California AHMCT Program
University of California at Davis
California Department of Transportation

# SUPPORT FOR BUSINESS CASE DEVELOPMENT FOR THE GPS-AUTOMATED TRAVEL DIARY (GPS-ATD) IN PREPARATION FOR THE 2010 STATEWIDE TRAVEL BEHAVIOR SURVEY – PHASE 1*

Kin S. Yen[1], Travis B. Swanston[1], Phillip W. Wong[1],
Ayalew Adamu[2], Mohammad Assadi[2],
Azzeddine Benouar[3], Bahram Ravani[1], &

Ty A. Lasky[1], Principal Investigator

AHMCT Research Report
UCD-ARR-09-06-30-01

Final Report of Contract IA 65A0210 – Task Order 08-14

June 30, 2009

**Affiliations:**
1. AHMCT Research Center, Department of Mechanical & Aeronautical Engineering, University of California, Davis, CA 95616
2. Caltrans Division of Transportation System Information, 1120 N Street, MS-38, Sacramento, CA 95814
3. Caltrans Division of Research and Innovation, P.O. Box 942873, MS#83, Sacramento, CA 95814

* This report has been prepared in cooperation with the State of California, Business Transportation and Housing Agency, Department of Transportation, and is based on work supported by Contract Number IA 65A0210 – Task Order 08-14 through the Advanced Highway Maintenance and Construction Technology Research Center at the University of California at Davis.

**Technical Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| CA09-1703 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| Support for Business Case Development for the GPS-Automated Travel Diary (GPS-ATD) in Preparation for the 2010 Statewide Travel Behavior Survey – Phase 1 | June 30, 2009 |
| | 6. Performing Organization Code |
| 7. Author(s): K. Yen, T. Swanston, P. Wong, A. Adamu, M. Assadi, A. Benouar, B. Ravani, and T. Lasky | 8. Performing Organization Report No. UCD-ARR-09-06-30-01 |
| 9. Performing Organization Name and Address<br>AHMCT Research Center<br>UCD Dept of Mechanical & Aeronautical Engineering<br>Davis, California 95616-5294 | 10. Work Unit No. (TRAIS) |
| | 11. Contract or Grant<br>IA 65A0210 Task Order 08-14 |
| 12. Sponsoring Agency Name and Address<br>California Department of Transportation<br>Sacramento, CA 95819 | 13. Type of Report and Period Covered<br>Final Report<br>January 2008 - June 2009 |
| | 14. Sponsoring Agency Code<br>Caltrans |

15. Supplementary Notes

16. Abstract

This report provides an overview of the effort to develop business case inputs that allowed Caltrans to quantify the benefits, costs, and impact of the GPS Automated Travel Diary (GPS-ATD) system. The GPS-ATD provides an intuitive user interface to capture trip activity information (trip purpose, travel mode, etc.), with minimal user input and burden during travel surveys. Survey participants interact with their own personal GPS-ATD, and information is automatically captured and logged from the High-Sensitivity GPS (HSGPS) receiver. This data allows for subsequent identification of corridors, route lengths, and regional and inter-regional trips.

Results from the analytical support and editorial review of information in support of Caltrans' development of a Feasibility Study Report (FSR) document are summarized within this document. The report also describes the commercial-off-the-shelf (COTS) hardware and custom software that serves as the current prototype GPS-ATD.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Longitudinal travel surveys, GPS, human-machine interface, HMI, highway maintenance | No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161. |

| 20. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 42 | |

Form DOT F 1700.7 (8-72)
(PF V2.1, 6/30/92)
Reproduction of completed page authorized

# ABSTRACT

This report provides an overview of the effort to develop business case inputs that allowed Caltrans to quantify the benefits, costs, and impact of the GPS Automated Travel Diary (GPS-ATD) system. The GPS-ATD provides an intuitive user interface to capture trip activity information (trip purpose, travel mode, etc.), with minimal user input and burden during travel surveys. Survey participants interact with their own personal GPS-ATD, and information is automatically captured and logged from the High-Sensitivity GPS (HSGPS) receiver. This data allows for subsequent identification of corridors, route lengths, and regional and inter-regional trips.

Results from the analytical support and editorial review of information in support of Caltrans' development of a Feasibility Study Report (FSR) document are summarized within this document. The report also describes the commercial-off-the-shelf (COTS) hardware and custom software that serves as the current prototype GPS-ATD.

# EXECUTIVE SUMMARY

As part of the 2010 Statewide Travelers' Survey, it is fundamentally important that surveys can be carried on for a long duration while maintaining the survey data accuracy and integrity, and yet minimizing the burden on survey respondents. Therefore, a new method is needed for comprehensive, highly-automated and efficient data collection for individual travelers. The survey data are crucial for modeling trip generation, predicting the effects of transportation policy changes, and supporting the decision making process at the Federal, State, county and city level. This project provided analytical and technical support and additional research and deployment efforts of a suitable ATD solution.

As described in the proposal, "Support for Business Case Development for the GPS-Automated Travel Diary (GPS-ATD) in Preparation for the 2010 Statewide Travel Behavior Survey – Phase 1," six main tasks were specified to support the business case input development. This report will documents these project tasks, and provides recommendations for future research and deployment of the GPS-ATD. Briefly, the six main tasks are:

1. *Review technical landscape and available commercial systems*

   The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center will review the state of practice and provide a current assessment to support the discussion and presentation of real alternatives needed for business case analysis.

2. *Evaluate promising existing commercial systems*

   Based on the results of Task 1, AHMCT will procure and test the most promising alternative systems.

3. *Support investigation of synergistic concepts*

   AHMCT will investigate synergistic concepts which will enhance the benefits of a GPS-ATD solution.

4. *Support Caltrans' development of FSR*

   AHMCT will provide inputs for the "Business Case" and "Proposed Solution" sections of the FSR, as well as investigate impact on the IT infrastructure due to introduction of the ATD device.

5. *Summary reporting*

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# DISCLAIMER/DISCLOSURE

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aeronautical Engineering at the University of California – Davis, and the Division of Research and Innovation at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, State and Federal governments and universities.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California, the Federal Highway Administration, or the University of California. This report does not constitute a standard, specification, or regulation.

