PAPER

Use of Electronic Travel Diaries and Vehicle Instrumentation Packages in the Year 2000 *Atlanta Regional Household Travel Survey*

JEAN WOLF
RANDALL GUENSLER
SIMON WASHINGTON
LAWRENCE FRANK
School of Civil and Environmental Engineering
College of Engineering
and
City Planning Program, College of Architecture
Georgia Institute of Technology

The Georgia Institute of Technology is currently performing research that will result in the development and deployment of three instrumentation packages that allow for automated capture of personal travel-related data for a given time period (up to 10 days). These three packages include

- A handheld electronic travel diary (ETD) with Global Positioning System (GPS) capabilities to capture trip information for all modes of travel;
- A comprehensive electronic travel monitoring system (CETMS), which includes an ETD, a rugged laptop computer, a GPS receiver and antenna, and an onboard engine monitoring system, to capture all trip and vehicle information; and
- A passive GPS receiver, antenna, and data logger to capture vehicle trips only.

The first two systems will be capable of capturing all 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 and passenger identification (for personal vehicle trips), trip purpose, start and finish time (or duration), origin location, destination location, and distance traveled. In addition to these traditional elements, route choice, functional classification of each link in the route, link-based travel speeds, and freeway traffic conditions can be determined by tying GPS data to a geographic information system (GIS) database and real-time advanced traffic monitoring system, greatly enhancing the original data collected.

The CETMS will also collect all vehicle and engine operating conditions affecting emissions that can feasibly be captured via an onboard engine computer monitor—on a second-by-second basis. These data include such variables as vehicle speed, acceleration, engine revolutions per minute (rpm), manifold absolute pressure, throttle position, catalyst temperature, gear selection, air/fuel ratios, and coolant temperature.

The third system, the passive GPS receiver and antenna, will be used with a subset of the household sample employing traditional paper diary methods. The GPS data will be used to compare actual versus reported trip data, allowing for the development of under-reporting and misreporting correction factors.

Upon completion of prototype testing and data collection in the summer of 1999, 27 ETDs with GPS, 27 passive GPS systems, and 5 CETMSs will be procured and assembled for use in the 1999–2000 Atlanta Regional Household Travel Study. The targeted sample size for the regional survey is 4,000 households. Of this number, approximately 50 households will have at least one vehicle equipped with the full instrumentation package, including the handheld travel diary. An additional 270 individuals will be given the handheld travel diary only. Finally, an additional 270 households will have at least one vehicle equipped with the passive GPS system.

The samples selected for the instrumentation packages will be controlled for all standard survey variables, including household income, number of vehicles, number of parents, number of children, etc., so that a direct comparison can be made of survey results between automated data collection methods and traditional manual methods. Key elements for evaluation include the number of trips made (reported and unreported), trip start and finish times, trip origins and destinations, trip length, and travel route. GPS-captured route choice will be compared with reported routes from the manual recording "control" group and possibly from the instrumented group using route recall data from post-survey interviews.

STRATEGIES FOR METROPOLITAN ATLANTA REGION TRANSPORTATION AND AIR QUALITY

The Strategies for Metropolitan Atlanta Region Transportation and Air Quality (SMARTRAQ) is a major research endeavor funded by the FHWA, the Atlanta Regional Commission (ARC), and the Georgia Department of Transportation (DOT). The basic research goal is to collect and analyze sufficient data to develop an enhanced suite of travel demand models capable of addressing the land-use, travel behavior, and air quality issues critical to the Atlanta Metropolitan Region. The future models will be used in regional transportation and air quality planning activities and as such must be capable of answering important policy questions related to transportation investment decisions. Complimentary efforts to address planning issues within the current regional transportation plan process and improved understanding of travel behavior currently underway at Georgia Tech are being supported by the Turner Foundation and FHWA, respectively. These efforts are focusing on existing ARC travel data and data collection methods, and will provide useful findings relating household emissions with urban form that will be meaningful in the near term.

Currently available land-use, travel activity, and travel behavior data need to be updated to more accurately model the transportation system and vehicle emissions implications of alternative growth scenarios for the region. The most recent wave of household travel data in Atlanta was collected in 1991. The region has grown rapidly in the last 8 years, both in terms of population and land area, resulting in significant changes in land-use and travel patterns (*1*). In addition, the 1991 Household Travel Survey did not capture sufficient numbers of transit and non-motorized trips to support model calibration and policy analysis across a variety of modes (*2*). The SMARTRAQ project will design and implement a periodic household travel survey that offers improved understanding of travel behavior as it relates to land use and emissions, coupled with the creation of a regional land-use database that includes parcel-level data. These tasks are fundamental to support a regional planning process that provides ongoing feedback between adopted transportation, economic development, and air quality policies and the programming of transportation investments in association with regional growth patterns. Three overall goals are being pursued in this research:

- Create an ability to *assess* how specific land-use policies relate to critical measures of travel choice (vehicle miles traveled, cold start production, and modal choice), vehicle emissions (NOx, volatile organic compounds, CO), and physical activity;
- Interpret data and models in a way that will assist local government officials in their understanding of how land-use actions impact transportation and air quality—and to the extent possible—convey economic and quality of life benefits of environmentally sound land development practices; and
- Identify potential incentives for local governments to adopt land-use strategies that support reduced vehicle emissions and congestion through the programming of transportation investments and potential growth management policies.

