TRAC-IT: A SMART USER INTERFACE FOR A REAL-TIME LOCATION-AWARE MULTIMODAL SURVEY TOOL

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ABSTRACT

Transportation professionals strive to gain a deeper understanding of household travel behavior patterns for the purposes of modeling, planning, and maintaining transportation systems. Decision-makers also strive to utilize these patterns for educating, promoting and encouraging the use of alternatives to driving in general and to driving alone in particular. This paper focuses on using innovative technology in travel data collection. The ubiquity of portable devices, such as mobile phones and personal digital assistants (PDAs) in today's world, provides opportunities to revolutionize travel surveys. In the past, data have been obtained through labor intensive paper and/or telephone interviews then input into computers for analyses. While mobile devices can be utilized as modern survey replacements, the requirement of constant user interaction presents many challenges. This paper discusses the design and field tests of TRAC-IT, a smart application for mobile devices that interrelates real-time user input with global positioning system (GPS) data, while adapting to user behavior to create a comprehensive tool that improves the quality and quantity of collected data. Initial limited field tests show a mean of 6.2 reported daily trips per individual. More comprehensive travel behavior data are anticipated when TRAC-IT is used by a larger number of households for longer durations.

INTRODUCTION

Transportation systems in the United States and the world provide the life line for economic prosperity. With rising fuel costs and increasing demand on transportation systems, intelligent solutions that increase capacity and efficiency without adding more lanes are now being sought more than ever. Transportation Demand Management (TDM) professionals are dedicated to the promotion of alternatives to driving in general and in particular to driving alone. In addition to alleviating demand on transportation systems, travel options provide better traffic flow, air quality, and mobility while reducing stress and saving time. It is therefore vital for transportation professionals to study human travel behavior and find effective methods of encouraging commuters to change their behavior *(1)*. Quantity and quality of collected data is important to analyze trip characteristics including start and end times, duration, distance, origin,

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destination, purpose, and mode *(2), (3), (4), and (5)*. Travel surveys are typically completed by self-reporting trips on paper and/or telephone interviews then input into computers by trained interviewers. These types of surveys have several intrinsic problems but for lack of better options are still being used. First, the amount of time and effort required to accurately complete a travel survey is significant. The burden on the respondent may be as long as 20 minutes for self-reporting in a diary for trips completed on the same or previous day. For household reporting, more than one hour is required to answer telephone interviews requiring participants to recall the specific details of trips completed on previous days *(1), (3), and (5)*. Recruiting participants for a one to two day survey is challenging due to the undue burden placed on respondents. This often makes the ideally-recommended longitudinal set of surveys, designed to gather information at multiple points in time, rather challenging due to participant's fatigue over time *(1), (4), and (5)*. Second, the desired level of detail and accuracy are impeded by poor self-reporting, user error, and apathy *(4), (5)*. Finally, once the surveys are collected, they must be manually processed, thus requiring a significant amount of time and effort with more opportunities for human error.

In recent years, modern computing devices such as PDAs and GPS have been successfully tested as in-vehicle replacements for paper and telephone surveys *(1), (4), and (5)*. With a PDA and a GPS device, data such as the exact physical location and time are automatically collected thus reducing some of the participant's burden. A few pieces of information such as trip purpose and vehicle occupancy remain to be provided by the participants since electronic devices cannot intuitively report them. Researchers can use the more accurate data collected with a GPS device confidently versus data collected by a paper diary or phone interview *(4), (5)*. However, these vehicle-based systems have limitations. First, these surveys track vehicles and not persons, which leaves the assessment of individual or household travel behavior open to interpretation *(4), (5)*. Second, since no real-time communication with the device is available, the data collection and processing tasks still require manual manipulation even when in an electronic format *(1), (4), and (5)*.

