

**TRAC-IT – A Software Architecture Supporting
Simultaneous Travel Behavior Data Collection &
Real-time Location-Based Services for GPS-Enabled Mobile Phones**

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ABSTRACT

Transportation demand management (TDM) strategies are designed to motivate people to modify their travel choices, particularly the drive-alone preference. TDM strategies and policies seek to increase transportation system efficiency and achieve specific objectives such as reduced traffic congestion, road and parking cost savings, increased safety, improved mobility for non-drivers, energy conservation, and pollution emission reductions. Marketing these strategies to the “consumer” in an effective way that results in behavioral changes necessitates a sustained understanding of how, when, where, and why people travel. Therefore, accurate, timely, and comprehensive data are vital in understanding/influencing the consumer as well as for general transportation planning. Data collection processes must make use of new, emerging technologies that help refine the task of monitoring and measuring the behavior to be modified as well as to reduce the burden of data collection on the participant. This paper presents the design, implementation, and testing of the TRAC-IT software architecture for GPS-enabled mobile phones in order to enable both passive and active travel behavior data collection while also supporting real-time location-based services that benefit the end-user. The resulting system presents a unique opportunity to collect high-resolution individual travel behavior data that are instantly transferred to a server for analysis by transportation professionals while giving the user a direct incentive for continuing to participate in long-term travel surveys.

1 INTRODUCTION

According to the 2007 Urban Mobility Report, “congestion is causing urban Americans to travel 4.2 billion hours more and to purchase an extra 2.9 billion gallons of fuel for a congestion cost of \$78 billion”. The report’s authors, Schrank and Lomax, (48) concluded “The [congestion] problem has grown too rapidly and is too complex for only one technology or service to be “the solution” in most regions. The increasing trends also indicate the urgency of the improvement need. Major improvements can take 10 to 15 years and smaller efforts may not satisfy all the needs. So we recommend a balanced and diversified approach to reduce congestion.”

Transportation demand management (TDM) strategies and supportive policies are an essential piece of the balanced and diversified approach. TDM strategies seek to influence travel behavior by mode (how), time (when and how fast), location (where and whether), or route (which way). The individual or personalized marketing of travel options measures behavior change as a result of one-on-one assistance to market segments that have indicated a willingness to consider travel options. The approach includes the distribution of a “before” survey, (self-administered mail-back one-day trip diary), personal contact to participants and an “after” intervention survey. Participants are identified from the “before” survey. The participants are those who have indicated they are willing and able to change their mobility patterns or those who are already using environmentally friendly mode(s) and are interested in receiving more information about the how, when, and why of public transportation and other alternatives to driving alone.

Previous research on these personalized approaches to providing travel options tailored to the individual or household’s own needs have reported success in changing behavior (49)(50). For example, according to Federal Transit Administration (FTA), Viernheim, Germany found that the use of individualized marketing reduced car use by 12%. Perth, Australia reported driver trips decreased by 14%; walking increased by 35%; cycling increased by 61%; and public transportation increased by 17%. Gothenburg, Sweden also showed car use reduction of 13%, an increase in walking by 4%, cycling by 45%, and public transportation by 45%. The FTA Individualized Marketing Demonstration Program (IMDP) pilot program was undertaken to test the effects of individualized marketing on public transportation ridership trends in the U.S. Successful changes in travel behavior were reported for the four cities in the FTA pilot. The reduction in vehicle miles of travel by participants receiving the personalized marketing ranged from 4% in Sacramento to 11% in Durham, North Carolina.

Tailoring travel options to the individual requires an understanding of his or her personal and household travel behavior and patterns. Therefore, accurate, timely, and comprehensive data are vital in influencing the individual. Accurate travel behavior data also plays a key role in transportation planning for new roads or transit routes. A challenge is how to collect multimodal travel in an efficient manner to influence behavior and provide insight into travel patterns.

Though some researchers have reported change in travel behavior, concerns have been expressed by others with the methodology for assessing these reported changes. O’Fallon and Sullivan (45) note several pitfalls with respect to sample sizes in measuring the effects of such programs in their review of personalized marketing programs to change travel behavior. They found that the self-selection biases of participants exposed to the “intervention” in the travel behavior program and changes in external factors (e.g., changes in gas prices between “before” and “after” surveys) can confound the results. Cleland and Winters (47) sought to address this limitation with the use of test and control groups. They examined the travel habits of households provided with personalized advice. The project offered a practical exercise that led households to re-appraise their needs and rationale for travel. Specific suggestions aimed at use of public transit service, bike paths, trip chaining, ridesharing, and e-commerce options were provided based on specific travel patterns observed in the activity diaries. Test and control groups completed two 7-day travel diaries that formed the basis of the testing the personalized advice provided.

Another issue of concern in travel behavior data is the size of the sample relative to the dependent variable of interest. One of the factors for determining accurate sample size estimates is the variability of the dependent variable (e.g., vehicle trips, vehicle miles of travel). The higher degree of the variability then the larger the sample size required. Determination of the sample size is based on the specification of the smallest effect wanted to detect, the Type I (rate of false positives) and Type II error rates (rate of false negatives), and the design of the study.

Researchers can reduce sample size requirements and related costs by moderating the variability of the dependent variable by using several approaches. First, a panel survey design (where the same people are measured at least twice – before and after personalized assistance) does not require sample sizes as large as repeated cross-sectional surveys. Sample size requirements also decrease if the travel behavior data by collecting data over extended periods

(week vs. day) as the variability should decline over longer periods. Finally, measuring travel behavior averaged across all people in a household would require lower sample sizes by further decreasing the variability. The selection of vehicle trips as the dependent variable also affects the sample size. As Richardson (46) noted, larger sample sizes are required to detect changes in distance traveled than to detect differences in vehicle trips due to the larger variability of mileage versus trips. Determining the appropriate sample size to account for known variability in measures such as VMT can permit the establishment of reasonable confidence intervals around the change in behavior.

These sample size reduction strategies can also make the survey data more difficult to collect. Richardson also observes that panel data are more difficult to obtain than cross-sectional data as the researcher is dependent on participants completing at least two rounds of surveys. Plus, weekly surveys are more burdensome than daily activity diaries when collected via paper surveys. In addition, problems with data accuracy and completeness when using methods such as paper diaries or phone interviews have been shown in past studies when reported behavior was compared against vehicle Global Positioning Systems (GPS) logs collected for the same period of time (8)(35)(40). These inaccuracies are due to the significant burden that an active diary places on an individual as well as the difficulties that participants have in recalling exactly when and where they traveled.

Data collection processes in recent years have made use of available technologies that help refine the task of monitoring and measuring the behavior to be modified (1)(8)(32)(33)(34)(36)(40). As mentioned above, GPS technology provides precise time and position information which can be recorded at frequencies around once per second and is therefore an excellent means of passively recording the time of travel and path of the participant while requiring little or no interaction with the user.

Several past pilot travel surveys have utilized vehicle-based GPS units because of the battery life and portability limitations of dedicated GPS devices. These devices provided a detailed log of vehicle movements, but are unable to record trips taken by the user for bus, carpool, biking, and walking trips and are not able to distinguish one user from another. Also, additional information about trips may be desired that are not easily extracted from GPS data such as trip purpose, mode of transportation, and vehicle occupancy. This information must be actively collected from the user. Combination PDA/GPS systems have also been utilized in studies (1)(40), but these units have been expensive and fairly large to carry. Newer technology in the area of GPS data loggers have created small units slightly larger than USB thumb drives that are far more portable and less costly than their older counterparts, but these devices do not have a wireless connection and therefore cannot provide real-time travel information services to the user as an incentive for participating in the survey and cannot remotely transfer travel data back to a server for analysis. These devices also do not have a user interface to record manual participant input that is required by the survey. Additionally, the public does not typically own this type of device and hardware would have to be purchased and distributed to potential survey participants and then collected at the end of the survey.

