

Development of a
Comprehensive Vehicle Instrumentation Package
for Monitoring Individual Tripmaking Behavior

Project Overview and Functional Specifications

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1. PROJECT GOALS, OBJECTIVES, AND DELIVERABLES

In travel diary studies, or trip surveys, randomly selected survey participants from a metropolitan region manually log in a paper diary the beginning and end of each trip that they make. These travel decisions are used to derive statistical representations of travel behavior throughout that region. The resulting statistical models become trip generation algorithms in 4-step travel demand models and are used to forecast travel patterns, such as: number of daily trips, trip purpose frequencies, trip origins and destination selection, trip duration distributions, and temporal distributions.

Motor vehicle emissions are related to the number of trips that are made. But the emissions from “clean vehicles” that pass normally pass standard smog checks are a strong function of the way that the vehicles are operated. A small fraction of high acceleration activity or moderate acceleration activity at high speeds lead to combustion conditions (“enrichment”) that increase emission rates by 10 to 1000 times for short periods (Kelly and Groblicki, 1992; LeBlanc, et al., 1995). In addition, the engine computers on modern vehicles that control air:fuel ratios (directly impacting emissions) are known to monitor the rate of change in throttle position in some vehicles. This means that driver interaction with the vehicle through the throttle can also lead to high enrichment emissions.

Travel behavior studies and vehicle activity studies have never been coordinated. Differences in driver behavior across demographic groups have been noted in travel behavior studies and differences in vehicle activity patterns across cities have been noted in vehicle studies. However, separating the impacts of driver behavior and driving patterns on emissions is not possible without detailed driver studies that simultaneously monitor vehicle and engine operating conditions.

The primary goal of the comprehensive electronic travel diary project is to develop an instrumentation package that will automate the capture and integration of travel activity (trip-level data) and vehicle and engine operating conditions. An ideal monitoring system should be easy to install in any personal vehicle (automobiles or trucks), should not require the participation of a certified mechanic, and should be unobtrusive. Data are to be collected and stored electronically.

The ultimate objectives of the comprehensive travel diary system are to: 1) automate the manual travel diary process, producing more and more accurate data for use in transportation planning model development, and 2) capture vehicle and engine operating conditions concurrently for use in motor vehicle emissions model improvement. Emissions models can be improved once the relationships between driver behavior, vehicle operations, engine operations, and vehicle emissions are determined through studies that employ the new equipment.

The system is designed to capture or compute the following data elements:

- All driver and passenger travel activities that would normally be captured using manual travel diary or telephone survey methods. For each trip, this information includes: vehicle (or other mode) identification, driver identification, passenger identification, driver and passenger trip

purposes, trip start time, finish time (or duration), origin location, destination location, and distance traveled. In addition to these traditional elements, route choice, travel speed, and functional classification of each link (with traffic conditions) can be determined by tying GPS data to a GIS database, greatly enhancing the original data collected.

- All vehicle and engine operating conditions affecting emissions that can feasibly be captured via an onboard engine computer monitor. These data include such variables as vehicle speed, acceleration, engine rpm, manifold absolute pressure, throttle position, catalyst temperature, gear selection, air/fuel ratios, and coolant temperature.

By having the unique ability to measure and record trip-making characteristics, exact origins, destinations, routes, and times, we make available a host of new research opportunities to better understand human travel behavior, and its impact on congestion and emissions.

The key product of this research initiative is the development, assembly, and testing of an vehicle instrumentation package for use in monitoring individual tripmaking behavior. To support this deliverable, a literature review and analysis of other travel diary automation and vehicle instrumentation projects has been conducted, along with an inventory of previous travel diary studies in Atlanta and other major metropolitan areas within the United States. This literature review also includes a review of suspected travel survey bias issues. Finally, a deployment plan incorporating the instrumentation package will be presented for use in the 1999-2000 Atlanta Regional Travel Survey.

Project status will be reported at the end of each major milestone in the form of the following reports:

- 1) Literature Review
- 2) Project Overview and Functional Specifications
- 3) Technical Specifications and Analysis
- 4) Test Plans and Results
- 5) Final Report (including deployment plan)

2. BACKGROUND

Recent studies undertaken in Atlanta, Baltimore, Spokane, and Los Angeles indicate that the number of trips, and subsequently the number of engine starts currently modeled in the 4-step travel demand process may be significantly underestimated for these cities. These studies relied upon electronic black boxes to monitor the actual activity of a large number of vehicles (Ross, et al., 1994; DeFries and Kishan, 1992), revealing that a large number of short trips are taken by residents of these cities (Enns, et al., 1995). Manual travel diaries were not simultaneously maintained during these studies, thereby making direct comparisons to travel diary information impossible. However, the analysis of travel patterns indicate that typical trip generation algorithms derived from travel diary information in these cities may be underestimating daily trips for study participants by as much as a factor of two. A larger number of short trips (in duration and distance) were observed, but were not predicted by the travel demand models. Despite the difficulty in making direct comparisons, the large differences observed in trip estimates for these cities clearly warrant further studies, as indicated by the following statements:

“Driving patterns, as distinguished from driving behavior, are the observed general characteristics of trips made in any given study region. For example, number of hourly, daily, or weekly trips made, distances traveled, trip speed and acceleration profiles, parked time between trips, etc., are all general trip characteristics.

Driving pattern differences can be caused by many factors including differences in transportation infrastructure, speed limit posting and enforcement, land-uses, jobs-housing balance, vehicle fleet composition, and driving behavior to name a few.” (Ross, et al., 1998)

The electronic data collected to date demonstrate differences across cities in temporal travel patterns (Ross, et al., 1998; LeBlanc et al., 1995). Yet, the studies do not provide any information on where these trips were made and for what trip purposes. Researchers lack the information necessary to explain why these differences are noted. Freeway and arterial driving patterns differ significantly (Effa and Larsen, 1993) and differences in travel patterns may also be associated with land use structure (CARB, 1993) and urban form (Handy, 1995). Yet, it is impossible to determine with current data whether observed travel pattern differences result from differences in infrastructure and traffic levels, vehicle characteristics, or driver behavior. Instrumented vehicle studies to date provide insufficient control over potential causal variables associated with infrastructure and congestion levels, confounding insight into true differences in driver behavior across cities.

“Driving behavior refers to the driving characteristics of individual drivers. Driving behavior includes the broad set of human factors involved in individual tripmaking decisions and the actual operation of a vehicle. Driving behavior is a function of such complex factors as preferences, reasoning skills, valuation of time, willingness to accept risk, environmental awareness, etc., as well as the complex set of interactions between all of these factors.” (Ross, et al., 1998)

To summarize, research suggests that travel pattern differences exist across cities, and that the general observed patterns are not consistent with same predicted by travel demand model algorithms. Furthermore, different sampling bias problems with contemporary travel diary studies may prohibit researchers from accurately determining behavior of individuals needed for air quality and other regional transportation analysis needs. This research proposes to develop electronic equipment for collecting less biased spatially and temporally resolved vehicle activity data, along with essential driver and vehicle characteristics, necessary to more accurately measure and record travel activity and quantify the effects of differences in actual driver behavior.

An improved monitoring system could be applied for many travel behavior purposes. For instance, travel demand models are relatively insensitive to the impacts of transportation demand management measures such as parking pricing or employer-offered incentives to carpool. Some attempts have been made to integrate enhanced travel demand impact modules into the current 4-step analytical process (using enhanced trip-generation or mode choice algorithms and providing feedback loops), but most impact assessment rely upon post-processing of assumptions related to reduction in drive-alone rates. New technologies for collecting detailed driver, vehicle, and trip information, could be coupled with follow-up home interview surveys to provide data for developing 4-step model algorithms capable of predicting changes in travel behavior from transportation demand management strategies. In addition, the new equipment could be finally be used to quantify the interactions between drivers, their vehicles, and the surrounding infrastructure. Such data can lead to significant enhancement of emissions models.

3. AUTOMATION OF THE TRAVEL DIARY PROCESS

Travel diary studies are one of the most common methods for collecting data used in developing travel demand models. Trip generation, trips distribution, and mode split components of 4-step travel demand models require personal travel diary data as inputs to model algorithm development. Automation of time and location data calculation and capture should produce great improvements in travel data accuracy, compared to manual methods. Electronic diaries also provide the potential to expand recorded choices. This makes such diaries suitable for use in activity-based or tour-based travel demand modeling. In addition, the electronic travel diary is intended to overcome several sampling-related problems related to manual travel diary studies. These problems include:

- Survey participants may be self-selected based on their willingness to ‘keep accurate records,’ thus resulting in sample bias.
- Survey participants may not keep accurate records (either accidentally or intentionally), which results in misreported or underreported travel, including the omission of entire trips.
- Due to the time-intensive nature of manual travel diaries, participants often feel fatigued or hassled by the process, which makes it difficult to collect extended panels of data. (Most manual travel diaries are limited to 1 to 3 days of travel.)
- Also, for various reasons, some participants may intentionally misreport travel activity, resulting again in non-representative travel data.

