Session Paper

Using Global Positioning Systems and Personal Digital Assistants for Personal Travel Surveys in the United States

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ABSTRACT

Information about daily travel patterns is generally captured using self-reported information from a written diary and telephone retrieval (or mail-back of diary forms). Problems with these self-reported methods include lack of reporting for short trips, poor data quality on travel start and end times, total trip times, and destination locations. Also, the burden on the respondent may be 20 minutes per person for reporting of 1 day (24 hours) of travel, and more than 60 minutes per household using telephone retrieval methods.

This project combined Global Positioning Satellite (GPS) and Geographic Information Systems (GIS) technology with small hand-held computers (Personal Digital Assistants—PDAs). In addition, respondents were mailed a training video to assist with installation and use of the equipment. A small, user-friendly, mail-able unit was designed to capture vehicle-based, daily travel information. Nearly 90 percent of person trips in the U.S. are made in a private vehicle. The unit was developed to capture variables that would be entered by the vehicle driver using a touch-sensitive menu, with items such as trip purpose and vehicle occupancy, and to capture automatically recorded variables such as date, start time, end time, and latitude and longitude at frequent intervals. Finally, after mail-back return of the units, the data are processed to include variables such as travel speed by road classification, trip distance, and trip time. The unit allows for collection of travel data over several days to avoid potential short-term, survey-induced travel behavior changes.

This method of data collection has two potential benefits: improving the quality of travel behavior data, and reducing respondent burden, e.g., time on the telephone for reporting travel information. Using GPS technology, while increasing privacy concerns, may improve overall survey data quality in travel behavior studies.

The field test was conducted in Lexington, Kentucky, in Fall 1996, with 100 households. The sample of drivers was stratified by age, gender, and presence of children under age 16 in the household. Respondents were asked to use the machine for six days, with the expectation that data from Day 1 and Day 6 may not be useable. Respondents were also asked to recall all their travel for one 24-hour period (Day 5). This process resulted in a complete 24-hour report of trips made by the selected driver by all modes and a 4-day report of trips made in the selected vehicle by all drivers and passengers. Geographic coding of destinations should be much improved using the GPS technology. Also, route choice, functional class usage, and travel speed information is available.

This paper focuses on respondents' perceptions on the installation and use of the equipment. Some comparisons between self-reported and machine-recorded travel are discussed, but are limited.

INTRODUCTION

Personal travel and how it changes is of continuing concern to transportation planners and policy makers. Information about daily travel patterns and trip purposes, time of day decisions, mode choice decisions, and trip chaining decisions, is generally captured using self-reported information with a telephone recall method, or some kind of diary.

Transportation professionals and other users of the collected data surmise that people likely omit very short trips using self-reported methods. The current trend in collecting this type of data is to use an activity, rather than a travel diary, to attempt to both capture these short trips as well as to identify at-home activities that are substituting for traditional at-work activities. Nonetheless, self-reporting is used for this approach as well. Other problems with self-reporting include the tendency to round travel times to 10, 15, and 30 minute intervals (*1*). Similarly, self- reporting of trip distances may be significantly in error and also prone to rounding problems. It may be that overall, vehicle miles of travel (VMT) reporting is fairly complete using self-reporting methods, but that people neglect to report the short stops made during a journey, like stopping at the post office, ATM, or video rental store. Another issue with the trend toward activity reporting is the burdensome nature of telephone interviews that are averaging close to one hour per household for a one-day household travel survey (*2*).

Computer-assisted self-interviewing (CASI) was used in time use surveys in the Netherlands as early as 1988 (*3*). The computers used were not portable. Despite concerns that have been expressed by some researchers that respondents may be computer-illiterate, the literature suggests that electronic diaries are less demanding than a paper diary, and that people may prefer responding to a computer (*4*).

Using hand-held computers for the automatic logging of vehicle trips was discussed at the 3rd International Conference on Survey Methods in Transportation in 1990 (*5*). Increasing use of portable computers to assist in household travel surveys was discussed at the same conference by Jones and Polak, although the discussion primarily focused on improvement to computer-assisted telephone interviewing (CATI) and computer-assisted personal interviewing (CAPI). Jones and Polak suggested that improvements in graphic interfaces could be used such that map-based routing choices could be included (*6*).

Vehicle instrumentation, including global positioning systems (GPS), has been used in various Intelligent Transportation Systems (ITS) projects, for example in the Orlando TRAVTEK project, the Chicago ADVANCE project, and an EPA-sponsored research project at Georgia Tech. In the TRAVTEK and ADVANCE projects, GPS has been used to assist drivers in routing. That is, the GPS "knows" where the vehicle currently is, and the on-board computer can then "direct" drivers to their destinations, potentially with the ability to include real-time information to direct the driver around congestion or accidents. These two projects rely on specially designed vehicles and combine GPS with other in-vehicle instrumentation (such as transmission sensors) to support dead-reckoning or map-matching techniques to pinpoint vehicle position. In the Georgia Tech project, the transponders are attached to personal vehicles to also provide information on engine operations and emissions (*7*). Other transportation applications of

GPS have been for congestion management systems (*8*), travel speed studies, and fleet management systems and freight tracking (*9*, *10*).

By combining self-reported information with GPS-recorded information, the utility of this technology for measuring personal travel can be evaluated. This technology has the potential for both improving the quality of data on travel behavior and reducing respondent burden for reporting this behavior.

OBJECTIVES

This project had three overall objectives:

1. Develop a method and hardware to integrate GPS technology with self-reported travel behavior to improve travel behavior data.
2. Document the differences between self-reported travel and GPS-recorded travel and document the pros and cons of each method.
3. Determine potential for using GPS technology with regional and national travel behavior surveys, with particular regard to subjective responses to privacy.

The project was conducted in three phases. Phase One defined a functional specification for the data collection device and compiled vendor and other technical information about GPS receivers, hand-held and palm-top computers and personal digital assistants (PDAs). Phase Two performed a series of bench tests using several GPS receiver configurations to test the ability of the GPS equipment to collect position data that would be useful to support the personal travel data studies. Phase Three of the project was a field test of the complete data collection device, collecting actual data from 100 households.

GENERAL DESCRIPTION OF THE DATA COLLECTION UNIT

The result of the Phase One activity established the general definition of the data collection device. The key components include the GPS receiver, the user interface, and the control unit. The user interface and control unit are made up of a single component, a hand-held PDA equipped with touch screen for user inputs. The GPS receiver uses integrated technology with the combination receiver and antenna mounted on the vehicle rooftop.

