Evaluation of a Shared-Use Electric Vehicle Program: Integrating a Web-Based Survey with In-Vehicle Tracking

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Abstract:

An experimental shared-use vehicle program in Irvine, CA is assigning 15 Toyota ecom electric vehicles to several public and private sector organizations who have identified a group of employees to utilize the ecoms in a shared-use mode. The primary goal of this experiment is to evaluate the potential of shared-use electric vehicles as a means of reducing urban traffic and vehicle emissions. The decision to travel with the shared-use vehicles can be understood only through examining the entire process of how participants schedule activities before, during, and after shared-use vehicles become a travel option. To effectively evaluate performance of this prototype application, a novel data collection procedure is proposed which integrates GPS-based vehicle tracking and web-based travel survey technologies. The data collection process will occur in three stages: (1) before the vehicle-sharing program, (2) during the program, and (3) after the program is completed.

A Computer-Aided Self-administered Interview (CASI) program, REACT!, is being used to collect travel/activity schedules from participants for one week periods. The data derived from the first stage will depict participants’ typical weekly activity programs before the alternative of sharing vehicles is present. After a simple installation of REACT! on a home or work personal computer, each respondent completes a 45 minute self-administered interview and summarizes known travel plans for the week. On each subsequent evening, REACT! prompts respondents to update what they actually did that day, as well as to update any plans for the remainder of the week (data is sent to a project web site at the end of each REACT! session). At the end of the week, REACT! provides a summary of travel/activity for the entire week.

In the second phase when electric vehicles are in shared-use, REACT! will be used in conjunction with the GPS tracing instrument, TRACER, equipped within the study vehicles. TRACER will be used to track each vehicle for the duration of the study, recording vehicle position and speed every second. At one of two intervals within the six month study period, respondents will repeat the REACT! study. These repeat applications will involve a brief initial self-administered interview and daily updates focused on use of the shared-use vehicles. The actual tracings of the vehicles will be provided to each respondent both as a memory-jogger to help them complete the survey as well to examine under what conditions shared-use vehicles were utilized. In the third stage, the stage 1 procedure will be repeated to test for residual effects on travel patterns.
1. **OVERVIEW**

The Holy Grail of many transportation planners is a viable transportation alternative to the automobile, probably the most praised and condemned technology ever created and certainly the primary influence today on the structure of urban form and everyday life in developed countries. While many have proposed inferior alternatives in various guises, the consensus appears to be that unless the automobile is made *less attractive* then no other alternative stands much of a chance in most applications. One increasingly popular alternative appeals to the benefits of the automobile (flexibility, personal autonomy, etc.) while simultaneously minimizing the costs (a range of environmental impacts) by actually being an automobile, but an automobile which is utilized in unique ways.

Shared use automobiles and station car concepts have seen limited yet somewhat successful applications internationally, albeit in essentially niche markets (see Shaheen *et al.*, 1998; Shaheen, 1999). A shared-use vehicle is owned and utilized by a group of drivers who share costs and benefits, often organized as a cooperative entailing membership and use fees. A station car is most often simply a car which is used between a residence and a transportation center/station (most often with rail systems) or a transportation center/station and an employment center. The car provides access to and from the line haul mode, and many commuters have found this a convenient way to cover long commutes while maintaining the benefits of a car at one or both ends of the trip (see http://www.stncar.com/).

There are many limitations to these concepts, most a direct result of the “ownership” model associated with the American automobile. Particularly on the work commute, when you get in your car, you’re already half way home. This satisfaction is not the same on public transit systems nor in most shared car systems. Station cars do not really address related transportation impacts since total vehicle usage and parking demand are not significantly reduced (although it may enable increased commuting by other modes).

A synthesis of these concepts is proposed, with a few other catalysts thrown in for good measure. The primary catalyst is the current State of California Zero Emission Vehicle (ZEV) mandate, which has legislated a proportion of total annual automobile sales for major manufacturers be ZEVs (see http://www.zevinfo.com/electric/electric.html). The program requirements to be released by the California Air Resource Board in July 2001 are expected to provide a credit system where electric vehicles (EVs) receive added credits toward manufacturer quotas if they are utilized in either an integrated multi-modal transportation system and/or an Intelligent Transportation System (ITS) program.