The convergence of market demand, technology advances, and regulatory requirements have created an opportunity for using cell phones as a data collection tool and as well as a new means for low cost delivery of traveler information services. Mass production has substantially lowered the cost of mobile phones, making them more affordable for the average consumer. Cell phone popularity continues to grow, as does the sophistication of the devices. It is estimated that currently over one half of the world's population, or 3.25 billion people, owns a cell phone (3). In the United States, the Federal Communications Commission (FCC) has mandated that all cellular carriers implement technology that is able to location an emergency caller within 50 to 300 meters (2). This mandate has resulted in the creation of GPS-enabled mobile phones that have integrated GPS chips and are able to determine the user's position quickly and with a high degree of accuracy (9)(36). Additionally, since mobile phones have an "always-on" wireless data connection, real-time travel information services can be delivered to the user. The cellular network also provides a secondary source of position information if GPS is not available.

This paper describes TRAC-IT, a software system for commercially-available GPS-enabled cell phones designed to track travel behavior of test and control groups over an extended survey period while providing personalized travel information services to the user as an incentive for ongoing survey participation. Using GPS data from cell phones to record travel behavior data will help overcome many of the limitations cited above. This method is easier, more comprehensive and more accurate than paper diaries for tracking of person movements, not simply vehicle movements. The GPS component provides a means of tracking origin, destination, start and end times, route, speed, and distance, while the cell phone user interface provides a means of recording items such as mode, occupancy, and trip purpose if desired. TRAC-IT also simultaneously delivers useful services, such as real-time traffic alerts based on the user's real-time and historical locations, to the user while collecting travel behavior data in order to provide

an incentive for the user to participate in extended travel behavior surveys. The project was conducted by the National Center for Transit Research at the University of South Florida (USF) and the USF Department of Computer Science and Engineering with funding provided by the Florida Department of Transportation and the United States Department of Transportation.

The following sections discuss previous research relevant to TRAC-IT, the system design criteria, TRAC-IT system architecture, and finally a field test demonstrating the TRAC-IT proof-of-concept.

2 RELATED RESEARCH

There are two main methods of utilizing mobile phones to obtain travel information. The first method uses cellular signaling data to estimate average speed or travel time on road segments. The second method uses positioning technologies such as GPS to determine the precise location of each individual mobile phone that is being examined. The two methods of data collection yield different types of information that can be used for different purposes.

The first method uses anonymous cellular signaling data gathered at cell towers to estimate travel time on nearby highways. This technique works by looking at where and when signal handoffs occur when the cell phone travels from one tower's coverage area to another. Proprietary algorithms then attempt to determine road segment speeds allowing estimates of travel times from this data. Mobile phone user's permission is not required to use this signaling data, although privacy advocates are pushing for more control over telecommunications records. Travel time and estimated travel speed on a specific road segment are the only items of information available from these types of systems, which may be sufficient for traffic operations. However, travel path, individual travel behavior, and origin and destination information are not available from this method of data collection.

Companies operating these systems in the U.S. have been evaluated by various DOTs with varying results of system accuracies (4), (5), (6). These studies concluded that systems work well at free flow speeds, but accuracies vary when traffic is traveling at lower speeds. These accuracy problems may occur because there are not as many handoffs between towers occurring when phones are not traveling a long geographic distance making it more difficult to extrapolate road speed data when the frequency of handoffs is low.

The second method is the use of GPS-enabled mobile phones to gather continuous position data for each mobile phone, including speed and heading data. TRAC-IT uses this method to calculate the phone's position using Global Positioning Systems (GPS), network triangulation, or a similar positioning technology. GPS is highly accurate, with most position calculations being accurate within 3 to 30 meters and speeds shown to be accurate within 0.2 meters/sec in past studies (7). GPS fixes can be collected with a frequency of up to once per second for each mobile phone, thereby generating a wealth of information of an individual's travel behavior. This method yields origin-destination (O-D) data as well as travel path information for each individual traveler and is a modern version of the traditional activity diary. GPS has been studied in the past as a method for replacing travel diaries and has exhibited excellent results (8). Travel speeds and estimated travel times can also be extracted from these data from multiple phones. The proliferation of mobile phones in the market place could potentially eliminate the equipment cost for survey deployment, while the device's portability allows it to track travel behavior by any mode.

While GPS-enabled mobile phones are a promising source of data, transportation professionals must overcome several challenges when designing and deploying such a method. First, a software infrastructure that spans both the mobile device and a server must be designed and implemented. There can be adverse effects on handset performance, such as battery life or the ability to receive incoming phone calls if the position requests are not efficiently managed by the software running on the phone. Additionally, users must opt-in to install the software application on their phone. Incentives may be required such as providing the user access to real-time traffic information alerts based on current location or predicted path. The TRAC-IT project examines this method of data collection and evaluates a prototype architecture that implements such a method.

3 METHODS

3.1 Research Methodology

The TRAC-IT project objective was to determine the capabilities of GPS-enabled mobile phones in tracking person movements across modes (car, bike, bus, etc.) and over extended time periods (e.g., weekly versus daily). TRAC-IT

aimed to produce a system which could simultaneously record travel behavior while providing useful real-time services to the end-user that could encourage them to participate in the survey for an extended length of time.

The research focused on the development of a widely-deployable mobile software application for commercially-available, GPS-enabled mobile phones in order to support next generation travel surveys, real-time traveler information dissemination, and travel behavior change techniques. The TRAC-IT architecture is also supported by a server developed to receive and store data collected by the mobile application.

The next sections will highlight the system requirements which influenced the design of the TRAC-IT architecture. Finally, a field test was performed with participants carrying GPS-enabled mobile phones with TRAC-IT software installed to evaluate the data collection capabilities of TRAC-IT.

3.2 System Design Criteria

The following sections detail the selection process for important TRAC-IT architecture components and the determination of certain TRAC-IT application features.

3.2.1 Positioning Technologies

With many different types of positioning technologies that can locate the position of a mobile phone, it was important to select a primary positioning technology that will best recreate the transportation patterns of the user. Assisted GPS was selected as the primary positioning technology due to its high accuracy and ability to generate updates as frequently as once per second on mobile phones. Additionally, GPS has been used in past travel behavior studies with excellent results (8). Less accurate, secondary positioning technologies, such as cell signal triangulation techniques and Cell-ID, can be used when GPS is not available.

3.2.2 Form-factor

Commercially-available GPS-enabled mobile phones provide a compact form factor that includes GPS hardware, wireless communications, and a user interface to receive additional survey input from the user. Compatible devices are already owned by the public, thus decreasing potential TRAC-IT deployment costs and requiring only the distribution of a software application.

3.2.3 Network-Initiated vs. Handset Initiated Location Requests

Network-initiated location requests are made by an application residing on a 3rd party web server, while handset-initiated location requests are made by a mobile applications running on board a mobile phone. User privacy and portability across multiple cellular carriers and devices are critical issues. The issues of data integrity and control by the software application eliminate the possibility of utilizing network-initiated location requests to record individual travel behavior.

Network-initiated location requests are limited to a maximum frequency of once every 5 to 10 minutes, which is insufficient to accurately recreate a user's travel behavior even if a GPS fix is returned on every update. Only position (i.e., latitude and longitude) and timestamp information are obtained for network-initiated requests. Velocity, heading and other GPS information are not accessible. Also, there is no control over the positioning method used to determine the cell phone's location. Therefore, long periods of time (i.e., 10 or more minutes) may pass without a GPS position update. Therefore, it is unlikely that a user's travel path, including starting and ending location could be reconstructed from such infrequent position updates. These facts eliminate network-initiated location requests from consideration as a method for obtaining travel behavior data for TRAC-IT.

Cellular providers would be unlikely to consider allowing network-initiated location requests for a large-scale travel survey of the public's mobile phones due to the increased load on their location server. Currently, network-initiated location requests are primarily limited to enterprise customers who query the location of their employees' devices. Additionally, although standards such as Mobile Location Protocol (13) and Parlay X (14) exist, there is currently no consistent implementation among cellular networks for network-initiated location requests. As a result, a different web application would have to be developed for each cellular network in order to request the position of mobile phones on that particular network.

Privacy concerns also exist for tracking methods utilizing network-initiated location requests. Once a user opts in to be tracked by network-initiated location requests, the only method available to the user to disable tracking is to turn off the cellular phone or completely opt out of the program via a website. Otherwise, the user's cell phone would be tracked 24 hours a day. One of TRAC-IT's system requirements is the ability for the user to opt in or out of being tracked at any time from their cell phone without interfering with their normal cell phone operations or their enrollment as a participant in the survey.

