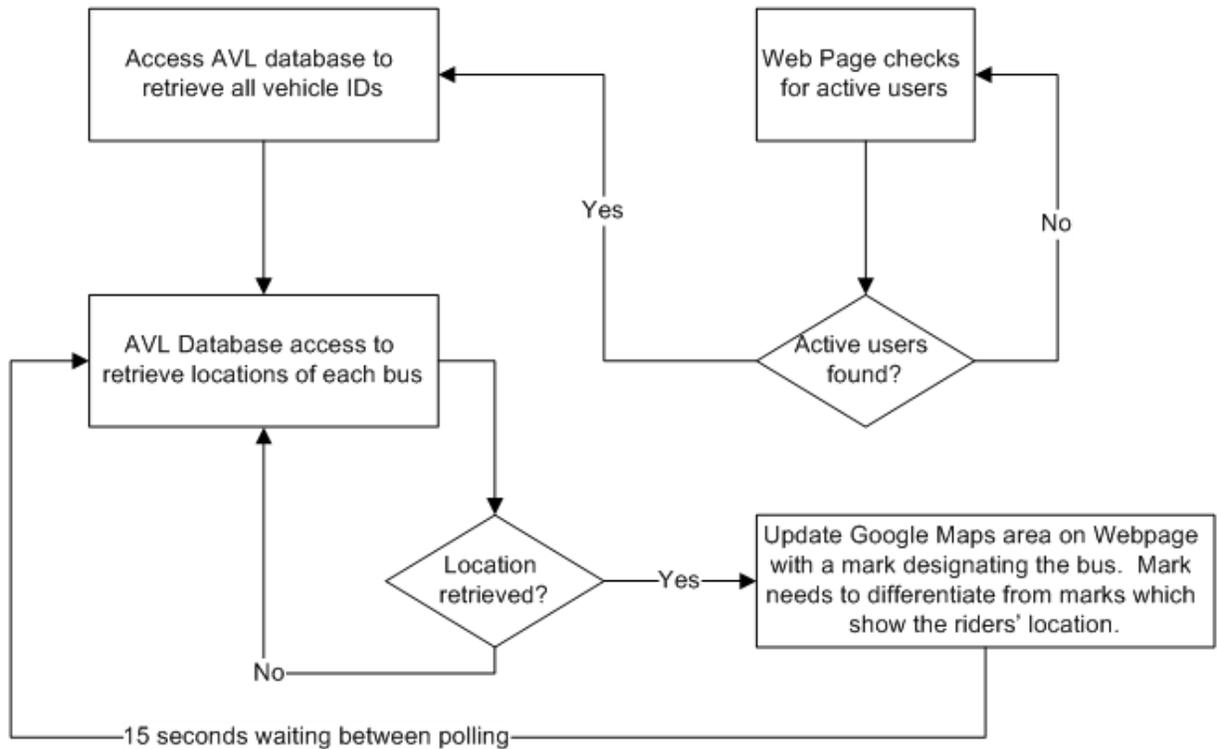
FIGURE 8 Real-Time bus locations

Figure 9 shows a screenshot of the new tracking map on the TAD Web page. Now, the icon 🚌 represents the location of buses in the map. The icon 👤 refers to the location of transit riders currently using TAD. By clicking on a transit rider icon, the corresponding information (name and phone number) is displayed. In addition, the Web page allows making a call (by means of Skype Voice-Over-IP software) or sending a SMS text message to the transit rider.
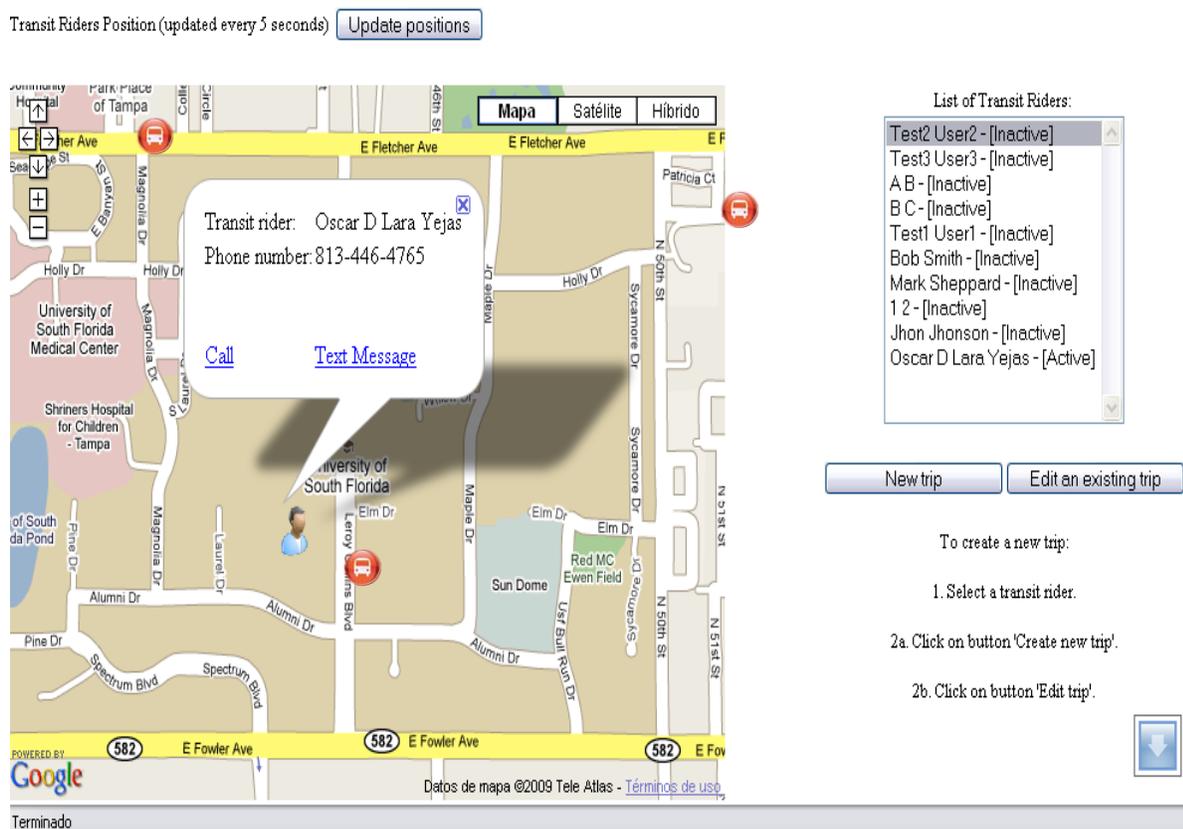
FIGURE 9 Tracking screen of TAD web page showing real-time bus locations

Updated Transit Rider Notification Trigger Algorithm

In field-testing of the TAD first phase, certain weaknesses were identified in the rider notification algorithm that prompts the user to request a stop when bus stops are close together, *(Barbeau, Labrador, Winters, Perez & Georggi, 2008)*. In an attempt to improve this initial algorithm, the research team implemented a new rider notification algorithm in this project. This new notification algorithm, described in Figure 10, detects the departure from the second-to-last bus stop instead of a simple radius surrounding the destination stop. It also uses the speed of the bus to determine when to ring the alerts. This combination of features provides a near optimal notification mechanism that alerts the user at the earliest possible time, immediately after passing the rider's second-to-last bus stop.

This rider alert algorithm has been tested on more than two dozen car trips and actual bus rides and has given the proper alerts. The alerts were given in two places, either right as the bus was passing the second-to-last bus stop at high speed or as the bus left second-to-last bus stop after making a requested stop. This alert system, compared to previous algorithm that used a single radius surrounding the

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destination stop, provided more alert-time to users in most circumstances. More alert time increased the chances of the user pulling the cord at the appropriate location.