As an initial foray into such programs, the Advanced Power and Energy Program (APEP) and the Institute of Transportation Studies (ITS) at the University of California, Irvine have entered into Phase 2 of a three phase program investigating the feasibility of deploying city electric vehicles in shared-use and station car modes within a corporate management structure. This program, described in detail below, is the subject of the research, development, and evaluation effort underway. This effort initially focuses on the implementation of novel survey systems in each electric vehicle to track vehicle
trajectories and to subsequently survey individual drivers, and their households, relative
to their use of the cars and the associated impact on household travel behavior. In a
nutshell, can a shared-use station car program actually reduce the environmental impacts
of the current automobile-dominated transportation system and help to achieve the goals
of California’s ZEV mandate?

This paper summarizes the independent development of the two survey techniques,
describes the modifications required in the initial phases of the program, and provides
some initial insight to the technological requirements of a full implementation of such a
system. After a review of related literature, each of the techniques is presented, followed
by a summary of the three phase shared-use station car system.

2. LITERATURE REVIEW

The focus of this paper is the application of web-based survey techniques and automated
tracking systems to shared-use station car program. Although the current project makes
exclusive use of electric vehicles, the intent is to develop a system that is applicable to
any vehicle fleet. Indeed, the ultimate goal is the development of Autonet, a peer-to-peer
vehicle computing and communication system which aspires to platform (i.e., vehicle)
independence. The following sections focus on the relevant literature of web-based
surveys and vehicle tracking, since this is the focus of the current application. This
review does not attempt to provide a review of relevant literature regarding car-sharing or
station-car projects, nor in the development of electric vehicles.

2.1 Web-based Activity Surveys

In recent years there has been a growing interest in experimenting with new approaches
for household activity/travel surveys. These experiments can be generally divided into
two groups. One involves the application of new technologies, such as Global Positioning
Systems and handheld computers, to obtain high resolution personal travel data (Battelle,
1997; Guensler, R., and J. Wolf, 1998). Such data has promise to advance existing travel
models and may even assist in a paradigm shift for travel forecasting. These data,
however, are outcomes of the decision process, often termed activity scheduling, that
determines when, where, with whom, and for how long to engage in various activities.
Axhausen and Gärling (1992) stressed the importance of this process by arguing that it is
at the core of travel behavior changes. Effects of transportation policies such as tolling,
congestion pricing, and travel demand management measures depend on how people
would adjust their daily activity and travel pattern to changes to their everyday lives.
They also argued that the process is “largely unknown” and new methods should be
developed to conduct in-depth study of the process. This second group of data collection
experiments is about the development of innovative approaches to unearth the process of
activity scheduling.

The REACT! software is based on the Computerized Household Activity Scheduling
Elicitor (CHASE) program developed by Doherty and Miller (2000). CHASE was unique
in that it collected data on the household activity scheduling process for a week long period. Members of sample households would run the program daily to record activities from their initial plans to final actions. CHASE was tested in several experimental surveys and proved to be an efficient data collection tool for study of household activity scheduling. Several critical areas for improvement were identified prior to the development of REACT! (Lee and McNally, 2001), a program aimed at extending the scope of CHASE. In addition to hardware and software enhancement, significant advancement were made in terms of tracing decisions involved in the scheduling process. REACT!, and a modified version of that software, are being used in the current project.

2.2 In-Vehicle Data Collection Methods

In-vehicle travel time data collection techniques that have emerged with the development of advanced ITS technologies include cellular phone tracking, automatic vehicle identification (AVI), and automatic vehicle location (AVL). GPS technology, which is among the newest of the AVL technologies, has become a commonly used data collection tool because of its ability to automatically collect the speed and spatial coordinates of vehicles at regular time intervals (e.g. one second). Applications of GPS for real-time in-vehicle tracking include probe vehicle surveillance, travel diary survey collection, congestion management, historical database generation, and fleet management.

Probe vehicle surveillance

Since the 1920s, transportation professionals have been using the floating car technique to collect travel time information. Traditionally, this technique used a manual method to collect travel time data. This method required the driver to operate the test vehicle while a passenger recorded elapsed time information at predefined checkpoints using a pen and paper, audio tape recorders, or portable computers. Although the manual method is advantageous in that it requires minimal equipment costs and a low skill level, the fact that it is very labor intensive is a significant drawback. Human errors that often result from this labor intensiveness include both recording errors in the field and transcription errors as the data is put into an electronic format (Turner, et. al., 1998).