To achieve these stated goals, the research team will undertake an integrated set of research tasks that will collectively address the issues and unanswered questions surrounding the relationships between land use, vehicular emissions, and travel behavior in the Atlanta region. As a result, a set of databases, models, and tools are being developed that can readily be used to confront many of the issues facing Metropolitan Atlanta and similar cities. In summary, the following tasks will be undertaken to reach the project goals.

- Design, implement, and analyze the data from an activity-based state-of-the-practice household travel survey specifically tailored to foster greater understanding of the relationships between land-use, vehicle emissions, and travel behavior in the Atlanta Metropolitan Region.
- Design and implement a targeted and detailed household travel survey using automation/instrumentation whereby a sub-sample of households provide significantly greater detail and insight into the relationships between land-use, emissions, and travel behavior.
- Develop an integrated parcel-level land-use database for the Metropolitan Atlanta region that can be used in the development of future regional transportation plans and updates.

As part of the survey research, certain strata of the population will be identified and surveyed to provide greater insight as to relationships that are of prime interest of the research effort. These strata include transit users, non-motorized mode users, and a-typical housing inhabitants such as mixed-used high density and mixed-use low density. Although the sampling plan has not yet been finalized, it is likely that samples drawn from these strata will be selected to receive instrumentation packages for detailed assessment.

STATE OF THE PRACTICE

The SMARTRAQ research team recently completed a literature review on state-of-the-practice travel survey methods. The team reviewed previous travel diary studies in Atlanta and other major metropolitan areas. This review of research literature focused on accuracy issues and suspected travel survey biases that could be avoided in future studies. The researchers also reviewed technologies and methodologies employed in previous automated diary and instrumented vehicle studies, including those that use GPS only and those that use onboard monitoring devices. The literature review was built upon a prior literature review completed for the project entitled “Development of a Comprehensive Vehicle Instrumentation Package for Monitoring Trip-Making Behavior,” sponsored by the FHWA and the Georgia DOT (Wolf et al., 1999a). To differentiate the comprehensive instrumentation package from the handheld ETD, the equipment developed in the previous project was renamed as the “CETMS.”

Travel Diary Studies

Travel diary studies are one of the most common methods for collecting data for use in travel demand model development. Travel diary studies randomly select a representative sample of survey participants from a metropolitan region and ask them to manually record the characteristics of each trip that they make in a standard paper diary. These data are then used to model travel behavior throughout the region and to forecast travel patterns for use in transportation systems planning, a process which often results in billion-dollar infrastructure decisions.

Within the past several decades, the traditional paper-and-pencil interview method of travel diary data collection has been supplemented or replaced with computer-assisted-telephone interviews (CATI). CATI involves telephone interviewers using specialized software who call survey respondents and ask them to provide details of all trips taken on a prior day; some CATI surveys provide respondents with paper diaries to assist in this recall process. Most recently, computer-assisted self interview (CASI) methods are being evaluated. There are numerous references available which review the traditional diary instruments and the transition to automated data collection methods (see Stecher et al., 1996; Sarasua and Meyer, 1996). Two recent European research projects have examined handheld personal computers (PCs) (Haubold and Axhausen, 1998) and Internet-based web sites (Plaxton et al., 1999) for long-distance travel data collection. Additional U.S. studies have begun to examine the opportunities of using GPS and GIS technologies in travel studies (Abdel-Aty et al., 1995; Greaves, 1997; Czerniak and Reilly, 1998).

GPS can add a new spatial dimension to trip-making data, by tracking actual route choice. Research projects investigating automated diaries with GPS include the completed FHWA-sponsored Lexington study (Wagner, 1997) and ongoing travel surveys in the Netherlands (Draijer et al., 1998). These two projects are the first to combine electronic travel diaries with GPS receivers to gain exact temporal and spatial details of each trip. Several other projects have installed passive GPS receivers in automobiles (Casas and Arce, 1999) and in trucks (Wagner et al., 1998) to capture travel route information. Finally, several European research projects have evaluated GPS receiver performance in London (Ochieng, 1998) and in Paris (Flavigny et al., 1998).