# LIST OF ACRONYMS AND ABBREVIATIONS

| Acronym | Definition |
|---|---|
| AHMCT | Advanced Highway Maintenance and Construction Technology |
| API | Application Programming Interface |
| BCC | Budget Change Concept |
| BCP | Budget Change Proposal |
| Caltrans | California State Department of Transportation |
| COTS | Commercial-Off-the-Shelf |
| DRI | Division of Research and Innovation |
| FSR | Feasibility Study Report |
| GB | Gigabyte |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| GPS-ATD | GPS-Automated Travel Diary |
| HMI | Human-Machine Interface |
| HSGPS | High-Sensitivity GPS |
| MB | Megabyte |
| MEMS | Micro-Electro-Mechanical Systems |
| MPO | Metropolitan Planning Organization |
| OBD | On-Board Diagnostics |
| OS | Operating System |
| PDA | Personal Digital Assistant |
| RAM | Random Access Memory |
| SDRAM | Synchronous Dynamic Random Access Memory |
| TSI | Transportation System Information |
| TTFF | Time-to-First-Fix |
| UCD | University of California-Davis |
| USB | Universal Serial Bus |
| XML | eXtensible Markup Language |

# ACKNOWLEDGMENTS

The authors thank the California State Department of Transportation for their support; in particular, the guidance and review provided by Dr. Ayalew Adamu, Chief of the Statewide Analysis Branch of the Office of Travel Forecasting and Analysis in the Division of Transportation System Information (TSI) of the California Department of Transportation (Caltrans), and the staff members of the Statewide Travel Analysis Branch and the Statewide Modeling Branch Staffs within TSI. He and his research staff created the idea and wrote specifications for the creation of the Global Positioning System Automated Travel Diary (GPS-ATD). The authors gratefully acknowledge the Division of Research and Innovation (DRI) of Caltrans which has supported this work through the AHMCT Research Center at the University of California-Davis, under contract IA 65A0210 Task Order 08-14, and thank Mr. Azzeddine Benouar in particular. The authors also thank the original GPS-ATD development team in the AHMCT Research Center: Kin Yen, Stephen M. Donecker, Kimball Yan, and Travis Swanston. Finally, the authors thank the current and former Caltrans Division of TSI team members who have supported and guided the GPS-ATD development: Coco Briseno – Division Chief of TSI, Sarah Cheseboro – Chief of the Office of Travel Forecasting and Analysis, Frank Law – Chief of the Statewide Modeling Branch, Mohammad Assadi, Gregory Miyata, Diana Portillo, Soheila Khoii, Leo Gallagher, and Azita Fatemi.

# CHAPTER 1: INTRODUCTION AND BACKGROUND

This chapter provides a brief introduction to traveler surveys, including a quick overview of previous methods of conducting surveys. Finally, a discussion and understanding of the context and need for the GPS-Automated Travel Diary (GPS-ATD) and the related business case inputs will be presented.

## Traveler Surveys

There is a need for finer-grained understanding of traveler behavior than current data collection techniques allow for. Traditional cross-sectional survey methods are coarse and seek to provide traffic measurements for a single point of a road or intersection, thus providing traffic loading at a specific location over time. While this may support conclusions regarding a particular location, it does not address information on traveler behaviors such as trip purpose, trip frequency, schedule, route selection, and speeds used throughout the entire route. A system which can monitor current traveler location, time, speed, and intent is required. From these data, the following planning data can be predicted:

- developing travel demand models and forecasting future demand,
- predicting the number of trips generated by households as a function of demographics, socioeconomics, and location relative to employment and commercial center,
- estimating travel mode choice and traffic volumes on various roads,
- measuring and understanding trends in population behavior,
- assessing the impact of changes in transportation policy or the transportation system,
- predicting emissions from motor vehicles and input for air quality analysis,
- developing activity-based travel demand models for AB-32 / SB-375 analysis and forecasting future demand,
- analyzing travelers' regular activity behaviors at different times and/or locations,
- and calibrating regional models.

Household-level travel surveys collect three categories of data: household information, household member personal information, and travel activity information for a particular day or range of days. Travel diaries are the standard method used to capture participating household travel activity information. Travel diary methods may involve self-administered paper or computer input. However, gathering complete information from travelers has been problematic; the respondents may underreport, have poor recollection or have survey fatigue. This approach is not suited for long-term mobility pattern observations.

The most common use of Global Positioning System (GPS) data collection in travel surveys to date has been to validate and adjust diary-based surveys. However, the passage of California State Senate Bill SB-375 requires regions to develop "Sustainable Community Strategies" and the use of activity-based models. For such models, GPS survey data provides much better travel behavior information as a primary data collection method than diary-based methods.

Previous surveys utilizing GPS receivers have shown great potential. GPS-based surveys are more accurate and minimize the respondent burden. This approach captures route choice, path, and speed profile, information not feasible with other survey methods. GPS travel diaries used in the past may be classified into two types: *interactive* and *passive*. An *interactive* electronic travel diary requires the respondent to interact with the hand-held device to input survey information. This information includes marking trip start and end, trip purpose, cost of trip, and travel mode. A *passive* travel diary requires essentially no interaction from the users, merely turn on or off the device. Other travel information is collected through the traditional paper or voice surveys.

Replacing traditional self-administered paper travel diaries with interactive GPS-enabled travel diaries has shown significant reduction in respondent burden. Additionally, the information gathered via the GPS location data significantly enhances the value of the collected data. Therefore, a GPS-aided interactive travel diary could save both surveyors and respondents time and money both during the data collection effort and data analysis effort.

Previous research conducted by AHMCT[1] has suggested an architecture to integrate GPS data into an Automated Travel Diary (ATD). The research report recommends that the surveys be divided into two phases, as shown in Figure 1: Data Collection and Data Post-Processing. The ATD device that is in the end-user's possession would collect all necessary raw data, but leave further processing for subsequent Agency or contractor data post-processing and analysis. Such a split in data collection and processing responsibilities would minimize the cost, weight, complexity, and power consumption of the end-user's device. Further flexibility would be gained since researchers and analysts may then process and re-process the raw data with various new criteria, methods, and other additional updated information during subsequent post-processing phases.

[1] Development of Vehicular and Personal Longitudinal Travel Diary Systems Using GPS and New Technology, December 31, 2006, Report No. F/CA/IR200645, UCD-ARR-06-12-31-01