As portable computers and other electronic technology improved, this manual method was automated through the use of an electronic Distance Measuring Instrument (DMI), which determines speed and distance using pulses from a sensor attached to the test vehicle’s transmission (Quiroga and Bullock, 1998a). In comparison to the manual method, the amount and variety of data that can be collected is increased, while the opportunity for error is decreased. More specifically, the advantages of electronic DMIs include: only one staff member (i.e. the driver) is needed per vehicle; data reduction and analysis time are decreased due to the automatic recording of data to a portable computer; and fuel consumption and mobile source emissions can be determined from the acceleration and deceleration data that is calculated (Turner, 1996). Electronic DMIs, however, are not without their limitations. These include: DMI units are not easily shared by vehicles due to the sensor wiring that is required; frequent calibrations and the
verification of factors which are unrelated to the unit itself (e.g. tire pressure) are necessary; and the overwhelming size of each data file can lead to potential disk storage space problems (Turner, et. al., 1998; Benz and Ogden, 1996).

Recent advances in GPS technologies have largely overcome the data quality and quantity shortcomings of the manual and DMI methods of collecting travel time data. The use of GPS for ITS probe vehicle applications has a major advantage over other floating car techniques in that GPS can be used in conjunction with geographic information systems (GIS) since GPS provides the automatic geo-coding of speed and positional data (Quiroga and Bullock, 1998b). Although the application of GIS to transportation dates back to the 1960s, the ability of a GIS-GPS interface to display and analyze travel information has grown immensely in recent years as the computing speed and functionality of GIS has increased (Goodchild, 1999; Shadewald, 2000).

Recent traffic engineering studies utilizing a GIS-GPS interface to assist with probe surveillance include those conducted by Quiroga (Quiroga and Bullock, 1998a). Other research efforts that have used GPS probe vehicle systems for the collection of travel time data include: an examination of the use of rural buses as traffic probes (Turnbull, et. al., 1998); an assessment of the feasibility of using freeway service patrol vehicles as probes for measuring level of service (Moore, et. al., 2001); and an analysis of the extent to which probe vehicles equipped with dynamic in-vehicle route guidance systems are useful to drivers (Schofer, et. al., 1996).

Critical issues that must be considered when using probe vehicles relate to the quality and quantity of data collected. Research efforts addressing these issues have examined such topics as the determination of the optimal level of probe vehicle deployment, the effect of sampling bias on the accuracy of probe estimates, and the result of integrating loop detector data with probe vehicle data (Van Aerde, et. al., 2001; Hellinga and Fu, 1999; Sen, et. al., 1997; Choi and Chung, 2001). Additionally, researchers conducting GPS studies with GIS must ensure that a good base vector map with links to a database is obtained (Quiroga and Bullock, 1998b).

**Travel Diary Survey Collection**

The modeling and analysis of travel behavior is based largely on records of reported trips, the demographic and socio-economic characteristics of respondents, modal characteristics, and land use data, *inter alia*. This information is typically collected via travel diary surveys. Although early travel surveys were conducted using paper-and-pencil interview (PAPI) techniques, computer-assisted telephone interview (CATI) methods became much more common in the 1980s and 1990s. In recent years, the travel diary survey collection process has become more automated as computer-assisted-self-interview (CASI) methods, in which respondents input their travel information directly into a computer, have become widely used. Most recently, GPS technology has been used to supplement or replace other forms of travel diary survey collection. When compared to other methods of travel behavior data collection, GPS is advantageous in that respondent burden is reduced, data quality is improved, additional information can be
collected, survey periods can be extended to multi-week or multi-year periods, and data analysis can be performed with greater ease (Wolf, et. al., 2001; Draijer, et. al., 2000; Murakami and Wagner, 1999).

Many of the GPS travel diary studies conducted in recently have either included the use of electronic travel diaries or have involved completely passive vehicle-based GPS devices. The first GPS-enhanced travel diary experiment in the U.S., conducted by the Lexington Metropolitan Planning Organization in 1996, falls into the first of these two general categories. This successful “proof-of-concept” study, which involved a sample of 100 households in Lexington, Kentucky, identified two distinct benefits to a survey method that includes GPS technology: route choice data becomes available and data can be organized by highway functional class usage and travel speed (Battelle, 1997). Subsequent analyses of this study indicate that the use of automated diaries with GPS data can also provide a detailed analysis of trip chaining behavior (Yalamanchili, et. al., 1999). Another recent study that has investigated the use of automated diaries with GPS was a 1999 study conducted in the Netherlands (Draijer, et. al., 2000). Passive in-vehicle GPS studies include Austin’s 1998 household travel survey, Quebec City’s vehicle-based GPS tracking system project, and Georgia Tech’s data collection effort in Atlanta (Casas and Arce, 1999; Doherty, et. al., 2001; Wolf, et. al., 1999).