Because manual travel surveys potentially suffer from these reporting and participant solicitation biases, new methods for obtaining personal trip making behavior can help minimize or reduce the impact of these biases on the estimation of trip generation rates. Global positioning systems can also add a new spatial dimension to tripmaking, by tracking actual route choice.

4. CONCURRENT CAPTURE OF DRIVER BEHAVIOR, VEHICLE AND ENGINE OPERATING CONDITIONS

Currently, driving patterns cannot be explained explicitly. The impacts of driver behavior cannot be separated from those of infrastructure, speed limit posting and enforcement, land-use, jobs-housing balance, vehicle fleet composition, etc. Interaction effects of driver, vehicle, and infrastructure characteristics on driving patterns also cannot be ascertained without the development of enhanced data collection techniques.

Because the electronic travel diary (ETD) will automatically log trip details, air quality models will benefit from the improved accuracy of trip and engine start counts, soak-time distributions, vehicle activity profiles, and on- and off-network activities. The new instrumentation package will link vehicle characteristics (e.g. size and horsepower), vehicle operating conditions (e.g. speed and acceleration), engine operating conditions (e.g. engine rpm, and throttle position), with driver characteristics (e.g. age and gender) , trip purpose (e.g. work and shopping), and route choice (e.g. freeway and local road, as indicated by monitored geographic position). The wealth of data collected by such a system provides the opportunity to learn a great deal about driver and households relationships with respect to trip generation, trip chaining, route choice, and driver behavior. A wide variety of emissions related research questions that are currently intractable due to lack of data can be addressed once the new instrumentation package is online. For example, the emission characteristics of various vehicle types operating under various roadway conditions can be discerned through analysis of data collected by the instrumentation package. The interactions of driver characteristics, vehicle characteristics, speed, acceleration, change in throttle position, and vehicle enrichment can all be studied.

5. LITERATURE REVIEW

In developing the specifications for the electronic travel diary, the research team created a literature inventory of state-of-the-practice travel survey methods. Previous travel diary studies in Atlanta and other major metropolitan areas were reviewed. The review of research literature focused on accuracy issues and suspected travel survey biases that could be avoided in future studies. The researchers reviewed technologies and methodologies employed in previous instrumented vehicle studies, including those that use GPS only and those that use onboard monitoring devices. Previous research results also helped the research team identify particular demographic characteristics believed to influence personal travel behavior for use in household sample selection and control. The literature review is summarized in a separate report (Wolf, et al.; 1999a).

5.1 Literature Review Objectives

1. To research past state-of-the-practice travel diary survey methodologies. This research includes the analysis both interactive and automated data collection methods, as well as the more traditional manual methods, in order to design an instrumentation system optimized to gather all feasible and relevant data while minimizing data collection errors and omissions. Driver procedures for system use will also result from analysis of this research. Sections include:
 - Travel Diaries: Manual Data Collection Methods (PAPI)
 - Travel Diaries: Interactive Data Collection Methods (CATI)
 - Travel Diaries: Automated Data Collection Methods (CASI)
2. To research trends within the field of travel behavior research. Sections include:
 - Trends in Travel Behavior Research
 - Stated Preference Surveys
 - Selection of Travel Surveys and Studies
3. To gain knowledge of other vehicle instrumentation studies and/or related technologies available for transportation analysis. Sections include:
 - Instrumented Vehicle Studies
 - Other Transportation-Related Technology Applications
4. To investigate driver and vehicle selection processes and methods used in past research efforts. This investigation will aid the research team in identifying successful driver solicitation strategies and promising sampling techniques. This research will also examine the effectiveness of monetary participation incentives. In addition, this research will assist in the stratification of drivers to be selected in Atlanta to obtain an unbiased sample. Sections include:

- Survey Bias and Response Rate Issues
5. To explore human factors elements of instrumentation. This will enlighten the research team as to potential impacts or nuances to ensure effective design of the onboard vehicle instrumentation package. Most of the research in this area is in the field of ATIS (Advanced Traveler Information Systems).
 - Route Choice/Driver Information Preferences

5.2 Related Projects

The research team has reviewed reports related to the following related projects to gain knowledge of lessons learned and to better differentiate our project from these projects (Wolf, et al., 1999a).

- 1) Battelle and Federal Highway Administration (FHWA) - Lexington Project
(Elaine Murakami, 202-366-6971)
- 2) Battelle, California Air Resources Board (CARB), and FHWA - California Project
(David Wagner, 614-424-4388)
- 3) CARB - Use of GPS for Collection of Motor Vehicle Activity Data
(Michael Benjamin, 818-459-4385)
- 4) Netherlands - PDA Travel Diary Project
(Geert Draijer, G.J.A.Draijer@AVV.RWS.minvenw.nl)
- 5) Texas Transportation Institute – Austin Household Survey 1998
(Dave Pearson 409-845-9933, david-pearson@tamu.edu)
- 6) European TEST - Long Distance Travel Diary (Kay Axhausen, axhausen@ivt.baum.ethz.ch)
- 7) National Cooperative Highway Research Program (NCHRP) Synthesis 258: Applications of GPS for Surveying and Other Positional Needs in Departments of Transportation

6. SYSTEM SPECIFICATIONS (FUNCTIONAL)

This section contains the functional requirements of the overall instrumentation package specified by the research team. Detailed functional specifications are provided for each component. The detailed technical specifications and analysis of vendor equipment are contained in a separate document (Wolf, et al., 1999b).

6.1 System Overview

The integrated instrumentation package will consist of a driver-accessible electronic data logger for capturing travel diary information, an onboard global positioning system (GPS) with a low-profile trunk-mount antenna, an onboard engine computer monitoring system, and an onboard personal computer. All equipment will be battery powered and integrated. With the exception of the driver data logger, all equipment should be self-contained in a single suitcase-sized package (although the power supply unit may be contained in a separate suitcase). Equipment will be left in the vehicle for up to one week. To conserve power, components should be configured to remain dormant when the vehicle is not in operation (data collection would be started by an auto ignition signal). If powering down the system is infeasible, data will be captured continuously, and post-processed to eliminate times when vehicle is not in operation. The configuration of the unit will be such that the system can be placed easily into the trunk of a vehicle with connecting cables to the travel diary logger, GPS antenna, the vehicle's onboard diagnostic system (OBD), ignition system (possibly), and the vehicle battery and/or supplemental battery pack. Equipment should be 'plug-and-play' so that Georgia Tech personnel can handle the installation without the assistance of a certified mechanic (to minimize installation cost). Primary system design objectives include minimizing the size and visibility of system, automating activation and deactivation, and providing a simple user interface.

The equipment package will be designed to provide cross-linked information on trip purpose, real-time vehicle position, and real-time engine operating conditions. Actual engine parameters such as rpm, manifold absolute pressure, throttle position, etc., that are related to engine emissions will be recorded simultaneously with vehicle operating profile (speed time trace) and location of the vehicle on the transportation network. The data collected by the system will provide a significant increase in spatial and temporal resolution to 'traditional' travel-diary-type data.

All of the information will be stored in ASCII or Binary format on a hard disk of the onboard computer. When the information is uploaded to an established GIS system currently used for development of a modal emissions model (MEASURE), information on roadway parameters (grade, lane width, etc.) will be linked to on-road operating conditions (Guensler, et al., 1998).

6.2 System-Level Criteria

- Easily installed and uninstalled (portable, no garage or mechanic required)
- Minimized respondent burden (automated system - activation, data collection, and deactivation)
- Minimized size and weight (reduce intrusion and load on vehicle)
- Minimized chance of theft or damage (low-profile and tamper-proof)
- Reliable data collection
- Durable
- Reasonable cost
- Compatible with external data streams (e.g., temperature, humidity, solar load, catalyst temperature)

6.3 Criteria Ranking and Issues

1. Easy to install and uninstall (portable, no garage or mechanic required)
 - The main issue to be addressed here is the provision of an adequate power supply. While it would be possible to tap into a vehicle's alternator to allow system batteries to be recharged directly, a certified mechanic would be required to perform the work. Plus, individuals may hesitate to participate because it will be more difficult to reassure that no damage will result. A sufficient independent power supply must be identified and/or systems to recharge the batteries that do not involve cutting into the electrical system must be identified.
 - A minimum number of connections to vehicle systems should be used.
2. Reduce respondent burden (automated system - activation, data collection, and deactivation)
 - The participant should not have to activate or deactivate equipment
 - In the case of system failure, automated detection and recovery routines should be provided. In the case of unrecoverable failure, a mechanism should be provided to alert the driver so that the error can be reported to the research team.
3. Minimize size and weight (reduce intrusion and load on vehicle)
 - Minimize intrusion of equipment to driver and into storage space.
4. Minimize chance of theft or damage (tamper-proof and durable)
 - Identify appropriate liability and response in case of vehicle damage due to vehicle damage caused by break-in and theft of equipment.