CASI methods such as electronic diaries provide the potential to expand recorded choices, making electronic diaries suitable for use in activity-based or tour-based travel demand modeling. In addition, the automated capture of time and location data provided by a GPS receiver produces great improvements in travel data accuracy compared to manual methods. Specifically, an ETD combined with GPS data collection is designed to overcome several problems related to manual travel diary studies:

- Paper survey participants may not keep accurate records (either accidentally or intentionally), which result in misreported or underreported travel, including the omission of entire trips (Richardson and Ampt, 1996). The screen flow of ETDs helps prevent the omission of individual trip data elements, and GPS can be used to detect the omission of entire trips. In addition, help screens can be coded to add clarification where necessary.
- 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 diary studies collect either one or three days of travel data per household). An ETD's nesting of screens can reduce the respondent's impression of the overall burden because the respondent sees only those screens necessary for the collection of data for the given trip.
- Actual route choice is rarely captured in travel diary studies due to the increased respondent burden. This burden is eliminated with passive GPS data collection. The ETD with GPS should be able to collect data for periods up to a week without imposing any additional reporting burdens.

Instrumented Vehicle Studies

Researchers cannot use current travel diary study data to explain driving patterns explicitly. It is impossible to separate the impacts of driver behavior 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.

Within the last several decades, the need for accurate vehicle fuel consumption and pollutant emission models has forced both researchers and practitioners into developing automated means for capturing second-by-second vehicle and engine activity data. These projects include research conducted in France in 1983 and 1990 with 55 instrumented vehicles (André, 1995), the Canadian-developed Autologger, which is an in-vehicle data collection device (Taylor, 1991), and several Environmental Protection Agency sponsored instrumented vehicle studies conducted in the United States (DeFries and Kishan, 1992; Ross et al., 1994). Concerns regarding cost of instrumentation, ease of installation, and data storage requirements are common across all instrumented vehicle studies. Power supply issues were also discussed, although most projects tapped into the vehicle's power supply (requiring the paid assistance of a certified mechanic). A description of each project follows.

The French research project involved data loggers and sensors installed in 35 vehicles in 1983 and in 20 vehicles in 1990. Data were collected at one-second intervals for periods of approximately one month; data elements captured include date, time, vehicle and engine speed, throttle position, fuel consumption, engine and ambient temperatures, and use of auxiliary equipment. Several conclusions of this research were:

- Vehicle uses, distances traveled, trip duration, and speeds experienced can be captured via instrumentation with a high degree of accuracy; and
- When compared with paper diaries, the instrumented data reveals that paper survey respondents tend to omit very short trips and intermediate trips made during long trips that are not considered as "trip purposes" (e.g., refueling, rest stop) and that respondents tend to misreport both short and very long trip lengths.

In Canada, the Autologger was developed to specifically address the need for measuring vehicle usage; through use of a drive wheel rotation sensor, the system measures instantaneous speeds. This data element, when combined with the time of day (in seconds), is then used to create an output file containing statistics including the daily trip rates, daily travel distances, soak times between trips, soak start times, and a speed/acceleration matrix expressed in terms of time and distance. The system itself, once installed, can be left in place for long periods since the data card is easily swappable by the driver and can be mailed back to the survey coordinator.

Within the United States, several 1992 Federal Test Procedure studies equipped 417 vehicles in Atlanta, Spokane, and Baltimore with data loggers capturing instantaneous vehicle velocity, engine revolutions per minute, and manifold absolute pressure. These surveys also indicated potential significant underreporting of short duration trips. The Atlanta study included an analysis of urban versus suburban trips and trip chaining events, and found that urban chained trips had consistently higher travel duration, distances traveled, and links per chain. These findings demonstrate how instrumented vehicle data can be used to better understand trip-making characteristics.

INSTRUMENTATION PACKAGES

As mentioned previously, three separate instrumentation packages are being developed for use in the Year 2000 Travel Survey for the Atlanta Metropolitan Region. These separate packages will share common components when it is appropriate to fulfill their overall functionality. However, the need for three separate packages arose from the need to automate three components of the travel survey:

- ETD, which includes a handheld PC with portable GPS—to be used instead of paper diaries to fully automate travel diary data collection for all modes of travel and to gain additional temporal and spatial trip elements provided by GPS technology.
- CETMS, which includes the ETD, GPS receiver, OBD engine monitor, and rugged laptop or data logger—to be used instead of paper diaries to fully automate travel diary data collection for all modes of travel, to gain additional temporal and spatial trip elements, and to gain temporal and spatial vehicle and engine activity data for all vehicle trips.
- Passive In-Vehicle GPS, which includes a data logger—to be used in tandem with paper diaries for the analysis of reported versus actual vehicle trip rates and for the development of correction factors.

The next three sections will provide a more thorough description of the functionality, components, and intended uses of data for each instrumentation package.