As mobile technology has progressed and powering requirements have improved, GPS-enabled PDAs and mobile phones have entered the commercial market. These devices have GPS and wireless communication technology integrated into a single mobile device. Carried by an individual for any amount of time, such devices record an accurate comprehensive representation of trips made by any mode of transportation including public transit or non-motorized modes (walking or biking) *(6)*. These systems also provide real-time data communication with external sources including the transfer of collected data back to a central database which can lend to extended deployment of the survey. All of the functions of an electronic travel survey tool have the potential to increase both the quality and quantity of data collected. However, the omnipresent, real-time nature of PDAs and cell phones introduces challenges that have not been present in past surveys. If the user is going to interact with the survey system throughout the day, each interaction must be streamlined to take as little time as possible. If the survey is too time-consuming or difficult, it runs the risk of being subject to the same vulnerabilities associated with paper and phone surveys. The result is mainly frustrating volunteers to apathy or dropping out of the survey. The real-time interface for the survey must be brief and succinct, yet capture useful data including trip purpose, vehicle occupancy, and transportation mode. It must take advantage of any information automatically gleaned from its environment to predict user input whenever possible to reduce the number of entries required from the user and increase the accuracy of recorded information. This paper describes TRAC-IT, a smart application for mobile devices that relates real-time user input with GPS data while learning and adapting to user behavior to create a comprehensive, accurate tool that improves the quality and quantity of collected data. The paper details the TRAC-IT system architecture as it impacts the requirements of the user interface design and discusses the unique smart features of the diary, including an intelligent, location-aware, interactive system with the ability to learn a user's behavior and continuously reduce participant effort required as more input is provided. The user interface screens as related to the electronic survey design are also presented. The initial field tests and findings of TRAC-IT are discussed in the paper.

TRAC-IT SYSTEM ARCHITECTURE AND USER INTERFACE REQUIREMENTS

The TRAC-IT system utilizes data collection clients, the commercially available GPS-enabled mobile devices such as PDAs or mobile phones. These devices can run third-party software and support real-time data communication. In addition to selected mobile devices, a server is present in the system architecture and runs applications that receive data from the devices, store the data in the server's database, and provide other processor or resource intensive operations such as Geographic Information Systems (GIS) analysis. Many of the principles discussed in this paper have also been applied to a mobile phone implementation of TRAC-IT since it is compatible with both PDAs and mobile phones. However, this paper focuses on the challenges encountered with the design of the client user interface for the PDA.

The TRAC-IT system provides more than a simple data collection mechanism. TRAC-IT can also analyze user behavior and provide personalized feedback to each individual using an expert system on the TRAC-IT server. This feedback includes the amount of money spent on gas during the week, the number and duration of trips, miles driven by vehicles, and suggestions to use alternative transportation options tailored to meet the household mobility needs. TDM techniques focus on informing the user of his or her current behavior and suggesting alternatives that might save time and money or alleviate traffic congestion *(3), (7).* While a detailed description of the Expert System is outside of the scope of this paper, the design of the user interface must record transportation behavior in a format that is understandable to the user when relayed to him or her at a later date.

TRAC-IT also automates data entry when possible. Several prototype algorithms are utilized that automatically determine data that a user would otherwise have to manually input such as trip purpose or mode of transportation. Therefore, the TRAC-IT user interface is also used as a verification mechanism for testing these algorithms. Ideally, manual input will be completely eliminated once these algorithms are refined to a very high accuracy. With these concepts in mind, TRAC-IT was created to advance the state of transportation behavior data collection technology, as well as develop a prototype for automating TDM feedback techniques.

The custom software developed for the PDA consists of several program modules:

- a graphical user interface (GUI) to obtain information from the individual traveler
- a GPS processing module that receives and analyzes GPS data
- a local relational Structure Query Language (SQL) database
- a central database synchronization module

The following section focuses on the GUI component of TRAC-IT, although other software modules are discussed when relevant.

FEATURES OF A SMART GRAPHIC USER INTERFACE

A basic flowchart of the GUI is shown in Figure 1. The custom software, TRAC-IT, was designed to guide the user through the data entry process via wizards (interactive screens that provide step-by-step instructions). These wizards collect trip information from the user that cannot be automatically determined from GPS data alone with 100 percent accuracy, including a description of the location visited, mode of transportation taken, purpose of the trip, and the occupancy of the vehicle.