For these reasons, handset-initiated location requests were selected as the primary means of obtaining the location data for a mobile phone. This method allows a mobile application to specify the frequency of GPS updates up to a frequency of once per second.

3.2.4 Portability of the TRAC-IT Software

Portability is defined as the ability to use a software application on more than one type of hardware device or software platform with few to no changes of the software code. Java ME is currently the most portable programming language across different mobile devices and cellular carriers. Java ME is the only language for mobile devices that has a well-established procedure for platform updates and additions that is open to many different companies via the Java Community Process (JCP). Java ME was therefore chosen as the programming language for the TRAC-IT mobile phone application.

Java Specification Request (JSR) 179 Location API 1.0 (10), and JSR293 Location API 2.0 when available (11)(12), should serve as the primary software interface to access location data from the handset since this is the only standardized location-related API implemented across multiple carriers and cell phone manufacturers. Proprietary Java ME APIs may be utilized for other features when the functionality has not been standardized under a JSR (i.e., accessing the phone number of the device), but the TRAC-IT application design abstracts that particular API so that proprietary modules can easily be switched out in favor of a new proprietary module when porting the application to a new platform. This feature ensures easy portability even when proprietary functions must be utilized to access certain features of the cell phone.

Java was also selected as the primary programming language for the server-side systems, since it is also portable across many different operating systems and application servers. It is therefore concluded that Java will enable the least expensive implementation of the TRAC-IT system since information technology departments can utilize the servers that they already have. Having both the server and cell phone software implemented in Java allows sharing of code between the two applications when possible, thus reducing development costs.

3.2.5 Coexistence of TRAC-IT with Cell Phone Operations

The TRAC-IT mobile application should not interfere with the cell phone's normal operation. The main areas of concern are background application execution, interfering with receiving or making phone calls, incurring additional financial cost to the individual who owns the cell phone, and significant impact on battery energy consumption.

For TRAC-IT to successfully coexist with other phone functions, Java ME platforms must support Multi-Tasking Virtual Machines (MVM) so that the application can execute in the background while other phone features remain functional. It is not practical to run TRAC-IT on platforms without MVMs since the TRAC-IT application will be paused if it is sent to the background or the phone is flipped closed. If paused, TRAC-IT will no longer monitor the position of the user and cannot send any position data to a server. Therefore, the presence of an MVM is critical to TRAC-IT operation as a passive tracking application.

Some cellular technologies do not allow data and voice sessions to exist simultaneously and therefore interference with voice calls is possible. While TRAC-IT is running and in a data session (i.e., transferring location and trip data to the server), incoming phone calls may be blocked and sent to voicemail instead of ringing at the phone. The TRAC-IT application must intelligently manage the amount of data sent to the server to avoid over-occupying the communication capabilities of the phone. The user can always make outgoing phone calls using their phone even if TRAC-IT is running in the background. However, the phone will interrupt any active data sessions (e.g. transferring trip or location data) if a voice session is initiated by the user. As soon as the user ends the voice phone call, the TRAC-IT application should be able to send data again. In emerging cell phones that support Internet Protocol Multimedia Subsystem (IMS), the limitation of mutually exclusive voice and data sessions will be removed as voice

sessions are converted to packet data communication over IP, and thus be capable of simultaneous operation with other data sessions.

Since mobile devices are battery-powered, energy is a critical resource that must be conserved. An application such as TRAC-IT cannot afford to render a device unusable due to extraordinary energy consumption. High-precision location-aware applications for cell phones require that GPS hardware be active while the device's position is being calculated. Therefore, additional power is consumed during GPS operation beyond the normal power consumption of the phone while it is in an active or standby state. While newer high-sensitivity GPS receivers in modern mobile phones are more power-friendly than their older counterparts the application executing on the mobile phone should reduce the number of requested GPS fixes to as few as possible to conserve power (19). Since wireless transmissions also consume power, the number of GPS fixes transmitted to the server should also be minimized. Intelligent monitoring software should be developed in order to calculate as few GPS fixes as possible and transmit only critical information needed to reconstruct a user's trip. Lightweight data transmission protocols such as User Datagram Protocol (UDP) should also be used when possible in order to avoid the additional transmission overhead of "reliable" protocols such as Transmission Control Protocol (TCP) (16)(17). Location fixes are calculated frequently, so the occasional loss of location data transmitted via UDP is acceptable.

3.2.6 Interoperability and Forwards-Compatibility of the TRAC-IT System

Mobile technology and cell phones, in particular, evolve at an astounding rate. Therefore, forward-compatibility of the TRAC-IT software architecture with future cell phones is a key component of the TRAC-IT system design. Java ME was selected as the mobile programming platform because it is the most ubiquitous computing platform for mobile devices that is not tied to a single device manufacturer or wireless carrier. Additionally, JSR293 Location API 2.0, scheduled for release in late 2008, is backwards compatible with JSR179 Location API 1.0. This means that any mobile software application utilizing JSR179, including TRAC-IT, will also work with future mobile phone that implement the Location API 2.0. Since TRAC-IT is designed for Connected Limited Device Configuration (CLDC) 1.1 and Mobile Information Device Profile (MIDP) 2.0, it should also be forwards-compatible with MIDP 3.0 when it is released, as well as with Connected Device Configuration (CDC) devices when they become widely available (15)(20)(27)(29).

To promote interoperability with all types of client devices (both Java and non-Java), all server functionality should be exposed via web services hosted on an application server. There are many open-source as well as commercialized, Java application servers (21), (22), (23), (24), (25),. Java EE 5 platform was selected for the TRAC-IT server application (26). This should allow small agencies to use free open-source application servers to host the TRAC-IT application while bigger agencies may choose to use better supported, but more costly, production application servers. The large number of supported application servers ensures that the TRAC-IT server application can be executed on an application server for years to come.

3.2.7 Final Selection of TRAC-IT System Components

The TRAC-IT mobile application therefore requires the following features to execute on a mobile phone:

- Java ME-compatible (CLDC 1.1 and MIDP 2.0) (Forwards compatible with CDC and MIDP 3.0) – basic Java platform for mobile devices
- Multitasking Virtual Machine – Allows background execution of the application while other phone features are being used
- UDP – supports efficient transfer of location data to the server. (Alternative version of TRAC-IT that uses TCP or HTTP could easily be developed for devices that do not support UDP, but performance will decline).
- JSR179 Location API 1.0 (forwards compatible with JSR293 Location API 2.0) – Allows programmatic access to location data on the mobile phone

3.3 TRAC-IT System Architecture

The general architecture which supports TRAC-IT is shown in Figure 1. The mobile phone runs the client-side application software that incorporates the user interface as well as the methods for obtaining user position information. The cellular data network and the general Internet are utilized as transport networks for data sent between a mobile phone and a web application server. The cellular network can also be used to provide user

position information through cell signal triangulation or Cell-ID of the base station if GPS is unavailable. The server-side component is responsible for managing interactions with the mobile phone and contains the database holding user and trip data generated by the client application. The various tables of the database schema are accessed during the course of TRAC-IT's operation to perform functions including:

- establishing a session,
- verifying valid application users,
- receiving and recording trip-specific data for each user,
- receiving and recording location data transmitted by the mobile phone,
- retrieving trip data for the analysis modules that provide feedback for user trips, and
- transmitting server-side-generated feedback to the end-user device.

3.3.1 *TRAC-IT Mobile Phone Application*

In the mobile Java ME application, TRAC-IT utilizes a location-aware state machine (39) to regulate the rate at which position information is requested from the GPS hardware in order to save battery energy during constant tracking. If invalid location information is repeatedly obtained by the application or if the user is standing still for a long period of time, it will gradually increase the amount of time between new position requests and go into a "sleep" state. Similarly, when valid location information is obtained, the amount of time between new position requests will slowly increase until a minimum value is reached. The State machine also supports the functionality of "snapping" back (i.e. "waking up") to the most frequent polling rate when location GPS fix with a speed above a threshold is obtained. TRAC-IT utilizes this functionality, since applications such as TRAC-IT should begin tracking at a rapid rate as soon as the user is discovered to be traveling.