ETD

Because manual travel surveys suffer from underreporting biases and survey duration limitations, the ETD is designed to help minimize or reduce the impact of these biases on the estimation of trip generation rates. Consequently, this ETD is designed to:

- Provide a portable, user-friendly, handheld device with independent data collection capabilities so that the unit can be employed for walking, cycling, and other trips made in addition to those made in the primary vehicle.
- Provide the capability to store GPS data directly on the handheld device.
- Collect all traveler 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, traveler/driver identification, passenger identification (if vehicle trip), trip purpose, trip start time, finish time (or duration), origin location, destination location, trip route, and distance traveled.
- Link route choice, travel speed, and functional classification of each link to the characteristics of each trip by linking trip data on the handheld diary to the GPS data collected simultaneously. A GIS provides the route matching routines that link trip origin/destination through the road network database.

Consequently , the ETD with GPS instrumentation package consists of several essential components:

- A handheld PC with user-friendly interface and at least 6MB memory;
- A portable GPS receiver and antenna;
- A portable radio receiver and antenna for real-time differential correction of GPS signal;
- Power supply and cabling for GPS receiver and radio receiver;
- Communications cabling
  - between the antennas and their receivers,
  - between the GPS receiver and the radio receiver,
  - between the GPS receiver and the handheld PC;
- Shoulder bag or back pack to contain all components, to provide secure connections between all components and power supply, to allow easy access to handheld PC keypad and for battery recharging, and to allow clear sky view for both GPS and radio antennas.

Comprehensive Electronic Travel Monitoring System

Collection of spatially resolved motor vehicle activity in instrumented vehicle studies is critical for estimating travel demand and properly allocating vehicle emissions throughout an urban area. It is commonly known that vehicle emissions are a function of the number of vehicle trips and vehicle miles of travel. These basic activity estimates are often underreported in standard surveys, overlooking many very short trips. Because the emissions from motor vehicles are elevated during the first few minutes of operation (due to unstable combustion and a cold catalytic converter) high emissions are associated with initial engine start activity. Hence, the missed trips can contribute significantly to total vehicle emissions. CETMS capable of capturing these missed trips will improve overall regional estimates. In addition, engine-monitoring systems that collect engine temperature data can provide valuable information for researchers developing enhanced emission rate models.

Emissions are not just a function of the amount of driving, but are also a function of the onroad operating conditions under which travel is undertaken. Hard acceleration and high vehicle speed activity require additional engine power, which often leads to enriched air and fuel mixtures and very high emissions outputs for short periods of time. Hard decelerations also tend to result in high instantaneous emission rates due to fuel control issues. Previous instrumented vehicle activity studies have been able to identify high-emission driving activity for individual monitored vehicles. However, these studies could not determine whether the high-emissions activity is attributable to traffic conditions or driver behavior. Data were not collected on driver demographics, route choice (local road versus freeway travel), or congestion levels. Hence, although instrumented vehicle studies can tell us that driving patterns differ across major cities such as Baltimore, Spokane, and Atlanta, they cannot tell us why. The CETMS will allow researchers to begin to test hypotheses about driver behavior and potential interactions between drivers and their vehicles.

Because the comprehensive vehicle instrumentation package will automatically log trip details, current 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. New motor vehicle emissions models now predict emission rates as a function of vehicle speed, acceleration, and engine/vehicle technology characteristics. While laboratory testing has defined the relationship between these variables and emission production, real-world vehicle activity and onroad technology characteristics must be made available as inputs to run the models. Hence, instrumented vehicle studies improve travel demand estimates, provide better data on modes of vehicle operation, and significantly improve resulting air quality impact assessments performed for transportation projects.

The CETMS includes the ETD, a rugged laptop or data logger, a GPS receiver and antenna, and an onboard engine monitoring system, as well as a power supply, all necessary cabling, and a protective case. Data are streamed to the rugged laptop and recorded to disk using LabVIEW software. The software also controls power conservation activities so that the equipment can operate for the entire sampling period using one 12V marine battery. Technical details for the CETMS can be found in Wolf et al. (1999a and 1999b).

The new instrumentation package links vehicle characteristics (size and horsepower), vehicle operating conditions (speed and acceleration), and engine operating conditions (engine rpm and throttle position), with driver characteristics (age and gender), trip purpose (work and shopping), and route choice (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 household 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 could 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. The interactions of driver characteristics, vehicle characteristics, speed, acceleration, change in throttle position, and vehicle enrichment can all be studied.

Passive GPS with Data Logger

One of the most relevant research questions in travel survey studies is “By how much are respondents under-reporting and misreporting travel by using paper diaries?” Richardson and Ampt (1996) report that the underreporting of trips and/or trip items is significant and can be attributed to a variety of variables, including the individual trip item, to the type and personal characteristics of the respondent, and to characteristics of the trip itself. Automated trip recording technologies, such as GPS receivers and data loggers, can provide great insight into estimating these kinds of reporting biases. In fact, reporting bias corrections could be applied to paper survey results for a large population if differences could be adequately estimated using automated technologies.