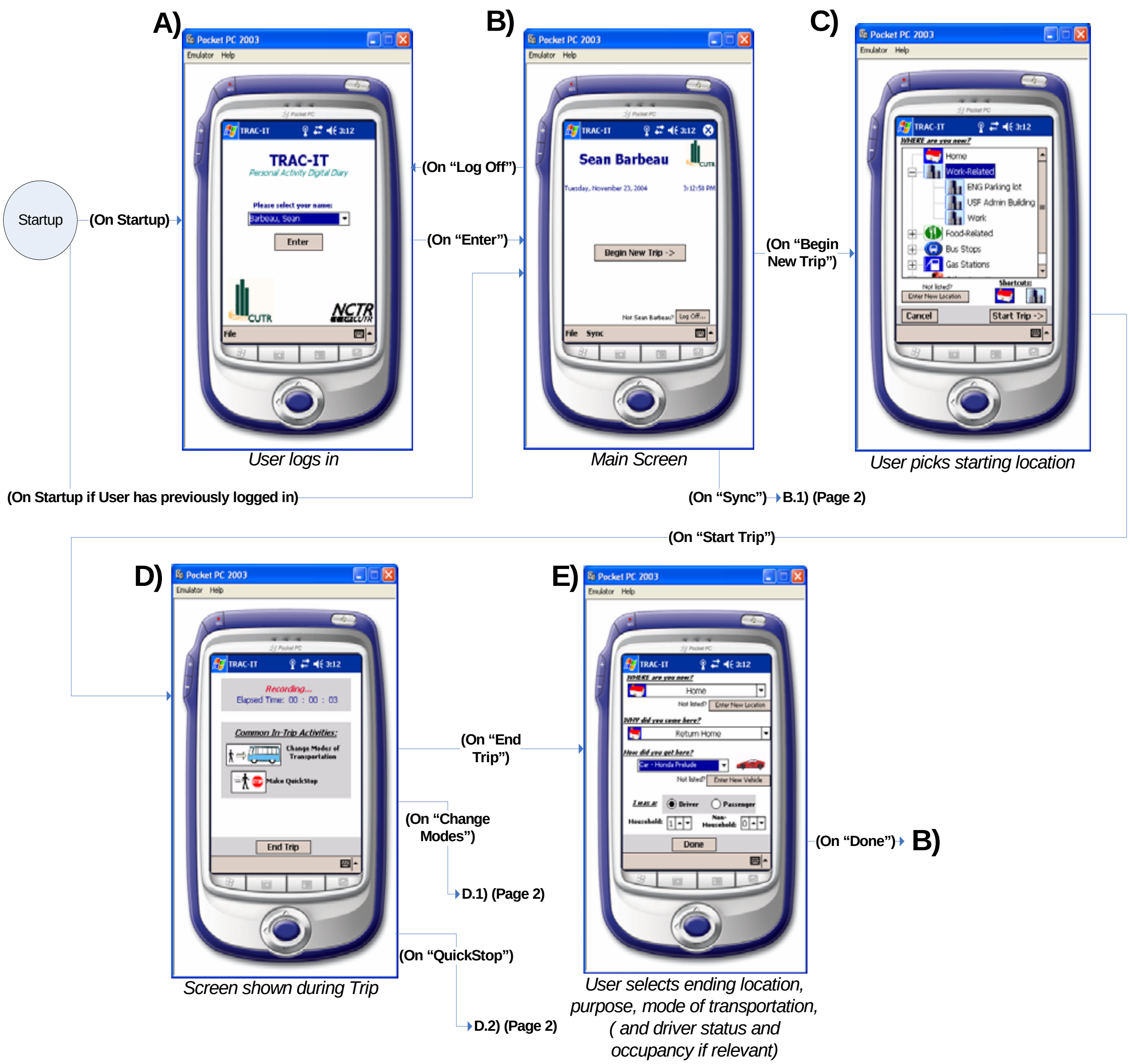

Figure 1 – TRAC-IT User Interface - Primary Screens

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The following list of trip purposes, used for TRAC-IT system design, is based on the National Household Travel Survey (NHTS) Glossary's definition of trip purposes *(8), (9)*:

1) Work
2) School or Religious
    - Go to school
    - Go to a religious activity
    - Go to the library: school related
3) Medical or Dental
4) Shopping and Errands
    - Buy goods: groceries, clothing, house needs, gardening needs, etc.
    - Buy services: post office, bank
    - Car services: pump gas, car maintenance
    - Personal or family business
    - Pick up or drop off an item: dry cleaners, video rental, etc.
5) Social and Recreational
    - Go to the gym, exercise, play sports, etc.
    - Rest, relaxation, or vacation
    - Visit friends or family
    - Go out: entertainment, theater, sports event, bar, etc.
    - Visit public place: historical site, museum, park, etc.
6) Transportation of Someone or Myself
    - Pickup someone
    - Take and wait for someone
    - Drop someone off
    - Change mode of transportation (go to train station, bus stop)
7) Meals
    - Go out to eat (restaurant, fast food)
    - To go (fast food, coffee, restaurant takeout)
8) Return home
9) Other

Trip start and end times, travel path, speed, and course heading are automatically recorded using GPS and do not have to be entered by the user. During the GUI design process, it was determined that the final design should contain as few screens as possible to avoid extensive user input and time spent switching between screens. Initial prototype evaluation showed that user fatigue quickly becomes an important issue and can deter the use of the system for data collection. Therefore, the main flow of application execution was designed to consist of three main screens: Pre-Trip, During Trip, and Post-Trip. These components can be seen in Figure 1 with screen A which provides log-on and log-off user options.

In addition to providing a guide to the user for data entry, TRAC-IT also acts as a Smart Diary, performing advanced real-time data processing and analysis to reduce the burden of user data entry. Each trip, which the user records along with associated locations and modes of transportation, is stored in a database on the PDA. These data are then referenced during future trips, preventing the user from manually entering the same information about his or her travel behavior. For example, when he or she travels to the grocery store for the first time while carrying the device, the user enters a short description of the location (e.g., Publix 56th Street) and classifies the type of location (e.g., food-related, work-related, gas station, bus stops, etc.). On future visits to the same location, the user can select this location from a drop-down menu instead of re-entering the trip location and purpose. The classification of the location type expedites the manual selection of locations since they are logically grouped by the activities that the user performs at that location. Identifying the specific location by name/type (not just by GPS coordinates) and referring to the same location in future trips will allow for further detailed analysis of repeated trip patterns to the same location. At certain locations, such as malls, it is important for the user to define by name his or her actual destination since the geographic location and address derived from GPS data via reverse-geocoding can be tied to several businesses at the same place. The classification of location type also aids in automatic processing of the data as it defines specific types of locations that are clearly categorized, as opposed to the many possible user descriptions of the same location (e.g., Publix vs. grocery store vs. my work vs. store). If the user does not enter a classification, the system will attempt to assign a classification based on the purpose that the user chose for visiting that location (e.g., a location will be marked as work-related if the purpose for visiting the location is work/work-related). For the Expert System, it is also vital to deliver trip feedback to the user that describes the locations in his or her own words since the latitude and longitude or even street address of the location will likely be unfamiliar to the user. The location classification feature allows the Expert System to easily identify location types and generate feedback based on the location category.

Similar concepts of user-defined descriptions apply to the modes of transportation that the individual uses. When first traveling by a new mode, the user can enter a short description of the mode such as Bob's Toyota, Bus Route A, or Red Bike and classify the type of mode (e.g., walk, bus, bike, truck, or car). As with locations, the mode can then be referenced during future trips to precisely define how the person traveled to his or her current location and establish patterns of travel by specific modes even to a specific household vehicle or bus route. These mode classifications aid the Expert System in applying mode-specific rules.

Perhaps the most significant feature of the Smart Diary is that the survey software is location-, user-, and time-aware. These features can be leveraged to further reduce the user's burden by implementing a significant amount of survey automation tailored to the current device user. Sample automation includes a location-stamping mechanism that tags the user's locations with GPS coordinates the first time a location is visited. At the beginning and end of subsequent trips, TRAC-IT performs real-time calculations that compare a list of the geographic position of the user's stored locations to the user's current GPS position. TRAC-IT automatically fills in the Current Location field with the closest location that is within a certain threshold distance (e.g., 20 meters) of the current position. If the location was correctly identified, the user can proceed to the next survey field without recording (keying in) additional information. If TRAC-IT selected an incorrect location, the user can key in the correct one. This pre-fill feature enables the user to verify that the information is correct before continuing and does not force manual selection of the same information repeatedly. The threshold can be raised or lowered based on the accuracy of the GPS receiver to an acceptable value that does not trigger a large number of false-positive location identifications but still provides a significant reduction in efforts by user.