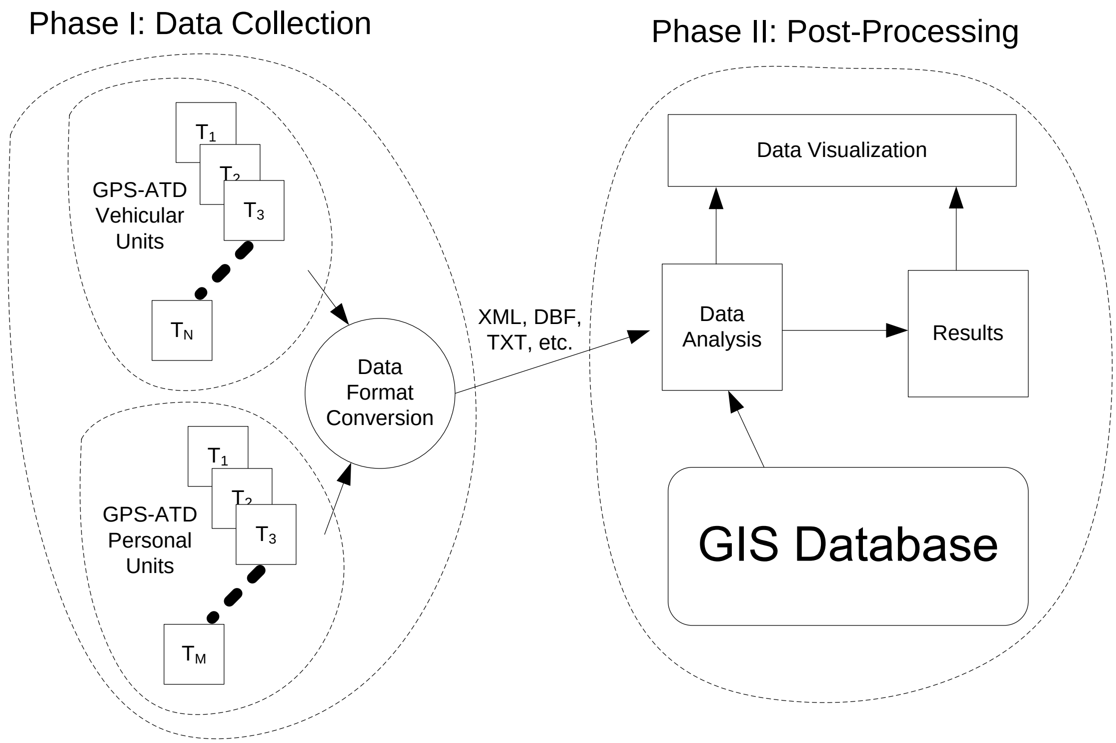


**Figure 1: Data collection and post-processing scenario**

# CHAPTER 2: REVIEW OF TECHNICAL LANDSCAPE AND AVAILABLE COMMERCIAL SYSTEMS

Recent technological developments and improvements in the Global Positioning System (GPS), low-cost small Micro-Electro-Mechanical Systems (MEMS) inertial sensors, low-power embedded computers, high-capacity storage devices, wireless communications, and high-speed Internet have converged to make a portable and low-cost data collection system a feasible reality. An overview of some of the devices and approaches are presented in the following tables.

These devices may be classified into four categories: GPS data logger, PDA with built-in GPS, GPS-enabled smartphone, and Personal Navigation Device (PND). Recently, GPS data loggers were developed for geo-tagging digital photos. These small GPS data loggers are battery powered and log position from their GPS receiver whenever they are turned on. Typically, the storage data are downloaded through USB connection to a computer. The user may configure the log frequency and data type using proprietary software. Their cost, run-time, and storage capacity are constantly improving with other technology advancements in battery, flash storage, and embedded GPS receiver. In addition, the decrease in size and power usage of GPS receivers makes portable PND possible. A few PDA and smartphone manufacturers have started to integrate a GPS receiver into PDA to support navigation applications. With the addition of AHMCT's GPS-ATD software and workflow, these GPS-enabled portable devices can be used as a GPS-ATD.

## Table 1: Comparison of GPS-ATD and commercially-available GPS-enabled devices

| | Passive GPS Logger | PDA with GPS | GPS-ATD |
|---|---|---|---|
| |  |  |  |
| Description | Passive GPS logger: AGL3080, RBT-2300, RGM-3800, GiSTEQ | PDA with GPS: Airis T610 or T620, Pharos GPS 535, Asus MyPal A696 | GPS-ATD (Automated Travel Diary) |
| Storage size | ~ 400,000 to 1.3 million points<br>100 to 250 hrs @ 1Hz | Up to 2 gigabyte (GB) with SD card | Built-in 256 MB |
| Run-Time | 8 hrs to 22 hrs | 4 to 6 hrs (1200 mAh battery) | ~ 11 hrs (1800mAh battery) |
| Data security | None | None<br>Data encryption may be an option | Yes (only authorized personnel can download data) |
| Data integrity | None (Anyone can modify the data easily) | None (Anyone can modify the data easily)<br>Data encryption may be an option | Yes (Nobody can modify the data) |
| Size | 9.0 x 4.6 x 2.3 cm<br>7.0 x 3.7 x 2.4 cm | 11.5 x 7.2 x 1.8 cm<br>11.7 x 7.1 x 1.6 cm | 11.7 x 6.6 x 2.1 cm |
| Weight | Smallest: ~50 g (2.0 oz) | Medium: 165 g to 170 g (5.8 to 6.0 oz) | Medium: 142 g (5.0 oz) |
| User Interface for Data input | None | Yes | Yes |
| Strong sunlight readability | N/A | Good | Best |
| GPS chipset performance | Good to Best (SiRF III, MTK, or NEMERIX) | Best (SiRF III) | Best (SiRF III) |
| Cost | Lowest ($55 to $120 ) | $199 to $380 | ~$500 @ QTY=1000 (estimate) |
| Future integration to OBD-II | None | Yes, with Bluetooth wireless (added $200) | Yes, with ZigBee wireless (added $200) |
| Additional software needed | None | Yes, Travel diary survey software is needed. | None |
| Advantages | Small, lowest cost, some have motion detection to trigger logging | Low cost, available now, and no manufacturing risk | Long run-time, secure data storage for long travel survey,<br>Custom software menu which allows the survey respondent to fill out the survey questionnaire quickly and easily, Long-term availability, Future integration to OBD-II |
| Risk factors | User will still have to fill out travel survey information on paper | Long-term availability is in question. These products change every year. The travel survey software written for this unit may have to be rewritten for future similar devices (risk - medium). | Parts are generally available for 4 to 5 years.<br>Software development risk (low)<br>Finding contract manufacturers to make the device (medium)<br>Making GPS-ATD in time for 2010 survey (high)<br>Higher manufacturing cost than predicted (medium) |

## Table 2: Comparison of GPS-ATD and additional commercially-available GPS-enabled devices

| | **Passive GPS Logger** | **Passive GPS Logger** | **PDA with GPS** | **PDA with GPS** | **GPS-ATD** |
|---|---|---|---|---|---|
| |  |  |  |  |  |
| Description | Passive GPS logger: AGL3080, RBT-2300, RGM-3800, GiSTEQ | Genie GT-31 with SD storage | PDA with GPS: Airis T610 or T620, Pharos GPS 535, Asus MyPal A696 | Rugged GPS/PDA | GPS-ATD (Automated Travel Diary) |
| Storage size | ~ 400,000 to 1.3 million points<br>100 to 250 hrs @ 1Hz | Up to 2 GB with SD card | Up to 2 GB with SD card | Up to 4 GB with SD card | Built-in 256 MB |
| Run-Time | 8 hrs to 22 hrs | 30 hrs | 4 to 6 hrs (1200 mAh battery) | ~ 6 hrs (1200 mAh battery) | ~ 11 hrs (1800mAh battery) |
| Data security | None | None | None<br>Data encryption may be option | None | Yes (only authorized personnel can download data) |
| Data integrity | None (Anyone can modify the data easily) | None (Anyone can modify the data easily) | None (Anyone can modify the data easily)<br>Data encryption may be an option | None (Anyone can modify the data easily)<br>Data encryption may be an option | Yes (Nobody can modify the data) |
| Size | 9.0 x 4.6 x 2.3 cm<br>7.0 x 3.7 x 2.4 cm | Not available | 11.5 x 7.2 x 1.8 cm<br>11.7 x 7.1 x 1.6 cm | 10.9 x 6.0 x 1.9 cm | 11.7 x 6.6 x 2.1 cm |
| Weight | Smallest: ~50 g (2.0 oz) | Not available | Medium: 170 g (6 oz) | Medium 133 g (4.7 oz) | Medium: 142 g (5.0 oz) |
| User Interface for Data input | None | None | Yes | Yes | Yes |
| Strong sunlight readability | N/A | Good | Good | Good | Best |
| GPS chipset performance | Good to Best (SiRF III, MTK, or NEMERIX) | Best (SiRF III) | Best (SiRF III) | Good | Best (SiRF III) |
| Cost | Lowest ($55 to $120 ) | $160 | $199 to $380 | $650 | ~$500 @ QTY=1000 (estimate) |
| Future integration to OBD-II | None | None | Yes, with Bluetooth wireless (added $200) | Yes, with Bluetooth wireless (added $200) | Yes, with ZigBee wireless (added $200) |
| Additional software needed | None | None | Yes, Travel diary survey software is needed. | Yes, Travel diary survey software is needed | None |
| Advantages | Small, lowest cost, some have motion detection to trigger logging | Small, low cost, large storage | Low cost, available now, and no manufacturing risk | Rugged, available now, and no manufacturing risk | Long run-time, secure data storage for long travel survey, custom software menu which allows the survey respondent to fill out the survey questionnaire quickly and easily, Long-term availability, Future integration to OBD-II |