In addition to evaluating whether or not the technical capabilities existed, other factors that influenced the design and development were costs per unit, ease of acquisition and operation by transportation professionals, and ease of operation by survey respondents. By limiting the unit costs and by making acquisition easy, the potential for actual use by metropolitan planning organizations would be enhanced. Thus, use of “off the shelf” equipment was a priority. Concern about loss of equipment owing to theft and breakage also influenced the goal of keeping unit costs as low as possible. Operationally, the data collection unit is a “plug and play” concept, requiring minimal installation and setup effort on the part of the user. The touch-screen user interface, used for the self-reported portion of the travel information, was designed to mimic the operation of an ATM, which is very familiar technology for a large segment of the population.

Travel data were collected over a period of six days, and thus, power management became a significant issue in the design. Both user inputs and GPS position data were stored on a PCMCIA memory card. The 1990 NPTS data indicated that to capture 95% of vehicle trips, the unit would have to store up to 158 minutes (2.6 hours) of data per day. So, for a 6-day period, fully operational power was required for at least 15.6 hours.

The principal power for the unit is supplied via the vehicle's cigarette lighter, with internal batteries to sustain the unit's operating system when the vehicle is inoperative. The unit automatically shuts off at the appropriate time both to conserve internal battery power and avoid draining the host vehicle battery. These power management activities also support more efficient use of available memory storage capacity by shutting down the GPS unit when the vehicle is not being used.

BENCH TEST OF GPS CONFIGURATIONS

Phase two of the project examined two technical issues. First, is GPS positional data alone sufficient for determination of travel along specific roadways, without reliance on a second, independent positional data source (such as dead reckoning)? Second, what type of GPS receiver technology is appropriate for this application? There is a wide variety of GPS receiver and ancillary equipment available.

To answer these two questions, a test route in Columbus, Ohio, was designed to capture representative roads and roadway obstructions. Some examples of roadway segments that were included are

- Traditional neighborhood with mature trees and relatively narrow streets,
- Newer subdivision-style neighborhood with typically wider streets,
- Suburban business district with relatively wide streets,
- Central business district streets in an urban "canyon" formed by a string of high-rise buildings, and
- State route limited access and interstate highways.

The test route was approximately 19 miles, and travel time varied between 45 to 60 minutes depending on time of day and traffic conditions. Three GPS units were tested, with a total of seven different receiver and antenna configurations.

The bench tests concluded that GPS data alone were sufficient for collecting personal travel survey information if one-second positional data are recorded. One-second data are probably needed to provide a complete track of the route driven, especially when the travel is at relatively high speed, such as on an interstate highway. This one-second trace is also useful for determining the functional class of highway traveled. Less frequent data, however, are sufficient for collecting travel distance and travel time. Differential GPS data, along with a positionally accurate geographic base file, permit easier post-processing for map matching along the road network. However, absolute GPS is probably sufficient if automated matching algorithms are used. Differential GPS offers no advantage for the point-to-point travel distance calculation.

The bench tests concluded that the GPS receiver should have at least 5 channels, and that a roof-mounted antenna provides much better response because of fewer problems with line-of-sight satellite viewing. In the bench test, both the five-channel and 12-channel receivers demonstrated good performance (*11*).

HARDWARE AND SOFTWARE USED IN THE FIELD TEST

The hardware selected for the field test shown in Figure 1 included a Sony MagicLink 2000, a Personal Digital Assistant (PDA) with a backlit screen, weighing about 1.5 lbs (700 gm). A Garmin GPS antenna/receiver (weight is about .5 lbs (225 gm)) is attached through the PDA serial port. Finally, a power cord connects the machine to the vehicle electrical system via the vehicle cigarette lighter. Equipment specifications are included in Table 1. The software includes the ability to capture data from the vehicle driver and the GPS unit. The vehicle driver uses a touch-screen menu to enter variables such as trip purpose and vehicle occupancy, but other data such as date, start time, end time, and vehicle position (latitude and longitude) are received by the GPS unit and stored in the PCMCIA card in the PDA at frequent intervals.

Components of the software included (1) administration, (2) user interfaces, and (3) communication between the GPS receiver and the PDA. The administration portion (Figure 2) included the screens for entering the individual driver and passenger names, data uploading to a desktop PC, and measures of memory availability, and when to "go to sleep" to conserve battery power. The user interface (Figure 3) required the driver to select the vehicle occupants (driver and passengers) and a trip purpose for each trip. Finally, the software had to store the GPS data after being received by the GPS unit.

The user's acceptance of this type of data collection device is key to the future use of this technology for large-scale data collection efforts. One factor in user's acceptance is the weight of the equipment. The configuration used in this experiment weighed about 2 lbs (925 gms). While this is an acceptable weight to ask people to carry to their car to install, the equipment is probably still too heavy to try to implement a travel survey requiring people to carry the equipment with them for all trips, e.g., walk, bike, transit. In addition, the battery requirements were such that the battery needed to be recharged every five hours. By restricting the survey to vehicle trips, finding equipment with an acceptable weight for people to carry is not a problem, and attaching the equipment to the vehicle's battery removes the limit of the five-hour battery life (without recharging).

A user-friendly interface was considered the key factor in user acceptance. Ease of use issues were addressed by incorporating a touch-screen interface in the device for user input. Operationally, the device mimicked an ATM machine, which is familiar technology to most of the people in the field test.

Vehicle occupancy identifies the driver and the passengers in the vehicle. This entry identifies the individual household members and includes a count of non-household members. The 1990 NPTS data show that for over 90 percent of vehicles, there is a primary driver (*12*). Many trips (67%) are also drive-alone (*13*), thus it is probably not much of a burden for the respondent to identify the driver and passengers. Since each household was individually recruited, the data collection unit includes an administration screen so that the menus were personalized to list the names of the individuals in the household. This personalization makes it easy for the driver to select the names of the driver and household members who are in the vehicle (Figure 2).

Trip purpose, on the other hand, was much more difficult to organize and to program into a simple menu system. The result was a two-stage trip purpose selection menu, with a total of 15 purposes for the driver and 15 purposes for passengers. Results of recent activity-based self-reported diaries were used to select those activities that appear most frequently and to include these activities on the primary screen shown in Table 2 (*14, 15*).

Since the unit was being designed for vehicle drivers, trips to day care and pre-school activities are confined to passenger trip purposes, shown in Table 3 and Figure 3.