A "critical point" algorithm (39) is also utilized by the TRAC-IT Java ME application in order to save battery energy by reducing the transmission of unnecessary location data to the server. When GPS data are recorded frequently by the mobile phone, a large amount of data that are not necessary to reconstruct a participant's trip is generated. Examples of unnecessary data include GPS points collected when the phone is not moving as well as multiple GPS points that create a straight line. The data that are needed to reconstruct a user's travel path are referred to as "critical points." To ensure that directional changes are not calculated due to readings that are inaccurate within the accuracy uncertainty limit, fixes are assessed only if the corresponding speed reported is greater than a speed threshold. The first and last points of every segment are also considered critical.

Active survey input is accomplished through a user interface shown in Figure 2. A series of screens is able to collect location descriptions, mode, purpose, and occupancy data. This information is automatically related to GPS data collected simultaneously, thereby giving a complete representation of the user's travel behavior. The user interface can also implement intelligent methods, such as pre-filling fields based on real-time or historical travel behavior, in order to further reduce the burden on participants during the active survey (41). If desired, TRAC-IT is also able to collect data in a passive mode where no user input is required and only GPS data is collected.

3.3.2 *TRAC-IT Server-side Modules*

The servers-side modules of TRAC-IT are responsible for receiving, analyzing, and providing feedback for travel data transmitted by the mobile phone. It consists of two main software elements: An application server that deals with communication and analysis and a database server that deals with storage and retrieval of trip information. Since TRAC-IT is a distributed application between the mobile phone and server, an application server must manage all interactions between the database and the mobile phone. The TRAC-IT protocol used between the mobile phone and application server is shown in Figure 3.

The TRAC-IT architecture uses a two-layer communication protocol to accomplish efficient location-based services. Communication between the mobile phone and server for application logic is transported over the HTTP protocol using the Representative State Transfer (REST)-ful web services design (43) which supports universal access for CLDC devices, since HTTP support is required in CLDC. For mobile devices that support the optional JSR172 J2ME Web Services API (18) direct communication with traditional web services based on XML and SOAP is possible. Since SOAP is implemented on top of HTTP, both traditional and REST-ful web services can be secured to guarantee user privacy using HTTPS. UDP is preferred to transport location data due to the limited resources available on a mobile device and also to support system scalability. The payload of UDP datagrams can be secured to protect user privacy using cryptographic techniques such as Elliptical Curve Cryptography (30). TRAC-IT can

also be easily adapted to transport location data over TCP or HTTP for system that do not support UDP, although there will be a degradation in system performance.

In order to support real-time traffic incident information delivery to the mobile phone, a Path Prediction algorithm was developed. Path Prediction seeks to provide users with information about incidents that may encounter along the path they are traveling in real-time (42). This service is accomplished by predicting the user's immediate route in real-time based on past travel behavior and the user's real-time position and then scanning ahead on each potential route to determine if any incidents lie along their predicted path. If an incident is detected, the user can be alerted via text or multimedia message (28). This service provides the user with a direct incentive to continue to use TRAC-IT to record their travel behavior, since they will only receive alerts if the TRAC-IT mobile application is running on their phone and they have recorded travel behavior in the past.

It is desirable to eventually transition to a completely passive, automated version of TRAC-IT that requires no manual entry in order to reduce the burden on the user. Such a system must extract enough meaning from GPS data and other contextual information to automatically detect trip purpose, mode, and other data that is currently collected via the mobile application user interface. Several modules were implemented to test purpose and mode detection within the context of the TRAC-IT system.

A purpose detection algorithm uses GIS-based Department of Revenue tax classifications of properties and GPS data from the ending points of trips to derive a traveler's trip purpose. Similarly to Wolf *et al.* (32), it was found that purpose detection was indeed possible using this method. The GPS accuracy improvements provided by the lifting of Selective Availability and the development of high-sensitivity GPS receivers since Wolf *et al.* allows very precise spatial queries against GIS datasets. It was found that the misclassification of properties (e.g. restaurants as "federal") and mixed-use properties (i.e. school for sports activities) were the primary sources of error in purpose detection, another finding similar to Wolf *et al.*

Mode detection has been implemented through the use of a neural network. The data from known bus, walking, and car trips are provided as input for the neural network, and then the common characteristics of these records are extracted and generalized for later comparison against data sets of unknown type. Trips with a sufficiently high degree of similarity with the training set of trips are considered to be of the same transportation mode. Field tests to date have yielded a total accuracy of this method approaching 92 percent for all modes, with 92.11 percent of car trips, 81.58 percent of bus trips, and 100 percent of walking trips successfully detected (31).

4 FIELD TESTING

4.1 Survey Method

Fourteen volunteers participated in the TRAC-IT mobile phone field tests. A Sanyo 7050 mobile phone on the Sprint-Nextel CDMA network, a belt clip, and a charger were provided to the participants. Car chargers were also offered, although only two participants opted to use them.

The TRAC-IT application was set in active mode so it would record GPS data only when the user selected that they were starting a trip via the user interface. TRAC-IT was set to query the GPS position of the phone every four seconds and send this information to the server during trip recording. In order to maximize the amount of GPS data available for analysis, both the location-aware state machine and critical point algorithms were turned off for the field tests as extensive testing of those software modules was not possible before deployment. A description of the benefits of the location-aware state machine and critical point algorithms are beyond the scope of this paper and are documented in Barbeau *et al.* (39). Glassfish was utilized as the Java Web Application server, with Microsoft SQL Server serving as the primary database server and PostGIS serving as the spatial database server.

Once the participant signed the Informed Consent form and agreed to participate in the testing, the volunteer was asked to specify a short description of several locations that they visited regularly. These locations were entered into the database by the research team to save the user the time of inputting these locations into the phone user interface as "new" locations. As a result, when the participant first started the TRAC-IT application and selected to begin a trip, the descriptions of location provided by the user were already available for selection as a trip starting or ending location.

The volunteers were asked to carry the cell phones around for a period of time that averaged between 2 and 3 weeks and to charge the phone battery nightly. Participants were given instructions regarding the user interface and were encouraged to enter their trips during the course of daily activities. No specific instructions were given to the user for where to position the phone during trip recording. In other surveys involving GPS, the users are often told to position the device on the dashboard of the vehicle in order to maximize the potential for the device to receive adequate GPS signals in order to calculate a position. However, since the cell phone is a personal device frequently used for other activities such as voice calls, it is not practical to request the volunteer to position the phone in this manner. The research team wanted an accurate representation of what type of GPS data could be collected when the mobile phone is carried as a normal phone, and therefore no specific instructions for locating or carrying the phone during trips was provided.

For each trip recorded using TRAC-IT, participants were emailed trip data that included a description based upon their use of the TRAC-IT interface, as well as a graphical representation of each trip. Participants who used Microsoft Outlook were emailed their trip information in the form of calendar entry so the time of the trip could be visualized along with their other appointments. Additionally, participants could easily accept or reject the information as an appropriate representation of their actual travel behavior and provide comments back to the research team by replying to the message.

Since no traffic data source allowing real-time programmatic access could be identified in Tampa, Florida at the time of the field tests, the Path Prediction algorithm was demonstrated separately from the TRAC-IT field tests. Data from these tests are available in Persad-Maharaj *et al* (42).

4.2 Results

During the initial phase of field testing for TRAC-IT, 317 trips were recorded by 14 volunteers spread out over a period of three months resulting in the collection of 66,523 location data points. Figure 4 shows an example of trip and GPS data recorded using TRAC-IT.

Of these location data, 53,290 data points represented GPS data points with an associated latitude and longitude and estimated accuracy. The remaining 13,233 location points represent the location of the cell tower the phone was communicating with when a GPS fix was not possible.

The location of the subjects' activity was primarily in the University of South Florida area of Tampa, although some trips were recorded in Seattle, Fort Lauderdale, and Orlando to test TRAC-IT in other geographic locations. A variety of modes were utilized, including walking, bus, car, and bike.

4.3 Discussion

Of the 317 trip segments recorded by the participants, only 7 of the resulting records were reported by participants as an inaccurate assessment of travel behavior. Five of these appeared by inspection of the recorded data and subject interaction to be errors in user input via the phone user-interface when labeling locations. In the other two cases, the GPS reception faded near the ending location, and therefore it appeared on the map that the ending location was earlier in the trip.