A research effort that aimed to examine the feasibility of completely replacing the paper or electronic diary with a GPS data stream was conducted at Georgia Tech. This proof-of-concept study, which involved a sample of thirty participants, demonstrated the capability to identify trip ends within a GPS data stream, to carry out land use and address “look-ups” with a GIS, and to assign trip purposes from the derived land use and address information. When the derived travel data was compared with travel data recorded by the respondents on paper diaries, the derived data was found to match or exceed the reporting quality of the respondents (Wolf, et. al., 2001).

**Congestion Management**

The consequences of traffic congestion extend well beyond the personal inconveniences felt by individual travelers. Environmental quality, roadway safety, and community access are among the many quality-of-life concerns that arise in areas plagued with congestion. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), which was re-authorized in 1998 as the Transportation Equity Act for the 21st Century (TEA21), mandates that congestion relief be considered in the selection of transportation improvement projects, and that all metropolitan areas with population exceeding 200,000 develop and implement a Congestion Management System (CMS). A CMS is a decision support tool used for selecting alternatives and strategies to better manage and operate transportation facilities in order to relieve traffic congestion and enhance mobility. As a result of the complex data management that is required for the efficient and effective assessment of any environmental, financial, social, and economic impacts of project implementation, many cities are using a GIS-GPS approach for the collection of congestion data. GIS is used to aid in the storage, retrieval and visualization of the traffic
corridor and congestion information that is collected via GPS (Sutton, et. al., 1994; Bullock, et. al., 1996).

Analyzed GPS travel time data can be used for congestion management in order to detect incidents and to determine the location and extent of bottlenecks and queues (Bullock, et. al., 1996; Jiang and Li, 2001; Gallagher, 1996). This information can in turn be used to estimate the effect of traffic congestion on vehicle emissions, wasted fuel, idling time, and traveler delay. Recent studies using GPS travel time data for congestion management have been conducted at the Remote Sensing and Image Processing Laboratory at Louisiana State University (Bullock, et. al., 1996) and by the Boston Metropolitan Planning Organization (Gallagher, 1996).

**Historical Database Generation**

Database generation is another application of GPS technology for travel time data collection. A major goal of San Antonio’s recent Metropolitan Model Deployment Initiative, for example, was to develop an extensive, real-time travel speed and roadway condition database. The Texas Transportation Institute (TTI) used the following four primary sources of data in order to develop this historical database: inductance loop and acoustic detectors, traffic simulation models, AVI tags, and GPS technology. Together these sources provided data on current link travel speeds and time, as well as on historical travel behavior. The GPS component of this data collection effort involved test runs along portions of the roadway network that were not covered by AVI and other Advanced Transportation Management Systems (ATMS) technology. For each segment, TTI conducted a minimum of three test runs with GPS equipment (per 15-minute time interval) during peak conditions and under recurrent conditions (Carter, et. al., 2000).

**Fleet Management**

GPS technology can also be used to translate fleet location data into real-time reporting. When combined with such technology as GIS, wireless communications, and the Internet, GPS technology helps provide a cost-effective tracking and services solution for fleets of all sizes. Commercial fleets, for example, use GPS to improve efficiency and increase profits by providing real-time vehicle location and status reports, navigation assistance, driver speed and heading information, and route history collection (WebTech Wireless, 2001). When combined with on-vehicle sensors, GPS can report when and where a commercial truck trailer is connected or disconnected from its tractor. This data helps trucking firms assess delivery performance or determine if a trailer has been stolen (@Track Communications, 2001). Emergency service fleets, such as police cars, fire trucks, and ambulances, use GPS to aid in the dispatching and route guidance of the nearest vehicle to an incident (MORPC, 1999). This helps ensure that citizens receive a high level of service no matter where they live or what types of emergencies they may face. Additionally, transit fleets use GPS technology to improve scheduling, enhance dispatching capabilities, and provide real-time information to passengers (Turnbull, et. al., 1998; Higgins, et. al., 1995).
3. **REACT! SURVEY INSTRUMENT**

The process of activity scheduling is crucial to the understanding of travel behavior changes. A new computer program, REACT!, has been developed to collect household activity scheduling data. Essentially a Computer-Aided Self-administered Survey (CASIS), REACT! is implemented as a stand-alone program with Internet connectivity for remote data transmission. It also contains a GIS for location identification and a special feature that traces the decisions in the scheduling process. A pilot study was conducted in Irvine, California (Lee and McNally, 2001) to evaluate functionality and performance. Preliminary analysis has validated the program's capability of guiding participants to independently complete data entry tasks, thus, the objective of reducing the cost and human resource of such behavior survey is achieved. Other positive results regarding objectives of reducing instrumental biases and expanding program capabilities were also obtained. Areas for improvement were also identified in the pilot. Based on the finding, REACT! represents an ideal platform for a computerized household survey that can produce data for activity-based travel models.