Our goal was to have respondents select their immediate destination on the trip purpose menu. This immediate destination may differ from their ultimate destination. Trip chaining has become an important topic in the travel behavior research community. Some research indicates that as many as 30 percent of trip chains are complex, containing more than one stop (*16*). It is difficult for someone in the general public to determine a trip purpose if their ultimate destination is to return home after work, but with a stop at the dry cleaner along the way. The respondent may select “Return Home” for both trips, instead of selecting “Personal Business - Errands” for the first destination to the dry cleaners.

Telephone interviewers can probe respondents for corrections during a telephone interview, but the in-vehicle hand-held unit will not have the same ability to judge reasonable choices and ask for corrections. However, the software permits the user to make corrections when they discover a mistake. After a trip purpose is selected, the respondents can select “change” if they need to select another trip purpose or change the list of vehicle occupants. Additionally, both the training video and the written instruction manual highlighted this potential problem for users.

Many other differences exist between this automated data collection device versus a travel diary or telephone interview. Since this device essentially tracks every movement of the vehicle (and thus the person), privacy issues were expected to be raised as a point of concern for the respondent. There are other concerns, principally liability issues, related to the physical installation of a device in a private vehicle. For these reasons, no corporately owned vehicles were permitted in the study. Also, licensed drivers under the age of 18 were prohibited from participating as the principal driver because minors cannot sign the required informed consent on behalf of the household.

FIGURE 1 Field test equipment.

TABLE 1 Specifications for the Field Test Equipment

Equipment	Unit Cost 1996 U.S. Dollars	Weight	Characteristics
Garmin GPS30 TracPak GPS Receiver	<$250US	.5 lb (225 gm)	8 channel satellite tracking NMEA 0183 V 2.0 output Differentially correctable Time to first fix: <2 sec reacquisition 20 sec warm; 2 min cold Size: 1.04"h x 3.80" l x 2.23" w (26.4mm x 96.5mm x 56.6mm) Magnetic mount and suction cup mount available
Sony MagicLink PIC-2000 PDA	$699US	1.5 lbs (700 gm)	Backlit, pressure sensitive ("touch") screen MagicCap v1.5 Operating System MC68349 processor 2 PCMCIA Type II slots Size: 1.0"h x 5.2"l x 7.5" w (25.4mm x 132.1mm x 190.5mm)
2.0 MG PCMCIA Type II SRAM memory card	$199US		Non-volatile memory
Wrapped connecting cable	<$200US		Custom built to prevent unintended disconnects. Power cable services PDA and GPS receiver via cigarette lighter/accessory port. Serial communications cable enables PDA and GPS to communicate.
Software Personal Travel Survey (PTS) v0.25	N/A		Developed by FASTLINE, Inc. in San Francisco, CA
TOTAL	<$1,350US		

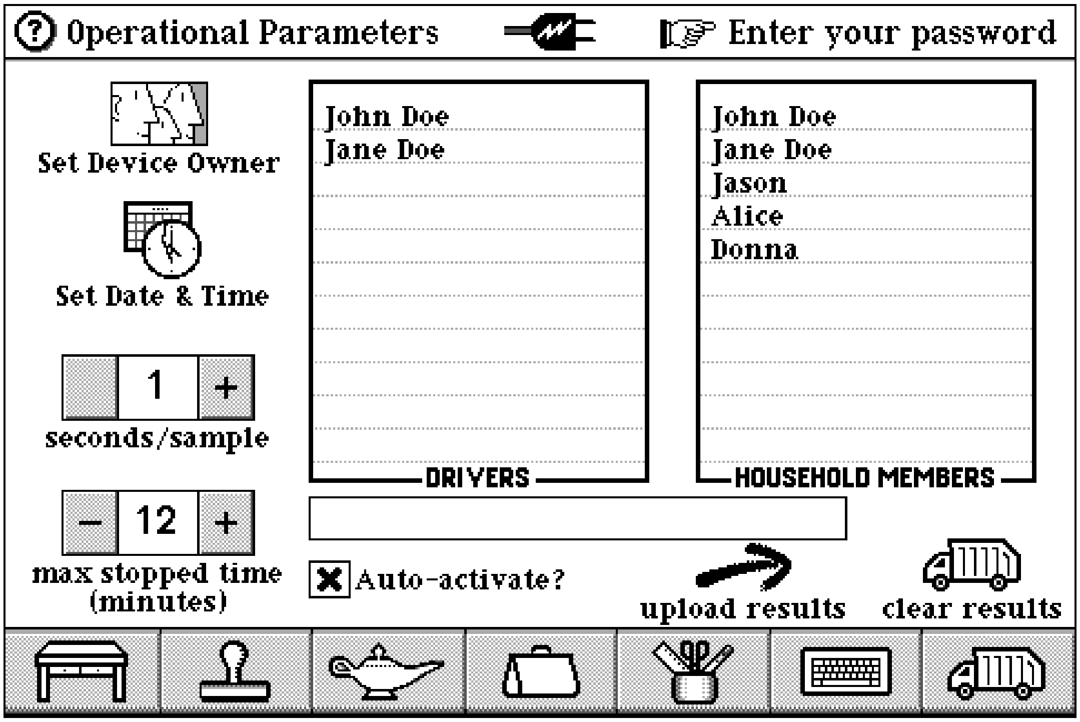

FIGURE 2 Administration screen of the PTS software.

TABLE 2 Trip Purpose Menus for the Driver

Primary Menu	Secondary Menu Choices
Pick Up or Drop Off Passengers	-Pick Up Passenger -Drop Off Passenger
Work or School	-Work Place -Work-related Business -School, College, University
Shopping & Personal or Household Business	-Shopping -Errands and other personal business, such as bank, post office, dry cleaner, video rental, barber, car repair, etc.
Eat Out	*None*
Social or Recreational	*None*
Medical or Dental	*None*
Return Home	*None*
Other	-Religious Activities -Volunteer Work -Community Meetings, Political or Civic Events -Other