| | | | | | |
|---|---|---|---|---|---|
| Risk factors | User will still have to fill out travel survey information on paper | User will still have to fill out travel survey information on paper | Long-term availability is in question. These products change every year. The travel survey software written for this unit may have to be rewritten for future similar devices (risk - medium). | Long-term availability is better than GPS/PDA | Parts are generally available for 4 to 5 years.<br>Software development risk (low)<br>Finding contract manufacturers to make the device (medium)<br>Making GPS-ATD in time for 2010 survey (high)<br>Higher manufacturing cost than predicted (medium) |

# CHAPTER 3: EVALUATE PROMISING EXISTING COMMERCIAL SYSTEMS

After the current reassessment of alternative systems was completed, a number of the most promising units were procured for a field test. The three main variants used for this phase of testing were the: 1) GPS-ATD, 2) GPS-Enabled PDA platform, and 3) Passive Data logger.

## AHMCT-Caltrans GPS-ATD

As part of the January 2005-December 2006 GPS-ATD project, AHMCT investigated the use of commercial-off-the-shelf (COTS) PDA systems with built-in GPS receiver as the platform for ATD development and deployment. The conclusion reached at the time was that no commercial system could meet the ~$500 per unit cost constraint. Note that COTS PDA systems with built-in GPS receiver were available for which software could be developed to meet most functional specifications, but these had unit costs far exceeding Caltrans cost constraints (~$2000 - ~$3000 per unit). Accordingly, therefore, as there were no available systems to meet the needs of the 2010 Survey, AHMCT researched, designed, and developed its own PDA platform from the TSI specifications. The units met TSI's functional requirements; however, during testing one performance issue was identified: the GPS reception was less sensitive than desired. AHMCT and TSI have discussed enhancements of the units, including the needed scope of work (time and funding); these enhancements have been deferred for future work, as no funding or contracting mechanism has been identified. It should be stressed that ***the prototype GPS-ATD meets all requirements and specifications, and is a viable platform for travel behavior surveys.***

With the needed GPS reception enhancements, contract manufacturing uncertainties and lags, and the proximity of the 2010 Travel Behavior Survey, at the time of this report (June 2008), it may still be feasible to use the AHMCT Caltrans GPS-ATD system; however, quick decision and action must be made by all parties. However, the risks of this approach must be carefully considered given the time constraints. It is estimated that, *assuming no contracting or external delays*, to reach availability from a manufacturer from start (prototype enhancements) to finish (delivery) two years would be required. The main risk factor would be identifying manufacturers and completing the necessary bidding and procurement processes. Due to vagaries in governmental laws and processes, this risk is difficult to mitigate and may be beyond control of AHMCT and Caltrans.

## GPS-enabled PDA Platform

By removing the variability of the contract, bidding, and manufacturing processes, using a commercial-off-the-shelf (COTS) Personal Digital Assistant (PDA)-type system with built-in GPS receiver mitigates the risk of having to deploy a custom hardware solution. Costs savings from "economy of scale" manufacturing accrue automatically. By choosing an appropriate open software architecture platform, the platform firmware and the software developed in the GPS-ATD prototype research will be directly applicable and transferable (with some modifications) onto a COTS-based PDA platform with built-in GPS receiver. The user interface (UI) software developed under the prototype research can be ported to a Windows CE or Linux-base PDA with built-in GPS receiver.

The newly-available COTS GPS-enabled PDA platforms AHMCT has evaluated meet the needs for the integration of the AHMCT software and firmware for the survey. The units provide nearly the same functionality as the GPS-ATD as a platform to host the software. As a general purpose computing device, the units are programmable and additional functionality can be supported by adapting the UI. The units we have evaluated are now approximately 40% - 80% the estimated cost of the GPS-ATD hardware platform at effectively the equivalent functionality; this is to be expected based on the low volume and custom nature of the GPS-ATD vs. mass-market devices. Since these are general purpose computing devices, access to stored log data by the general public could be a concern; encryption of the data files will effectively address this issue. Another issue identified during testing is lower run times. Many of the COTS units have 4-6 hours of continuous run time (versus ~11 hours for the GPS-ATD platform). Aggressive power management, in-vehicle charging, and survey participant training to monitor and charge the units appropriately will mitigate the lower run times. In addition, the majority of COTS GPS-enabled PDA platforms use Window CE as their base OS, which generally limits the degree of customization possible. Most important, in this case, the PDA cannot be locked down to just run the GPS-ATD software. This increases chances of misuse and user error in recording their travel activities.

## GPS-enabled Mobile Phone Platform

Midway through our research, GPS-enabled mobile phone platform become increasingly available and popular. The new devices have the Assisted-GPS (A-GPS) feature that enables them to achieve a GPS Time–To-First-Fix (TTFF) in a few seconds compared to 30 to 60 seconds for a typical embedded GPS found in PDA or PND. In addition, A-GPS allows devices to get GPS positional solution faster in GPS-challenged conditions. The hardware cost is about double of a GPS-enabled PDA, and the A-GPS feature requires activation of the mobile phone data services which incurs a fixed monthly cost. In the past, GPS-enabled mobile phones used proprietary OS that did not allow development and installation of software by third parties. Recently, a few mobile phone makers have opened up their phone OS platform and provided a development environment and Application Programming Interface (API) for third parties developers. Viable candidate platform for GPS-ATD software include Apple iPhone, Research In Motion Blackberry phones, Microsoft Window Mobile OS based phones, and Google Android OS-based phones. Except for Android, all candidate OS are proprietary and closed-source. Early, versions of the iPhone OS (before version 3.0) did not support multi-tasking. In addition, Apple’s iPhone development licensing and software distribution have been more restrictive compare to the Android platform.