6.4 System Configuration

The functional specifications for system and component performance led to the system configuration as seen below, with the driver interface functioning as an independent unit. Separate components offer the most flexibility and somewhat better performance than integrated solutions.

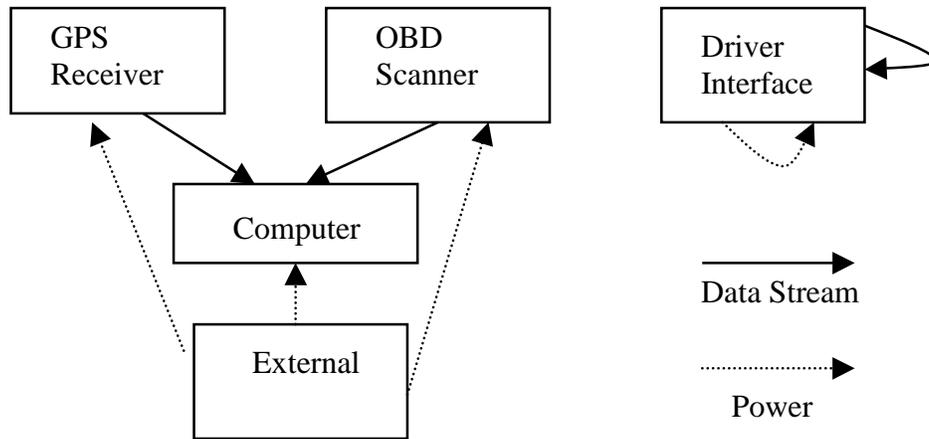


Figure 1 - Separate Components, Driver Device, and External Battery

With the exception of the driver device and the GPS antenna, the rest of the instrumentation package will be contained within a case which will be stored in the trunk of the automobile, in the rear compartment of a sports utility vehicle, or directly behind the seat of a pick-up truck. The key components and their location within an automobile can be seen in the following diagram:

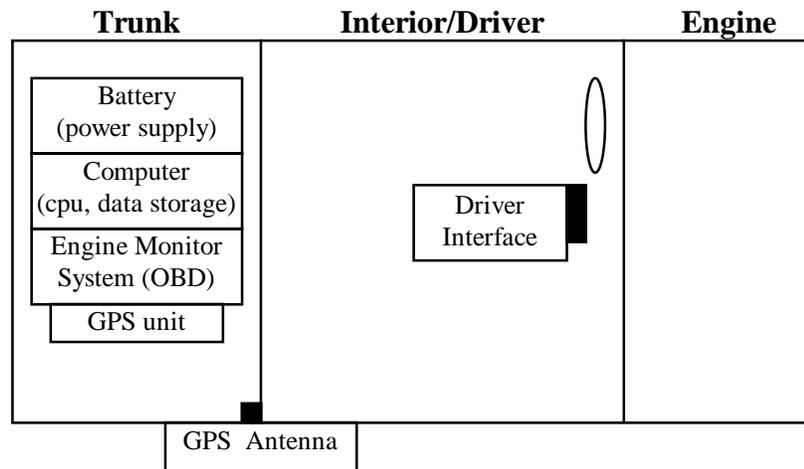


Figure 2: Location of System Components within Vehicle

Key Components

- Driver Interface
- Computer
- Power Supply
- GPS Unit with Antenna
- Onboard Engine Monitoring System
- Connecting Cables / Wires
- Any Additional Sensor Devices

Additional Potential Components and/or Features

- Power Surge Protection
- Noise Suppression
- Cooling Mechanism
- Security Devices
- Mounting and Vibration Mitigation

6.5 System Integration

The development of the electronic travel diary requires integration of the GPS position sensor, engine monitor, driver interface, and other vehicle sensors to produce a datastream relating driver entered trip information to vehicle location and engine parameters.

All data must be time-stamped to relate it to all the other data. The CPU clock and the GPS clock should be available for time-stamping. An accurate CPU clock is essential to quality data collection. A method to keep the CPU clock synchronized with the GPS clock needs to be determined. For standalone sensors, the accuracy of the internal clock should be verified.

Optimally, the data stream generated by the ETD would be saved complete and ready for analysis. The choice of components will determine whether the data will be available in real-time. If an GPS-only unit is used, data must be post-processed to provide differential accuracy. A unit that simultaneously monitors US and Russian satellites (GLONASS-GPS) might be able provide the required accuracy without post-processing (reducing labor costs). However, such units are more expensive and outside the scope of the exiting project. The choice of driver

interface will dictate the ability to combine trip information into the location/engine data stream. Additional, standalone sensors will have to be combined with the vehicle data stream during post-processing.

The system will need to be placed in low power mode while the car is off to conserve battery power. If power can be acquired from the vehicle, safeguards to ensure that the ETD will not fully discharge the car battery need to be put in place. Power management has to be handled by the master control program, triggering the acquisition devices into a low power mode or off for power saving and then restoring them within approximately 10 seconds to record the trip data.

Many of the identified components have proprietary interfaces. To complete the system, these proprietary programs must be integrated. Optimally, open software interfaces to the individual components will allow the master program to fully control the components.

6.6 Other Technical Issues:

During the evolution of the project, a number of significant technical and sampling issues were raised:

- In-vehicle methods designed to replace a manual travel diary do not necessarily allow for electronic capture of non-vehicle trips, such as those made via walking, cycling, or transit. Individual diaries also do not record separate trips made by other household members. However, because the driver data entry device is portable and lightweight, the stand-alone handheld unit can be used as a personal travel diary rather than a vehicle diary. The interface program can be modified, inserting a mode query, so that non-vehicle trips can be entered. It is also possible to adapt the Psion unit for simultaneous collection of positional data. A GIS signal can be integrated through a data COM port. By issuing electronic diaries to all household members (or an electronic diary to one member and manual diaries to other members) a comprehensive set of trip data can be captured for the household. If GIS is coupled with the diaries, enhanced positional data can also be captured. The units can be used as travel diaries or activity diaries.
- Because participants can undertake travel without recording trip-level data, it is still possible for some vehicle trips to go unrecorded. The data collected automatically by the vehicle will still be available, but trip purpose information would be lacking. On the other hand, if driver data entry is made mandatory (for example, systems can be developed to prevent the car from starting until data are entered), inaccurate data may be captured instead. The driver procedure will remain optional. There should be no GPS loss (except when the vehicle is in an urban canyon environment or in a parking garage). Therefore, the GPS data can be used to identify missing trips and spatial matching can be performed to assist with trip purpose identification.
- Some vehicle makes and models have installation limitations (such as minimal storage space available or lack of onboard monitoring modules for some vehicle types/model years). Hence, some vehicles may need to be screened from the study (pickup trucks, small sports

cars, pre-1984 vehicles, some foreign models, etc.). The exclusion of vehicles has the potential to bias the sample. In addition, other participant issues may also bias the sample selection, such as fear of technology and maintenance of personal privacy. The research team will identify any limits imposed by the onboard monitoring modules, including identification of all vehicle models with computer interface located under the hood. From a travel behavior perspective, the vehicle data are 'bonus' data – the team will capture the essential travel diary and GPS data from the other system components. The solution will be to design a modular system, with the electronic travel diary as the minimum specification, with travel diary and GPS data as the preferred minimum data set, and with the travel diary, GPS, and onboard monitoring data as the desired data set.

- A less expensive (and less comprehensive) equipment configuration (perhaps the Battelle equipment without the onboard vehicle computer monitoring device or a Pision/GPS combination) will be considered for secondary vehicles. Pre-participation surveys must be developed to identify basic personal travel characteristics and to identify how much each household vehicle is used, as these details may affect the household equipment setup. For households with two primary vehicles, the research team will investigate the economic feasibility of instrumenting both vehicles.

7. COMPONENT SPECIFICATIONS (FUNCTIONAL)

The research team developed a set of desired functional specifications for each system component by evaluating the relative importance of the following general functional characteristics of concern:

- User Interface (keyboard, display, audible, none, etc.)
- Power Supply (real-time or off-line charging, in vehicle or in home)
- Connections (power, data transfer, etc.)
- Initial Setup
- Activation (power on)
- Data Storage (what, when/how often, where)
- Data Transfer (if necessary, at what speed)
- Deactivation (power down)
- Size
- Portability (fixed mount or portable)
- Durability (heat, vibration, impact, and liquid resistant)
- Security (locks, cover panels, concealment)
- Ease of Use (user friendly, minimal user burden)
- Exception Handling (missing codes, children playing with buttons)
- Contingency Plans (in case of partial or complete component failure)

Specifications on available equipment for each component, along with any correspondence, articles, and reports, have been separated into folders and are available for review:

- Driver Interfaces (Handheld devices / keypads / displays)
- GPS units
- Onboard Monitoring Devices
- Computer/CPU
- Batteries
- Software
- Misc. Equipment

In addition, detailed project technical specifications and analysis are contained in a separate document (Wolf, 1999b).