Unfortunately, difficulties arise when one tries to estimate these differences using both paper and electronic technologies. For instance, if one control group used paper diaries and another used electronic diaries with GPS capabilities, how would an analyst know if differences found were due to real travel differences or to errors and omissions in reporting? It is also not feasible to obtain an unbiased estimate of underreporting by administering both a paper diary and an ETD to a single household. In this case, the active use of the electronic instrument would bias recording on the paper diary, and respondents would be made doubly aware of their travel behavior—this increased awareness could cause an unintentional reduction in underreporting. On the other hand, the respondent burden would be dramatically increased over that of using either instrument alone, potentially resulting in an increase in trip and data non-response rates.

Instead, the SMARTRAQ initiative will use a passive GPS equipment package, installed in a vehicle’s trunk, to collect and record all vehicle trip information (both temporal and spatial), while the driver fills out the same paper diary that the rest of the paper-based sample is given. The passive GPS equipment package will include a GPS receiver, GPS antenna, and a data logger. To improve the accuracy of the GPS coordinate, a radio receiver and antenna capable of receiving GPS real-time differential corrections will also be included in this equipment package. Finally, the power supply, cabling, and all components will be placed in a protective case.

This GPS equipment package will be used to record each trip’s origin, destination, purpose, travel path, length (distance), start time, finish time, and trip duration (time). These data, when compared with the paper diary data, will be used to derive estimates of mis- and underreporting of travel. Key to this approach is the passive nature of the package; drivers should become progressively less aware that the device is recording their travel. Although motorists will be aware of the package when it is installed in their vehicle, it is hoped that the lack of interaction with the package once it is installed will make most drivers forget its presence. The equipment is being designed to passively collect and record GPS location of the vehicle and driver, along with the time of day during the survey period without any interaction from the driver whatsoever.

Although some influence of the passive GPS equipment package on reported travel is possible, it is anticipated that the information obtained by comparing actual versus reported trip data will provide a reasonable estimate of the mis- and underreporting of travel via paper diaries. These estimates, by trip type, trip purpose, demographic strata, etc., can then be used to correct for biases introduced by the larger sample of paper diaries obtained in the SMARTRAQ research.

DEPLOYMENT PLAN

The sample size for the year 2000 Atlanta Metropolitan Region Travel Survey will most likely fall between 4,000 and 5,000 households. Households will be surveyed using traditional paper diary methods with data collected via telephone interviews. However, 10 to 15 percent of the households will be provided one of the three equipment packages previously presented in this paper:

- ETD with portable GPS (to survey all travel modes)—used instead of paper diaries to fully automate travel diary data collection and to gain additional temporal and spatial trip elements provided by GPS technology.
- CETMS, which includes the ETD, GPS receiver, and OBD engine monitor (to survey all travel modes)—used instead of paper diaries to fully automate travel diary data collection, and to gain additional temporal and spatial trip elements and vehicle and engine activity data for all vehicle trips.
- Passive In-Vehicle GPS—used in tandem with paper diaries for analysis of reported versus actual vehicle trip rates.

The initial goals for the number of households to be instrumented/automated are:

- 250 households with ETD and GPS (all modes)
- 50 households with ETD, GPS, and OBD (all modes)
- 250 households with passive GPS (vehicle only)

The duration of both the instrumented and paper-based surveys will be 4 days per household. Given the burden introduced by this length of time, respondents will be provided monetary incentives for their participation (in the range of $100 per household).

Deployment Centers

Four regional deployment centers will be established to provide centrally located operations within each quadrant of the Atlanta Metropolitan Region. In addition, a fifth deployment center will be operated at Georgia Tech to provide service for those who work or live in the downtown/midtown area. Participants will be given the option to visit any deployment center location or to have the installation performed at their home. The deployment team will rotate from center to center according to the schedule presented later in this section.

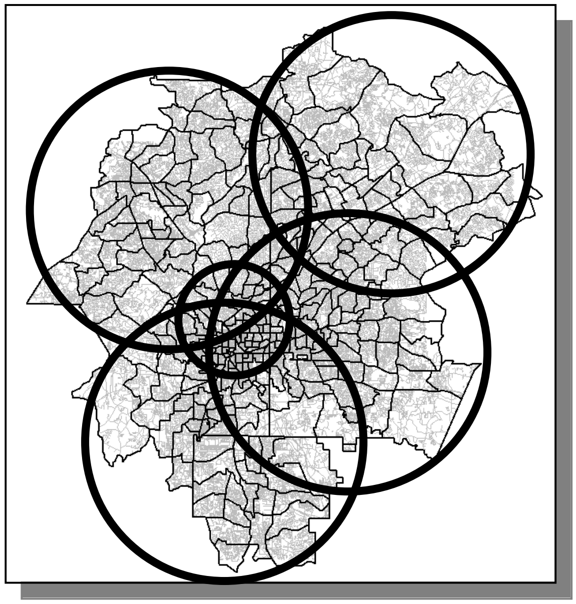

FIGURE 1 Potential service areas for the five Atlanta regional deployment centers.