### 3.1 Program Features

REACT! is implemented as a stand alone program because it provides the desired speed and stability. The program is written as a windows application with Internet connectivity and packaged with self-executing installation and un-installation files. It inherited the survey structure of CHASE by dividing the process into two self-completing data entry stages: Initial Interview and Weekly Activity Diaries. Initial Interview is a series of questionnaires intended to collect the same information as those collected in CHASE's up-front interview. The process of activity scheduling is collected in the Weekly Activity Diaries. Participants of the survey have to install the program and finish the Initial Interview before the Sunday evening when the recording of Weekly Activity Diaries begins. Data collected from the interview will be automatically written to the main database linked to Weekly Activity Diaries. Thus, participants can enter details (e.g., activity titles, locations, and other people involved) of an activity by selecting from what they have entered in the interview.

**Initial Interview**

When users launch the program for the first time, they will be guided to complete a self-administered Initial Interview. Data requested includes household and person level responses to questions involving: (1) Household Information, (2) Frequently Visited Locations, (3) Household Vehicles, (4) Household Persons, (5) Person-level Information, (6) Transportation Modes, and (7) Activity Information, including (a) Activity Selection, (b) Activity Frequency, (c) Activity Duration, (d) Activity Time and Day, and (e) Involved Persons. The average time to complete this interview was 26 minutes for the first adult, and 13 minutes for subsequent persons.
**Weekly Activity Diaries**

Weekly Activity Diaries contains two separate graphical user interfaces for interviewees to record their activity scheduling process. The Weekly Calendar (Figure 1) is used to record activity intentions before they occur, and The Daily Calendar (Figure 2) is to keep track of what activities actually occur during a day. Instructions on how to enter data to the calendars are given to users through an automatic slide show that launches itself when the program is turned on after Initial Interview is completed.

**Weekly Calendar**

On the Sunday evening when the surveying week begins, users will be taken to an empty Weekly Calendar on which they will enter activities they know they will do on each day of the coming week. To minimize the potential "fill-up" bias (i.e., encouraging unnecessary planning by showing respondents time tables), a Weekly Calendar does not contain a time scale. Interviewees enter known activities in the calendar, and may leave details of an activity (e.g., time, location, and duration) as unknown if those features have not yet been planned. The "Any Day" list is used to enter activities that will be done in the week but on an as of yet undetermined day. Activities of particular interest produce dialog boxes to elicit further information from the interviewees.

**Daily Calendar**

At the end of each day during the survey week, interviewees are taken directly to the Daily Calendar. On this calendar (see Figure 2), activities indicated for the current day are listed in a stack of boxes on the Tentative Activities column (on the left hand side). "Any Day" activities are listed in the same fashion on the right hand side. The Final Schedule for the current day is placed in the middle with a specific time scale. Users first review the Tentative and Any Day activities and identify those that were actually executed in the current day and then specify activity details. This is followed by a series of dialog boxes inquiring about changes in plan or unplanned activities (see the section on Decision Tracing Dialogs). When questions in the dialog boxes are answered, they can move this activity to the Final Schedule by clicking on the left (from Tentative to Final) or right (from Any Day to Final) arrow buttons. After a user has completed updating the Final Schedule for the day, REACT! returns them to the Weekly Calendar and asks them to review the activities for subsequent days and to update them if changes have been. The process of updating Daily and Weekly Calendars continues everyday until the final Sunday when the survey ends.

**Decision Tracing Dialogs**

REACT! is implemented with mechanisms intended to trace decisions involved in everyday activity scheduling. When a respondent manipulates a specific activity record in a certain way, a series of dialog boxes will show up to trace the decision process underlying the manipulation. Nine different questions may appear when interviewees change or add a specific activity record in their Daily Calendars. Depending on the
response, subsequent dialogs may be triggered to trace other information that may be relevant to the decision. Details are provided in Lee and McNally (2001).

**The Send Data Utility**

Each day when the adult members of a household have finished recording their activity diaries, the last respondent establishes an Internet connection and activates REACT!’s Send Data Utility. Currently, the program databases reside on the clients’ end to achieve privacy and efficiency with a minimum deployment cost. When Send Data is activated, the program will compress and encrypt the database of the entire household and the data package will be sent to the survey administrative server via FTP. The entire Send Data process is performed automatically without user intervention. When it finishes, users will receive notification to exit the program.