## Using Android GPS-enabled Mobile Phone Platform for GPS-ATD

Google Android OS-based phones were chosen based on OS openness, development platform cost and documentation, and licensing flexibility. The entire Android OS source code is available to the user/developer under the Apache License, a free and open source software license. Licensing requirement can be a major hindrance for Caltrans final deployment. Furthermore, the open-source nature of Android allowed us to customize the OS and ATD application to take over the entire device interface for the dedicated purpose of recording user position and travel diary user interface inputs. The Android OS, based on the Linux kernel, is designed for mobile devices. It was initially developed by Google and later the Open Handset Alliance. It allows developers to write managed code in the Java language, controlling the device via Google-developed Java libraries. The Open Handset Alliance includes Broadcom Corporation, Google, HTC, Intel, LG, Marvell Technology Group, Motorola, NVIDIA, Qualcomm, Samsung Electronics, Sprint Nextel, T-Mobile, and Texas Instruments. The choices of Android-based GPS-enabled smart phones and similar devices will be much greater than for any other platform because of the multiple hardware, software, and service providers participating. All these new upcoming Android OS-based smartphone and similar devices should run the developed GPS-ATD software with little or no modification.

**GPS-ATD Hardware**

The GPS-ATD software platform was developed and tested on the HTC G1 Dream (a.k.a. “Google phone”) and its successor, the HTC Magic / MyTouch smartphone. Detail specification of these Android smartphones can be found at www.htc.com. Figure 2 shows the HTC Magic smartphone running the GPS-ATD software. The HTC Magic is the currently preferred Android smartphone to run the GPS-ATD software because of the device’s lighter weight and longer battery life compared to the G1. A 2 GB microSD card was installed into the smartphone for logging data produced by the GPS, along with the user input. We expect many more Android based devices with built-in GPS will be available in the near future, many by the end of 2009. It is highly likely that there will be a better hardware platform to run the GPS-ATD software, and reasonable to conclude that pricing will be quite competitive as a greater number and diversity of devices emerge.

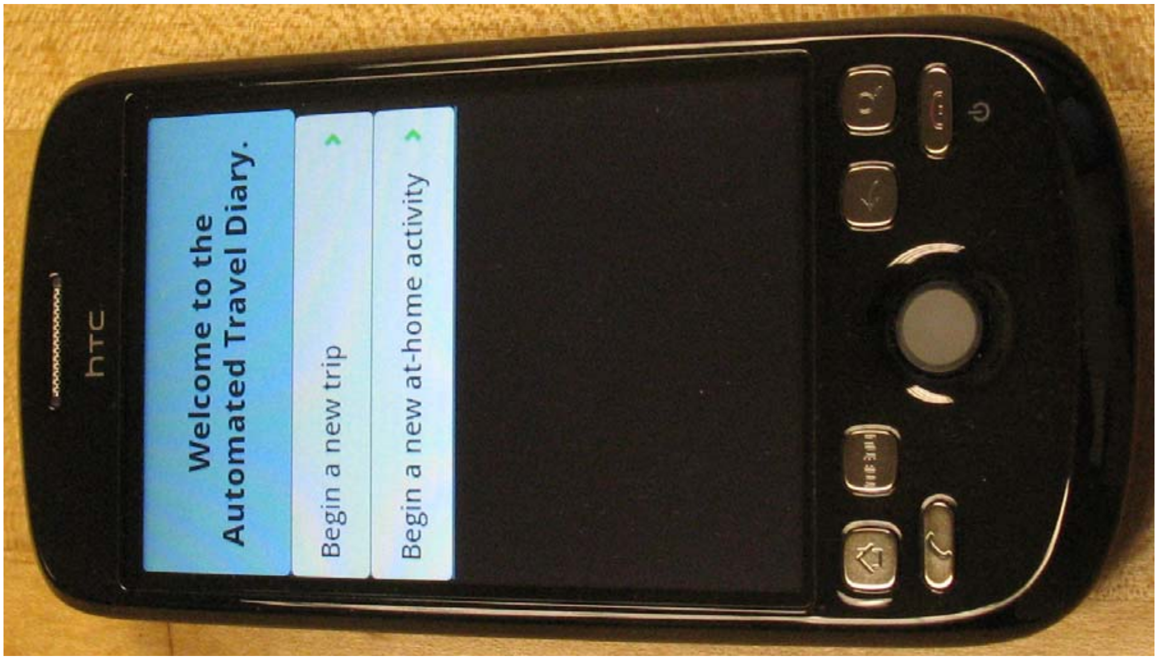


**Figure 2: HTC Magic Android smartphone running GPS-ATD software**

### GPS-ATD Software

The GPS-ATD software was designed and implemented to leverage available capabilities within the Android OS and API, to the extent possible. This approach reduces the need to "reinvent the wheel", maximizes the benefits of the open-source model, and provides the best path for future upgrades and maintainability. The user interface (menu structure) is implemented in eXtensible Markup Language (XML), a text-based approach, allowing relatively easy customization of the menu system for future surveys. This approach also provides support for internationalization and localization, which facilitates providing menus in languages besides English. This will be an important point for the deployment of the GPS-ATD in the 2010 survey; at a minimum, it is expected that the GPS-ATD would be able to support both English and Spanish.

### User Interface

The GPS-ATD software user interface leverages the base Android touch screen user interface. The standard Android "notification" or status area was unchanged; it provides the user with operating status of the Android device such as GPS status, network signal strength, battery level, and local time, as shown in Figure 3. The travel diary questions appear in sequence in the blue background area at the top of the screen below the "notification" area. The available answers appear below the question area as buttons with white background. If there are too many available answers to show in a single screen, a yellow bar will appear on the right side of the display and the scroll button at the bottom will be highlighted. The user can briefly touch the page up and down buttons to page up and down to see and find the most appropriate answer. Alternatively, touching and sliding a finger vertically up or down in the answer area on the touch screen will also accomplish scrolling up or down, which is an Android standard approach. The user can briefly touch the appropriate answer option to select and enter the answer of the travel diary questionnaire. The user can go back to the previous question and revise the answer by touching the red "back" touch button. Backward navigation is supported to the beginning of the current trip's inputs.