The four regional centers will be centrally located at test-only inspection and maintenance (I/M) facilities in a local strip or rural shopping mall. The state DNR will be approached to see if they will provide free I/M tests as an additional incentive for participants. Figure 1 represents likely coverage areas for each deployment center.

Deployment Team/Equipment Rotation

Each equipment package will be deployed on a 5-day cycle.

- Day 1: Equipment installed in the afternoon and respondent begins using equipment.
- Days 2–5: Respondent enters data that are saved as travel diary information.
- Day 6: Equipment returned to the study team in the morning and redeployed in new studies during the afternoon.

In this deployment plan, Monday deployments return on Saturday. The deployment team will attempt to schedule equipment returns in the morning hours and equipment installations in the afternoon hours to allow time for data offloading and battery recharging. Of course, the deployment team will work within the respondents' scheduling limitations.

The deployment team will devote 1 day at each of the four regional deployment centers, and then 1 half-day at the Georgia Tech center, and deploy at respondent homes as required. A single pass through this 5-day schedule is equivalent to one cycle. Given five deployment locations and a 5-day cycle, the team will work each day of the survey period. Consequently, days off must be scheduled throughout the survey period for individual team members.

The plan calls for the team to receive and install 13 equipment sets per day, which includes 6 passive GPS systems, 6 ETDs with GPS, and 1 full instrumentation package (with ETD, GPS, and OBD components). The day at Georgia Tech will entail the turnaround of three passive GPS systems, three ETDs with GPS, and one full instrumentation package. The deployment rotation schedule for the ETD with GPS group is illustrated in Table 1, where the numbers indicate the sample number from 1 to 270, for up to 270 participating households (this will ensure that at least 250 households with valid data will be captured). The gray diagonal lines represent individual waves of deployment. This same deployment schedule applies to the passive GPS equipment package group.

Finally, the deployment schedule for the full instrumentation package calls for one uninstall and install per deployment date given five instrumentation packages. Given five installs per cycle and a 10-cycle data collection period, this yields a total sample size of 50. If more complete instrumentation packages are purchased, the sample size will increase accordingly.

On any given day, the passive GPS deployment will be implemented as follows: First, respondents from the previous cycle will be scheduled to stop by the center to have the equipment removed and to discuss any participation issues. The data will then be off-loaded from the data logger and the equipment reinitialized for the next installation. The turnaround time for the equipment package could range from 0.5 to 1.5 h, depending on the data storage and battery technologies used. As new participants arrive, the processed equipment packages collected for that day will be installed and the participants will receive any relevant training information before departing. This complete process will occur for six passive GPS systems, six ETD with GPS systems, and one full instrumentation system each day.

INSTRUMENTATION STUDY DURATION

The sampling plan goal is to automate or instrument some portion of the travel diary study for 550 households: 250 households for passive GPS only, 250 for ETD with GPS, and 50 with the full instrumentation package. There will be 59 households processed every 5 days, in 10 waves, yielding a total sample of 590 households. This larger sample allows for 40 occurrences of household withdrawal or catastrophic equipment failure (7.4 percent for the passive GPS and ETD with GPS groups). The total data collection period lasts 55 days, from mid-May through mid-July 2000. This time frame has been selected to provide adequate coverage for both school and non-school seasons (the Atlanta school system begins summer break in mid-June).

To fulfill this deployment plan, 27 passive GPS packages, 27 active ETD/GPS units, and 5 active ETD with GPS and OBD full instrumentation packages must be purchased and assembled. One wave’s worth of extra batteries and/or power systems will also be purchased. As a result, power supplies can be swapped out during equipment turnover, reducing equipment turnaround time. Data storage devices such as PCMCIA cards and flash cards are also under consideration to reduce real-time downloading requirements during equipment rotation. Finally, this deployment plan can be easily modified to increase the sample size or to decrease equipment needs by extending the data collection period beyond the 55 days currently scheduled.