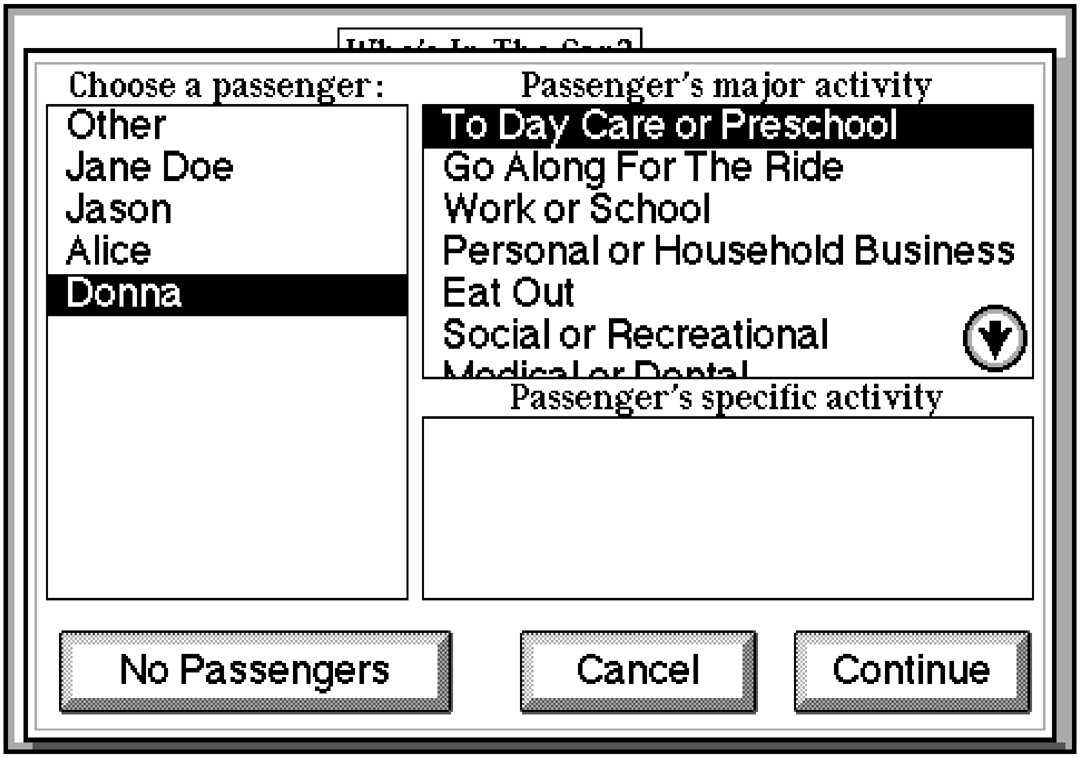

FIGURE 3 Screen to select passenger name and trip purpose.

TABLE 3 Trip Purpose Menus for the Passenger

Primary Menu	Secondary Menu Choices
To Day Care or Preschool	*none*
Go Along for the Ride	*none*
Work or School	-Work Place -Work-related Business -School, College, University
Shopping & Personal or Household Business	-Shopping -Errands and other personal business, such as bank, post office, dry cleaner, video rental, barber, car repair, etc.
Eat Out	*none*
Social or Recreational	*none*
Medical or Dental	*none*
Return Home	*none*
Other	-Religious Activities -Volunteer Work -Community Meetings, Political or Civic Events -Other

FIELD TEST SITE SELECTION

The Lexington, Kentucky, Metropolitan Planning Organization (MPO) was selected to assist with the field test. The metropolitan planning area of Fayette and Jessamine covers 461 square miles with a total population of about 350,000. The MPO was selected based on the willingness of the MPO to provide 300 hours of staff support during the field test, and on the positional accuracy, currency, and completeness of the geographic base file. The street centerline file for Fayette County is positionally accurate within 5-7 feet, and address ranges and street names are updated within 45 days of the changes.

SAMPLE STRATEGY

Although the total sample was small, the sample was stratified by three characteristics: age, gender and presence/absence of children. Different age groups were expected to respond differently to a "high technology" project requiring the use of a computer. Also, young adult males tend to have low response rates to traditionally conducted surveys. Similarly, women were expected to have more concerns about installing equipment on their cars and more concerns about their privacy. Finally, people with children were expected to be more easily distracted, or in a hurry, and would be more likely to forget to use the PDA when they got into the car. The sampling strategy is shown in Table 4, showing both the targeted values and the actual sample that was achieved.

TABLE 4 Sampling Strategy for the Lexington Field Test

	Age	Gender	Children	Target	Actual
1	18-24	M	Yes	8	4
2	18-24	F	Yes	8	7
3	18-24	M	No	8	8
4	18-24	F	No	8	8
5	25-29	M	Yes	9	9
6	25-29	F	Yes	9	10
7	25-49	M	No	9	10
8	25-49	F	No	9	9
9	50-64	M	Y/N	8	9
10	50-64	F	Y/N	8	9
11	65+	M	Y/N	8	8
12	65+	F	Y/N	8	9

RECRUITMENT RATE OF ELIGIBLE DRIVERS

Recruitment of eligible drivers was more successful than anticipated. The Lexington MPO had arranged for both newspaper and television coverage of the field test shortly before recruiting began. A presolicitation letter from the Lexington MPO, with an enclosed copy of the article from the local newspaper, was sent to approximately 1,300 households with listed telephone numbers. A concern was that the response rate could be as low as 20%; however, once the telephone interviewers determined that there was an eligible driver in the household, 67% of those eligible consented to participate in the field test. Their agreement to participate was followed by a mailing including the informed consent papers for them to read, sign, and return before the equipment would be released for their use. Only two of the households declined to participate after reviewing the informed consent papers.

For the 100 households, the average household size was 2.94 persons, with an average of 2.17 vehicles. The sample of drivers was quite highly educated, with 20 percent completing college, and 20 percent with post-graduate education. The average estimate of annual miles driven was 13,118. This average should be higher than a typical average, because the sample selection process excluded persons who drove less than 3 days per week.

The sample of drivers was selected using a sample of residential addresses with listed telephone numbers. Each driver was asked to attach the equipment in his or her “primary” vehicle. In the U.S., it is often the case that each driver has a vehicle that is nearly exclusively used by that individual.

However, other people may drive the car occasionally during the survey period, and likewise, the selected driver may drive other household vehicles. Thus, this is somewhat a survey of vehicles, since six additional household members who drove the GPS-equipped vehicles during the survey period were also interviewed.

Future surveys may want to equip all vehicles in selected households, as it appears that the household remains the accepted unit for travel demand modeling and simulation.