Transit Vehicle Direction

Get Ready Check:
If (Device within W meters of 2nd to Last Stop) Then
Trigger "Get Ready"

Zone2 Departure Check:
If ((Zone1Arrival = true || Zone1Departure = true) && (Device in Zone 2))Then
Trigger "Pull Cord Now

Second-to-Last Stop

Destination Stop

X — Y

Zone 1 Arrival Check1:
If ((Current_Speed > **SPEED_THRESHOLD**) && (Device in Zone1)) Then
Trigger "Pull Cord Now"
Set Zone1Arrival = true
Set Zone1Departure = true

Zone 1 Arrival Check2:
If (Device in Zone1) Then
Set Zone1Arrival = true
Set Zone1Departure = true
If(1st alert not triggered) Then
Trigger "Get Ready"

Legend

Threshold W – example value of 160 meters
Threshold X – example value of 20 meters
Threshold Y – example value of 50 meters

Zone1   **Zone 2**

SPEED_THRESHOLD – used to indicate that the bus is not stopping at the 2nd-to-last stop - example value of 15 meters/sec

FIGURE 10 New rider alert system

Trip Export in Phone Emulator Format

To test the TAD mobile phone software for errors, it became evident the research team needed a means to complete rapid tests without having to board a transit vehicle. To facilitate testing, the TAD Toolkit software was modified under this project to allow exporting previously recorded bus trips into a format that a phone software emulator for a desktop computer can understand. The trip information from the database is exported in the following format:

```
<waypoints>
        <waypoint time="1000"
                latitude="28.054105752" longitude="-82.413940429" altitude="310" />
                <waypoint time="1000"
                latitude="28.054711717" longitude="-82.415142059" altitude="215" />
</waypoints>
```

In this XML code, time is measured in milliseconds, which means that script spends 1 second moving from the current waypoint to the next. Intermediate positions are automatically interpolated by the phone software emulator based on the amount of time spent moving between the two sets of coordinates, the distance between the two coordinates, and the GPS update frequency used in the emulator. Using this

data, a GPS data production rate of one fix per second can be simulated. The created XML file is then loaded into Wireless Toolkit phone emulator software and replayed to simulate a bus trip when the emulator is executing the TAD mobile phone application. While there is no substitute for testing new TAD features in the real world due to the uncertainty of GPS, re-using recorded trips allowed researchers to identify potential errors in the TAD software before field-testing TAD on-board a bus. This tool will prove useful in testing future transportation-related mobile phone applications relying on real-time data.
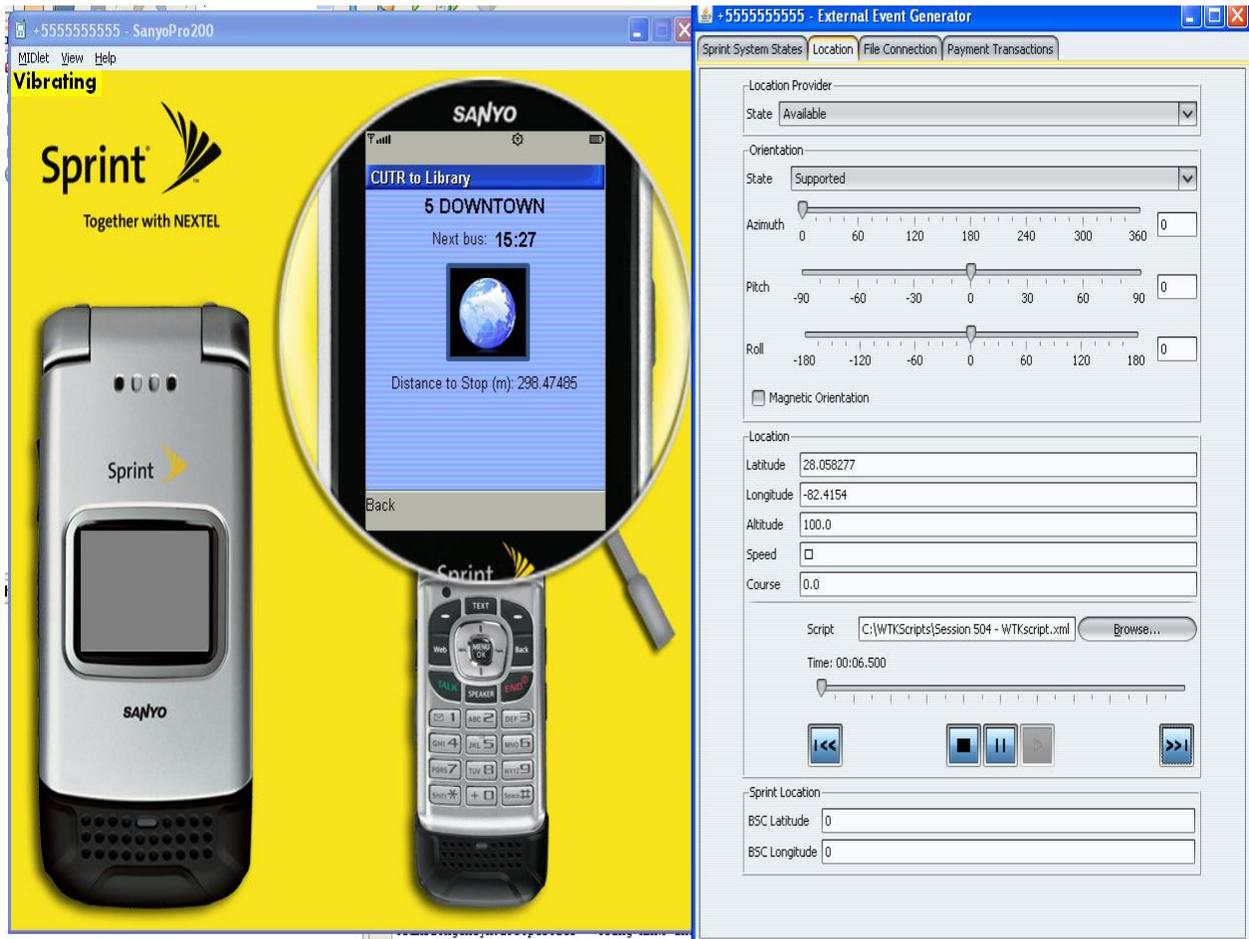
FIGURE 11 Screenshot of phone emulator playing back a trip recorded with TAD

Additional Features Investigated

The initial concept of utilizing AVL data in the TAD system included other features such as using the bus AVL data for a backup to alert the transit rider if the phone GPS fails while on-board or providing an alert if the rider boards an incorrect bus or exits at the incorrect stop (e.g. is separated from the bus earlier than expected).

After gaining access to the HART AVL system, the research team discovered that the typical amount of time between when the AVL system calculates the on-board GPS bus location and when the TAD system would receive that location from HART's system exceeded sixty seconds. Additionally, a position is typically reported from each bus only once per minute. Due to the uncertainty of GPS (from both vehicle and phone) and lack of high frequency and timely vehicle location updates, it was determined that the tested AVL system could not be used to provide a reliable, adequate backup alert for the rider. It is difficult to build a high degree of confidence in the association between the rider's position

and vehicle position under these circumstances and therefore any service based on this information will likely yield an unacceptably high number of false-positives or false-negatives. From conversations with HART, the limited frequency in vehicle location updates is primarily a result of HART's AVL radio system capacity for data communication for their particular AVL solution. If other modern AVL solutions allow a more frequent and timely update rate as part of a higher capacity AVL data communication system linking the bus and the dispatch center, an AVL-based backup for rider notification may be feasible to implement with such AVL systems.