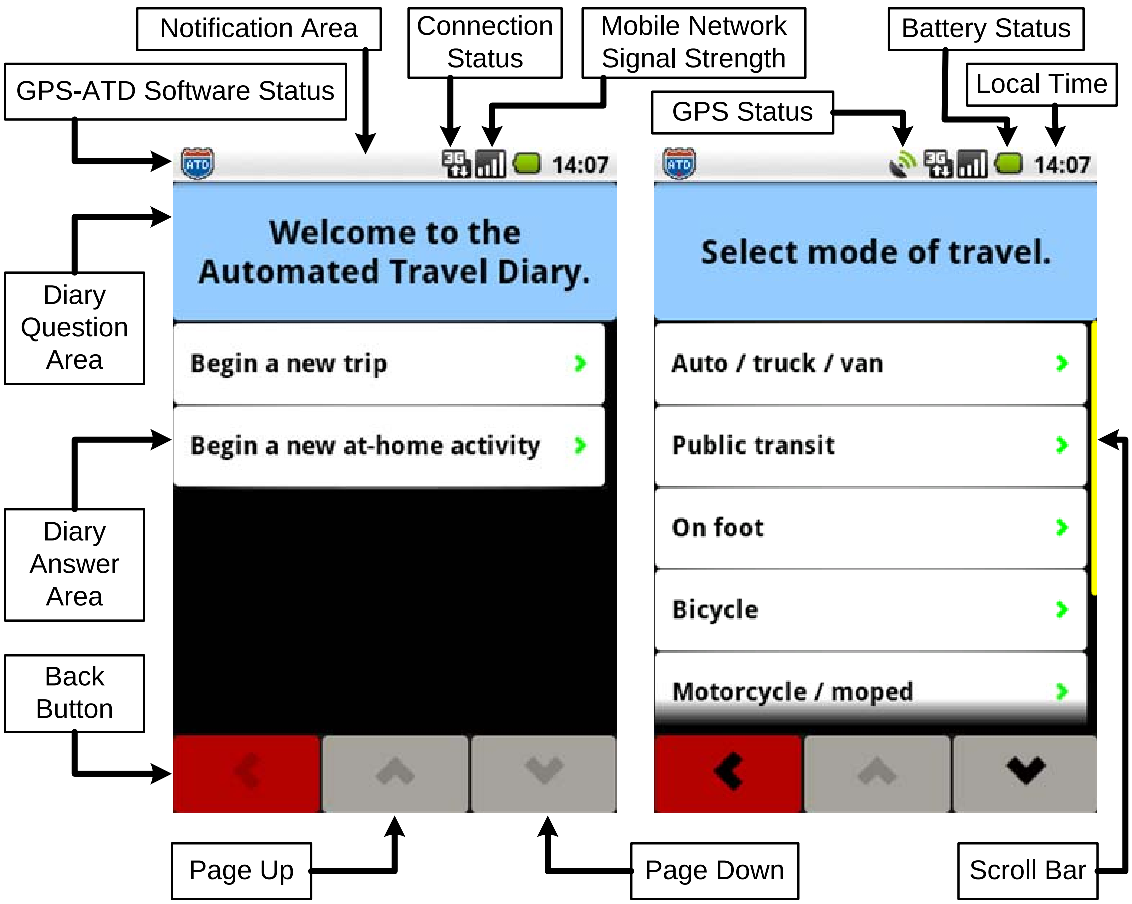


**Figure 3: GPS-ATD user interface overview**

## Passive Data Logger

Finally, the lowest-risk equipment item was evaluated – the passive GPS data logger. Additionally, these units are also the lowest-cost item, within the range of $60-$120 per unit. These units can augment the traditional paper travel diary forms with exact route and location data and require no user interaction other than turning them on and off, and charging them appropriately. The units AHMCT has evaluated store between 400,000 and 1.3 million locations at a rate of 1 point per second, which translates into 100-250 hours of travel. Survey participant training would need to be augmented to include these devices; however, training is minimal and includes how to turn them on and off and charge the batteries regularly.

A typical GPS data logger consists of four major components: a high-sensitivity GPS (HSGPS) module, solid-state storage, a battery, and a microprocessor. Because of solid-state-storage technology improvements, GPS data loggers' storage capacity generally improves over time. In addition, their continuous battery run-time will increase due to battery capacity improvement and lower power consumption of the GPS module. Thus, the best available GPS logger model, recommended for travel behavior study today, may not be the best candidate in the future. At the end of the project, the Visiontac VGPS-900 and Columbus V900 Bluetooth GPS loggers (Figure 4) are the best currently available logger for traveler position logging. The two loggers are identical. It uses a 51-channel MTK HSGPS module, and a microSD card for data storage. The maximum size microSD card currently supported is 2 GB, which can store about 25 million position records (289 days of continuous logging) in CSV format. The logger could run on its rechargeable internal 1000 mAH LiIon for 13 to 15 hrs of continuous logging. The unit size is 2.875” x 1.75” x 0.375”. The MTK GPS module performs well compared to other GPS modules such as the SiRF III GPS chipset module. The TTFF is about 30 to 60 seconds.


**Figure 4 Columbus V900 GPS logger (external and internal photography)**

# CHAPTER 4: SUPPORT FOR FSR DEVELOPMENT AND BUSINESS CASE FOR GPS-ATD

The major focus of this research was to address practical aspects of deploying the GPS-ATD for Caltrans' use in the 2010 Travelers' Survey. A key related task, support for Feasibility Study Report (FSR) development, is discussed in this chapter.

## FSR Development

In order to support Caltrans' development of the business case for the introduction of an ATD device into the 2010 Travelers' Survey, a more through understanding by AHMCT of the California State governmental business and legislative processes was needed. Through numerous conversations with representatives from the State Chief Information Office (CIO), the Feasibility Study Report (FSR) generation process was deemed the best starting point. Towards that end, two AHMCT researchers (Kin Yen and Phillip Wong) attended the in-house FSR orientation sessions at Caltrans headquarters. Kin Yen attended the May 14, 2008 session, and Phillip Wong attended the May 16, 2008 session. These sessions were comprehensive all-day sessions that reviewed the rationale and purpose of an FSR, as well the procedures for properly compiling a report for eventual inclusion with and support of a Budget Change Proposal (BCP). Heavy emphasis was placed on discussing within the FSR the impact of the proposed new project development on the existing capacity and security of Information Technology (IT) infrastructure. Concise project goal setting and project milestones were also emphasized as a means of project cost-containment. A quick summary of the rationale and process for the FSR is provided in Table 3.

In support for the generation of the FSR, AHMCT researched and summarized various IT scenarios for the implementation of the ATD into the travelers' survey, and the impacts of these scenarios on Caltrans IT. The scenarios considered generally involved the partitioning of responsibility between the contractor and Caltrans. This was an essential consideration, as it drives much of the further development of the technology as well as the business case inputs. The final scenario selected assigned much of the responsibility to the survey contractor, as illustrated in Figure 5.

Based on the partitioning of responsibilities, as well as the decision to use Commercial Off-the-Shelf technologies for the deployed GPS-ATD, Caltrans TSI, DRI, and AHMCT revisited the need for an FSR with IT and State CIO representatives. As a result of the decisions made and the scenario selected for eventual implementation, the clear indication to Caltrans TSI, DRI, and AHMCT, was that an FSR would not be required for this project. As such, the inputs developed for the FSR were archived, and further development of the FSR was terminated.