7.1 Driver Interface

7.1.1 Functionality

Upon entering the vehicle, the driver will activate the driver interface and enter (or select) his/her identification within the household. Passenger identities will also be entered. The driver will then enter the origin and destination of the trip that is about to commence. The device can then be deactivated until the beginning of the next trip. Hands-on instruction and a simple written manual will be provided to explain how to use the device.

Initial setup procedures should establish the default driver identification and the arrangement of options in the origin-destination list. Origin and destination codes will be configured to provide information required to identify trip purpose for activity-based modeling. Standard origin-destination codes will be used, plus some additional codes: home, work, shopping, dining, visiting friends, video rental, recreation, and others defined in the screening process. Because the origin of each trip should be the destination of the last trip, trip origins will default to the last destination. Drivers are required to verify the trip origin. Drivers override the origin code by reporting a missed trip. This override contingency results in the key entry of trip(s) that were not recorded by the driver.

The driver interface must be interactive, user-friendly, simple, and non-intrusive. The time for data entry must be kept at a minimum (the target maximum is 15 seconds). Cables connecting the driver device to a power source, to a data storage device, and/or to the computer (if necessary) must be bundled and fixed so that they will not interfere with the driver or passengers. Contingency procedures will be necessary in the event of disconnected cables (resulting from driver or passenger actions).

An alternate configuration, the stand-alone handheld device, allows the driver interface to be independent of the computer that is located in the trunk of the vehicle. The device could either be kept with the driver or in the vehicle at all times. The driver would enter the vehicle, turn on the interface, and enter required information that would be stored on a self-contained PCMCIA, ATA, SRAM, or similar memory card. Power for the device could be provided either by a cigarette lighter connection cable, by recharging at home, or for low power draw units, by providing fresh AA batteries at the beginning of every week. The advantage of this configuration is that it eliminates cables running from the cab to the trunk and reduces possibilities of vehicle occupants inadvertently disconnecting the cable(s). However, this configuration does require that the data to be time rectified with GPS and scanner data collected on the computer located in the trunk. In addition, post-processing software would be needed to detect trips not recorded by the driver (this event could be detected in an on-line configuration, with driver prompting for missing trip data).

7.1.2 Device Features

The interface for the driver to record necessary information may be a keyboard (connected to computer in trunk), a handheld data capture device, or a voice/audio recorder.

Keyboard:

The keyboard or keypad would allow the user to input the driver identification, trip origin, and trip destination. The keys should be positioned in a logical manner so the user can easily and quickly enter the required information. (Wand / barcode scanning may be evaluated as an alternative to driver key entry; however, this will introduce an additional data element into the vehicle – the barcode sheet.)

Size: The minimum number of keys on the keypad will be dependent on the number of keys required to adequately represent the driver, passenger, origin, and destination selections. Of course, a combination of list scrolling, highlighting, and selecting would eliminate the need for individual numbers or codes for each data need. Total keys available for key entry should be minimized to make device user-friendlier. Alphanumeric keypads are probably necessary for entry of personal names or unusual destinations not preloaded by software.

Marking: Keys on the device should be easily recognized by the user. When entering information, the user should be able to look at the keys and determine which one is applicable for the given prompt. This can be accomplished by marking the keys uniquely with an overlay, with color-coded keys, or with text on each key.

Lighting: Backlighting of the keys would ease data input during dusk and nighttime travel. Problems with backlighting include the additional power draw on the batteries and the threat of theft if the unit's lighting remains on when the vehicle is not in operation. However, if the device is only powered on during key entry, these problems will not exist. If the device is powered on at all times, an on/off switch for backlighting could be provided.

Display:

The display will query the user for required information such as driver and passenger identification information, origin information, and destination information. If the device is connected to the rest of the instrumentation package, other information could be relayed to the driver through the interface, such as problems detected with other components.

Size: The size of the display is defined by the number of lines of text by the number of characters displayable on each line. Thus, a 4x20 display will display 20 characters of text on each of the four lines. The size of the display will limit the information to be displayed to the user. Thus, explanations for each origin / destination will not be possible on units with small display sizes. There are two related issues to investigate: 1) the size of the viewable window; and 2) the ability to scroll within the logical window.

Character size: The size of the characters in the display (typically measured in millimeters, with a range of 4 to 10) will affect the readability of the display.

Type: The type of display (LCD, vacuum fluorescent) will affect the power draw, the ability to read in direct sunlight or at night, character format, and the display color, brightness, and viewing angle.

Backlighting: Backlighting of the display would provide easy reading of information during dusk and nighttime events. Problems with backlighting include the additional power draw on the batteries and the threat of theft if the unit's lighting remains on when the vehicle is not in operation. However, if the device is only powered on during key entry, these problems will not exist. If the device is always powered, an on/off switch for backlighting could be provided. Finally, backlighting may affect the ability to read the display in the sunlight.

7.1.3 Power Supply / Power Draw

Power to the unit can be supplied through the vehicle (cigarette lighter), a 12V battery supply in the trunk of the vehicle, or self-contained rechargeable batteries. Each option has particular advantages and disadvantages, depending on the type of interface selected. The power supply options will be limited by characteristics of available equipment and will have different advantages based on the where the data are stored.

Power draw, in general, should have a low amp-hour rating. If a vehicle cigarette lighter is used to supply power, the power draw should be such that the vehicle battery retains a serviceable charge for starting the vehicle at all times. The amount of power required will be a key item for interfaces connected to and powered by external 12V batteries. Below is a brief analysis of power options:

Cigarette lighter: The driver interface is connected to the cigarette lighter in the vehicle to power the unit. Dependent on the connection, data will be stored on the unit or on the CPU placed in the trunk. By eliminating the connection to the trunk, setup time is reduced and drivers are not inconvenienced by the wired connection to the diary. On the other hand, such a power configuration may require the driver to connect/disconnect the device for each trip. Some vehicles may not have a functional cigarette lighter port. Smokers may need the lighter.

Self-contained batteries: Batteries contained within most driver interfaces provide power. For rechargeable units, the interface would be taken inside the home every night and placed in a cradle which would recharge the batteries and provide enough life for one full day of operation (minimum). Many of the units have battery life long enough to be used for a week without requiring recharging or, in the case of units with alkaline batteries, replacement of the batteries. Other units could be used which are powered on for recording of trip information, then powered off during non-operation phases. Power requirements for this type of operation would be low and no recharging would be necessary during the one week data collection period. Battery types include alkaline, NiCad, or lithium, with varying life-cycle costs and power available. Advantages are no power cables are required from the trunk and no connections to the vehicle are required

for operation. Disadvantages are that the user will either have to remember to carry the device into the home and back into vehicle (for in-home recharging) or will have to power on and off the unit to conserve batteries (for no recharging option during data collection period). The units should have an auto shutdown feature to shut off the unit when not in use to conserve batteries.

12V battery: Power is provided to the unit through 12V batteries in the trunk of the vehicle, which are also providing power for the GPS, scanner, and computer. Power cables would extend from the batteries to the unit (along with any RS232 cables). No intervention is required on the part of the user to provide power. However, running cables from the trunk batteries to the cab and the additional power draw on trunk batteries are disadvantages.

Note: The research team must investigate the availability of battery-switching hardware. For example, can the system switch from Battery A to Battery B whenever the voltage drops below a specified level.

7.1.4 Driver Interface – Integrated vs. Stand-Alone

Two basic system configurations can be employed, one with the driver interface connected to the computer (Alternative 1), and the other with the interface as a stand-alone product (Alternative 2). There are several issues with the two options and each has particular advantages. The table below summarizes the two options' advantages and disadvantages.

Alternative	Cost	Time Stamp	Integration Complexity	Setup/Cables	Power	Convenience	Non-Auto Trips	Data Storage
Integrated	+	+	-	-	0	0	-	0
Stand Alone	-	-	+	+	0	-	+	-

Cost of the alternatives. The two alternatives are a dummy terminal or keyboard (Alternative 1) versus a handheld computer (Alternative 2). The dummy terminal would provide a substantial cost savings over the handheld computer, especially given the eliminated requirement of a separate CPU. Supplemental memory would most likely need to be provided on the handheld in the form of a PCMCIA card (probably via an SRAM or ATA card which are supported by many manufacturers). Because the program and data can be stored together, internal cards can be

swapped out after a study to increase the speed of equipment turnover to new participants. However, the internal cards add to the cost of the stand-alone alternative.