Field Prototype Testing

HART's travel instructor identified 6 individuals with special needs who were previously travel trained as potential users who would benefit from TAD. In accordance with USF's Institutional Review Board (IRB) process, the research team obtained permission for these individuals to participate in pilot testing of TAD with AVL integration. The pilot test was conducted with observers accompanying the participants. Additionally, 15 final field tests were conducted by members of the research team to evaluate AVL integration system performance and troubleshooting problems as necessary.   The observer noted the following details for each trip, along with any relevant comments:

- Did the participant have problems finding the bus stop?
- Did the observer help the participant cross the street?
- What was the HART Route number and trip start time?
- What were the starting and ending bus stops IDs and locations?
- Were the Participant's and Observer's cell phones showing the same ETA time?
- Did the observer see the countdown ETA for the bus?
- Did the five-minute ETA reminder vibrate the phone?
- Did the "Now Arriving" message show within 2 minutes of bus arrival? If not, how much time was left on the ETA or how late was the bus?
- Was the Route Number displayed on the phone?
- Did the participant successfully board the bus?
- Did TAD give the "Get Ready" notification at the correct time?
- Did TAD give the "Pull the Cord Now" notification at the correct time?
- Did the participant request the stop at the correct time?
- Did the participant exit the bus at the correct stop?

Figure 12 is an example of a field test log sheet completed by an observer with the results from an incoming trip where the system worked as intended.

Incoming trip			Comment
Did the participant have problems finding the next bus stop	Yes	(No)	
Did you help participant cross the street?	(Yes)	No	
HART Route #	12		
Time trip started	4:35		
Starting Stop (ID and Location)	Skagway St		
Were the Participant's and Observer's ETA times synchronized?	(Yes)	No	Not observed	
Did you observe the phone countdown to ETA of bus?	(Yes)	No	Not observed	
Did the 5 minute ETA reminder vibrate the phone?	(Yes)	No	Not observed	
Did "Now Arriving" show within 2 min of bus arrival?	(Yes)	No	Not observed	*Bus came within the "Now Arriving" window*
If not, how much time was left on ETA?				
Or how late was bus?				
Did Route Number show?	(Yes)	No	Not observed	
Did participant successfully board the bus?	(Yes)	No	Not observed	
Did " Now Arriving" message disappear when the bus started moving?	(Yes)	No	Not observed	
Did TAD give "Get Ready" notification at the correct time?	(Yes)	No	Not observed	
Did TAD give "Pull the cord now" notification at the correct time?	(Yes)	No	Not observed	
Did participant request stop at proper time?	(Yes)	No	Not observed	
Did participant exit bus at correct stop?	(Yes)	No	Not observed	
Ending Stop (ID and Location)	UATC		
Observations			

FIGURE 12 TAD Observational Field Test Log

The following section describes the comments from one of the testing sessions where the estimated time until arrival data was incorrect. This issue is discussed in detail in the "Lessons Learned" section:

"The participant and observer were ready to leave the University Area Transit Center (UATC) at 3:35pm, and TAD said a bus was arriving in 12 minutes. It gave the warning vibrate with 5 minutes remaining, then went into "Now Arriving" mode, however the bus never arrived. After displaying Now Arriving for about 5-10 minutes, TAD switched to the next bus, which was suppose to arrive in another 8 minutes. The bus had arrived with an ETA of 6:30 on the phone, and we ended up leaving when the ETA said 4:30.

The participant seemed to have problems understanding the "Get ready" audio message played back over the cell phone. The observer noted that this may be due to the quality of the phone's speaker or the quality of the audio file, especially in relationship to the amount of noise present on the bus. The participant was able to "Pull the Cord" at the correct time, exit the bus and the participant waited at the next bus stop."

Another comment of interest noted by a student observer:

"While waiting at the bus stop, an individual asked and I told him it was an application to help know to get off the bus . He stated that he wishes he had something like that because it's hard to see the bus and the stops."

The link between the TAD system and AVL system worked successfully and for the majority of the tests estimated-time-of-arrival information was successfully delivered and shown on the cell phone. The research team was able to identify several issues during testing which prevented the system from accurately displaying the correct time-of-arrival on every trial. These issues are generally resolvable with further development and testing, and are described in detail in the "Lessons Learned" section.

Additional field testing to evaluate the TAD proof-of-concept in terms of delivering the "Get Ready" and "Pull the Cord Now" alerts at the correct time was conducted during the initial TAD prototype development and is reported in existing literature *(Barbeau et al, 2009) (Barbeau et al, 2008)*. Therefore, the discussion in this report focuses primarily on AVL integration issues with the TAD system.

LESSONS LEARNED

Valuable experiences and lessons were learned during the implementation of this project which can be useful to future implementers of such systems. Many of these lessons can also be applied to the general design and implementation of other Intelligent Transportation Systems projects, which may or may not be within the transit environment. Below, the lessons learned are divided according to the different stakeholders in designing and implementing an intelligent transportation system (ITS) project.

Lessons Learned for Transit Agencies: Exposing Transit Data – System Designs

There are several types of information that a transit agency may be interested in providing to external entities. Often, this information is provided to inform customers of general information about the transit system (e.g., schedules, bus stop locations) or to provide them dynamic real-time information about the current state of the system (e.g., bus location or estimated arrival time, etc.).

Common types of exposed transit data:

- Schedule data
- Route data
- Stop data
- Trip data (combination of stops, route, and schedule)

- Real-time vehicle location
- Estimated time of arrival information (based on real-time vehicle location data)
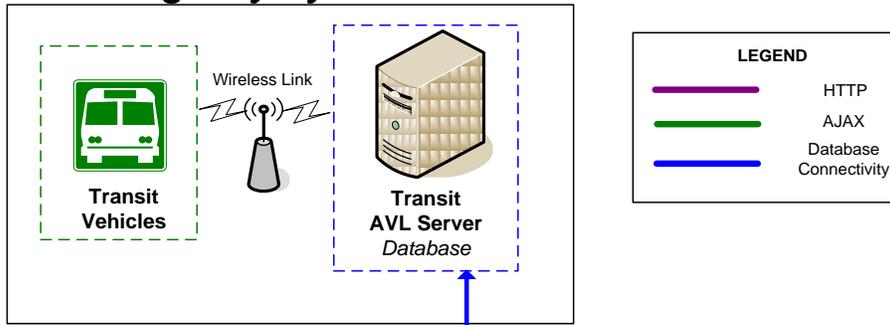
Transit agencies, together with transit information technology vendors, are primarily responsible for implementing the information systems that expose transit information to external systems. Typically, transit agencies utilize proprietary scheduling software packages such as Trapeze and HASTUS to manage their information internally for operations purposes.

For static information that does not frequently change in real-time (e.g., schedules, routes, stops, trips), the GTFS has emerged as a defacto standard with more than 417 transit agencies placing their data in this format worldwide and more than 110 transit agencies participating in the United States. The TAD system utilizes GTFS data feeds from transit agencies to import new agencies and update the bus stop and route information for existing agencies.

For real-time dynamic information access, the information system must be modified to make information available to external applications. Typically, this is done by either directly exposing the database (e.g., SQL Server, Oracle) containing the information (Figure 13), or by creating an intermediate application hosted on a web server (Figure 14) positioned in between the external application and the transit agency database.

Most mobile devices, including the popular Java Micro Edition, Google Android, and Apple iPhone, cannot access database engines directly since drivers that connect to the database do not exist on mobile platforms. Therefore, from a mobile application design perspective, it is highly preferred to expose the data via a web service hosted on the transit agency's web server. This allows the mobile device to contact the transit agency's system directly, without having to use a proxy server hosted at another location to access the transit agency's system. When timeliness of the transit agency data is important, as is the case with real-time vehicle positions and estimated time until arrival information, having direct access from a mobile device to the transit agency's real-time data is crucial for reducing the time between when the data is generated at the transit agency to when it is made available to the mobile device. The overhead for the mobile application developer is also reduced in the web service model, since the mobile application developer is not responsible for duplicating transit information on their back-end servers. The use of web services from mobile phones is discussed in detail in the Mobile Phone Developer section.