**Table 3: FSR development summary[2]**

| | |
|---|---|
| What is an FSR? | Feasibility Study Report is required for IT projects; This document explains the project need and explains the rationale for selecting the preferred alternative above other alternatives. |
| What is an IT project? | • Any project, or project component, that creates computerized and automated information used to make decisions, or delivers infrastructure upon with information travels.<br>• Rule of thumb – if the project involves analysis or storage of data, it is most likely an IT project. |
| Why does the FSR matter? | • Documents the business need for the project<br>• Shows due diligence<br>• Documents the rationale<br>• Provides decision making information |
| Developing a Project Concept | • Documents business case for approving funds to conduct a Feasibility study<br>• Explains **what** the problem is and **why** it needs to be fixed – ***not how***. |
| Why is a feasibility study important? | • Business problem is well understood and quantified.<br>• Defines nature and scope of the project<br>• Defines project objectives and performance measures<br>• Expected benefits are analyzed and quantified<br>• Best solution is identified<br>• Improves likelihood of achieving business objectives |
| 10 Steps to A Feasibility Study | 1. Assemble team<br>2. Define business problem or opportunity<br>3. Analyze existing processes or environment<br>4. Determine business objectives<br>5. Determine business functional requirements<br>6. Identify or evaluate alternatives<br>7. Select best alternative<br>8. Develop project plan<br>9. Evaluate study results<br>10. Document study results |
| Success Factors | • Involve IT early and often<br>• Identify all stakeholders<br>• Set project business objectives<br>• Identify and evaluate all reasonable alternatives<br>• Select the alternatives that will achieve the objectives |
| Key Messages | • FSR is required by law<br>• FSR due to IT by December<br>• FSR due to Finance by July<br>• BCP due to Finance by September<br>• FSR must be approved **before** IT project starts |

[2] Office of Project Implementation (OPI), http://it.dot.ca.gov/projmgmt, 916.651.8474

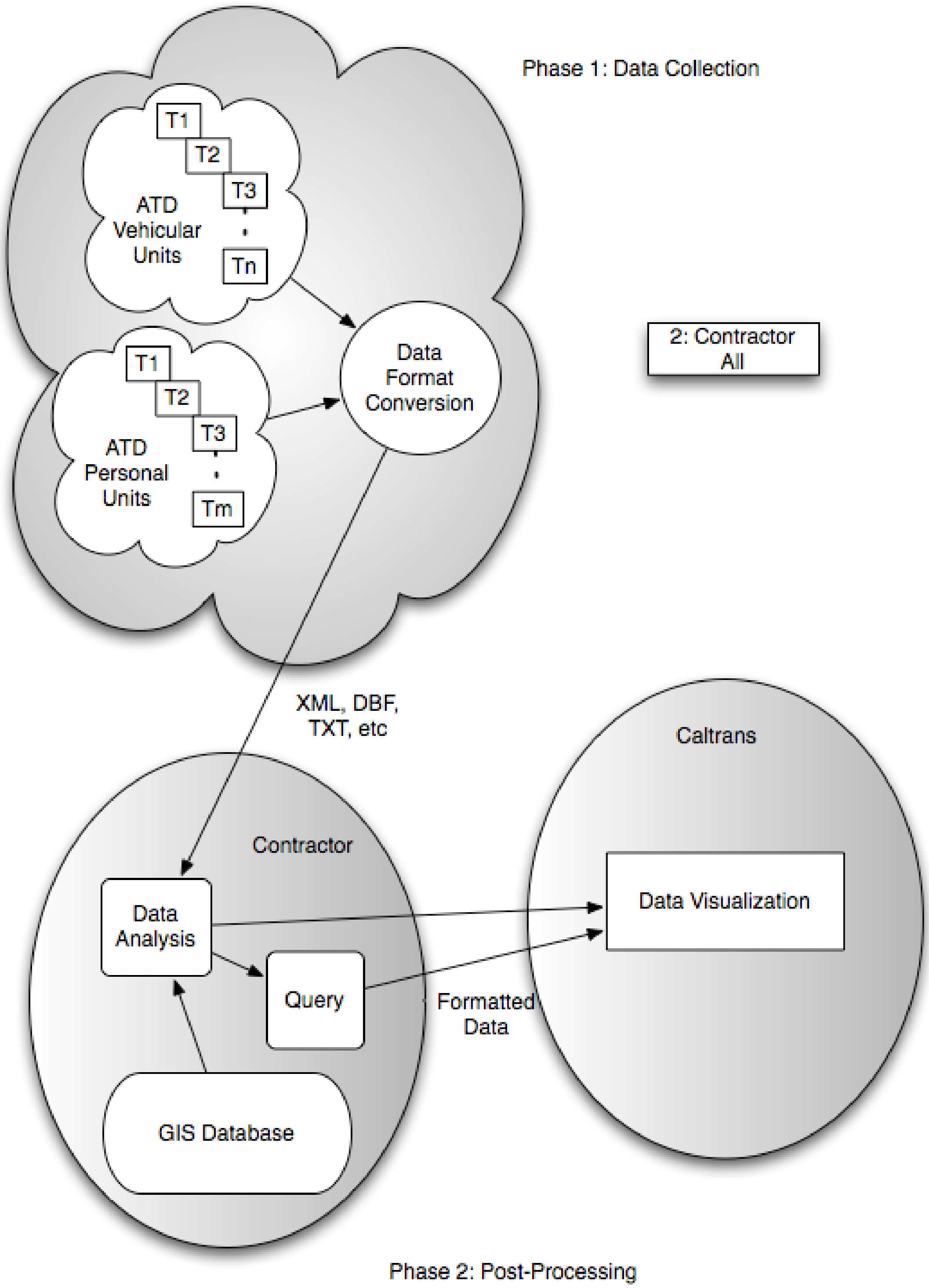


**Figure 5: Selected scenario: Caltrans visualization / Contractor full responsibility**

## Business Case for GPS-ATD Development

In support of this project AHMCT met approximately once a month with TSI and DRI during the initial half of this research project to provide technical information to support GPS-ATD development. AHMCT provided relevant expertise and guidance to Caltrans. This section presents information for the business case for the GPS-ATD.

### Investigation of Synergistic Concepts

The GPS-ATD platform can support the diverse applications envisioned within Caltrans. Other state agencies may benefit from the leverage of the knowledge, firmware, software, and other technologies developed under the prototype GPS-ATD research, as well as enhancements under the current research project. Location-based data, in conjunction with logging of the associated activities, is especially useful in gaining insight into the movement of people, goods, and services.

Current envisioned applications include monitoring the use of alternative fuels (e.g. E85), replacing paper vehicular usage logs with electronic logs, and fleet and asset management applications. For example, the California Air Resources Board (CARB) may use the alternative fuels data for fuel use and emissions studies that may result in the optimal placement of E85 refueling stations that would provide for the most cost-effective benefit for the public. Traffic data may provide support for congestion management techniques by various regional and county entities. Data obtained by Caltrans TSI or others can also be leveraged to support land-use planning and modeling.

For many applications, combining the ATD with additional sensors and data loggers will be an optimal approach. For example, for CARB studies, the ATD would provide the full range of data obtained in travel surveys. Instrumenting vehicles with an additional data logger connected to the On-Board Diagnostics (OBD-II) port would allow collection of engine data and parameters of interest to CARB. Such data may include fuel use and economy data, when such data is available in a standardized format for that vehicle and engine type. As the ATD and typical data loggers maintain an internal clock setting, and the systems can be sufficiently synchronized, it will be feasible to correlate the ATD and OBD-II vehicle data during post-processing, supporting a wide range of analysis and reporting.