Time stamping of data on the two configurations. Alternative 1 provides direct connection with the computer time (GPS & OBD). Thus, each trip entered can be directly related to operation and location of the vehicle. Alternative 2 would have to be time-reconciled in the post-processing phase, introducing possible data synchronization problems (although trip-purpose data should be of low enough frequency to provide accurate matching).

Integration complexity. Alternative 1, by definition, requires more real-time processing and integration than Alternative 2. Data from the stand alone unit would be integrated in a post-processing phase. This means that Alternative 1 requires more ‘up-front’ integration efforts, although the driver log file could actually be stored separately on the main computer and post-processed later, similar to the stand-alone post-processing step.

Setup and installation of the vehicle interface. Setup of the integrated unit would require an RS232 cable running from the cabin of the vehicle into trunk, while Alternate 2 would be free of any cables (except possibly power from cigarette lighter).

Power required by the interface. Power for Alternate 1 would come from 12V batteries in trunk, if any auxiliary power is required. A keyboard without a display would not require any power connection. But because the driver would not be able to confirm data entry, a keyboard without a display is not likely to be a viable solution. Alternate 2 would obtain power from the cigarette lighter or from internal batteries (possibly recharged in the driver’s household).

Inconvenience to driver. Both alternatives require data entry at the beginning of each trip. The unit itself could remain on a mount, on the passenger seat, or on the floor of the vehicle when not in use. Alternate 2 does have some additional driver burden due to the power source, with the driver either carrying the device in and out of the vehicle once a day to recharge the battery in-home or plugging the device into the cigarette lighter before entering data. On the other hand, the portability of the stand alone unit would allow its use in activity and mode choice studies.

Capture of Mode Choice. Alternate 1 is strictly for in-vehicle use and could not be used to record non-auto trips. Alternative 2 provides a useful interface for recording all trips of an individual, provided the subject carries the unit with them.

Data Storage. Storage of driver-entered trip information can occur at several locations, depending on the alternative chosen. In Alternative 1, the data would be stored in a file on the main computer. In Alternative 2, the data could be stored in a file on the unit or on the CPU. Most of the handheld devices have minimal memory, 1MB to 2 MB. The cost of additional memory increases cost significantly in the units. Storage requirements will depend on the control program size, the amount of data to be stored, and possible interim data transfer capabilities. Collection of trip information is a minimal but essential task; data elements required are driver and passenger identification, trip origin and destination, and possible start time and date verification. Coding of selection choices will drastically reduce storage requirements.

7.1.5 Units Evaluated

The following units have been evaluated for use in the project:

<u>Abbreviation</u>	<u>Product Name</u>
PGI	Phoenix Group Vehicle Data Terminal
Telxon	Telxon PTC-610
OT30	WPI Oyster OT30
PT1000	WPI Oyster PT1000
IEE CDU	IEE Control Display Unit
JAMAR	JAMAR Technology TDC-8
Percon	Percon PT2000
Organiser II	Psion Organiser II
Workabout	Psion Workabout

A table of features for each unit and a more in-depth analysis of each unit can be found in the technical specifications document (Wolf, et al., 1998b).

7.1.6 Initial Recommendations

In the original proposal, the research team identified point-of-sale (cash register type) technologies as the likely travel diary solution. These units consist of a combined keyboard and display unit. Several point-of-sale devices of this were identified, but proved infeasible due to cost (IEE CDU), size, or because they were custom manufactured for large quantity purchasers (PGI).

Other handheld terminals can be used in this fashion; however, the unit cost could be much higher. One low-cost dummy terminal available is the *Oyster OT30*, which has no data storage capability (~\$400). The *Percon PT2000* (~\$2000 with accessories) bridges the gap between dummy terminals and self-contained handheld computers (with a price approaching the handheld terminals). The *Oyster PT1000* is a handheld programmable data terminal with many functions that allow for capture of in-vehicle trips as well as other trips (cost approximated at \$2000 with accessories). The *Psion Workabout* is the device with the most comprehensive list of available options, including a docking station and in-vehicle cradles. Data storage can be expanded to 16 MB and the unit provides a graphic user interface. The research team has decided to acquire these four representative technologies, which offer a range in functionality and price, and to assess their usefulness in the overall instrumentation package.

7.2 GPS Unit and Antenna

7.2.1 Functionality

The Global Positioning System (GPS) receiver and antenna must be capable of providing real-time (1 Hz or 2 Hz) spatial location for the vehicle to within 10 meters (with or without differential correction) whenever a minimum of 4 satellites are in line-of-sight. The GPS unit will provide geocoded x-y coordinates that can be tied to the trip purposes coded by the driver. The GPS unit provides spatial resolution of origin, destination, and detailed information on route selection and trip distance. Satellite time codes provide complete temporal resolution to the data stream. This information will provide an additional dimension to current travel demand data that can be readily used in improving 4-step travel demand model development for trip distribution and route choice. Data accuracy should be greatly improved, because driver estimates of trip distances and travel times are eliminated by incorporating GPS. In addition, the GPS unit provides a validation check against the electronic trip log by recording trips made even when the driver does not.

A low profile trunk-mount antenna has been identified that reduces concern that high-profile antennas will be lost or stolen. Magnetic mount antennas will also be evaluated but are less desirable due to theft risk. Requiring the driver to lock the antenna in the car when not in use may result in the loss of GPS data if the driver forgets to remount the antenna prior to a trip.

The accuracy of GPS-collected speed data (distance traveled per second) is to be adequate for estimating average speed. In addition, the GPS data will provide an opportunity for determination of traffic conditions (congestion/delays, intersections, etc.) based on vehicle speed and road classification, which is available in a local GIS database. However, equipment specifications and the functionality of the onboard device may preclude the GPS unit from being used for collection of accurate acceleration rate data. The engine computer monitor is being tasked with collecting the required acceleration rate data.

The following component specifications should be met:

- The unit should be capable of collecting/computing the following data elements: latitude, longitude, elevation, date, time, speed (if not calculated in real time, can be calculated in post-processing mode), heading, number of satellites used, PRNs of satellites used., PDOP and RMS (for use in error estimates).
- The user should not be required to interact with the GPS system. A software interface via computer should trigger data collection.
- Power consumption should be minimized. Computer power-down (power-saver mode) is desirable with a software to trigger to the battery saver mode. A single power supply is preferable to power all of the electronic equipment.
- Desired position error should be less than 10 meters at a minimum data update rate of 1 Hz. A configurable data rate is desired.

- Initial positions should be determined a maximum of 20 seconds after the unit is powered up on a warm start (60 seconds for initial system activation). Reacquisition time on satellite loss should be no more than 3 seconds.
- An active antenna with low susceptibility to multi-path error is desired. The unit should securely fasten to the exterior of the vehicle to reduce theft risk.
- Base Station Range - Accuracy degrades as the distance is increased between the base station and the rover. Real time differential correction was not an option in Atlanta. If real-time differential correction is used in other areas, communications range must be taken into account.
- A multi-channel receiver is required for kinematic GPS. At least 10 channels are preferable for simultaneous monitoring of up to 10 satellites.
- A dead reckoning capability is desirable because it allows vehicle tracking even when the GPS is blocked.
- One week's worth of data should be accommodated in storage. Data transfer should be easy and efficient.
- Systems that monitor US satellites must be capable of differential correction to reduce position errors. Previous experience with non-differentially corrected data revealed that route identification cannot be easily automated by the computer (hand matching is required). Real time differential correction is desired, but not currently possible in the Atlanta urban center due to frequency restrictions. Post processing differential correction should be provided.
- GIS Database Accuracy (base maps) - Critical for automated map matching in post-processing; manual map matching must be minimized
- Post-processing of data - Differential correction should be accommodated. Thus, a RINEX compatible data stream should be provided so that a high-resolution Ashtech base station (carrier phase unit) can be used. Map matching should be accommodated. Missing data should be processing forwards and backwards (capable only on very high end receivers). Data streams must be capable of merging with other data streams. Data merging may be done during data collection depending on communication capabilities.
- A multi-connector/wiring harness is preferable over several individual connectors/loose wires
- Software and hardware should be easy to install
- In case of partial or complete component failure, the user should be notified so that the research team can be contacted.