Transit Agency System

Transit Vehicles

Wireless Link

Transit AVL Server
Database

LEGEND

———	HTTP
———	AJAX
———	Database Connectivity

TAD Server Requests
Vehicle Positions/ETA,
Vehicle Positions/ETA
are Returned

TAD System
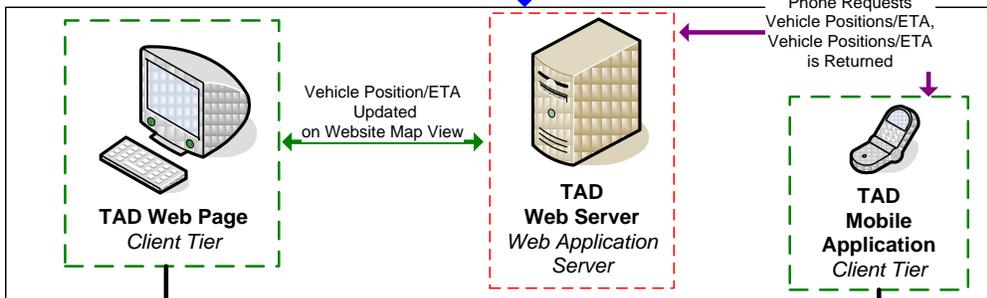
Phone Requests
Vehicle Positions/ETA,
Vehicle Positions/ETA
is Returned

TAD Web Page
Client Tier

Vehicle Position/ETA
Updated
on Website Map View

TAD Web Server
Web Application Server

TAD Mobile Application
Client Tier

Website User

Work to Home

5 DOWNTOWN
Next Bus:
4:58 minutes

Transit Rider

**FIGURE 13 Transit agency data exposed via direct database access
no direct mobile device access**
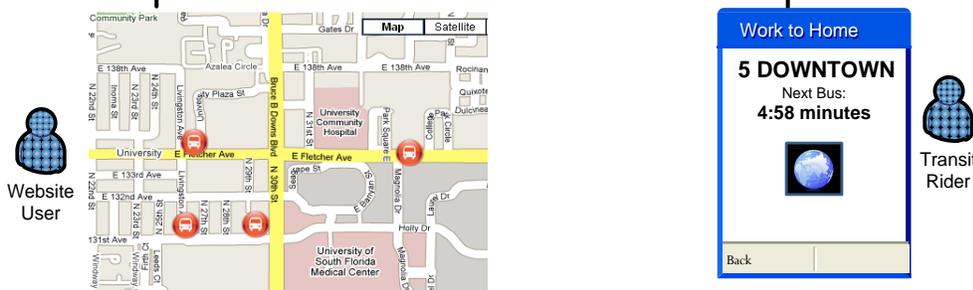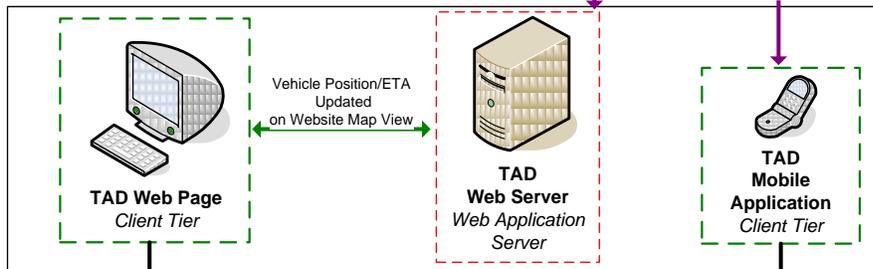
**FIGURE 14 Transit agency data exposed via web services
preferred method for mobile device access**

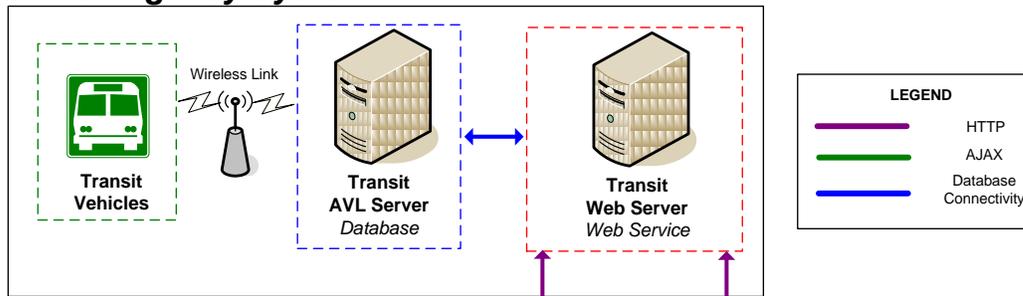A third architecture, not pictured, can also be used when near-real-time information updates, such as a mobile phone depending on automatic vehicle location updates to alert the user when to exit the vehicle, are required. In this third architecture, the transit agency maintains subscription information between transit vehicles and mobile devices and "pushes" information updates to the device as they are generated from within the transit agency's Information Technology (IT) system. By pushing the information, instead of requiring the mobile device to repeatedly poll and "pull" information from the transit ITS system, real-time information is available at the mobile device as soon as possible. However, the implementation of such a subscription-based system is significantly more complex than a simple web service that responds to individual requests from external systems. This additional timeliness will likely be of interest to consumers of ITS information in the near future, especially for mobile devices that may not have their own embedded GPS receiver. However, for many current transit IT systems, the bandwidth between the vehicles (where location information is usually calculated using technologies such as GPS), and the transit IT center is constrained, which prevents frequent second-by-second updates of vehicle position data. In such constrained systems, updates of location data from transit vehicles normally occur at a higher interval such as once per minute. Without a high frequency of vehicle position updates (e.g., in the order of seconds), the relative improvements in timeliness of delivering the data via a

"push" to the mobile device do not justify the complexity of the implementation of the third architecture. Therefore, since HART's system is constrained to vehicle position updates around once per minute, the research team focused primarily on the first two architectures shown in Figures 11 and 12.

The TCIP standards released by APTA in 2006 cover many different use cases and standards of transferring transit information from one entity to another for both static and dynamic information. Currently, there are no operational implementations of TCIP interfaces in the U.S., although a TRB Transit IDEA project is currently underway to develop a proof-of-concept implementation in Orlando, Florida at the LYNX transit system *(TRB, 2009)*. Other implementations are currently in the design or development stages at King County Metro in Seattle, Washington; the Maryland Transit Administration in Baltimore, Maryland; and the Chicago Transit Authority *(Ayers, 2009)*. Since this project made use of existing data sources that do not implement the TCIP standard as part of this system prototype (e.g., AVL web service and database, GTFS), making TAD TCIP-compliant would not result in a working prototype. However, it is planned in future TAD software implementations that will interface with TCIP-compliant systems (e.g., different AVL systems), a TCIP-interpreter will be developed to allow seamless interaction of the TAD system with TCIP-compliant systems.

The current architecture used to connect HART's system and the TAD system is shown in Figure 13. This system is an adaptation of the above two architectures to fit HART's specific method of exposing information to external systems. HART exposes vehicle position updates through direct access to a replicated version of their SQL Server database server. To show the vehicle positions on the TAD website, the TAD Glassfish Java web application server contacts HART's database server directly using Java Database Connectivity (JDBC) drivers. The vehicle positions are then pulled back to the TAD server, which passes them to the web browser client to be displayed to the TAD website user on a map. Vehicle position data is not provided to the TAD mobile phone application, since it does not have a visual map upon which to show the information. The total transfer time for GPS data to propagate from the HART vehicle until it was exposed in the replicated SQL-Server database for TAD system access was approximately 90 seconds, on average.