SURVEY PROCESS

The survey process was more complex than a traditional telephone/mail-out/telephone retrieval survey. A consent form had to be delivered, signed, and returned to the agency before the computer equipment was even delivered to the survey participant. Participants had to complete the PDA/GPS travel survey and, in addition, complete a telephone survey that included a one-day travel recall survey and equipment evaluation.

Respondents received a total of $50 for their participation. A money order for $20 was included when they received the equipment, and an additional money order for $30 was mailed to them after the equipment was returned. The impact of the incentive is not known. One purpose of the financial incentive was to assure the prompt return of the equipment.

The equipment was delivered to and picked up from the households by a local courier service for approximately $19 per household. The equipment package contained the PDA/GPS equipment, a 12-minute instructional video tape, an illustrated installation and user’s guide, the initial $20 incentive, confirmation of the intended vehicle and expected use dates, and instructions for returning the equipment.

HARDWARE AND SOFTWARE PERFORMANCE

The hardware and software performed much better in the field than had been anticipated. Of the 15 units that completed the four-month test cycle, only one failed and had to be returned to the manufacturer for repair. Repairs took the unit out of service for about a week; then it was returned to the field test and experienced no further problems. One serial extension cable was pulled apart and had to be replaced. Otherwise, the equipment survived the field test with just normal wear and tear.

The software generally worked well; however, one-second GPS data capture was not achieved as planned. GPS data points were recorded at irregular intervals, averaging between 20 and 30 records per minute. This irregular recording was a software problem that has since been corrected in later versions of the software. Other software anomalies appeared infrequently and each has been investigated for possible correction.

Data collection performance was judged to be good. In two instances, the equipment was returned with absolutely no data records on the memory card. The cause was undetermined. The battery power supply in the PDA was sufficient to capture the user-input portions of the data without an external power source, but no data were recorded. There were six instances were there were no GPS data recorded; however, the data records for the user-input trip information were intact. In these cases, a faulty external power supply (vehicle cigarette lighter) was suspected since the GPS receiver requires an active power source to produce position data.

Overall, 92 of the 100 field subjects returned good data describing over 2,200 individual trips during the field test. Of these, approximately 1,800 had valid GPS data to at least partly describe the travel activity.

Figure 4 is an example of collected GPS data. This example illustrates four separate trips made by the respondent during a single day of the survey period.

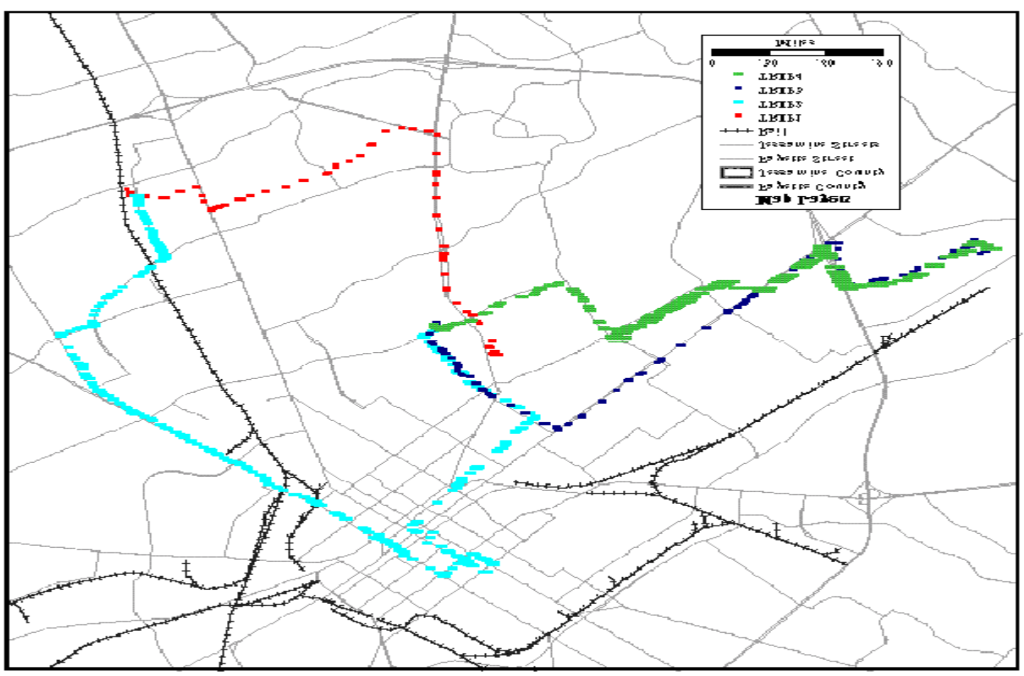

FIGURE 4 Example of complex route choice behavior.

USER ACCEPTANCE

The post-usage survey focused the travel day recall interview on Day 5 of the household's test period. Since the test was designed for six days in each household, Day 5 was expected to be the last full day that the equipment was used by the household. The post-usage interview also included questions about the installation and use of the equipment, general concerns and issues for the households (e.g., privacy), and additional demographic information. Evaluation of the travel recall data is not yet complete. The following results are from the post-usage interviews focusing on evaluation of the equipment and general concerns and issues for the households.

The sample included 100 persons who were each regarded as the primary driver of a particular vehicle. The equipment was to be kept with a specific vehicle. In addition, other members of the household who drove GPS-equipped vehicles were asked the questions about use of the equipment. Overall, the 100 primary drivers and six additional household members drove the vehicle on the recall day, resulting in 106 persons included in the post-usage survey.

EQUIPMENT INSTALLATION

Although most people installed the device themselves (Table 5), women were much more likely to have someone in their household install the GPS device for them. Thirty-one percent of the women, compared to 10 percent for men, had assistance from someone in their household.

TABLE 5 Equipment Installation Results

Question: Did you yourself install the GPS device?		Male	Female	Total
	Yes	43	35	84
	No	5	17	22

People aged 24 and under were more likely to use the video (Table 6) to learn to install the GPS unit (57 percent compared to about 50 percent for all other age groups). For those who installed the unit themselves, there was no difference by gender in preference between the written manual and the video guide. Those who used the video for installation guidance rated it higher than those who used the written guide. Eighty-eight percent of video users, compared to 77 percent of written guide users rated the guide "very clear."

TABLE 6 Choice of Installation Instruction Results

Question: Which of the installation instructions did you use?		<24	25-49	50-64	65+	Male	Female	Total
	Written guide	13	22	10	11	33	23	56
	Video	19	21	12	7	35	23	58
	Hotline	1	1	1	1	3	1	4
	In-person help				1		1	1
	Other		1			1		1

USE OF THE GPS EQUIPMENT

Similar to questions on installation, younger age groups (age 24 and under, and 25-49) were more likely to use the video to learn how to use the equipment (Table 7), compared to older groups. And also, there was no difference by gender between using the written guide or the video for using the equipment.