The user's mode of transportation can also be identified based primarily on the speed detected during the last trip. Once the user reaches his or her destination, TRAC-IT examines the travel data and eliminates certain modes that are not probable, given the detected maximum speed during the trip. For example, if the top speed is 60 miles per hour, any modes of type *Walk and Bike* can be eliminated from consideration. Current research continues to evaluate mode detection algorithms that have shown high success rates.

The *Purpose* field is pre-filled based mostly on the classification of the location selected as the *Current Location* pre-fill. For example, if the location is Work-Related, then the Work/Work-Related purpose is selected. If the location is of the type *Home*, then the *Return Home* purpose is selected.

If unassisted GPS is utilized, or if the user is in an environment such as a parking garage where GPS may not be available, it may not be possible to obtain a GPS fix when the user starts the trip recording process. If GPS is not available, other methods of pre-filling fields can be triggered. Pattern recognition techniques are used to identify the most likely type of travel based on the behavior history stored in the PDA for that particular user. A simple method is to recall the last visited location when the user begins a new trip and fill the *Current Location* field with this last location. This way, if the user is carrying the PDA at all times, the *Current Location* field always will be filled with the correct information. For example, if the person travels to work in the morning and he or she begins the trip in the afternoon to return home, the current location will be selected as Work.

Other more sophisticated methods perform data analysis based on the time of day and day of week that the trip is taking place. This system learns as the person makes trips and provides pre-filled data that are more accurate over time. For example, the first time the user records a trip; it may begin at 5:00pm and end at 5:30pm from *Work to Home* with the purpose of *Return Home*. The next day, if the person takes a trip around 5pm and arrives at his or her destination at 5:28pm, TRAC-IT will automatically select the *Return Home* purpose. After the user records trips for a week, TRAC-IT will take into consideration the day of the week when pre-filling the purpose. For example, if the user goes home from work on Tuesday and Thursdays but on Mondays, Wednesdays, and Fridays goes to the gym before returning home; the purpose of *Return Home* will be selected for a trip completed after leaving work on a Thursday. However, if he or she leaves work and arrives at the destination on a Wednesday, the purpose *Go to Gym/ Exercise/Play Sports* will be selected.

If desired, this pattern detection could be extended to include specific months as well to create seasonal predictions of travel purposes. Each time the purpose pre-fill algorithm is executed, it takes into account all the data collected for that particular user up to the current date. TRAC-IT is able to predict trip purposes with more accuracy the longer it is carried by the participant. However, if GPS data are available, it will be utilized instead of pattern recognition techniques since knowledge of the real-time position of the user is used to detect nearby locations which have an associated purpose.

USER INTERFACE FLOW – THE FORMAT OF ELECTRONIC TRAVEL SURVEYS

Aside from the significant advantages associated with the electronic Smart Diary, an important characteristic that differentiates the paper diary format from this system is the method by which the user is prompted to create diary entries. In the paper format, the user is asked to recall what activity he or she performed in a retrospective manner hours or even days after the trip was made. Trips are sometimes forgotten or inaccurately reported. Research has shown that participants in travel surveys tend to round times and distances when recalling a daily trip schedule from memory *(4), (5).* However, GPS data recorded on the same day show that arrival/departure times and traveled distances are more evenly distributed than remembered by participant *(4), (5).* These data suggest that GPS-based diaries recorded in real-time are significantly more accurate than paper- or telephone-based surveys that rely on the recollection by participants. If location information is inadvertently misreported, other user-reported information associated with the trip regarding mode, occupancy, and trip purpose may compound more of the same inaccuracies. It is therefore very important when creating an effective survey instrument to prompt the user for trip information in real-time.

Figure 2 - Quick Stop feature - This screen is shown when a user chooses to perform a brief stop, such as buying gas or fast food. It is accessed from screen "D" in Figure 1.