### 3.2 A REACT! Pilot Survey

The major purpose of the pilot study was to evaluate program performance with a small number of households residing in the same geographical area designated for the shared-use program. Prior to execution of the pilot study, a prototype of REACT! was subject to beta testing with nine households. The program was incrementally modified each week until the pilot version was completed.

A total of 47 households finished the pilot study in Spring 2000. During the process, four households were withdrawn by the survey administrator, because they did not run the program within the designated time. Many of the participants were students residing in two student communities located adjacent to the main campus of UCI. The study area is focused on the city of Irvine, and includes portions of neighboring to form a large, dense area with numerous opportunities for most activities. Locations within this area were predefined in the program for users to indicate their activity locations. The GIS component displayed the map of this entire area when activated by users.

The sample was solicited and a Web site (http://www.its.uci.edu/~react/) was established to give participants a brief introduction of what questions and tasks they should be expecting from the survey. A package containing the REACT! program on CD and other administrative materials was sent to each participant. During the survey week a dedicated phone line was available for technical support. At the close of the survey period, an evaluation survey was sent by email to each participating household. Participants in the pilot were financially compensated.

### 3.3 REACT! Summary

REACT! was developed to collect data on household activity scheduling process. The program was tested in a pilot study in Irvine, California and preliminary analysis validated the program's capability of guiding participants to independently complete data entry tasks, thus, reducing the cost of gathering activity behavior data. Significant reduction of instrumental bias was achieved relative to CHASE and critical software
capabilities were added regarding user interface. The full potential of the Internet has yet to be explored. Currently, the program has a one-way interaction in uploading survey data to a survey server on a daily basis. The survey administrator can examine the data on the server side and use emails and phone calls to inform participants of errors in previous entry sessions.

Lawton (1998) noted the inefficiency of the current data collection methods and stated, “We should seriously evaluate the use of more carefully chosen, smaller samples, using direct contact and paying for cooperation (their time). Data collection needs to be automated (laptop, etc.), and we need to design interactive stated response experiments that key directly from revealed data at the same collection time.” According to the finding from this study, REACT! represents an ideal platform to realize Lawton’s vision of a computerized household survey. The Decision Tracing Dialogs can be easily adapted to stated-response or stated-preference questions. In addition, the sample size of such a survey can be augmented by providing potential participants who do not have PCs a laptop on which to complete the survey.

4. THE TRACER SYSTEM

The in-vehicle data collection system, deemed TRACER, has been developed for a variety of applications. It combines a GPS with an automated data collection system and a wireless modem which allows data to be accessed (and the vehicle to be tracked) any time the vehicle is under power. A brief review of the design of this system is followed by a sample application.

4.1 Application Requirements

While the potential uses of GPS-enhanced vehicle-based data collection vary significantly, a set of generic applications can be defined that span functional requirements for the various uses. Four data collection applications are envisioned:

1. Basic: basic multi-day survey of vehicle trajectories;
2. Probe: obtaining real-time traffic stream conditions via probe vehicle,
3. Enhanced: enhanced multi-day survey of trajectories with behavioral logging;
4. IVNS: routing behavior under real-time route guidance

The most crucial of these for the initial shared-use station car applications are the first three applications (the fourth is not currently required but will play a significant role in full deployment). The following sections detail the parameters for each of these data collection applications.

Basic Survey

In the basic survey application, the data collection system records a vehicle’s trajectory for later analysis of route utilization. A prototype application compares basic survey data
with traffic flow data collected from loop sensors on local Irvine freeways. Parameters for this application include positional fixes taken as frequent as 1-second intervals at differential GPS accuracy, storage of associated data, and minimal requirements of drivers regarding data collection. Post-analysis of collected data requires that data be accessible in a flexible format.

**Probe Vehicle Study**

In probe vehicle study applications, the data collection unit collects data from a vehicle traveling in the traffic stream. The data is logged in the on-board unit, and transmitted in near real-time to a base station over a wireless communications network. Parameters for this application include the ability to collect data for logging and remote transmission including position and speed of the vehicle, point-to-point travel times, and other vehicle data, such as acceleration or emission profiles.

**Enhanced Survey**

The enhanced survey application extends the basic survey to include additional logs of respondent activity during the data collection process. For instance, log data might be the results of questions asked of drivers about the purpose, characteristics, expectations, etc. of a trip before or after it is made. A prototype solution extends the data collection device designed for the basic survey by connecting a user interface for gathering the additional information. Parameters for this application include minimizing driver interface, particularly when actively engaged in driving, user-friendly interfaces.