HART exposes estimated vehicle arrival times via a web service. This web service is implemented using both XML-based Simple Object Access Protocol (SOAP) web services as well as a RESTful web service using HTTP-POST and HTTP-GET methods. The TAD mobile phone application uses the RESTful web service to directly request the ETA of the bus from the transit IT system and then displays this information to the transit riders on their cell phone screen. RESTful web services are preferred to SOAP XML-based web services for access from mobile devices due to issues surrounding the limited support of SOAP on mobile devices, as well as the negative impact of the XML overhead on mobile device battery life, discussed in detail in the Mobile Application Developer section below. Since the web service pulls information directly from HART's production SQL Server database, the response time between ETA changes as a result of updated vehicle positions seemed to be much shorter. In other words, changes in ETA values were updated as frequently as every 15 seconds under certain conditions observed by the research team.

It is expected that external systems accessing IT systems at other transit agencies may have to use this hybrid approach as well depending on the order of implementation of different ITS services, as well as the level of coordination and time delay between the projects implementing the ITS services. However, the implementation of these ITS systems separately can have its challenges.

One challenge faced by the research team when using the ETA web service was data consistency between the HART ETA web service and HART's GTFS data. HART formats their transit data into the GTFS file format and posts a zip file containing this information on their website. The TAD system then downloads this zip file, extracts the files, and imports the latest bus stop, schedule, route, and trip information into the TAD database. This same process is followed for all agencies that put their data into the GTFS format and are users of the TAD system. The GTFS data format allows an agency to add

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directional information for trips (an ordered visitation of stops on a route at a particular time) in their dataset. However, the GTFS format requires that each trip specify the directional information as either outbound or inbound with a value of 0 or 1, respectively. Therefore, when HART's data is imported into the TAD database, it contains 0 or 1 directional information.

HART's web service is designed to provide ETA information for vehicles when given the input of a stop ID, route ID, and direction ID. However, HART's web service requires that directional information be given as North/South/East/West with the values of 1, 2, 3, or 4, respectively. Therefore, there is no direct information connecting the GTFS data and HART's web service in regard to direction information, which prohibits a web application from retrieving the estimated arrival time for a specific direction at a bus stop.

The research team implemented a work-around to query the web service for each direction until a value is returned by the web service. This works correctly for normal bus stops that are only visited by a bus in one direction (e.g., one side of the street), but if there are multiple buses arriving at a bus stop from multiple directions (e.g., transit center), there is no guarantee that the correct arrival information will be shown to the end user. The research team is currently working with HART to update their GTFS dataset to include cardinal direction information as well as the ETA web service vendor to add the capability to query the ETA information by using the GTFS inbound/outbound directional information.

During testing as part of this project, a few arrival times returned by HART's web service were significantly different than the actual bus arrival, up to a 20-minute difference. Many of these differences occurred at transit centers or at bus stops that are visited by buses on the same route in two different directions. However, often the ETA times returned by HART were accurate to within about 30 seconds of the actual arrival. The true accuracy of the system will be apparent after the above issues are resolved to ensure that the ETA for the proper bus stop and route is always returned to the cell phone.

To help other agencies understand the estimated cost of implementing a 3rd party web service to show estimated time of arrival information, HART has provided the research team with estimated costs for their system. In order to implement information access for external parties, HART contracted with a vendor to set up this part of their information system. Assuming that an agency has an AVL system that calculates on-time performance (i.e., real-time vehicle location and schedule comparison), the estimated costs for additional components to implement the web service were as follows:

1. Additional module in the AVL software to build and calibrate prediction table, and web service implementation which accesses the AVL short term database = $10,000

2. Server (i.e., physical equipment) to host the web service = $5,000

3. Staff time and support to maintain the system = $1,200 per year

This comes to a total one-time estimated cost of $15,000, and an annual estimated cost of $1,200. According to HART and other transit agencies, this relatively small investment to open up the agency's data on location and arrival time, for the public and others to work with, has great returns. As Tim McHugh, TriMet's Chief Technology Officer, stated in an interview[1]:

"One of the pressures that we have as an IT department in a transit agency is we're small and we can't provide every customized solution people ask for. It's difficult to keep pace with the changes in technology. So making the data available is something that we're very familiar with, and we can spend our energies on making it well-formed for the public to consume, and then turn it around so that they can develop the tools themselves. It's like having an army of developers available to us."

When asked, Justin Begley, HART's Operations Project Manager at the time responsible for ETA web service implementation said,

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[1] http://www.trilliumtransit.com/blog/2008/09/11/trimet-innovations-in-transit-data-publishing/

"An example of a great way to leverage investments made in AVL technologies is to expose the data this system generates to the public so it can be used in other real-time information systems, which provides a great deal of value for a modest investment."

**Lessons Learned for Mobile Application Developers**

Battery life is a key consideration for any mobile application, especially with use cases that have the application running in the background and using energy-intensive features. When wireless communication is involved, battery life can be significantly impacted since each wireless data transmission consumes battery energy. For example, a transit rider might wait for extended times for a bus to arrive and wants to receive continuous updates on the status of the bus. If the phone is continuously refreshing the time of arrival information every few seconds by communicating with a server, the battery life will be drained quickly. If the bus is several minutes or more away, this high frequency of updates is unnecessary and needlessly wastes battery energy.

To demonstrate the impact of the frequency of wireless data transmissions on mobile device battery life, a battery life benchmarking application created by the research team was used. This application measures how long the phone battery lasts while wireless transmissions are repeated at fixed intervals. By comparing the resulting battery life from each execution, the energy cost for each transmission at the given interval is apparent. Figure 15 shows the impact of wireless transmission interval on the battery life of a Motorola i580 cell phone on the Sprint-Nextel iDEN network. Using a HTTP-POST method to request the information from a RESTful web service every 4 seconds, battery life is approximately 9.5 hours. When the exact same information is transferred every 15 seconds, battery life nearly doubles to almost 18 hours. The trend continues as the time between wireless data transmissions increases, with battery life increasing to over 24 hours when data is transmitted every 60 seconds. It should be noted that during these tests no other normal cell phone operations (e.g., voice calls, lighted display screen, etc.) were active. Therefore, during the actual use of the phone with these additional activities the battery life would be reduced even further.
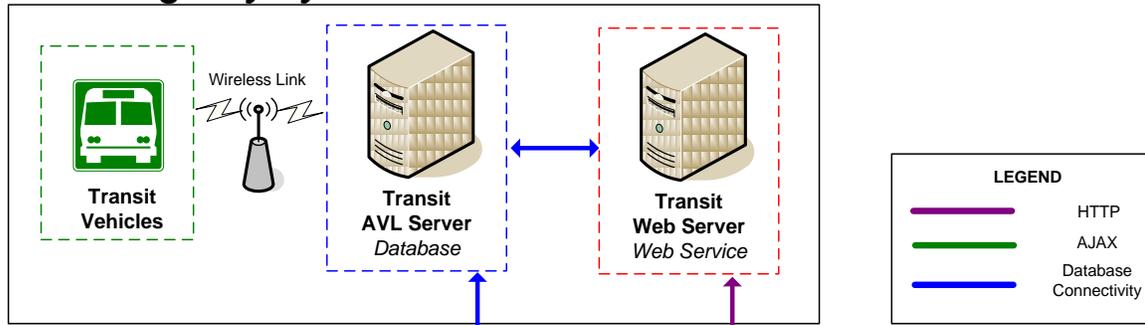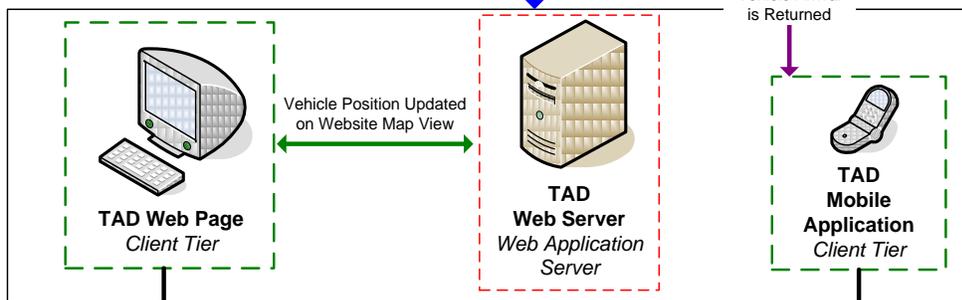
FIGURE 15 Current interactions between HART and TAD system