One of the primary design choices for the user interface involves the placement of trip purpose and the trip destination prompts. An initial GUI prototype was formatted to ask the user to provide a planned destination and a trip purpose in addition to his or her current location when a trip began. A preset feature was made available in which the user can define frequently taken trips with a fixed source and destination, such as *Work to Home* then select this pre-set option at the beginning of the trip. However, this format proved to be functionally inadequate as many users did not follow their planned itinerary, even when defined in real-time at the beginning of the trip. For example, when traveling from *Work to Home* with the purpose of *Return Home*, several users actually stopped at an intermediate location, such as the grocery store or gas station before reaching the *Home* location. Even though a user may view this as one trip with the purpose of *Return Home*, it should actually be recorded as two separate trips with the first purpose as *Shopping and Errands* and the second as *Return Home*. This concept of trip segmentation with unique destinations within a longer trip with separate purposes is referred to as trip chaining. Trip chains are usually anchored by home or work locations *(10).* The original GUI prototype format either failed to record the intermediate locations or required the user to review and correct the original purpose and planned destination. This problem has been experienced in other GPS-based surveys and is a disadvantage to using a prospective diary format *(4), (5).* Since some research suggests that up to 30 percent of trips are complex chains that contain more than one intermediate stop, then asking the user to review and correct almost one third of his or her trips would have been extremely taxing on participants *(10), (11).* These corrections essentially doubled the effort required by the user for reporting any trips in a chain. Therefore, the GUI was modified as follows to include a "Quick Stop" feature, as shown in Figure 2:

- Upon beginning a trip, the user is asked to select only his or her current location. After selecting the current location, the user clicks on <Begin New Trip>. The timer then begins to count the time elapsed during the current trip. The user is given three options to choose from when the user reaches his or her next stop: <End Trip>, <Make Quick Stop>, and <Change Modes of Transportation>.
- If the user selects <End Trip>, he or she is asked to select his or her current location, purpose for coming to the location, and his or her mode of transportation. When the user selects <Done>, the trip is saved with the original source location and the recently entered data.
- If the user selects <Quick Stop>, the user is asked to identify his or her current location, purpose for coming to the location, and his or her mode of transportation. However, instead of returning to the main menu screen when the user completes the form, the user is redirected to the recording screen again. The collected trip data is recorded in the local database with two primary differences from the <End Trip> option. Both differences are transparent to the user. First, the recently completed trip is identified as a link in a new trip chain. Secondly, a second trip is created with the starting location of the current position (i.e., the end location of the recently completed trip), and with the destination location, mode, and purpose defined once the user chooses to end the trip or make another quick stop. Using this method, multiple trip links can be recorded sequentially without the user entering duplicate information for the destination of one link and the source of the next. All subsequent trips, including the trip for which the user finally chooses End Trip, are identified as links in the trip chain.
- If the user selects <Change Modes of Transportation>, the <Quick Stop> protocol is followed. The sole difference is that the user is not prompted for the trip purpose because it is already known that the trip purpose is to <Change Modes of Transportation>.

The <Quick Stop> feature gives the user the flexibility to automatically redefine trip parameters in real-time without being burdened with the task of low-level information manipulation. Additionally, when crossing between two modes of transportation, a user can quickly identify his or her new mode without going through the process of ending one trip and beginning another. This diary format can be considered real-time, immediate, and retrospective implementation. Ideally, this format avoids the memory failure issues involved with the long-term retrospective diaries, while preventing duplicate user effort associated with prospective formats.

The diary format is also important when considering automation field pre-fills, as discussed earlier. The device can provide only an estimate of the user's mode of transportation and pre-fill this field intelligently if it can examine the GPS data from the trip. Therefore, the question related to mode of transportation must be asked after the user chooses to end the trip, as opposed to asking his or her mode before the trip starts. Similarly, the purpose can only be estimated using a post-trip prompt since knowledge of the trip and the current ending location must be available. Therefore, an additional advantage to the real-time retrospective implementation is that it alleviates some of the data entry burden on the participant by allowing such automation.