**Route Guidance Study**

In the route guidance study drivers are provided with descriptive information about network conditions and/or prescriptive guidance about the best routes to take via real-time wireless communication with the vehicle. In addition to the capabilities given for the probe vehicle application, this application requires two-way communication between a base station and the vehicle (for the transmission of descriptive and/or prescriptive guidance from the base station to the vehicle and positional fixes of the vehicle back to the base station) and a user interface, such as in the enhanced survey, that is flexible enough to display route guidance information to the driver (such as current position, desired destination, and suggested routing instructions).

**4.2 TRACER System Specifications**

The TRACER system incorporates a prototype extensible data collection unit (EDCU) meeting the application requirements above with a suite of base station processing software (for real-time and post-processing). Thirty in-vehicle EDCU devices are available for use in the shared-use station car program. These self-contained units are built around a power-efficient x686-class, 133MHz microprocessor running a Linux-based embedded operating system. The unit uses flash-RAM as its primary storage, and
controls both a GPS receiver and a cellular packet data (CDPD) modem. The operating system runs programs to control the various EDCU applications outlined.

Figure 3 shows the prototype unit, the GPS antenna, and the CDPD antenna (the diskette is included for scale). Figure 4 shows the inside of the unit, with various input and output ports, and the flash ram memory card (the CDPD modem is not shown to improve the view of the interior).

Under normal operation, the units are designed to operate by tapping a vehicle's power supply via the cigarette lighter. With the addition of a battery pack, they can also be isolated from the vehicle's power for short duration applications. The units are enclosed in a weather resistant case that is suitable for the relatively harsh environment found in an automobile.

Because the equipment is intended to fill multiple data collection roles with significantly different requirements, versatility is a primary design goal. The data collection system therefore employs a modular design to ensure such flexibility. The device consists of the following modules:

1. a data collection unit controller (DUC),
2. a global positioning system module (GPS),
3. a on-board logging module (LOG),
4. a communications module (COMM),
5. a user interface module (UI), and
6. a base station unit (BSU).

The prototype units contain the DUC, GPS, COMM, and LOG modules. The DUC and the LOG modules form the heart of the extensible data collection unit (EDCU), with the DUC responsible for the operation of the data collection unit and the LOG responsible for saving the collected data. The DUC is implemented as a computer on a board, with a 16 MB flash RAM module to use as system memory. The flash RAM has been partitioned such that there is adequate space for data logging. To the software applications, the LOG unit exists as a distinct mount point in the Linux file system. Saving data to the LOG is as simple as writing to a file.

The COMM unit is handled as a communications device implementing a TCP/IP stack -- in other words, it is not much different at the applications level from a modem connected to the Internet. Sending data to a base station unit (BSU) is accomplished by writing data to a data socket connected to the BSU. Receiving incoming instructions from the BSU is accomplished by listening to an open socket. In practice, accessing data from the unit is accomplished through the usual programs such as FTP, telnet, or through a web browser (or by reading the flashram directly). Since the Linux operating system was selected along with standard CDPD modems, the BSU module effectively becomes any computer connected to the Internet. In practice, the BSU role will be filled by a dedicated server computer to ensure the integrity and security of the collected data.
4.3 TRACER Support Software

The GPS-enabled travel survey data must be integrated with geographic information systems (GIS) for real-time and post-processing. The power of knowing where a vehicle is during a survey period is increased when one can merge that information quickly with a GIS program. BBN Technologies' OpenMap (http://openmap.bbn.com) GIS is written in Java and was ideally suited to Internet-based. The software can probe a EDCU over the Internet and posts that information on a map. An EDCU in a survey vehicle can send tracking data to the driver's personal computer for subsequent consideration in REACT!.

4.4 Sample Application

Figure 5 shows the output of a test drive in the Irvine area, layered (with no map-matching algorithms) over a map generated from TIGER-Line files. The data in this figure were processed using a laptop connected to the EDCU. The third layer is a mapping of freeway loop detector locations. These detectors provide vehicle counts and occupancies and, from these occupancies and assumptions on the mix of vehicle lengths, speed estimates may be derived. We compared GPS generated speeds (checked versus vehicle speedometers) with loop estimates on a lane by lane basis (see Figure 6). While a general level of consistency was obtained, the units provided evidence that the variability of loop detector speed estimates over short time intervals are significant, thus, the use of these speeds in traveler information systems is unreliable at best.