In 34 cases, there were insufficient GPS data to provide meaningful feedback to the volunteers for verification of the trip path. In 32 cases, most of them overlapping the 34 instances of no GPS being recorded, the end trip information recorded by the participant using the user interface of the phone was lost and not recorded in the database due to technical issues with the TRAC-IT system. These intermittent technical issues also prevented users from logging in and starting the TRAC-IT application at times, so an unknown number of trips were not recorded due to these technical problems. While recruitment of additional participants beyond the initial phase of recruits was planned when field tests began, once these technical issues were observed the TRAC-IT research team focused on troubleshooting tasks and maximizing the amount of data collected from this single phase instead of deploying additional phases that could potentially exacerbate the problem. Despite these technical difficulties, there was still a significant amount of trip and GPS data collected that successfully demonstrated the proof-of-concept of the TRAC-IT system. Technical issues are discussed in depth in the TRAC-IT Phase 3 final report and can be resolved for a large scale deployment (44).

Trips made by certain modes seemed to have reoccurring GPS characteristics for different users that reflect the initial observations made during the performance testing of the GPS-enabled mobile phones for estimated accuracy uncertainty. For example, walking trips sometimes have frequent GPS gaps in the path since the phone is usually obstructed by a bag or the user's clothing. However, some walking trips were observed that were a perfect recreation of the users path. Car trips usually had the most accurate portrayal of the user's path. This is likely because the user tends to physically place the phone in the cup holder or other location in a car where it has a clear view of the sky. However, occasional GPS gaps do occur. Bus trips showed characteristics somewhere between car and walking trips depending on the specific bus route and area. A few trips were also recorded using a golf cart by one TRAC-IT participant. The GPS data recorded during these trips seem to have properties somewhere between walking and car trips.

For trips where GPS was not available (i.e., a travel path was not recorded), at least one GPS fix was almost always recorded at the starting and at the ending locations of the user's trip. This may be because the user must hold the cell phone to input information about the start and stop locations of the trip via the user interface and the user will likely keep the phone out in the open (i.e., not in a bag or other concealed location) for at least several seconds during this time. While the phone is out in the open, it is more likely to receive GPS signals and obtain a position fix. This characteristic of TRAC-IT seems to indicate that origin and destination information will be recorded for the vast majority of trips. Origin and destination information could also be extracted from user's manual entry of starting and ending location information. Each time the user visits a location, it is "stamped" with latitude and longitude information if GPS is available at that time. Therefore, for future trips to the same location when GPS may not be available, latitude and longitude information can still be extracted from the database for the location the user indicates via the user interface. This process was possible for several few trips recorded during field testing that lacked any GPS data.

Participants indicated that the biggest challenge they faced was remembering to start a trip via the TRAC-IT user interface. Therefore, the passive recording feature of TRAC-IT should be tested further. In the passive data collection mode, the phone would always be sending location data to the TRAC-IT server unless the user selected to turn this feature off via the TRAC-IT user interface. This feature would not require the user to always remember to start a trip, since it would be recording even if no action was taken by the user. However, passive tracking could negatively impact cell phone performance, including battery life, and has additional privacy issues since the user would have to "opt-out" of having a trip recorded instead of "opting-in." Therefore, further analysis of the State Machine and Critical Point functionality should take place to determine if these "smart" resource management techniques can fully offset any negative impact on cell phone functionality when passive tracking is active. Privacy protections such as the implementation of "sensitive zones" where no tracking is allowed should also be explored.

5 CONCLUSIONS

The use of GPS-enabled mobile phones and an application such as TRAC-IT presents a unique opportunity to collect high-resolution travel behavior data for individuals. These data represent an improvement over traditional OD data, since GPS data accurately represent the path of travel and additional user input can be collected through the survey in the user interface. TRAC-IT uses actual positioning technologies such as GPS, not just aggregated cell signaling data, to yield extremely precise position data within 3-5 meters of the true position for each time point that is captured with a supported frequency of up to one fix per second. The use of handset-initiated GPS requests allows the simultaneous delivery of real-time location-based services, such as those provided by the Path Prediction algorithm, to the user and therefore provides a direct incentive for the user to participate in a survey for an extended amount of time.

Trip and GPS data recorded using TRAC-IT are instantly transferred to a server for analysis by transportation professionals. Additionally, field equipment costs are eliminated since TRAC-IT is a software application that is deployable to any privately owned GPS-enabled mobile phone that supports the popular Java ME platform and the standardized method of accessing location data, JSR179 Location API. As more high-sensitivity GPS chips become available in the mobile phone market in the next year, GPS data collected from mobile phones should be more accurate and should be able to obtain location fixes where present phones cannot.

As of early 2008, only Sprint-Nextel's CDMA and iDEN networks have been opened to mobile application such as TRAC-IT that utilize standardized methods to acquire location data. Currently, this does provide some limitations to the statistical validity of using TRAC-IT to sample the general population's travel behavior. However, it appears

as though other wireless providers will be opening up their networks within next few years, which would allow TRAC-IT to be deployed to nearly everyone who owns a mobile device. Since there are more than 262,000,000 U.S. wireless subscribers, this is a significant population to survey. Additionally, the recent FCC auction of the 700MHz spectrum to be used for future commercial services will be held to the condition of “open devices and open applications,” thus further opening up wireless carriers to application such as TRAC-IT. Due to the growing number of individuals that own only mobile phones and do not own landlines, TRAC-IT may eventually be accessible by more individuals than traditional land-line based surveys.

Because of the many issues involved in the deployment of a location-aware application such as TRAC-IT, USDOT, along with state DOTs, should engage wireless providers in a single dialog to discuss how a large-scale test of TRAC-IT (i.e., over 200 users) could be realized. As part of this dialog, it should become apparent whether there are any policy-based or logistical issues that would prevent a large-scale deployment of TRAC-IT, including any access restrictions by cellular carriers. If there are no access restrictions or logistical barriers to deployment of TRAC-IT on a wireless provider, testing should be slowly escalated in the number of simultaneous mobile phones to determine whether there are any unforeseen scalability issues with the TRAC-IT system. While the design of the system has scalability in mind, there can be unknowns in the real-world implementation of technology.

Due to the many different mobile phone devices on the market, it is also recommended that DOTs create a process to test and certify specific devices with the TRAC-IT application before TRAC-IT is deployed to that particular device. This is especially important when devices are tested across multiple wireless providers, since significant differences can exist in Java ME implementations across providers. Since GPS hardware in mobile phones have different levels of sensitivity, accuracy testing should also be performed on specific GPS chipsets to determine whether that particular platform would yield data accurate enough for TRAC-IT purposes. Also, since the end-user device is privately owned, testing should ensure that no personal mobile phone functions will be compromised by TRAC-IT. As Java ME for mobile devices continues to mature during the next year, future development and testing for new devices should become easier as Java ME implementations become more consistent.

The unique methodology of TRAC-IT enables departments of transportation to explore new types of incentives in coordination with wireless service providers. For example, DOTs could potentially arrange with the wireless carrier to provide free unlimited data plans during the survey period to any participants willing to install and use TRAC-IT on their phone. Participants then have access to new services on their mobile phone in addition to TRAC-IT, including email, internet browsing, online search, etc. DOTs would benefit from reduced deployment costs through cost reductions in unlimited data plans, and the wireless carrier would benefit both by the DOT paying some cost for unlimited data plans during the survey period and by the participant potentially paying full cost for the plan after the survey period ends.

The concept of path prediction and traffic incident alerts described in this paper could also be used as an incentive by itself. For example, if participants use the TRAC-IT application to record their behavior, then they would automatically receive free, personalized traffic alerts based on their own travel behavior as well as their real-time location. This service could be valuable enough to mobile phone users that they overcome any reservations regarding privacy and would be willing to allow their travel behavior to be tracked.

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6 REFERENCES

- (1) Winters, P., N. Georggi, and S. Barbeau (2005), “Traveling Smart: Increasing Transit Ridership through Automated Collection (TRAC) of Individual Travel Behavior Data and Personalized Feedback.” National Center for Transit Research, Center for Urban Transportation Research, University of South Florida. Florida Department of Transportation. <http://www.nctr.usf.edu/pdf/576-16.pdf>, accessed February 11, 2008.