7.2.2 Issues

- Second-by-second capture of position is desired so that the datastreams from equipment can be linked with specific positional data (e.g. road grade and congestion levels) available through the Georgia Tech GIS system and Georgia DOT advanced traffic management system. 1Hz sample rates are desired, but 0.5 Hz rates may be acceptable.
- Issues associated with data generation rate, transfer rate, and CPU operating speed may arise as a function of manufacturers' hardware specifications.
- Given the warm-up time required for initial GPS position identification, it may be necessary to develop a mechanism that will activate sleeping equipment before the engine is started so that data will be collected before the vehicle starts moving. Startup position data will be known from the previous shutdown. Route interpolation should only be for a few seconds. A clock capable of recording an engine start (voltage sensor) may need to be employed.
- Some GPS units employ proprietary software developed by the of GPS manufacturer. Such software may prevent the unit from being used in a system because proper processing of binary GPS unit data may not be allowed unless the proprietary software is integrated into the system. Avoid proprietary software.
- Because the GPS signals can be obscured in urban street canyons and under broad leaf canopies, a dead reckoning capability is being investigated. This will involve the incorporation of an electronic compass which can be used to link observed direction and engine monitored speed/distance to determine route choice.
- The team will investigate the accuracy of a GIS base maps as an issue in this project. If automated map matching is to be made possible with minimal errors and user intervention, the GIS base map must be accurate. A separate paper is being prepared on this issue for presentation at the Annual Meeting of the Transportation Research Board.

7.2.3 Potential Source / Supplier

- ASHTECH -- Ashtech has several midrange GPS receivers, including the Sensor II Receiver with 12 channels and the GG24 Sensor 24 channel receiver, which uses both GPS and GLONASS.
- GARMIN GPS receivers with post-processing differential correction (SRVY II, Super C/A Sensor)
- Low-End GARMIN Receivers --The Garmin GPS II Plus was evaluated. It is a 12-channel parallel GPS receiver. Accessories available for the Garmin unit include the trunk mount antenna, RS232 cable, and connection to 12V DC power source. Output is available in NMEA-0183 format. Size is very small (6.15 x 2 x 1.23 inches). Acquisition time is 15

seconds on a “warm” start, 45 seconds on a “cold” start, and 5 minutes to auto-locate. The update rate is 1 Hz, with 15-meter positional accuracy.

- System Integrated GPS Chipset --The Motorola Oncore GPS is a chipset for use by OEM and systems integrators for embedded applications. The system is essentially a board for insertion into a system to build in a GPS system. GeoResearch has the GPS Workhorse, which also uses the Motorola 8-channel Oncore Receiver.

7.3 Onboard Engine Monitoring System

7.3.1 Functionality and Purpose

Onboard engine monitoring devices connect to the data ports of engine control computers on 1982 and later model domestic and foreign vehicles. One such device, the Snap-On Scanner, is capable of monitoring up to 70 vehicle and engine operating parameters second by second and is typically used in automobile repair facilities to display those parameters to a repair technician. A proprietary software interface (previously developed for the research team) allows the information to be downloaded to a computer on a real-time basis for subsequent analysis.

Based upon previous field testing, the onboard scanner provides more accurate data on vehicle speed and acceleration than is provided by low-end GPS systems (Grant, et al., 1996). The goal of integrating the scanner unit into the package is to link vehicle speed, acceleration, engine rpm, manifold absolute pressure, throttle position, and other parameters known to affect emission rates, with driver and vehicle characteristics, geographic position, and trip purpose. A wide variety of emission-related research questions that are currently intractable due to lack of onroad engine data can be addressed once this capability is developed. For example, the interaction of driver characteristics, vehicle characteristics, speed, acceleration, and change in throttle position provides a wealth of data that can be used to separate driver behavior from road-induced driving patterns. The engine operating characteristics of various vehicle types under various operating conditions can also be discerned through analysis of data collected by the scanner units.

7.3.2 Issues

- The sampling rate of data from the engine computer can vary across vehicle makes and models. Hence, 1Hz resolution of the datastream may not be possible for all vehicles. Low frequency datastreams will not necessarily provide reliable data for acceleration or other outputs that employ measured parameters in their estimation. Similarly, if data are only reported in integer values, calculations using the data may not provide desired accuracy. Smoothing techniques may need to be developed to address low frequency sampling rates.
- The time and date stamps need to be reconciled across units.
- It is important to monitor vehicle activity during the first few minutes of operation, as emissions are very high until the catalytic converter warms up. The minimum power up time

for the unit may be an issue. The OBD scanner may need to be started prior to engine start so that the first few seconds of operation are not omitted from the datastream.

- Current limitations of the Snap-On Scanner software must be removed and/or fixed in order to use this device in the instrumentation package. The company that developed the software for the Snap-On unit informed the research team that they would require \$40,000.00 to perform the necessary programming work to adapt the unit to our system. Since the time that the OTC unit was integrated into the system (OTC is Snap-On's competitor) the company has now offered to develop the software for \$5,000.00. The Snap-On unit will be developed through supplemental research.

7.3.3 Potential Sources/ Suppliers

- Snap-On Scanner – A standard OBD monitoring device for use in engine diagnostics and repair.
- OTC Scantool - A standard OBD monitoring device for use in engine diagnostics and repair.
- AED, Inc. VCS PC card - This provides a solution that plugs into a PCMCIA slot on a computer requiring no user interaction with a separate box to setup. This unit only works with OBD-II compliant vehicles.
- Nu-metric's Nitestar Distance Measuring Instrument (DMI) - The DMI record the distance a vehicle travels over fixed intervals (1 hertz). The information from a DMI would be speed/acceleration, and no engine operating parameters.
- Radian Corporation's 3-Parameter Datalogger - The datalogger has been used to collect speed, MAP, and RPM of vehicles. The installation procedure varies by vehicle make and model (and the unit must be installed by a certified mechanic). This unit does not allow the measurement of throttle position.
- Instrumental Solutions' Autologger

7.4 Temperature / Relative Humidity Sensor

7.4.1 Functionality

The engine and accessories are monitored and reported by most engine computers. Air conditioning operation is known to affect vehicle emission rates through the addition of an engine load. Analysis of vehicle accessory usage needs to be related to such factors of ambient temperature, cabin temperature, and relative humidity. Data streams from environmental sensors could be used to relate air conditioner operation to these variables.

Temperature and humidity should be captured at appropriate intervals for data analysis. External temperature and humidity will not vary significantly over time periods, thus the frequency of measurement can be increased to reduce the amount of data. The temperature (and possibly humidity) internal to the vehicle will need higher frequency of measurements to assess the usage of air conditioning. These data streams are supplemental to the original goal of the project, but could provide valuable information for modeling vehicle accessory operations.

The times associated with each measurement should be reconciled with other data to provide accurate comparison of the data. Integrating the measurements into the computer would provide this data measurement. External probes are available which measure these variables, with storage on the computer via a data acquisition card and software. Loggers are also available which record temperature and humidity on self-contained units along with the time. The time is preset by a computer, along with the variables to capture and sampling frequency. Clock / time synchronization will be needed if this configuration is selected.

7.4.2 Potential Sources / Suppliers

Data loggers have been ordered and received from Onset Computer Corporation. The devices are small, self-contained units that log temperature and relative humidity at intervals specified by the user. The temperature devices have external temperature probes that can be used. One device, the Stowaway, can store 32,500 readings. Thus, the maximum sampling rate for a full seven-day data collection process is one temperature measurement every 30 seconds. The HOBO logger can store 4 data streams...humidity and temperature at the unit and humidity and temperature at an external probe. With all four variables selected for capture, the minimum time between readings would be five minutes.

7.5 Solar Load (Light Intensity) Sensor

7.5.1 Functionality

Measurement of the solar load, or light intensity, is seen as a supplemental measurement that is important for operation of the air conditioner and other equipment on the vehicle. Previous data

collection on air conditioner usage showed that the humidity and solar load are likely to be important variables for determining the usage and load on the compressor.

Measurement of light intensity is made in terms of lumens/square foot. Full sunlight is approximately 10,000 lumens/ft², office lighting at 50 lumens/ft², and moonlight at 0.03 lumens/ft². The sensor should be able to properly measure sunlight conditions. Measurement of the solar load should integrate with the other data streams to provide the optimal analysis of the data.

Times should be consistent with the other devices, and the frequency of measurement should be sufficient for analysis of data. Data can be stored on the computer with other data, or logged separately and time rectified in the post-processing.

7.5.2 Potential Sources / Suppliers

One device has been received from Onset Computer Corporation, the HOBO LI. The HOBO LI measures from 0.01 to 15,000 lumens/ft². Another logger also measures light intensity (along with temperature, external, and RH) but it only measures up to 1,000 lumens/ft², which is not sufficient for measuring sunlight intensity. The HOBO LI will store a measurement once every 5 minutes for a 7 day period before filling the memory.

7.6 Other Sensor Devices

Air conditioning measurement has been targeted as one supplemental use of the system. Specifically, additional sensors could be installed to which could be used to measure a/c usage, load, and impact on emissions. The ideal measurement would be the load induced on the compressor, along with measurements of temperature, RH, solar intensity, and a/c settings (recirculation, full, fan only, etc.). The scanner unit should be able to distinguish when the compressor is on, thus resulting in measurement of compressor on fraction. However, measurement of load on the compressor is not possible with the scanner.

Another measurement that may be necessary is a temperature measurement of the catalyst. The catalyst temperature is a key variable during starts for determining when the vehicle reaches closed loop operation. This measurement would have to be completed with an external probe (thermocouple), connected to a data acquisition card to record the temperature.