5. SHARED-USE STATION CAR PROGRAM

In response to the California ZEV mandate, a consortium of researchers, manufacturers, and state agencies is developing an intelligent transportation system that will use wireless networks to link small electric vehicles to corridor rail transportation in the form of shared-use station cars. This will take advantage of the corridor's natural potential for rail travel for the line haul portion of many commutes, while still providing commuters with the mobility and flexibility they demand at both ends of that line haul. This hub and spoke access system, once successfully implemented to serve commuter rail corridors, can be extended to office parks, entertainment complexes, and residential neighborhoods.

The demonstration project proposed is designed to: (1) develop and test the information technology and infrastructure for station cars in the U.S. Market, (2) satisfy the major credit outreach of California's ZEV (zero emissions vehicle) mandate, (3) initialize the U.S. market for station cars, and (4) integrate the station car infrastructure into the emerging distributed energy era.

In Phase 1 of the prototype system, 15 Toyota ecom "city" electric vehicles were distributed to participating companies in UCI's University Research Park where individual drivers were assigned a vehicle for private use for one month. At the end of this six month "introduction" period, the vehicles were removed for subsequent reallocation to the same companies but in a shared use mode. It is at this stage, Phase 2,
that the REACT! and TRACER technologies are being applied. Each participating company will receive one to three ecoms which will be shared among all participating drivers during the conventional work day. Selected drivers will have access to the vehicles at night and on week-ends and, in particular, will be able to access free preferred parking with EV chargers at the Irvine Transportation Center (served by Amtrak and MetroLink commuter rail). A full implementation of ZEV NET (Zero Emission Vehicles – Network Enabled Transportation) would be realized in Phase 3 where full prototype development of the necessary information technology will be implemented in a fleet of EVs deployed at several regional transportation centers which feed the Irvine employment centers.

For the Phase 2 evaluation, the data collection process is proceeding in three stages: (I) before the vehicle-sharing program, (II) during the program, and (III) after the program is completed. The REACT! Computer-Aided Self-administered Interview program is being used to collect activity schedules from participants. Each phase lasts for an entire week, beginning on a Sunday evening till the next Sunday evening. The data derived from the first phase will depict participants’ typical weekly activity programs before the alternative of sharing vehicles is in presence. During this phase, participants execute REACT! and follow the instruction given by the program to fill out the survey. On the first Sunday evening, respondents first indicate basic household and personal information. Then they will be asked to indicate the activities they are going to do for the coming week. On Monday evening, they will be asked to update what they actually do throughout Monday and indicate if there are changes to the plans of the following days. The process will repeat on each evening of the surveying week. In the second phase when electric vehicles are in use, REACT! will be used in conjunction with the GPS tracing instrument, TRACER, equipped within the study vehicles. In addition to typical weekly activity schedules, the integration will facilitate the exploration of route choice dynamics that may be affected by the unique characteristics of electric vehicles. This scenario combines data on vehicle paths with contemporaneous data on traffic conditions along that path and also with information from respondents about why specific routes were selected. In the third phase when the program ends, the procedure carried out in the first phase will be repeated again to see if there is any residual effect in participants’ activity/travel patterns.

6. SUMMARY AND PROJECT STATUS

At this point, the initial REACT! application is in the field. A revised version of REACT! has been developed which is directed explicitly toward assessing shared vehicle usage. This version is integrated with the TRACER system to provide tracings of travel each travel day to respondents as they complete the REACT! survey.

It is believed that the proposed computerized survey will significantly reduce data collection costs, improve data quality and scope, and allow for continuous data collection. Furthermore, a panel-like comparison among all three phases will facilitate the identification of the spatial and temporal patterns of electric vehicle usage and the
underlying determinants governing those patterns. Only through such a comprehensive understanding of the patterns can vehicle-sharing schemes be effectively evaluated and revised.

The fusion of next generation information technologies (IT) and intelligent transportation systems (ITS) presents an opportunity to adopt cleaner technologies, such as a ZEV shared-use car, while maintaining the flexibility of a private car. A Station Car program is a logical approach to achieving this goal. A Station Car demonstration project will also benefit automobile manufacturers by identifying system-level alternatives that have a substantive opportunity to strategically reduce emissions and manage congestion.

REFERENCES


Battelle Transportation Division (1997) Global Positioning Systems for Personal Travel Surveys: Lexington Area Travel Data Collection Test, Final Report to the FHWA.


FIGURE 1 Weekly Calendar
FIGURE 2 Daily Calendar
FIGURE 1. TRACER EDCU Outside View
FIGURE 4. TRACER EDCU Inside View
FIGURE 5. Sample Tracings with Loop Detector Overlays
FIGURE 6. Comparison of GPS and Loop Speed Estimates