- (2) “FCC E911 – Wireless Services” Official Website at <http://www.fcc.gov/911/enhanced/>, accessed February 11, 2008.
- (3) K. Ridley (2007) “Global Mobile Phone Use to Hit Record 3.25 Billion,” Reuters. © Reuters 2007. Available online at <http://www.reuters.com/article/email/idUSL2712199720070627>.
- (4) Wunnava, Yen, Babij, Zavaleta, Romero, and Archilla (2007), “Travel Time Estimation Using Cell Phones (TTECP) for Highways and Roadways,” Final Report for Florida Department of Transportation.
- (5) Guin, Bachman, and Demidovich (2007), “Strategies for Evaluating the Usefulness of Cellular Probe Traffic Data in Representing Aggregate Traffic Conditions on Freeways,” Final Report for the Georgia Department of Transportation, 2007.
- (6) Liu, Danczyk, Brewer, and Starr (2008), “Evaluation of Cell Phone Traffic Data in Minnesota,” Transportation Research Board 2008 Annual Meeting (CD-ROM), Washington, D.C.
- (7) Witte and Wilson (2004), “Accuracy of non-differential GPS for the determination of speed over ground,” *Journal of Biomechanics*, 37(12):1891-8.
- (8) E. Murakami and D. P. Wagner (1999), “Can using global positioning system (GPS) improve trip reporting?” *Transportation Research Part C: Emerging Technologies*, Volume 7, Issues 2-3, p. 149-165. © 1999 Elsevier Science Ltd.
- (9) van Diggelen, F., “Indoor GPS Theory & Implementation,” IEEE Position, Location & Navigation Symposium, 2003. http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=998914, accessed February 11, 2008.
- (10) Sun Microsystems, Inc. “Java Specification Request (JSR) 179: Location API for J2ME™,” <http://jcp.org/en/jsr/detail?id=179>, © Sun Microsystems, Inc. 2007.
- (11) Sun Microsystems, Inc. “Java Specification Request (JSR) 293: Location API 2.0,” <http://jcp.org/en/jsr/detail?id=293>, © Sun Microsystems, Inc 2007.
- (12) S.J. Barbeau, M.A. Labrador, P.L. Winters, R. Pérez, N.L. Georggi (2008), “Location API 2.0 for J2ME – A New Standard in Location for Java-enabled Mobile Phones,” *Computer Communications*. Future online address doi:10.1016/j.comcom.2008.01.045.
- (13) Open Mobile Alliance (OMA) Location Working Group. “TS 101 - Mobile Location Protocol Specification – Version 3.0.0,” <http://www.openmobilealliance.org/tech/affiliates/lif/lifindex.html>, © 2007 Open Mobile Alliance Ltd.
- (14) The Parlay Group. “Parlay/OSA Specifications,” <http://www.parlay.org/en/specifications/>, © Parlay 2007.
- (15) Sun Microsystems, Inc. “JSR118: Mobile Information Device Profile 2.0,” <http://jcp.org/en/jsr/detail?id=118>.
- (16) Information Sciences Institute (1981) “Request for Comments (RFC) 793 – Transmission Control Protocol DARPA Internet Program Protocol Specification,” Information Sciences Institute.
- (17) Postel, J. (1980) “Request for Comments (RFC) 768 – The User Datagram Protocol.”
- (18) Sun Microsystems, Inc. “JSR172: J2ME Web Services Specification,” <http://jcp.org/en/jsr/detail?id=172>, accessed February 11, 2008
- (19) Abraham, Charles and van Diggelen, Frank (2001) “Indoor GPS: The No-Chip Challenge,” *GPS World*, September 1, 2001.
- (20) Sun Microsystems, Inc. “JSR271: Mobile Information Device Profile 3,” <http://jcp.org/en/jsr/detail?id=271>, © 1995-2008 Sun Microsystems, Inc.
- (21) Sun Microsystems, Inc. “GlassFish – Open Source Application Server,” <https://glassfish.dev.java.net/>, © 1995-2007 Sun Microsystems, Inc., accessed February 11, 2008.
- (22) JBoss. “JBoss Application Server,” <http://labs.jboss.com/jbossas/>, © Red Hat Middleware, LLC., accessed February 11, 2008.

- (23) Sun Microsystems, Inc. "Sun Java System Application Server – Downloads," <http://developers.sun.com/appserver/downloads/index.jsp>, © 1994-2008 Sun Microsystems, Inc., accessed February 11, 2008.
- (24) BEA Systems, Inc. "BEA WebLogic Server 10," <http://www.bea.com/framework.jsp?CNT=index.htm&FP=/content/products/weblogic/server/>, © 2008 BEA Systems, Inc., accessed February 11, 2008.
- (25) IBM. "WebSphere Application Server," http://www-306.ibm.com/software/webservers/appserv/was/index.html?S_TACT=103BGW01&S_CMP=campaign, © IBM Corporation 1994, 2007, accessed February 11, 2008.
- (26) Sun Microsystems, Inc. "Java Platform, Enterprise Edition 5 (Java EE 5)," © 1994-2008 Sun Microsystems, Inc., accessed February 11, 2008.
- (27) Sun Microsystems, Inc. "JSR 139 – Connected Limited Device Configuration," <http://java.sun.com/javame/reference/apis/jsr139/>, © 2006 Sun Microsystem, Inc.
- (28) Barbeau, Labrador, Winters, Perez and Georggi (2006) "A General Architecture in Support of Interactive, Multimedia, Location-based Mobile Applications", IEEE Communications Magazine, Vol. 44, No. 11, pp. 156-163.
- (29) Sun Microsystems, Inc. "JSR 218 – Connected Device Configuration," <http://java.sun.com/javame/reference/apis/jsr218/>, © 2006 Sun Microsystem, Inc.
- (30) Sun Microsystems, Inc. "Next Generation Crypto," <http://research.sun.com/projects/crypto/>, accessed February 11, 2008. © 1994-2008 Sun Microsystems, Inc.
- (31) Gonzalez, P., Weinstein, J., Barbeau, S., Labrador, M., Winters, P., Georggi, N., Perez, R. (2008), "Automating Mode Detection Using Neural Networks and Assisted GPS Data Collected Using GPS-enabled Mobile Phones," 15th World Congress on Intelligent Transportation Systems, New York, New York, November 16-20, 2008.
- (32) Wolf, J., R. Guensler and W. Bachman (2001), "Elimination of the Travel Diary: An Experiment to Derive Trip Purpose from GPS Travel Data," Transportation Research Record 1768, p. 125-134. Transportation Research Board.
- (33) Wolf, J. (2004), "Applications of New Technologies in Travel Surveys," International Conference on Transport Survey Quality and Innovation, Costa Rica, August 2004.
- (34) Draijer, G., Kalfs, N., and Perdok, J. "GPS as a Data Collection Method for Travel Research," Transportation Research Record, 1719, 147-153.
- (35) Casas, Jesse and Carlos Arce; NuStats International (1999) "Trip Reporting in Household Travel Diaries: A Comparison to GPS-Collected Data," 78th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1999.
- (36) David P. Aguilar, Sean J. Barbeau, Miguel A. Labrador, Alfredo Perez, Rafael A. Perez, and Philip L. Winters (2007), "Quantifying the Position Accuracy of Real-time Multi-Modal Transportation Behavior Data Collected using GPS-Enabled Mobile Phones", Transportation Research Record: Journal of the Transportation Research Board, No. 1992, pp. 54-60.
- (37) CTIA – The Wireless Association. <http://www.ctia.org/>, accessed February 11, 2008.
- (38) Fram, Alan (2007), "Trend sees cell phone only use growing," USA Today. © 2007 The Associated Press.
- (39) Sean J. Barbeau, Miguel A. Labrador, Alfredo Perez, Philip Winters, Nevine Georggi, David Aguilar, Rafael Perez. "Dynamic Management of Real-Time Location Data on GPS-enabled Mobile Phones," UBICOMM 2008 – The Second International Conference on Mobile Ubiquitous Computing, Systems, Services, and Technologies, Valencia, Spain, September 29 – October 4, 2008.
- (40) Murakami, E., Wagner, D. P., Neumeister, D. M. (1997) "Using Global Positioning Systems and Personal Digital Assistants for Personal Travel Surveys in the United States," International Conference on Transport Survey Quality and Innovation, Grainau, Germany. http://gulliver.trb.org/publications/circulars/ec008/session_b.pdf, July 2004.