TABLE 7 Use Instruction Choice Results

Question: Which of the instructions for using the equipment did you use?		<24	25-49	50-64	65+	Male	Female	Total
	Written guide	12	23	13	12	30	30	60
	Video	20	28	16	10	39	35	74
	Hotline	1				1		1
	In-person help				2		2	2
	Other		2			1	1	2

Over 70 percent rated the device "very easy" to use. The groups that were more likely to rate it "somewhat easy" were females 25-49 with children, women 50-64, and both females and males age 65 and over.

Members of households with children were hypothesized to be more easily distracted and thus more likely to forget to use the computer each time they got into the vehicle. However, self-reporting on use indicates the contrary (Table 8). Households with children were more likely to report that they used the machine "all of the time." Respondents age 24 and under were the least likely to report that they used the machine "all of the time."

TABLE 8 Frequency of Use Results

Question: How often were you able to enter trip data into the hand held computer?		<24	25-49	50-64	65+	Under age 50		Total
						With Children	Without Children	
	All of the time	16	28	14	11	25	19	59
	Most of the time	11	12	6	5	10	13	34
	Some of the time		1		1	1		2
	Almost never/never							0

Entering trip data was expected to be easy and require little of the respondents' time once they became familiar with the menu choices. Approximately 74% reported that entering trip information took 1.0 minute or less per trip, and over 95% reported (Table 9).

TABLE 9 Data Entry Time Results

Question: How much time was needed, on average, for data entry before each trip?	.1 to .3 min	26
	.5 to .8 min	18
	1.0 min	34
	1.5 min	3
	2.0 min	19
	3.0 min	4
	10 min	1

One of the reasons that the MagicLink PDA was chosen for the field test was because it had a backlit screen and adjustable screen contrast. However, as lighting and glare conditions changed, the contrast setting for the screen needed frequent adjustment to clearly see the screen. This frequent need to readjust the screen contrast was the most frequently reported problem when using the device (Table 10).

TABLE 10 Usage Problem Results

Question: What problems did you have in using the hand held computer?	Screen contrast	36
	Choices not obvious	9
	None	31

Acceptance of the equipment is evidenced by the responses in Table 11. The respondents preferred the computer data entry over a written log by almost a 9 to 1 margin, and nearly all indicated that they would use the device again for this type of study. Only one respondent reported changing driving habits during the field test, and that change was reported as omitting a regular, brief stop at a convenience store on the way to work.

TABLE 11 Equipment Acceptance Results

Questions:	Yes	No
Would you have preferred keeping a written log of driving instead of using the hand held computer?	11	94
Would you be willing to use this device again in a similar study?	103	2
Did you change your driving habits in any way because the device was in the vehicle?	1	105

GENERAL CONCERNS AND ISSUES

Most respondents indicated no concerns about the type of data collected and the government's role in collecting personal travel data (Table 12). Most of the concerns that were expressed from about 5% of the respondents focused on individual privacy concerns. More respondents, approximately 26%, expressed concerns about the safety of their vehicles. These concerns focused on possible break-in and/or theft related to the device. Some respondents reported that they routinely removed the device from their vehicle every evening and reinstalled it in the morning to prevent theft. Others reported other tactics, such as placing a towel over the device to conceal it when they were away from their vehicle.

TABLE 12 Individual Concerns Results

Questions:	Yes	No
Did you have any personal concerns about having your vehicle's movements recorded by the device?	7	99
Do you have any concerns about the government collecting personal travel data?	5	101
Did you have any concerns about the safety of your vehicle while the device was installed?	28	78

TRIP REPORTING—MACHINE RECORDED VS. SELF-REPORTS

The in-vehicle data collection units were in operation for 5 or 6 days in each vehicle. A "recall" telephone interview with the respondent was conducted on one day during the data collection period. This telephone interview was similar to the travel day portion of the 1995 Nationwide Personal Transportation Survey, where information on trips for a 24-hour period is collected. The recalled travel data will be compared to the machine-recorded travel data, in terms of overall number of trips, trip purpose, travel time, and travel distance.

The preliminary results of the trip start time data are revealing. It is well known that trip start times reported in interviews are often rounded to nearest quarter-hour or half-hour—people simply do not report an accurate trip start time. The Lexington field test equipment recorded these times automatically for each trip initiated by the respondent. Figure 5 shows the frequency distributions of trip start times for the 1995 NPTS 6-month interim dataset, the Lexington data collected automatically during the field test, and the Lexington self-reported (interview) data. The NPTS and self-reported data clearly show peaks at every quarter hour and lesser peaks at every five-minute interval. The Lexington data have no such peaks. Trip start times are almost evenly distributed over the entire hour.

Similar results can be seen in the reports of trip distances. Figure 6 shows the cumulative frequency distributions of reported trip distances for the 1995 NPTS 6-month interim data set, the Lexington data collected automatically during the field test, and the Lexington self-reported (interview) data. Again, the NPTS and Lexington self-reported data show many similarities in report trip distance. The automatically collected Lexington data reflect shorter average trip distances and a much smoother distribution of trip distances.