TABLE 1 Possible Deployment Schedule for ETD with GPS

Week	Day	Site 1	Site 2	Site 3	Site 4	GT
1	Monday	1–6				
	Tuesday	1–6	7–12			
	Wednesday	1–6	7–12	13–18		
	Thursday	1–6	7–12	13–18	19–24	
	Friday	1–6	7–12	13–18	19–24	25–27
	Saturday	1–6/ 28–33	7–12	13–18	19–24	25–27
	Sunday	28–33	7–12/ 34–39	13–18	19–24	25–27
2	Monday	28–33	34–39	13–18/ 40–45	19–24	25–27
	Tuesday	28–33	34–39	40–45	19–24/ 46–51	25–27
	Wednesday	28–33	34–39	40–45	46–51	25–27/ 52–54
	Thursday	28–33/ 55–60	34–39	40–45	46–51	52–54
	Friday	55–60	34–39/ 61–66	40–45	46–51	52–54
	Saturday	55–60	61–66	40–45/ 67–72	46–51	52–54
	Sunday	55–60	61–66	67–72	46–51/ 73–78	52–54
3	Monday	55–60	61–66	67–72	73–78	52–54/ 79–81
	Tuesday	55–60/ 82–87	61–66	67–72	73–78	79–81
	Wednesday	82–87	61–66/ 88–93	67–72	73–78	79–81
	Thursday	82–87	88–93	67–72/ 94–99	73–78	79–81
	Friday	82–87	88–93	94–99	73–78/ 100–105	79–81
	Saturday	82–87	88–93	94–99	100–105	79–81/ 106–108
	Sunday	82–87/ 109–114	88–93	94–99	100–105	106–108

continued on next page

TABLE 1 (*continued*) Possible Deployment Schedule for ETD with GPS

4	Monday	109–114	88–93/ 115–120	94–99	100–105	106–108
	Tuesday	109–114	115–120	94–99/ 121–126	100–105	106–108
	Wednesday	109–114	115–120	121–126	100–105/ 127–132	106–108
	Thursday	109–114	115–120	121–126	127–132	106–108/ 133–135
	Friday	109–114/ 136–141	115–120	121–126	127–132	133–135
	Saturday	136–141	115–120/ 142–147	121–126	127–132	133–135
	Sunday	136–141	142–147	121–126/ 148–153	127–132	133-135
5	Monday	136–141	142–147	148–153	127–132/ 154–159	133–135
	Tuesday	136–141	142–147	148–153	154–159	133–135/ 160–162
	Wednesday	136–141/ 163–168	142–147	148–153	154–159	160–162
	Thursday	163–168	142–147/ 169–174	148–153	154–159	160–162
	Friday	163–168	169–174	148–153/ 175–180	154–159	160–162
	Saturday	163–168	169–174	175–180	154–159/ 181–186	160–162
	Sunday	163–168	169–174	175–180	181–186	160–162/ 187–189
6	Monday	163–168/ 190–195	169–174	175–180	181–186	187–189
	Tuesday	190–195	169–174/ 196–201	175–180	181–186	187–189
	Wednesday	190–195	196–201	175–180/ 202–207	181–186	187–189
	Thursday	190–195	196–201	202–207	181–186/ 208–213	187–189
	Friday	190–195	196–201	202–207	208–213	187–189/ 214–216
	Saturday	190–195/ 217–222	196–201	202–207	208–213	214–216
	Sunday	217–222	196–201/ 223–228	202–207	208–213	214–216

continued on next page

TABLE 1 (*continued*) Possible Deployment Schedule for ETD with GPS

7	Monday	217–222	223–228	202–207/ 229–234	208–213	214–216
	Tuesday	217–222	223–228	229–234	208–213/ 235–240	214-216
	Wednesday	217–222	223–228	229–234	235–240	214–216/ 241–243
	Thursday	217–222/ 244–249	223–228	229–234	235–240	241–243
	Friday	244–249	223–228/ 250–255	229–234	235–240	241–243
	Saturday	244–249	250–255	229–234/ 256–261	235–240	241–243
	Sunday	244–249	250–255	256–261	235–240/ 262–267	241–243
8	Monday	244–249	250–255	256–261	262–267	241–243/ 268–270
	Tuesday	244–249	250–255	256–261	262–267	268–270
	Wednesday		250–255	256–261	262–267	268–270
	Thursday			256–261	262–267	268–270
	Friday				262–267	268–270
	Saturday					268–270

NOTES

1. It is estimated that the Atlanta Metropolitan Region grew from 68 mi north to south in 1990 to 121 mi north to south by the end of 1997 (Leinberger, *Interview*, 1998).

2. To date, the ARC has utilized MARTA ridership and other applicable data to support model calibration and policy analysis related to transit usage.

REFERENCES

Abdel-Aty, M., R. Kitamura, P. Jovanis, R. Reddy, and K. Vaughn. New Approach to Route Choice Data Collection: Multiphase, Computer-Aided Telephone Interview Panel Surveys Using Geographic Information Systems Database. In *Transportation Research Record 1493*, TRB, National Research Council, Washington, D.C., 1995, pp. 159–169.

André, M. *Vehicle Uses and Operating Conditions: On-Board Measurements; Understanding Travel Behaviour in an Era of Change.* Pergamon-Elsevier, Oxford, U.K., 1995, pp. 469–481.