Tailpipe emissions would be another option for additional sensors. The sensor would measure the concentration of pollutants emitted from the tailpipe, and would also have to measure the flow out the tailpipe to arrive at emissions rates. This measurement would also need to be logged on a computer which takes the sensors in through a data acquisition card. The USEPA is developing the ROVER system which will be capable of capturing vehicle emissions. The research team has been working with the EPA staff to ensure that the system developed at Georgia Tech will be compatible with their emissions monitoring system.

During project development, the research team identified conditions under which GPS data are not collected: 1) in the deep street canyons of downtown Atlanta, and 2) under broad tree canopies. Although the GeoResearch Workhorse unit collects data better than other units tested, there are still areas where data will not be collected (and route information will be lost). The research team plans to add an electronic compass to the package to allow dead reckoning to be conducted. By recording vehicle speed and direction with time, approximate route information can still be determined when GPS signals are not available.

7.7 Computer / CPU

7.7.1 Functionality

The computer will serve as the connection point for the various systems installed within the vehicle. Various components will input data to the computer for synchronization and storage. Data from the user interface (if integrated), OBD engine monitoring system, and the GPS unit should all feed into the computer. Other additional devices may also stream data into the computer, including ambient temperature, relative humidity, catalyst temperature, or pollutant concentration measurements.

The computer will serve several purposes, based on the final configuration of the equipment interface. The computer should be fast enough, and have enough memory and hard disk space to record activity for the design length of 7 continuous days. The processing needs of the machine are not thought to be very great, with minimal computation for time stamping, running of software to save data streams, and other software for energy management.

Hard disk space (or a SRAM card) will have to support the one week time frame of operation. Actual space will depend on the operation and output from other devices. If the GPS runs continuously (and data are stored continuously), then the amount of space required will be enormous. However, if data are only saved during vehicle operation, the requirements will be significantly less. The scanner will also provide large amounts of data when operating (40+ parameter values at 1 Hz). The time the vehicle is in operation, and any storage compression (binary formats) are needed to properly specify hard drive sizes. The driver interface and sensors will also provide input, however these data will not require much hard drive space for storage. Additional hard drives can be added to meet the needs of data, either through additional IDE drives or PCMCIA flash cards, based on data requirements on acquired and tested equipment.

The COM ports and PCMCIA card slots will complete connections of equipment to the computer. All equipment will be specified to output to an RS-232 port. The software running on the computer can then control input data. Standard configurations of COM ports are two, with some systems having the capability to increase the number to four. PCMCIA slots on laptops are type 2 and type 3, with standard configurations of two slots for type 2, and one for type 3. The computer chosen should meet the minimum requirements of having COM ports and PCMCIA slots for data input. Some equipment (such as GPS) can be integrated on a card for connection to a PCMCIA slot.

Accuracy and synchronization of time and date stamps from different sources must be addressed. From previous instrumentation experience, times from different devices can drift, with large differences possible over a one week period. Time-stamp accuracy among devices will expedite post-processing, as well as reduce possible errors due to matching different data streams. Sampling rates of 1-2 Hz will be investigated. Actual rates will depend on data necessary to map-match GPS data and information required to complete analyses. It is possible different devices will have different sampling frequencies.

Software running on the computer may be in several formats. Proprietary software is not desirable, but may need to be running to capture data from the scanner and/or GPS. Other software will be developed to handle all data transfer, storage, and uploading. Computer requirements of the software will depend on the manufacturer. The software operating system (DOS, Windows, or Windows 95/NT) may depend on the manufacturers. The multitasking abilities of Win95/NT may provide an option for running several programs.

The computer must function within an extreme temperature environment, humidity, shock, vibration, and thermal cycling. Portable computers generally do not meet the durability requirements. In addition, the risk of using portables without detachable screens is too high, as the screens are easily damaged and very expensive. Ideally, a ruggedized industrial computer will be selected that operates without the need of additional cooling.

7.7.2 Potential Sources / Suppliers

- DataLux DataBrick computer

The DataBrick is a compact (8"x3"x2") computer that provides a boot-sequence capability. The durable unit is designed for field work and has a detachable screen and keyboard so that the computer can be programmed and then dropped into an equipment package with minimal risk of computer damage common to portable laptops. Options available on the DataBrick include a 486 or 586 processor, RAM of 8 MB to 128 MB, hard drives up to 1.4 GB, up to 4 COM ports, PCMCIA slots, external floppy, detachable keyboard, detachable monitor, and ability to operate on AC or 12V DC power. Of all the portable, rugged computers investigated, the DataBrick is the most affordable with the options available for field use. This unit was deemed the only practical solution available given the functional specifications.

7.8 Power Supply

7.8.1 Functionality

The goal of the research team is to develop a system that will perform with minimal intrusion on the automobile. Hence, it is desirable to power all equipment without connecting to the vehicle's electrical system. The power supply system should provide enough power to operate the unit for a 7 day period, without failure. Interruption in power will cause problem with data collection, and may disable the instrumentation packages. Provisions should be incorporated to ensure power to all equipment, with a plan of priority for shutdown of equipment for low power. The power requirements under these constraints will be based on the time of equipment operation (i.e., automatic shutdown of GPS, sleep operations, etc.) and power draw of all the equipment (amp-hours of operation).

The power system chosen for the ETD should not affect vehicle operation, either by inducing additional load on the engine through increased alternator usage, or adding excessive weight to the vehicle. The system needs to be flexible for all vehicle types, including vehicles with limited trunk space (sports cars, pickups), vehicles without cigarette lighters, and vehicles where the cigarette lighter is in use with other accessories. The system should also be safe and capable of withstanding high temperatures in the vehicles. The goal is also to avoid introduction of any wiring that would require the participation of a certified mechanic.

Under the worst case, all equipment would have to be powered for the full 7 day period by external 12V batteries. The number of batteries required under this scenario would be very large. Other possibilities include shutting down some equipment when not in use, triggering on equipment with opening of doors, recharging and discharging batteries, or getting power through the cigarette lighter. All equipment will be specified to operate on 12V DC power, therefore not requiring inefficient power converters.

The choice of power will be based on the system integration requirements, programming of equipment, and data requirements. External high capacity 12V batteries will be very heavy, on the order of 150 pounds for a 250 amp-hour battery, at a size of 21x11x10 inches. Additional capacity can be achieved by wiring 12V batteries in parallel to increase the amp-hours. An initial estimate of power necessary to operate equipment on a 7-day period was 550 to 750 amp-hours, resulting in over 300 pounds of batteries.

Using the vehicle's electrical system to recharge batteries is an option, however the voltage of most vehicles is not calibrated for deep cycle applications, only for recharging of a starting battery. In addition, the short time frame of vehicle operation is probably not sufficient for complete recharging, where deep cycle batteries typically need 24 hours to achieve a full charge. The research team will investigate the option of battery switching; where the vehicle's battery is used as the primary power source while the vehicle is moving and the unit is switched to reserve power when the vehicle's battery voltage reaches a certain threshold, e.g. 9 volts.

8. DATA HANDLING REQUIREMENTS

8.1 Overview

There are four data handling components of the instrumentation package:

- 1) Initializing the system upon installation
- 2) Acquisition and storage of trip data
- 3) Shutdown of system upon removal of equipment
- 4) Uploading trip data onto a workstation and into a geographic information system (GIS)

A continually appended log file will be created for each vehicle, and a unique file will be created for each trip. The vehicle log file will record a list of trips made by the vehicle. The log file will be re-opened upon each new trip and appended so that it records the trips in chronological order. Each individual trip record will contain: vehicle identification number (linked to vehicle characteristics such as make, model, engine size, etc.), driver identification number (linked to driver characteristics such as age, gender, etc.), date and time of trip, and origin and destination classifications for the trip (e.g. home, work, shopping, etc.).

For every second of vehicle operation, real-time trip and vehicle data will be recorded to the trip file: time, position (x, y, and z coordinates), speed, engine speed (rpm), manifold absolute pressure, throttle position, etc. The final system configuration may drive the need for separate data files for each data source (GPS, OBD, Driver Interface, etc). Each trip file (or set of files for a single trip) will be assigned a unique trip which will also be recorded to the vehicle log file, thus ensuring data synchronization across files. File save procedures will be automated for both log and trip files to ensure minimal data file loss potential. All vehicle trip data will be collected in either ASCII or BINARY format. A single, consistent format will be employed. For all data handling procedures, a standard coding format and data dictionary will be developed. A quality assurance/quality control plan will be developed to ensure that data are handled appropriately.