In a similar manner, the ATD can be combined with additional sensors and data loggers to monitor the use of alternative fuels. For example, it is feasible to monitor the percentage use of E85 in the recently purchased Caltrans fleet of flex-fuel vehicles. Such a system would include a modified (reprogrammed) ATD as the UI and vehicle-to-office communications, and would combine with a back-office server system for a user-friendly web-based interface for supervisors and managers to visualize data and statistics. This capability would allow data-driven and objective decisions regarding fleet and fuel usage, and the deployment of additional flex-fuel filling stations.

The ATD, with software modifications, would also provide an excellent in-vehicle usage log. The system could replace current paper logs for vehicle use. The addition of location tracking along with potential interfaces to other vehicle sensing systems would make the vehicle log easier to use, while simultaneously providing a greatly enhanced tool for Caltrans (or other agency) fleet management.

**COTS GPS-ATD Cost information**

Cost information for the Commercial Off-the-Shelf devices and data services evaluated and recommended in this research is included here. Note that this information is valid at the conclusion of this research project (June 2009), and these costs typically evolve rapidly in this market area. For an effort such as the Statewide survey, we anticipate that a State Agency would be able to negotiate excellent volume rates for hardware and data services, so that the numbers indicated here should certainly represent a worst-case cost.

**Table 4: Approximate component and service costs, as of June 2009**

| | |
|---|---|
| HTC Magic smartphone (each) | $500 |
| Passive GPS data logger (each) | $100 |
| Data plan (per device, per month, to support A-GPS) | $33 |

A few qualifications are immediately in order, with respect to Table 4:

- The HTC Magic phone price is before release by any major U.S. carrier, and definitely represents a premium price. Between the time of this report draft and revisions (approximately one month), the price has dropped from about $560 to about $460. The $500 price in Table 4 must thus be updated in any future discussions and decisions.
- Price drops fast on phones. For example, in 2008 a G1 phone cost over $500, and is now available for about $280.
- All pricing in Table 4 are based on single or small quantity purchases.
- With a long-term contract, price drops significantly. In some cases, the price may be $100 - $200 for a smartphone.
- The data plan above (unlimited) is overkill for the Statewide survey. This plan was used for maximum flexibility for research and testing.
- For the Statewide survey, a lower bandwidth (telemetry) data plan is likely sufficient. The data plan is only needed to support A-GPS enhanced solution. Here, $10 / device / month is a good (likely high) estimate (public price).

**Anticipated Savings and Benefits from Use of GPS-ATD**

The primary benefits for the use of the GPS-ATD are increased data quality and information, obtained simultaneously with decreased user burden. The system is designed to minimize user burden for travel survey participants, and is meant to be at least as easy, and generally easier, than the standard paper-based diary approach. The approach will also greatly reduce underreported (particularly short) trips, a known issue with traditional survey methods. In addition, the system captures important trip-related information, including purpose, linked trips, and exact route and speed information. The improvements in data quality and enhanced information will have a ripple effect on the products that leverage the information obtained in the Statewide travel behavior survey. These products include travel behavior models, trip generation models, land use planning, and information affecting commute behavior, such as optimal park-and-ride locations. The benefits then flow from these products to provide improved mobility, enhanced safety, and reduced environmental impact.

The passive GPS logger will provide a subset of these benefits, but cannot directly capture any information other than location and speed data. Correlation of this data with paper-based or telephone interview responses will yield more of the noted benefits. The most important aspect for the passive GPS logger is that, due to its lower cost, it can be provided to a much larger set of survey participants.

The researchers envision the greatest benefit arising from an appropriate mix of active GPS-ATD devices for a statistically significant sample size, combined with a large set of respondents equipped with passive GPS logger and traditional means for collecting diary information. In an ideal scenario, all participants would receive either the GPS-ATD device or a passive GPS logger; however, it may be statistically valid to provide a smaller set with the passive loggers.

# CHAPTER 5: CONCLUSIONS AND FUTURE WORK

The GPS-ATD provides increased data quality and information, with simultaneous decreased user burden. The system is designed to minimize user burden for travel survey participants, and is meant to be at least as easy, and generally easier, than the standard paper-based diary approach. The approach will greatly reduce underreported (particularly short) trips, a known issue with traditional survey methods. In addition, the system captures important trip-related information, including purpose, linked trips, and exact route and speed information. The improvements in data quality and enhanced information will have a ripple effect on the products that leverage the information obtained in the Statewide travel behavior survey. These products include travel behavior models, trip generation models, land use planning, and information affecting commute behavior, such as optimal park-and-ride locations. The benefits then flow from these products to provide improved mobility, enhanced safety, and reduced environmental impact.

The prototype software has been developed for a generic GPS-enabled Android-based device. We have currently demonstrated the software working on three devices: the two HTC devices discussed in Chapter 3, as well as the Neo device from OpenMoko. It is expected to be portable with little or no modification for subsequently introduced GPS-enabled Android-based devices. The one aspect that would be anticipated to require some software modifications would be variations in available user input, e.g. different button arrangements, scroll wheels, 4-way rocker buttons, and similar.

Based on current announcements, many more GPS-enabled Android devices are anticipated by the end of 2009, and beyond. The devices are expected to exhibit increasing diversity, and cover a wide range of price points. It is reasonable to assume at this time that a viable device well-suited for use as the GPS-ATD hardware should be available in the range of $400. It is quite feasible that a much cheaper device could provide all of the needed capabilities, including the enhanced A-GPS solution. It is important to include the A-GPS capability, which will require some form of cellular data communication, as A-GPS can reduce the Time-to-First-Fix from minutes down to a few seconds. In addition, it is expected that by the time of the Survey, there will be multiple wireless service providers for Android devices, which should enhance competition, and satisfy the need for multiple bids in any procurement process.

While the GPS-ATD was developed specifically for the Statewide Travel Behavior Survey, and according to Caltrans TSI concepts and specifications, it was also developed to be quite flexible and reprogrammable. As such, it is well-suited for similar travel surveys by Metropolitan Planning Organizations (MPOs) and other agencies. In particular, the approach used for implementing user menus will allow easy revision for other agencies' needs.

While the COTS prototype has demonstrated ideal functionality for the survey application, it will be important to continue monitoring pricing in preparation and planning for the actual survey. As noted in Chapter 4, pricing for these types of devices is quite volatile, with rapidly decreasing costs the norm. As part of this effort, it will be essential to approach wireless data carriers well in advance of the survey, in order to determine pricing options, and to negotiate the best volume discounts. It is anticipated that these discussions will involve both AHMCT and Caltrans. As an additional component of the cost consideration, TSI will need to evaluate the appropriate combination of active GPS-ATD and passive GPS logging devices, including cost tradeoffs vs. statistical data quality.

While it is clear that the GPS-ATD prototypes will meet the data collection needs, a survey using these units will produce large and complex sets of spatiotemporal data. Analysis of this data will require development of appropriate techniques and tools to support and facilitate extraction and reporting of useful survey data. Future work is recommended to research and develop techniques and tools for analysis and automation. These tools will enable planners to effectively search and query the large set of data to generate general statistics.