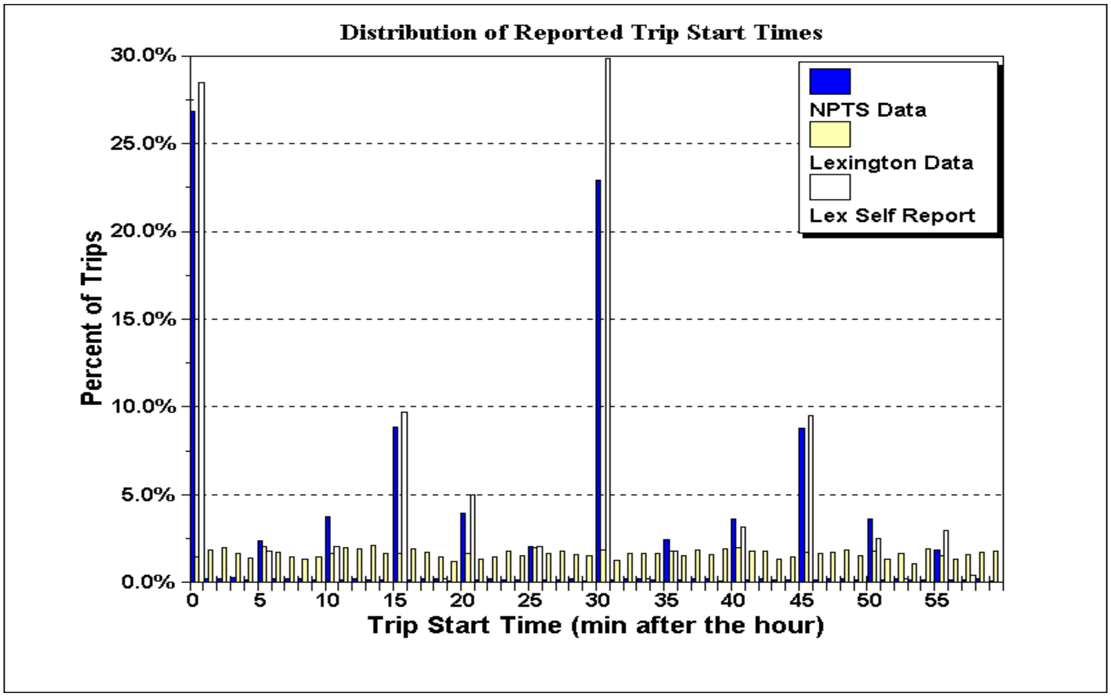

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FIGURE 5 Distribution of trip start times.

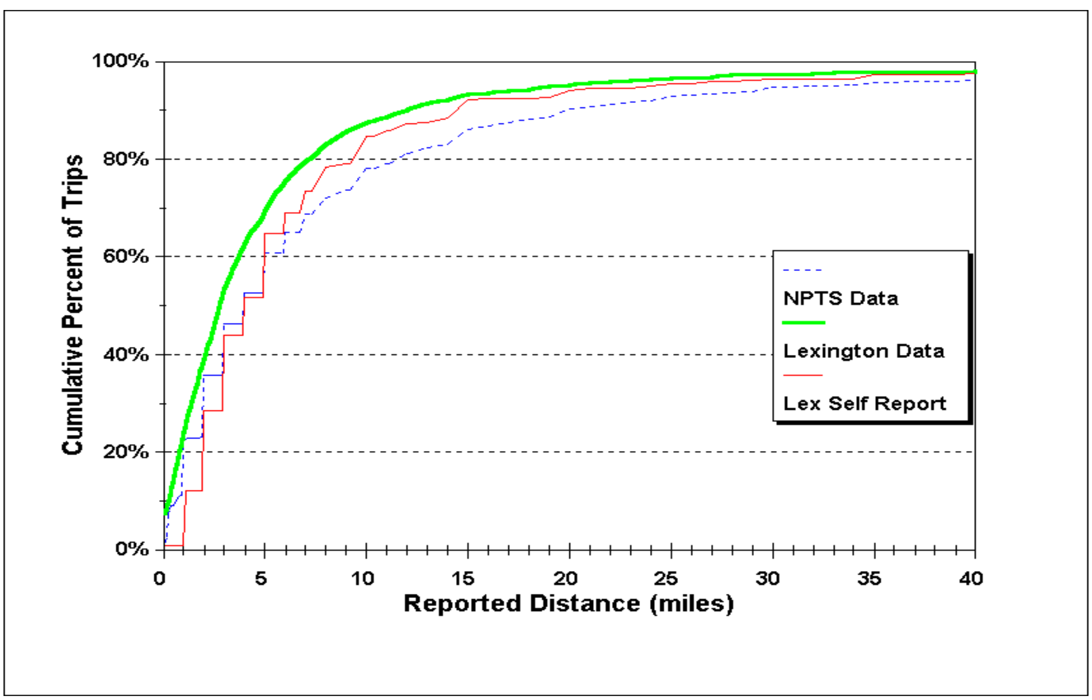

FIGURE 6 Cumulative distribution of trip distances.

CONCLUSIONS

How good are the data? The jury is still out on some data questions because the comparison between self-reported and machine-recorded travel data is not yet complete.

However, some of the questions raised at the beginning of the project can be addressed.

- Is the technology adequate for the purpose?

Combining GPS technology with small hand-held computers is a functional reality, particularly for use in private vehicle surveys. The technology has progressed to the point that small, relatively light-weight, and relatively inexpensive equipment can be delivered to respondents for self-installation and use. Using GPS without additional equipment (gyroscopes, dead reckoning) is sufficient to plot most trips on the roadway network, even without the availability of differential correction. In addition, matching to the roadway network could be done sufficiently without a positionally accurate geographic base file. That is, map matching is possible, using only the TIGER/Line files available from the U.S. Census Bureau, although errors in some roads would be more likely in areas with parallel roads in close proximity. However, GPS technology alone will not be sufficient to track vehicles in areas with many high rise buildings ("urban canyons") and in dense tree cover where the GPS signals may be reflected or obscured.

The weight, power requirements, and the memory capacity of hand-held computers are changing so rapidly that it is conceivable that within two or three years, a unit that could be easily carried to capture walk, bike, and transit trips could be designed. We do not know if different privacy concerns will arise with this approach compared to a vehicle-based approach.

The touch-screen interface was easy to use, even for people over age 65. The general public is responsive to this technology and is willing to participate in multi-day surveys, given a financial incentive.

- What are the advantages of this approach?

This project has shown that computer-assisted self-interviewing (CASI) combined with GPS technology can improve the quality of data from household travel surveys. Because the machine is tracking the start and end times, and the actual routes traveled, the respondent is no longer responsible for reporting similar items. In particular, the reporting of destination addresses is long and time-consuming, and often frustrating for the respondent. The frustration may be because the respondent does not know an actual address and may get to a destination using landmarks, or because the telephone interviewer cannot correctly spell or type in the street name.

In addition, the time taken for the respondent to begin each trip using this technology takes about one minute. This is not perceived to be as burdensome as spending 20 minutes on the telephone in one session to report travel of one day.

Another objective of this project was reducing missing (unreported) trips. In this project, the respondents were required to turn the equipment on each time they made a trip. If a respondent failed to turn the equipment on (either deliberately or inadvertently), then no trip was recorded, and the data record would contain a gap in the positional information that was recorded. However, when the equipment was on and the respondent made an intermediate stop, the time and positional record reflected those stops although there was no trip purpose assigned to the activity. Thus the attempt to reduce unreported trips is incomplete. The equipment is currently being modified for a truck activity survey so that the equipment will turn on automatically when the engine is operating; thus, the machine can be designed to collect time and position data, even if the respondent does not actively communicate with the machine.