Completed data are uploaded from the instrumentation package onto another storage media for analysis and for integration into GIS. Software will be developed to transfer the data from the instrumentation package to an 'analysis' workstation. Intermediate or backup storage will also be explored, including the applicability of a PCMCIA SCSI host adapter with ZIP disk or JAZ drive. Another program will be written for copying files into a file subdirectory system for easy classification and access. An interface program for converting BINARY to ASCII will also be used if necessary. Additional software will be developed or utilized to post-process the GPS data and to convert it to a standard GIS format (see section 8.2 for specific details on GIS processing).

The data matrix on the following page summarizes the various data sources, and their corresponding uses, elements, frequency of capture, window of capture, and potential storage devices.

Instrumented Vehicle Components / Data Matrix

Component	Intended Use of Data	Data Elements	Frequency of Capture	Time Window of Capture	Data Storage - where/when
Driver Interface	Travel diary data	Vehicle ID (default) Driver ID Passenger(s) ID Trip Purpose Time/Date Verification	Each trip	Start of Trip	Options:
GPS	Location (trip start, end, travel path) Time (for master timestamp and speed calculation)	Latitude and Longitude Elevation and PDOP Date and Time	1 Hz	Each second that vehicle is 'on'	Options: 2) Separate data logger
OBD /Engine Monitor	Engine and vehicle activity	30-70 individual elements Date/Time (if stored separately)	1 Hz	Each second that vehicle is 'on'	Options: 1) Computer/CPU
Other vehicle probes	Additional vehicle elements not captured by OBD	Temperature (I/E) Relative Humidity (I/E) Light Intensity Catalyst Temperature	Each second Variable (as Needed)	Each second that vehicle is 'on'	Options: 1) Computer/CPU 2) Separate data logger 3) Device
Emission Sensors	Tailpipe Emissions	Various	1 Hz		

APPLICATIONS IN THE ATLANTA REGION: YEAR 2000 TRAVEL SURVEY

In 1999 and 2000, the vehicle instrumentation package and the electronic travel diary will be employed in the Atlanta region in conjunction with a regional travel diary study. The regional study, sponsored by the Atlanta Regional Commission, Georgia DOT, and the Federal Highway Administration, will collect data from approximately 4000 households using standard 3-day paper travel diaries. Data from the study will be used in the year 2000 regional travel model update.

At the same time that the regional study is being conducted, an electronic travel diary study will collect a subset of the regional study data. Detailed 7-day travel diary data will be obtained from 270 households using electronic travel diaries (handheld electronic travel diaries with GPS), another 270 households will have passive GPS receivers installed in their vehicles for a duration of 7 days, and 70 to 140 households will have the full instrumentation package installed. Estimates for equipment package quantities are 27 electronic travel diaries, 27 GPS only receivers and data loggers, and 5 to 10 full instrumentation packages.

The electronic diary study is being conducted for two purposes: 1) to determine if there are significant differences in reported travel between groups that use the electronic diaries and those that use standard paper diaries, and 2) to collect detailed data from a 200-vehicle fleet to determine if significant driver behavior (e.g. acceleration rate and throttle position distributions) differences exist across participants. Developing a truly random sample of drivers that is large enough to be considered representative of the Atlanta metropolitan region would be cost-prohibitive. The electronic travel diary study is not meant to be a representative cross-section of the Atlanta region. Instead, the sampling plan will be designed to control for the major variables known to influence tripmaking patterns so that a representative sample of sub-populations are obtained and compared with similar sub-populations in the regional study.

The number of trips made per day is a strong function of household size, income, automobile ownership, and life-cycle stage (as revealed by marital status, number of children, etc.). Hence, the electronic travel diary study will include a sub-population that controls for these major variables. For example, a sub-population that might be included in the study could be a household size of four, with a household income between \$40,000.00 and 60,000.00 per year, with an ownership of two vehicles, with two parents and one dependent of driving age. By controlling for the major influencing factors in tripmaking, the variance in trips generated per day across the electronic travel diary group and the paper diary group is reduced. Statistically significant differences in travel behavior across the two groups are much more likely to be observed with the controls in place. Control factors deemed important for variance reduction are identified in the regional sampling plan (Hallmark, et al., 1998).

Once the major controls that prescribe sub-populations are in place, the sampling plan identifies additional variables that are expected to affect tripmaking patterns and driver behavior. For example, within the sub-population, factors such as age, gender, vehicle type, driving experience, residence type and location, and other characteristics are expected to influence the number of trips made and how the driver interacts with the throttle. These factors are allowed to vary across

the participant pool so that researchers can identify the significance of these independent variables on tripmaking and driver behavior.

Approximately 200 drivers will be selected for the study based on demographic characteristics identified in the sampling plan as controls and as test variables. A pseudo-random sampling technique, stratified by demographics and geographical location, will be undertaken. Drivers will be selected via a two-stage driver solicitation process. In the first stage, potential drivers are identified through a random sampling scheme (random telephone dialing procedures, Department of Motor Vehicles random search procedures, advertisements, etc) and interviews. The interview is used to determine if the potential driver meets the sub-population criteria. A pool of approximately 2000 participants is developed during the first stage. The pool is then stratified according to the demographic (including residential location) and socioeconomic characteristics identified as test variables. Finally, equal size random samples are drawn from each stratification group for a total of 200 participants.

Drivers will have the instrumentation packages installed in their own vehicles. The instrumentation packages will be installed with as little intrusion as possible. A series of carefully and consistently delivered written and oral instructions will be given to each of the participants. Selected individuals will be asked to participate for a 10 day period. The first participation day will be installation of the equipment and training of the participant. The second day will be a 'throw out' day, whereby all data collected will be discarded to eliminate the effects of an equipment learning curve (participants will also be asked to call a research team member on this day with any operational questions). The next 7 days of travel activity will be recorded on the instrumentation package. The final, or 10th day will consist of removal of the instrumentation package and compensating the participant. Randomization will be used whenever possible. For example, study participants will have staggered starts, so first day data biases will be randomized across days of the week. Also, research instructors/trainers will be randomly assigned to participants from different strata, so that any training biases will be randomized across these demographic groups.

Travel-diary-type studies involve a lengthy time commitment, daily tasks, and multiple contacts with the research team. Therefore, self-selection bias is always a potentially significant problem. A monetary incentive of \$100 to \$150 is being considered as an incentive for participants selected for the full study.

8.2 Analysis of Travel Patterns

The 1999-2000 Atlanta electronic travel diary study should yield information on somewhere between 5000 and 8000 individual trips. An abundance of detailed information will be obtained in the electronic diary study, providing the opportunity to develop numerous descriptive statistical measures of trip making. A variety of standard statistical techniques will be employed to develop descriptive measures and statistical models. Analytical techniques and modeling tools will likely include histograms, boxplots, pie-charts, scatter plots (for descriptive measures), regression (ordinary least squares, weighted least squares, logistic, robust methods), analysis of variance, tree-based methods, factor and cluster analysis, and generalized linear models.

8.3 Data Analyses

Analyses of the electronic travel diary data will proceed on the four general fronts:

1. *Temporal Trip Making Trends*: There will be a great abundance of temporal trip making information in the survey data. Of interest are when specific trip types are made, and if and how trips are ‘chained’ together. Of course, a great deal can also be inferred about parking conditions, leading to useful information about engine soak times. Combined with engine temperature and closed/open loop operation flags contained in the engine data, a great deal can be learned about start conditions of the surveyed vehicles.
2. *Route Choice Information*: For the first time, travel survey information will contain direct information on route choice. A rich research base will be made available by these data. As an example, route choice algorithms in travel demand models can be validated. Of perhaps greater interest, insights into human decision making with regard to route choice can be assessed since travel times and travel histories will be recorded over a week of travel, where the same trips were made repeatedly. Travel times on alternative freeway routes can be assessed using data obtained directly through the advanced traffic information system (network of cameras and Autoscope equipment) currently operating in Atlanta. Similar insights can be gleaned from shopping, recreation, and other travel decisions made by surveyed individuals.
3. *Trip Generation*: With demographic information on surveyed individuals, households, and detailed trip making patterns, we can examine in depth the relationships between household structure, occupation, income, etc., and trip generation. Trip generation models developed from the new data can be compared to those generated from census data to determine whether census data is sufficient for extrapolating accurate trip making information. In addition, trip distances will be known from the GPS and GIS, so information about annual mileage by trip purpose can be determined. Finally, parking information, since x, y, and z coordinates are known, could be used to learn more about parking availability and its relation to willingness to walk, or acceptance of increased travel times of individuals.
4. *Travel Behavior and Emissions*: The database will provide a wealth of data for examining engine operating conditions in response to driver inputs and travel patterns. Engine and vehicle operating parameters will be analyzed as a function of trip type, route choice, driver type, and vehicle type. Driver interaction with the throttle will be analyzed explicitly and compared with speed/acceleration measures. With the ability to pair grade (already coded in the GIS system for Atlanta) and engine operating conditions across time, commanded enrichment conditions can be identified and quantified.

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