Casas, J., and C. Arce. *Trip Reporting in Household Travel Diaries: A Comparison to GPS-Collected Data.* Presented at the 78th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 1999.

Czerniak, R., and J. Reilly. *NCHRP Synthesis of Highway Practice 258: Applications of GPS for Surveying and Other Positioning Needs in Departments of Transportation.* TRB, National Research Council, Washington, D.C., 1998.

DeFries, T., and S. Kishan. *Light-Duty Vehicle Driving Behavior: Private Vehicle Instrumentation: Final Report.* Office of Mobile Sources, EPA, Washington, D.C., Aug. 1992.

Draijer, G., N. Kalfs, and J. Perdok. *Possible Application of Global Positioning System (GPS) for Collecting Travel Data.* Project Report, Transport Research Centre of the Ministry of Transport, Public Works, and Water Management, The Netherlands, 1998.

Ettema, D. F., and H. J. P. Timmermans. New Data Collection Methods in Travel Surveys. *Activity-based Approaches to Travel Analysis,* (N. Kalfs, and W. E. Saris, eds.), Pergamon Press, New York, 1997.

Flavigny, P. -O., J. -P. Hubert, and J. -L. Madre. *Analysis of Road Traffic Data Observed by GPS and Comparison with Other Sources.* Presented at ADEME-INRETS Conference, Number 9815, Sept. 1998.

Greaves, S. Applications of GIS Technology in Recent Household Travel Surveys. *Proc., GIS-T Symposium,* March 1997, pp. 95–133.

Haubold, I., and K. Axhausen. *Handheld PC-Based Travel Data Collection by Self Administered Interviewing.* Presented at the Association of Survey Computing Conference on New Methods for Survey Research, Southampton, U.K., Aug. 1998.

Plaxton, J., P. Jackson, J. Polak, and D. Wofinden. *Using the Internet to Collect Data on Travel Behaviour.* Presented at the 78th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 1999.

Ochieng, W. *ATT Positioning Requirements: GPS Performance in the City of London.* Centre for Transport Studies, Imperial College, London, U.K., Dec. 1998.

Richardson, A. J., and E. S. Ampt. Nonresponse Issues in Household Travel Surveys. *Conference Proceedings 10: Conference on Household Travel Surveys: New Concepts and Research Needs,* Irvine, Calif., 1995. National Academy Press, Washington, D.C., 1996, pp. 79–114.

Ross, C., M. Meyer, S. Barker, and Y. Zemere. Analysis of Travel Behavior Using Three-Parameter Dataloggers. *Journal of Transportation Engineering,* Vol. 121, No. 4, 1994, pp. 338–344.

Sarasua, W., and M. Meyer. New Technologies for Household Travel Surveys. *Conference Proceedings 10: Conference on Household Travel Surveys: New Concepts* *and Research Needs,* Irvine, Calif., 1995; National Academy Press; Washington, D.C., 1996, pp. 170–182.

Stecher, C., S. Bricka, and L. Goldenberg. Travel Behavior Survey Data Collection Instruments. *Conference Proceedings 10: Conference on Household Travel Surveys: New Concepts and Research Needs*, Irvine, Calif., 1995, National Academy Press; Washington, D.C., 1996, pp. 154–169.

Taylor, G. AUTOLOGGER: A Long Duration Vehicle Use Data Collection System. *Conference Proceedings: Sixth International Conference on Travel Behaviour,* Vol. 2, May 1991, pp. 432–443.

Wagner, D. *Lexington Area Travel Data Collection Test: GPS for Personal Travel Surveys.* Battelle Memorial Institute. Final Report for OHIM, OTA, and FHWA, Sept. 1997.

Wagner, D., J. Seymour, N. Malcosky, J. Kinateder, and J. Nguyen. Determining Heavy Duty Truck Activity Using Global Positioning System (GPS) Technology. *Presented at the 8th CRC On-Road Vehicle Emissions Workshop*, San Diego, Calif., April 1998.

Wolf, J., R. Guensler, S. Washington, W. Sarasua, C. Grant, S. Hallmark, M. Oliveira, M. Koutsak, R. Thittai, R. Funk, and J. Hsu. *Development of a Comprehensive Vehicle Instrumentation Package for Monitoring Individual Tripmaking Behavior—Literature Review (GTI-R-99001).* Georgia Transportation Institute, Georgia Institute of Technology; Atlanta, Ga., Feb. 1999a.

Wolf, J., R. Guensler, S. Washington, W. Sarasua, C. Grant, S. Hallmark, M. Oliveira, M. Koutsak, R. Thittai, R. Funk, and J. Hsu. *Development of a Comprehensive Vehicle Instrumentation Package for Monitoring Individual Tripmaking Behavior—Technical Specifications and Analysis (GTI-R-99003).* Georgia Transportation Institute, Georgia Institute of Technology; Atlanta, Ga., Feb. 1999b.