This CASI approach not only improves the quality of data that are traditionally collected using self-reported methods with paper diaries and telephone or mail-back retrieval, but also information that was previously nearly impossible to collect can be collected (Table 13). For example, in the 1990 NPTS conducted on the telephone, one trip of each respondent was selected, and the respondent was asked to estimate how many miles were traveled on what type of roadway (i.e., Interstate, major arterial, collector, local road). Previous efforts to collect this type of information have asked respondents to draw their selected routes on paper maps. Neither of these two methods captures accurate departure time or travel speed. Not only is route choice information easily available by including a GPS component, but because the survey period covers 6 days, variability by day, by day of week, and departure time can be analyzed.

TABLE 13 Comparison of Traditional Telephone Survey with GPS/PTS Survey

Data Item	Traditional Telephone Survey	GPS/PTS Survey
Trip start & end times	Estimated	Machine recorded
Trip distance	Estimated	Calculable from GPS trace Link distances from GIS
Route choice	Modeled "shortest path"	Actual path from GPS trace
Origin/destination	Recalled street address or intersection	GPS point Address/link match from GIS
Travel speed	Not available	Available from GPS Speed by link from GIS
Functional class	Not available	Available by link from GIS

- What needs to be done to improve upon what was learned from this test?

Hardware

The greatest advances in the near future will be greater standardization of palm-top operating systems and GPS PCMCIA units. The operating system used in this project operates on only one palm-top unit currently in production. The GPS unit used in the project transmits in NMEA 0183 ASCII format, and in GARMIN proprietary format. Other GPS manufacturers typically have their own proprietary formats as well. These proprietary formats make it difficult for software developers to establish programs that could work with a variety of GPS hardware. Also, GPS PCMCIA card receivers were excluded from this test because the power requirements were not compatible with the PDA. Equipment that is sturdier, or hardened for field use, would be necessary for large-scale deployment. Smaller and even more lightweight units with extended battery operating capabilities would also make it possible to use this technology to capture non-vehicle trips.

Software

Because the transportation industry is just now seeing the value of GPS in transportation projects, there is little software available for automated post-processing of data. Typically, for transportation applications, map matching of GPS points to a roadway network would be a critical first step. GIS software vendors and GPS hardware vendors need to be more responsive to transportation data user needs.

Because of hardware costs, it is unrealistic to think that this approach of using hand-held computers and GPS equipment will replace traditional telephone and mail-out/mail-back surveys in the near future. Rather, as travel surveys move toward a continuous data collection approach, similar to the U.S. Census move to replace the decennial "long form" with an ongoing monthly survey, a small number of hardware units could be used in a continuous survey. In the short term, it may be useful to equip only a subset of a transportation survey samples, e.g., as was planned for Austin, Texas, in 1998.

REFERENCES

1. Kitamura, R. Time of Day Characteristics of Travel in *1990 NPTS Special Reports on Trip and Vehicle Attributes*. Report FHWA-PL-95-033. FHWA, U.S. Department of Transportation, 1995.
2. AMPG report to NCTCOG Dallas-Fort Worth Household Travel Survey Pretest Report, August 1995. (Page 31--even for 24-hour shorter format, average = 58 minutes; for 48-hour longer-format average = 94 minutes.)
3. Kalfs, N. and Saris, W.E. New data collection methods in travel surveys. In D.F. Ettema and H.J.P. Timmermans (eds.). *Activity-Based Approaches to Travel Analysis.* Pergamon Press, 1997.
4. Ettema, D.F., Timmermans, H., and van Vehel, L. *Effects of Data Collection Methods in Travel and Activity Research.* European Institute of Retailing and Services Studies, 1996.
5. Lee-Gosselin, Martin. Diary Surveys, Workshop Summary. In *Selected Readings in Transport Survey Methodology*. E.S. Ampt, A.J. Richardson, A.H. Meyburg (eds.). Eucalyptus Press, Melbourne, Australia, 1992.
6. Jones, P. and Polak, J. Collecting Complex Household Travel Data by Computer. In *Selected Readings in Transport Survey Methodology*. E.S. Ampt, A.J. Richardson, A.H. Meyburg (eds.). Eucalyptus Press, Melbourne, Australia, 1992.

7. Ross, C.L., Meyer, M.D., Barker, S., and Zemere, Y. Analysis of Travel Behavior Using Three Parameter Data Loggers. *Journal of Transportation Engineering.* July/August 1995, pp. 338-344.
8. Bullock, D., Quiroga, C., and Kamath, N. Data collection and reporting for congestion management systems. Paper presented at National Traffic Data Acquisition Conference (NATDAC), May 1996, Albuquerque, NM.
9. Williams, B. *Existing and Emerging Techniques for the Automatic Collection of Data for Transport Modeling.* Smith System Engineering for United Kingdom Department of Transport. 1997. (http://www.smithsys.co.uk)
10. Zito, R.D., Este, G., and Taylor, M.A., Global Positioning Systems in the Time Domain: How Useful a Tool for Intelligent Vehicle-Highway Systems? Transportation Res-C. Vol. 3, No. 4., pp. 193-209, 1995.
11. Wagner, D., Neumeister, D., and Murakami, E. Global Positioning Systems for Personal Travel Surveys. Paper presented at National Traffic Data Acquisition Conference (NATDAC), May 1996, Albuquerque, NM.
12. Research Triangle Institute. 1990 NPTS User's Guide to the Public Use Tapes. Report FHWA-PL-92-007, FHWA, U.S. Department of Transportation, 1991, page C-23.
13. Hu, P. S. and J. Young. *1990 NPTS Databook Volume 2*. Report FHWA-PL-94-010B. FHWA, U.S. Department of Transportation, 1994.
14. Triangle Transit Authority, Draft Report for the 1994 Travel Behavior Survey, p. 7, 1995.
15. Bay Area Congestion Pricing Project, Technical Memorandum #9, RP Pilot Study Results, p. 27, November 1995.
16. Strathman, J. G. and K. J. Dueker. Understanding Trip Chaining in *1990 NPTS Special Reports on Trip and Vehicle Attributes*. Report FHWA-PL-95-033. FHWA, U.S. Department of Transportation, 1995.