TRAC-IT FIELD TEST RESULTS

Since the goal of the initial TRAC-IT field test was to ensure that the prototype worked under various data collection scenarios, six participants that utilize different modes of travel and represent varied household dynamics were recruited, including:

- A two-income household – two adults, two-car ownership, and one child under driving age
- A single-income household – one female adult, zero-car ownership
- A single-income household – two adults, one car and one bicycle, and three children under driving age
- A single-income household – two adults, two-car ownership and one child under driving age (trips collected from one household member only)

The TRAC-IT client software was implemented in Visual Basic.NET on a Hewlett Packard (HP) iPAQ 6315 PDA. Since there were no commercially available PDAs with embedded GPS running Microsoft's Windows Mobile Platform at the time of the TRAC-IT field tests, a Navman 4410 GPS receiver was utilized and connected to the PDA via the Bluetooth™ wireless protocol. A server running Microsoft SQL Server software was utilized to permanently store survey data.

Participants carried TRAC-IT for approximately one week. Due to a discharged battery in one of the PDAs, data from one participant was lost before it could be analyzed. Of the five remaining datasets, a total of 229 trips were recorded over a total of 37 survey days, with a mean of 6.2 trips reported per participant per day. In addition to the trip data entered by the user, a total of 36,493 GPS data points were collected representing participant travel path via modes including car, bus, biking, and walking. Comparatively, the 2001 NHTS reported a mean of 4.1 trips per individual per day using data collected by telephone interviews *(12)*. While the TRAC-IT field tests were not fully representative of the general public's travel behavior, the results are encouraging and suggest that TRAC-IT should be tested with a larger population.

A focus group was held with participants after the study completion to obtain qualitative feedback regarding their experience. Overall, participant feedback was positive, with all individuals saying they would volunteer to take the survey again in the future. No one reported any difficulties entering data via the user interface on the PDA. Users found the <Quick Stop> feature useful, although they suggested that examples of <Quick Stop> should be provided in the next orientation session to reduce user anxiety. While the research team intentionally did not give the users any direction regarding the <Quick Stop> feature, all participants in the field test used the feature as expected for tasks such as picking up carry-out food, fueling cars, and picking up passengers. Participants also reported that even with the ease of using TRAC-IT, they occasionally forgot to use it to start a trip or forgot the PDA at home at the beginning of the day. Participants expressed hope that with the development of the next version of TRAC-IT for mobile phone users, the survey tool will be available on their own personal mobile phone and will therefore report a more accurate number of actual trips travelled.

Since the initial TRAC-IT field tests were conducted, several commercially available PDAs with embedded GPS have been released. Future field tests can utilize these devices as the TRAC-IT client instead of combining two separate PDA and GPS devices.

Subsequent research performed for the TRAC-IT project has examined the use of GPS-enabled mobile phones as an all-in-one, low-cost replacement for the GPS-enabled PDA (13). Initial field tests have indicated that a TRAC-IT client implementation in Java Micro Edition (Java ME) can be downloaded and installed on standard, commercially-available mobile phones and successfully utilized to collect both user input and GPS data. However, mobile phone resource limitations require careful implementation of client software that utilizes device functionality with a high impact on battery life only when necessary. For example, intelligent software can be used to increase battery life by dynamically adjusting the GPS position recalculation rate as well as filtering GPS data before it is sent to the server (14). The design of the user interface for a mobile phone is challenging due to the small display area, and real-time field pre-filling techniques as discussed in this paper may be difficult to implement.

CONCLUSION

Highly accurate travel behavior data for multiple modes of transportation can be collected using GPS-enabled mobile phones and PDAs. However, to collect information such as trip purpose and mode that cannot be derived with an extremely high level of accuracy from GPS data, a user interface must be implemented to capture this data. To prevent the electronic trip diary from becoming susceptible to the same burdensome qualities of its paper and phone interview counterparts, the design of the interface must be carefully considered. This paper presents TRAC-IT, a smart application for GPS-enabled mobile devices that learns travel behavior and attempts to reduce the burden on the participant by completing fields with educated guesses based on the current time, location, and past travel history of the current user. In field tests, a total of 229 trips were recorded from five users over a total of 37 survey days, with a mean of 6.2 trips reported per participant, per day. In addition to the trip data entered by the user, a total of 36,493 GPS data points were collected that represent participant travel path via modes including car, bus, biking, and walking. Comparatively, the 2001 NHTS reported a mean of 4.1 trips per individual per day using data collected by phone- and paper-based survey methods. Mobile devices, including GPS-enabled mobile phones appear to be an excellent tool to supplement, and perhaps eventually replace paper- and phone-based travel surveys.

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