- (41) Sean J. Barbeau, Miguel A. Labrador, Philip L. Winters, Rafael Perez, Nevine Labib Georggi. "Trac-It - A 'Smart' User Interface For A Real-Time, Location-Aware, Multimodal Transportation Survey," 15th World Congress on Intelligent Transportation Systems, New York, New York, November 16-20, 2008.
- (42) Narin Persad-Maharaj, Sean J. Barbeau, Miguel A. Labrador, Philip L. Winters, Rafael Perez, Nevine Labib Georggi. "Real-time Travel Path Prediction using GPS-enabled Mobile Phones," 15th World Congress on Intelligent Transportation Systems, New York, New York, November 16-20, 2008.
- (43) R. T. Fielding (2000), "Architectural Styles and the Design of Network-based Software Architectures," Ph.D. Dissertation, © Roy Thomas Fielding, 2000, University of California, Irvine, retrieved on May 28, 2008, URL: <http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm>
- (44) Winters, Philip, Barbeau, Sean, and Georggi, Nevine , (2008). "Smart Phone Applications to Influence Travel Behavior (TRAC-IT Phase 3)". National Center for Transit Research, University of South Florida. Florida Department of Transportation. <http://www.nctr.usf.edu/pdf/77709.pdf> (accessed June 26, 2008).
- (45) O'Fallon, Carolyn, and Charles Sullivan. Personalized Marketing – Improving Evaluation. 26th Australasian Transport Research Forum. Wellington, New Zealand. 1-3 October 2003.
- (46) Richardson, A.J., Ampt, E.S. and Meyburg, A.H.. Survey Methods for Transport Planning. Eucalyptus Press. Melbourne, 1995
- (47) Cleland, F. and Philip L. Winters. "Reducing Vehicle Trips And Vehicle Miles Of Travel Through Customized Travel Options," Center for Urban Transportation Research. University of South Florida. Tampa, Florida, 1999
- (48) Shrank, David and Timothy Lomax. "The 2007 Urban Mobility Report". Texas Transportation Institute. The Texas A&M University System. College Station, Texas. September 2007.
- (49) Department for Transport. "Making Personal Travel Planning Work: Research Report". London. 2007
- (50) Brög, Werner, Erhard Erl and Nicola Mense. "Individualised Marketing Changing Travel Behaviour for a better Environment" Paper presented at the OECD Workshop: Environmentally Sustainable Transport. Socialdata. Berlin, 05./06.12 2002

LIST OF TABLES AND FIGURES (in order of appearance in text)

FIGURE 1 – TRAC-IT Software Architecture.

FIGURE 2 - TRAC-IT User Interface Diagram for Active Survey Data Collection.

FIGURE 3 – Communication Protocol Between Mobile Device and Server in TRAC-IT Distributed Software Architecture.

FIGURE 4 - Sample GPS Data Collected using TRAC-IT System.

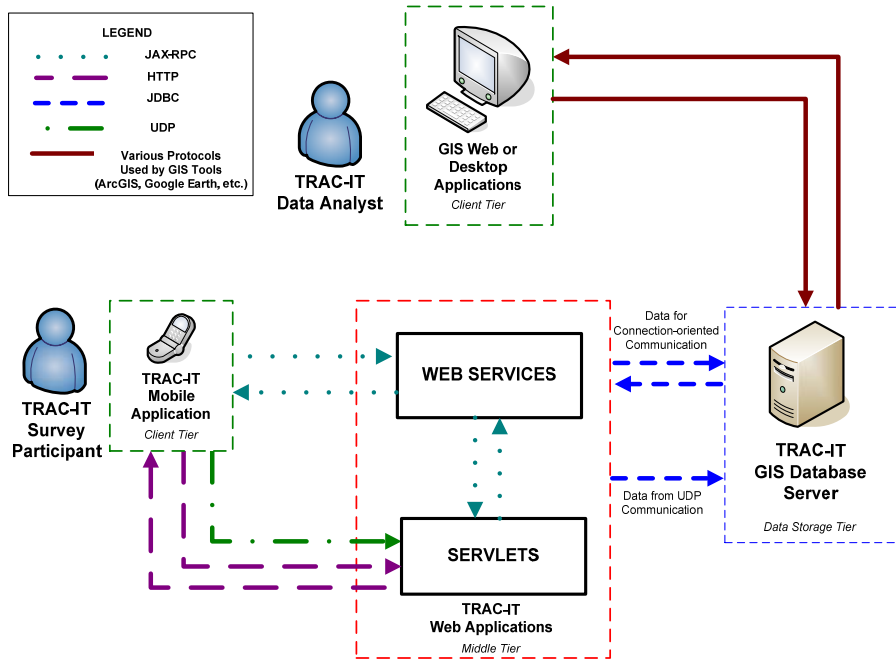


FIGURE 1 – TRAC-IT Software Architecture.

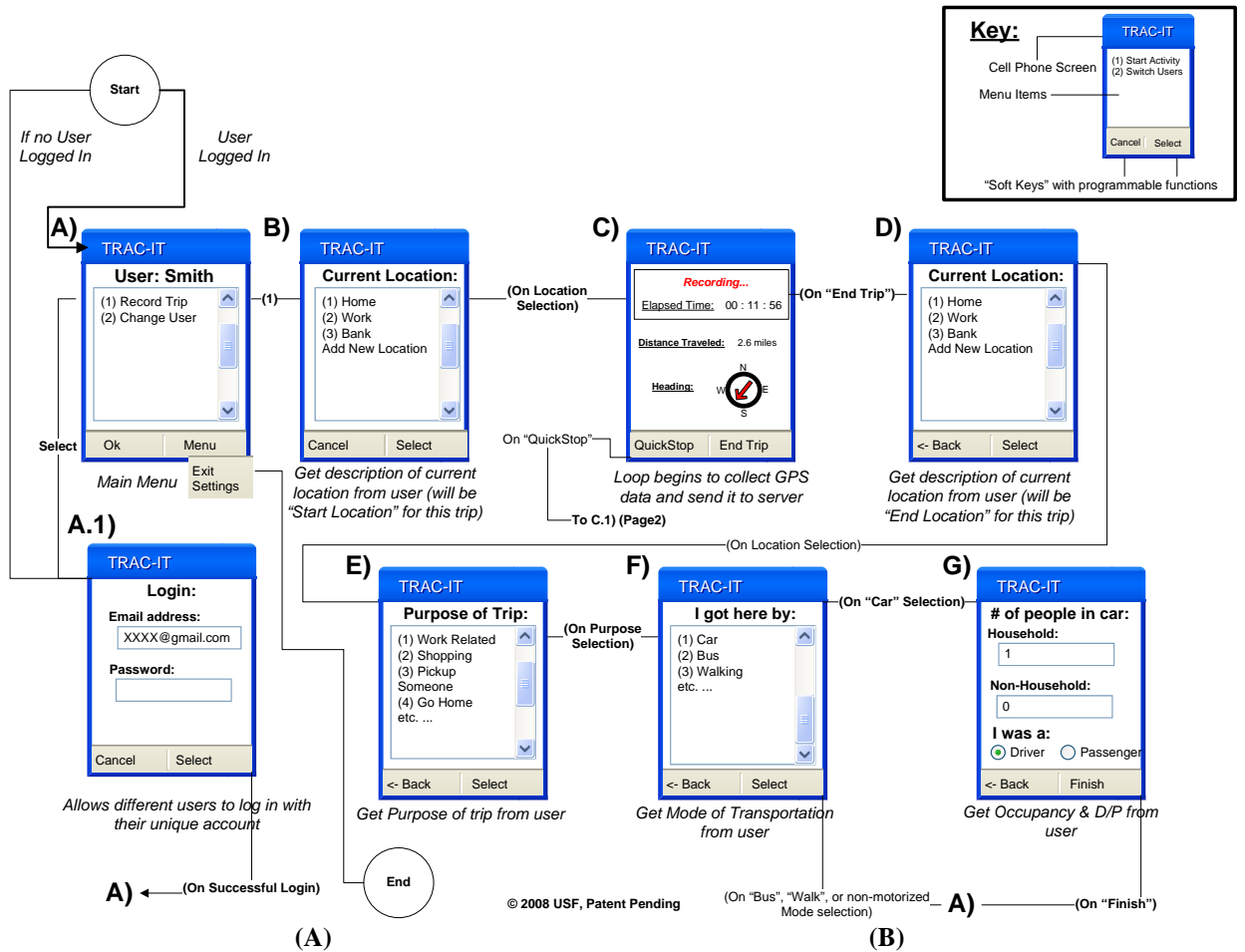


FIGURE 2 – TRAC-IT User Interface Diagram for Active Survey Data Collection.