a hybrid database/web service design

As demonstrated by these results, even small reductions in the number of wireless data transmissions can positively impact mobile device battery life. Intelligent systems should be designed to periodically refresh information while dynamically varying the refresh rate depending on the timeliness of the information. For example, if there is an estimated 10 minutes until a bus will arrive, the phone does not need to request an update for at least several minutes. Similarly, if a bus is expected in less than a minute, then the phone should request updates at a more frequent pace until the vehicle arrives, at which time it should reduce the frequency of updates again. The TAD mobile phone software implements such an intelligent algorithm to provide timely updates while maximizing battery life.
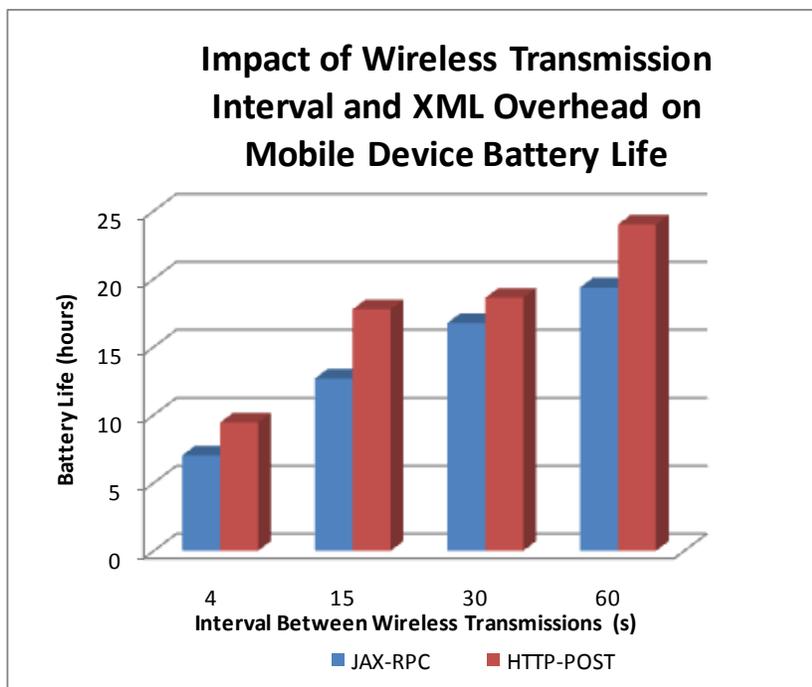
FIGURE 16 The impact of wireless transmission interval and XML overhead on mobile device battery life.

Most cell phone platforms (e.g., Java Micro Edition, Google Android) do not directly support XML-based SOAP web services. SOAP is an XML-based protocol for exchanges messages between a web service and client. SOAP is usually implemented on top of the HTTP protocol. Alternatively, RESTful web services are usually implemented directly using HTTP method such as GET and POST, and therefore have far less communication overhead than the same exact web service implemented using SOAP. Therefore, for mobile application, it is preferred to use simple RESTful web services that utilize the widely-supported HTTP protocol directly without the need for an XML SOAP parser on the mobile device. For parsing XML-based responses (e.g., transit information), which may be returned by RESTful web services, kXML is a good open-source library for basic XML parsing of message content (*kXML, 2009).*

From an energy-use perspective, XML-based SOAP web services should be avoided by mobile applications, when possible. The XML tags add significant overhead to the message, resulting in a greater energy loss as the radio must be active for a longer period of time. Additionally, in wireless environments where interference is common, the longer a message is, the greater the probability that it will be corrupted and require re-transmission. At 60-second transmission intervals, battery life when using JAX-RPC is 19.3 hours, and battery life when using HTTP POST is over 24 hours. Similar results are found at lower interval values, thus justifying the choice of HTTP POST over JAX-RPC as the more energy-efficient application-layer communications protocol (Figure 14).

It may be possible to implement additional AVL features such as using vehicle position as substitute for phone position when phone position fails with other AVL systems with additional wireless bandwidth that support more frequent vehicle updates. As frequency of vehicle updates increases over approximately once every 20 seconds and approaches true real-time, User Datagram Protocol (UDP) should be used to send real-time vehicle position to phones instead of phones continuously requesting position from server via a protocol such as HTTP. Cell phones will need to be provisioned with the correct data plans to ensure they can receive UDP datagrams, as typically cell phones are not provisioned

for "push" data services. Some cell phone networks are packaging publically addressable IP addresses with unlimited data plans, so this type of service may be available on most phones with unlimited data plans.

For location capabilities on the Java Micro Edition (Java ME) platform, the JSR179 Location Application Programming Interface (API) at <http://jcp.org/en/jsr/detail?id=179> is the primary source of real-time GPS information. Version 2.0 of this API, JSR293 Location API 2.0, was finalized in November 2008 and should appear on commercially available handsets in 2010. The LandmarkExchange formats defined in Location API 2.0 will allow the easy exchange of "landmark" information between a cell phone and another entity (e.g., server or phone). It is recommended that mobile developers understand the abilities of this new API and take advantage of landmark datasets, such as transit bus stop inventories, that could easily be imported to a mobile device through these formats.

During frequent software revisions, the ability to "replay" existing recorded trips through the TAD software using the emulator proved to be very valuable. One trip was tested by traveling on the bus with TAD running on the cell phone; the GPS data observed on the phone during that trip is automatically saved to the database. Using the export tool developed as part of this project, this GPS data can be exported to an XML format that can be loaded into software emulators that run on desktop PCs for future testing. This process saves a significant amount of time when debugging software or testing a new software revision for stability before actually spending the time in the field to go on a bus trip. However, due to the uncertainty associated with GPS, there is still no substitute for evaluating the performance of location-based applications using a real cell phone and actual field testing in the environment in which the mobile application will be operated. For example, the performance of new transit rider notification algorithm was evaluated using actual trips taken using the bus, or, when the timeliness of the bus system wasn't practical, a car with the phone hidden in a compartment without clear line-of-sight to the sky. It is only during these real field tests that the potential accuracy and reliability of the system can be properly evaluated.

In the future, a Bluetooth headset will be investigated as a possible delivery tool for the audio prompts. In these field tests, one of the participants seemed to have trouble understanding the "Get Ready…" audio alert due to background noise on the bus. Utilizing a Bluetooth headset should help avoid some of this noise interference and deliver the audible alerts clearly.

Lessons Learned for Researchers: Field Test Recruitment and Training

One significant delay associated with this project was in the process of recruiting and testing the TAD system with individuals with special needs to produce case studies. The research team attempted to recruit six individuals with cognitive disabilities to participate in the field tests as part of this project. Successful recruitment was difficult over the summer due to summer vacations and limited communication with participants. Field testing was therefore completed with three cognitively disabled individuals. For future tests, additional time throughout the year should be allowed for the recruitment and field testing processes. The initial TAD prototype was evaluated by six additional individuals with cognitive disabilities during system development and tests *(Barbeau et al, 2009) (Barbeau et al, 2008)*. These tests focused on the evaluation of the timing of the "Get Ready" and "Pull the Cord Now" alerts.