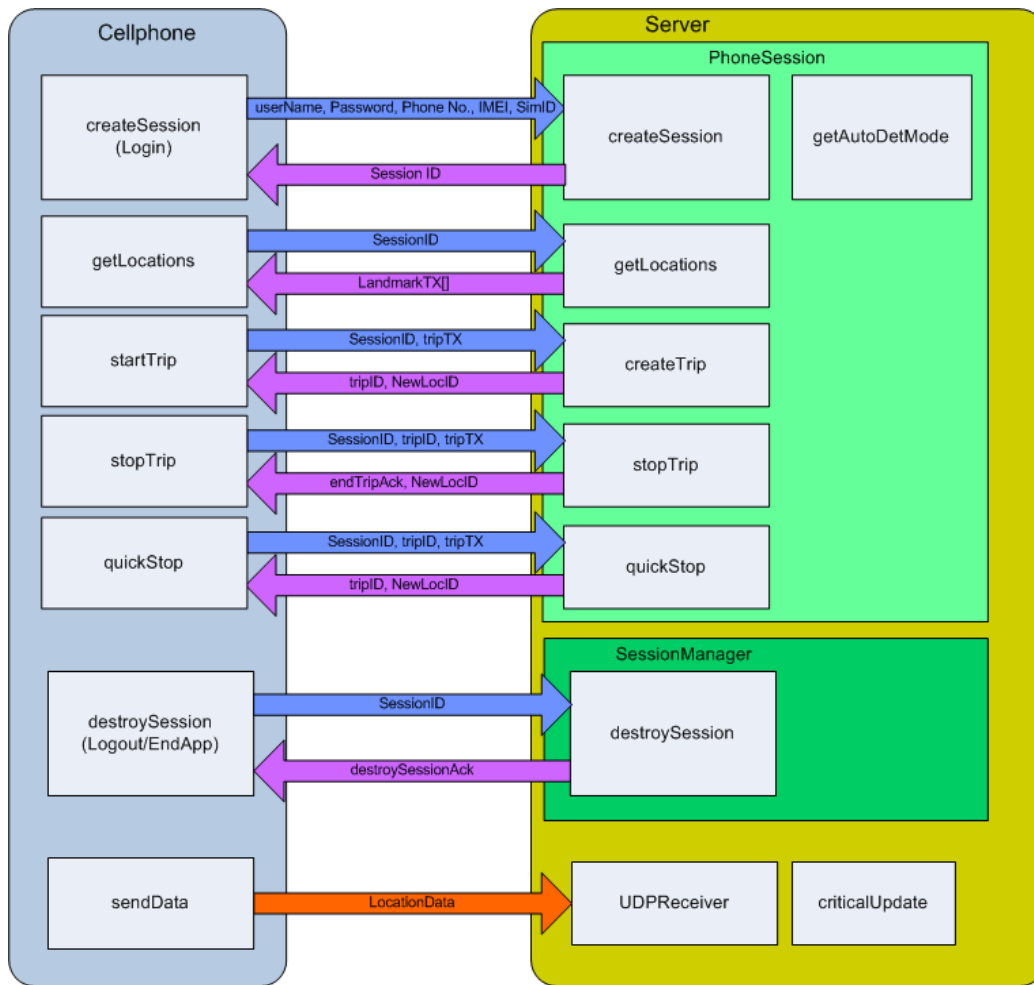


FIGURE 3 – Protocol for Remote Procedure Calls used in TRAC-IT Distributed Software Architecture.

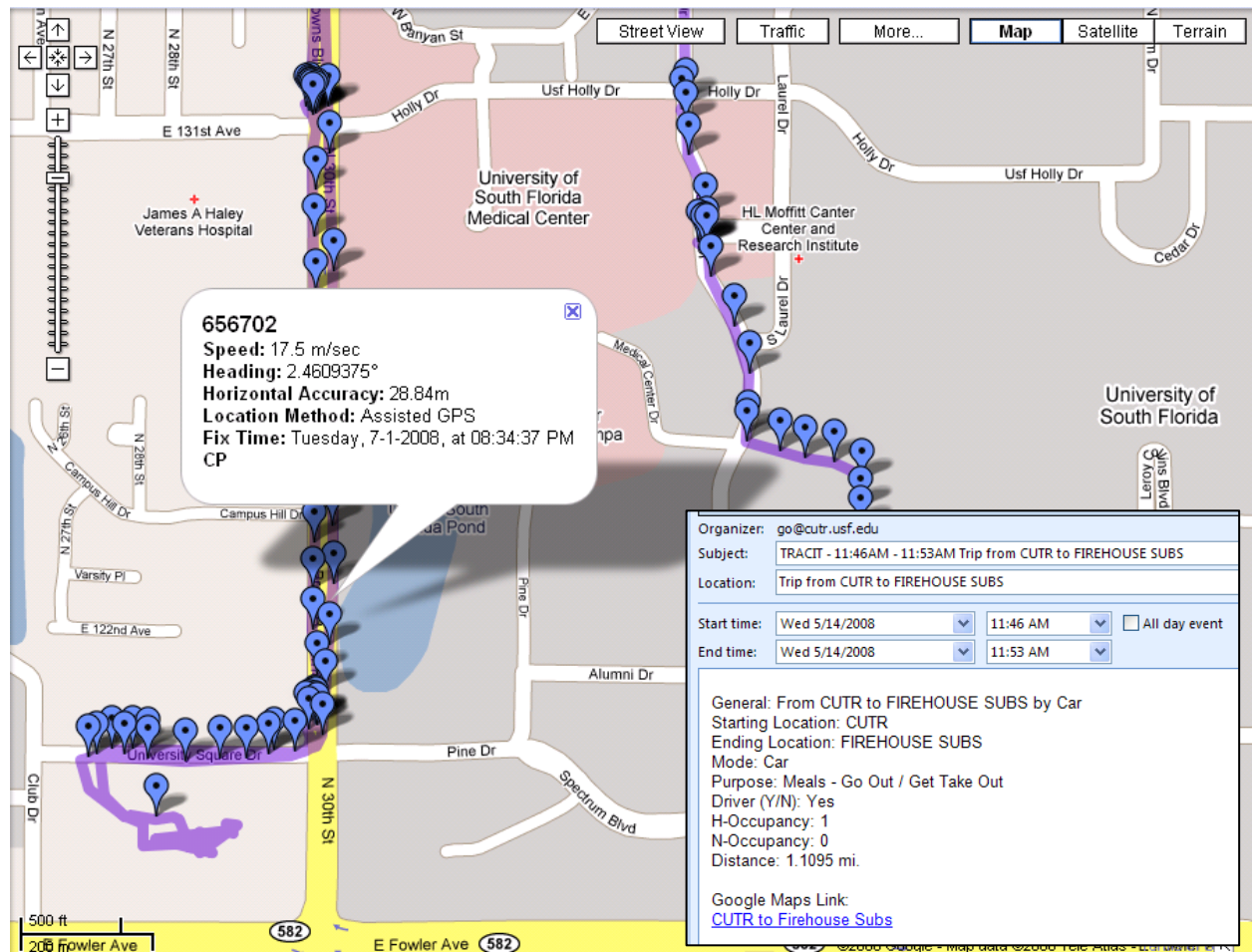


FIGURE 4 – Sample Trip and GPS Data Collected using TRAC-IT System.