Overall, the research team's experience with individuals that have tested the TAD mobile application, and anecdotal information from travel trainers and special education professionals, has indicated that a typical "flip-phone" cell phone with the TAD mobile application installed is not a problem for the majority of users to operate. In fact, many individuals with special needs that travel without supervision already carry phones so that their parents or caretaker can communicate with them in case of an emergency. The TAD cell phone application has only three simple screens: a screen to select a trip by name (e.g. "To Work") which has been previously planned for the user via the TAD website, a screen which shows the ETA to the rider while they are waiting for the bus as well as a distance count-down as the rider travels on the bus, and a screen shown to the user when it is time for them to request their stop.

HART's travel trainer that delivers the TAD to participants stated that it took no more than 5 minutes to give a basic explanation of how to use the TAD mobile application and what to do when it prompted them to "Get Ready…" and "Pull the Cord Now!" Each trainee that heard the announced alerts responded positively to the prompts and requested the stop as directed during the tests. The trip planning portion of TAD is conducted using a website, and this step would most likely be executed by a travel trainer or parent/caretaker for individuals with cognitive disabilities since it requires higher-level planning. Trip planning could be conducted by the transit rider if the individual is capable of completing the tasks required to successfully plan a trip. The research team is also currently examining website technologies that may be useful to aid visually impaired individuals in independently planning a trip via the TAD website. Future work with the Florida Mental Health Institute at USF is also planned to provide a more thorough human behavior analysis of the impact of TAD on transit riders with cognitive disabilities.

A demo TAD application should also be developed to demonstrate what the transit rider is expected to see and hear before the participant boards the bus. Currently, the device actions were verbally explained to the participant before the test but no demonstration of the actual device actions were performed. This could avoid some lack of understanding for certain issues, such as the participant who could not understand the audible "Get Ready…" announcement, because the participant would know what to expect.

A structured TAD training plan should also be developed to help "train the trainers." There were several errors made by the field testing team when planning a trip via the website (e.g. selecting the incorrect bus stop as the destination stop), coding observations in the observation sheet (e.g. recording that the "Route Number" didn't appear on the phone display when the route description text displayed on the phone didn't contain numeric values), or using the system in ways it was not designed to be used (e.g. having the same user name logged in on two phones simultaneously) that affected some of the field test results. While most of the instruction of the field testing team was done ad-hoc under this project due to time constraints, it is possible that a more structured and uniform training session for field test personnel could reduce the occurrence of avoidable errors during future field tests.

PLANS FOR IMPLEMENTATION

The purpose of this Transit IDEA project was to foster the development and testing of innovative concepts and methods for advancing transit practice. To advance the state of the practice, the research team has aggressively pursued steps aimed at ultimately deploying TAD to more transit agencies and transit riders during the course of this project.

Funding from other sources was subsequently secured for expanding the demonstration and testing of TAD to additional transit agencies. Additionally, follow-on work funded by the U.S. Department of Transportation and the Florida Department of Transportation through the National Center for Transit Research at the University of South Florida will seek to evaluate: (1) the level of effort required by a transit agency to establish the TAD systems in their community, (2) changes in mobility and quality of life among TAD users, and (3) customer satisfaction with TAD from riders, parents/guardians, and transit agencies. The follow-on work is expected to be completed in October 2010.

With the assistance of USF's DPL, two patents have been filled directly related to the TAD project. USF DPL has also been actively supporting the commercialization through dual tracks: consideration of creating a new company with the researchers but lead by a serial entrepreneur, as well as consideration of the licensing of the TAD technology to an existing company. After an initial review period with a serial entrepreneur identified by USF DPL, the entrepreneur and research team decided that the partnership was not an ideal fit and parted amicably to pursue other opportunities. In the meantime, USF DPL was soliciting licensing arrangements (exclusive and non-exclusive) with several companies. At the time of this report, USF DPL believes we are on the verge of developing a long-standing relationship with a company in this field, including opportunities for continued support of the research and the development

of a workforce in mobile location aware information systems, in addition to the nationwide deployment of TAD as a commercial application.

CONCLUSIONS AND FUTURE WORK

In summary, substantial results have been achieved with TAD under this Transit IDEA project. The integration of AVL technology with the Travel Assistance Device system was successfully demonstrated through a proof-of-concept testing. The TAD mobile phone application now shows the transit rider the estimated amount of time until the bus is expected to arrive while they are waiting at their bus stop. Additionally, the real-time vehicle locations are shown on the map on the TAD website. Because both of these features are driven by the GPS location of the cell phone and bus, the rider does not have to supply any additional information such as a bus stop ID or route number to receive the information. USF is actively pursuing the licensing of the TAD technology to an existing company and expects to finalize the partnership in the immediate future. Through this partnership, USF hopes to offer TAD as a nationwide commercial service within the next year.

During the course of this project, a few reviewers raised concern for the safety of cognitively disabled transit riders if the TAD mobile application malfunctions while the user is traveling on the bus. HART's travel trainer, Mark Sheppard, was interviewed about these safety concerns and summarized the safeguards in place at HART as part of their current travel training program, which he believed would also be used for travelers using TAD:

> *"Two safeguards are generally always provided to assist in making sure someone does not miss their assigned bus stop. (1) HART's Travel Training Program spends sufficient time with a trainee to insure that their "second nature" (on their own) independent skills ability is up to the task. Something out of the ordinary would have happened to cause a missed bus stop, such as falling asleep on the bus. (2) Nearly all of the developmentally disabled trainees I've worked with have their own cell phones and they know how to use them. They call to report the problem and seek help."*

TAD has never been intended to replace a travel trainer for individuals with cognitive disabilities. Instead, it was created to be a tool to help reduce the learning curve for using public transportation and to provide additional assistance to those who have been previously travel trained on how to successfully ride the public transit system in his or her community. TAD acts as an additional safeguard when the transit rider is traveling independently by delivering the reminder to the rider when they should exit the vehicle, the real-time tracking feature on the website which can help identify the location of the rider if they are lost, and the feature of TAD which sends a text message to the travel trainer and/or parent/guardian when TAD believes that the user has deviated from their planned route. According to Sheppard, TAD may also increase the efficiency of training by reducing the training time for the most difficult travel skill: when to request a stop to exit the transit vehicle at the proper location. While travel training may vary from agency to agency, Sheppard noted the HART travel training course instructs the trainee what to do in case of a missed bus stop:

> *In HART's case: (1) If it is a close by miss (only a block or two back), simply go ahead and pull the stop request cord and get off the bus and walk back. (2) If the missed bus stop is out of sight and the trainee is not sure where they are, they are to request assistance from the bus driver. In some cases by just staying on the bus and coming back on its return trip it will place them back where they should be. They are also encouraged to call the travel trainer and get advice. HART may not advise a patron to crossover a street to catch a reverse direction bus. With varying traffic conditions, it may not be a safe option, especially if there is no pedestrian crosswalk signal system to use.*

There are several recommendations and future directions of research as a result of this IDEA project.

Extended field testing of TAD should continue in order to gather additional data on system performance and reliability. The main feature of TAD that alerts the transit rider when they should exit

the transit vehicle utilizes the GPS hardware inside the mobile phone and is triggered by the TAD mobile application running on the phone, and therefore AVL technology is <u>not</u> required for this basic feature. In other words, TAD can be made available to riders on transit systems that do not have AVL technology. While field tests that focused on assessing the reliability of the "Get Ready" and "Pull the Cord Now" alerts were successfully conducted as part of the initial TAD development, data collection should continue to build a larger dataset of test locations and conditions, *(Barbeau et al, 2009) (Barbeau et al, 2008)*.

Since the mobile application uses the built-in GPS hardware to trigger the "Get Ready" and "Pull the Cord Now" alerts to the user, the reliability of this feature is dependent only on the GPS signal strength and can be successfully triggered independent of the cellular network. In other words, if the phone completely loses a cellular signal (e.g., in a rural area) while the user is traveling on the bus, the phone will still be able to deliver the "Get Ready" and "Pull the Cord Now" alerts to the user at the proper place and time. If GPS signal is significantly obstructed near the destination stop while the user is traveling in the transit vehicle (e.g., the vehicle enters a tunnel, or goes underground), the reliability of the destination alert will be negatively affected. Additional data collection will help identify transit stops at different agencies where harsh GPS conditions may impact the performance of the main TAD feature. In the initial TAD field tests, GPS signal loss was not found to be a significant problem. Additionally, GPS technology is expected to continue to improve both due to advances in GPS hardware design in mobile devices, as well as improvements to the general space and ground GPS systems maintained by the U.S. Air Force. In January 2010, the Air Force announced a new GPS satellite constellation configuration "24 + 3" planned to take affect over the next two years which will have a "profound effect on GPS capabilities. The number of GPS satellites in view from any point on earth will increase, and potentially increase accuracy of GPS receivers," (*GPS World, 2010*)

Cellular signal coverage is required for the TAD mobile application to load newly planned trips, for the TAD website tracking feature to display the real-time location of the rider, for the phone to retrieve real-time ETA values from the transit agency server, and for the cell phone to make calls placed by the transit rider. Cellular signal coverage can be lost in rural areas with fewer cellular towers or in areas (e.g. underground) where cellular signals from above-ground towers cannot penetrate. However, the cellular industry has completed significant tower build out over the last decade and continues to expand coverage with the number of cell sites in the United States increasing from 178,025 in June 2005 to 245,912 in June 2009 *(CTIA, 2010)*. There is now even cellular coverage in some underground subway stations, as evidenced by recent installations in Washington, D.C. and San Francisco, and planned installations in New York *(Metro Magazine, 2009) (Bay Area Rapid Transit, 2008) (Washington Metropolitan Area Transit Authority, 2009)*. Cellular signal coverage, as well as GPS signal coverage, will vary by geographic area and environmental conditions, and therefore additional testing in new areas will help identify areas that may be problematic to TAD operation.

When designing components of transit IT systems, the vendor and agency should work together to ensure that all data sets produced by the agency can be interconnected. This is especially true when dealing with unique identifiers in datasets such as stop and route IDs. If a stop is assigned a unique ID in one dataset, it should be assigned the same unique ID in another dataset. Direction information related to routes should be represented using common values for each dataset. If direction information is represented differently in separate data sets (e.g., "outbound/inbound" and "North/South/East/West", the records in each dataset should be assigned both types of directional representations so that the datasets can be easily cross-referenced. Additionally, if some values (e.g., direction) can be left as optional when designing interfaces between systems, allow these fields to be left blank so that the interface can still be utilized if that information is unknown. An example of this is HART's web service requiring directional information for a route and stop. For the majority of stops in the system, direction information is not required since a bus stop on one side of the street is only visited by a route traveling in one direction. By allowing the directional information to be left blank, the external application can still call the web service

even if it does not have directional information. For stops such as transit centers where routes running in both directions will visit the same stop, the web service can return the arrival information for both directions if direction is not specified in the input so that both directions can be shown to the user. Otherwise, no information can be shown to the user since the external system does not have a representation of direction.

TriMet (http://developer.trimet.org/ws_docs/) is a good example of a transit agency that has implemented centralized access to both vehicle position information as well as estimated arrival information from one RESTful web service. All data returned is part of the same dataset with corresponding ID values that can be cross-referenced between TriMet's GTFS data. Additionally, direction information is not required as an input.

When possible, transit agencies/vendors should implement both XML-based SOAP and RESTful versions of web services exposing transit information. There are many tools for desktop and web application developers to utilize SOAP-based web services, so exposing SOAP web services may speed development of web and desktop applications. However, due to the lack of SOAP support on mobile phone software development platforms and the negative impact of the additional XML overhead on mobile phone battery life, RESTful web services should be exposed to properly support the development of mobile phone applications that utilize real-time transit information. Web service software development tools such as Microsoft's Visual Studio are beginning to support the deployment of web services in both formats, and HART's web service is a good example of an implementation that supports identical SOAP and RESTful versions of the web services.

Web services are the preferred method of exposing transit data to external systems. However, if a transit agency cannot afford to develop web services or host a web server and decides to directly expose data to external applications through access to their database server, care must be taken to avoid exposing the agency to IT security risks. Ideally, a replicated (i.e., copied) database server should be exposed to external systems to avoid opening up the transit agency's primary operational database to security threats. While adding replication from a primary database server to a secondary database server adds latency to real-time updates, this trade-off is acceptable to reduce the potential impact of a security breech and interruption of operational service resulting from an attack on the primary operations database server. Alternate subscription-based architectures can be investigated in the near future for delivering timely vehicle location updates from the transit system to mobile devices to allow new features such as using the vehicle location as back-up for the cell phone location when cell phone GPS is interrupted. However, transit AVL systems must first be designed to provide timely vehicle location updates (e.g., every 10 seconds of less) before these types of real-time services will be possible.

As mentioned earlier in the Mobile Phone Developer section, on the Java Micro Edition (Java ME) platform for cell phones the JSR293 Location API 2.0, expected to appear in 2010 on commercially available handsets, will add significant new capabilities. The Landmark Exchange formats defined in Location API 2.0 will allow the easy exchange of "landmark" information between a cell phone and another entity (e.g., server or phone). It is recommended that transit agencies understand the abilities of this new API and format their landmark datasets, such as transit bus stop inventories, in this format so that it can easily be imported to a mobile device.

Finally, the research team recommends that further consideration be given by the transit industry toward standardizing web service design for exposing real-time transit information. Currently, there is no widely-accepted standard for exposing real-time transit information via a simple lightweight (e.g., RESTful) interface that is practical for mobile devices. The TCIP standard should be consulted during this process. Even though currently planned implementations of TCIP appears to be heavily oriented towards the use of XML, some of the design principles used to create TCIP should be useful in determining a common format for querying and retrieving real-time transit information from transit agencies' IT systems. All stakeholders should be involved in this process, including transit agencies,

transit IT system vendors, and mobile application developers. The design of existing web services operated by transit agencies such as TriMet and HART that are being used by external systems should be reviewed to determine the pros and cons of existing designs.

Future work suggested by the research team includes:

1. Pilot test deployment with multiple agencies to assess implementation challenges and customer satisfaction. The development will look at issues such as the level of staff support required to put TAD into service, as well as AVL polling frequency for agencies that have AVL capabilities. The polling frequency question could allow TAD to use vehicle position as substitute for phone position when phone position fails. Scalability of current system design should be evaluated with a large number of users.

2. Obtain approval from additional cellular carriers to test TAD on devices on their networks. TAD has been tested on the Sprint/Nextel system, but it was designed to be platform-neutral. To expand use of the software and pool of potential participants, other carriers need to be included. This spring, the research team began working through local contacts for AT&T and Verizon with connections to the USF Research Foundation to gain access to installing the various mobile applications, including TAD, on phones on their networks. We have made more progress with AT&T at this point.   If AT&T is added as a TAD compatible network, the potential pool of people who could benefit from TAD, cognitively disabled or not, increases significantly. The research team has gone through the registration and authorization process with AT&T and Geotrust and gained access to the Code Signing Portal through which permission is given to sign applications on the AT&T network. Future work should include tests on other providers' devices to determine if the devices would be suitable as potential TAD deployment devices.

3. Continue development of relationship with corporate partner(s) to facilitate national implementation and deployment of TAD as a commercial service. USF's Division of Patents and Licensing is in licensing negotiations for TAD with a vendor now.

4. Continue to use standards-based design, such as Java Micro Edition JSR179 Location API standard for cell phones and GTFS for static transit data formatting, in system design.

5. Investigate future standards development for lightweight RESTful web service interface for retrieving dynamic real-time AVL information from transit agencies, especially as related to mobile device software development. This may be part of TCIP.

6. Continue to report on the projects' results to bring attention to the use of mobile phone technologies as a lower cost solution of "pushing" real-time traveler information when and where needed.

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