TRIP RATE ANALYSIS
IN GPS-ENHANCED PERSONAL TRAVEL SURVEYS

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1. **ABSTRACT**

Trip underreporting has long been a problem in household travel surveys due to the self-reporting nature of traditional survey methods. Memory decay, failure to understand or to follow survey instructions, unwillingness to report full details of travel, and simple carelessness have all contributed to the incomplete collection of travel data in self-reporting surveys. To fully understand the nature of these effects and their contribution to underreporting, it is necessary to collect independent data on observed trips. In the late 1990’s, several pilot studies were conducted to investigate the use of Global Positioning System (GPS) technology as a supplement in the collection of personal travel data. These pilot studies confirmed the feasibility of applying GPS technology to improve both the accuracy and completeness of travel data.

Consequently, household travel surveys scheduled for 2001 in Atlanta, California, and Ohio have substantial GPS data collection components. In each of these studies, the primary goal of the GPS component is the derivation of trip rate correction factors for CATI-reported travel data. Each household recruited into a GPS-enhanced travel study will be provided with both paper diaries and in-vehicle GPS data loggers. The data recorded on the paper diaries will be collected by CATI-retrieval methods and then compared with the processed GPS data to identify under-reported trips and other reporting discrepancies.

This paper will present the preliminary results of the California Statewide Household Travel Survey GPS Study. In this study, three separate geographic regions were selected for GPS deployment, with the participating households controlled for demographic and lifestyle characteristics. The GPS data collection began in February 2001 and will be completed in June 2001. This first version of the paper includes a review of the trip rate analysis process developed for this study using the first 15 completed households. It is expected that at least 200 households will be processed and ready for review at the conference in August.
2. BACKGROUND

Trip item nonresponse is a common and documented nonresponse problem in travel surveys. It refers to the failure to obtain complete travel information from travel survey respondents, either at the trip or trip detail level. Although both types of trip item non-response occur with travel surveys, under-reported trips are considered to be the most serious problem of incomplete information, since trip rates and general trip-making behavior are the focus of travel surveys. In fact, trip-level nonresponse causes more significant problems for travel demand modeling since trip rates are the essential input variable for predicting future demand.

Understanding the reasons behind trip item nonresponse has helped researchers identify methods of identifying and correcting for these omissions. In 1982, Brög identified three reasons for non-reported trips (Brög, 1982):

a) Trips that are not reported by the respondents due to the lack of care in case of survey periods of several days' length;

b) Trips that are not reported by the respondent because they forget or consider them redundant; and

c) Trips that the respondent does not want to report on the basis of their own deliberate decisions.

Later, Richardson (1996) confirmed the Brög list and added reasons related to a respondent’s screening and elimination of trips considered too short, too unimportant, or non-motorized.

Research results from mail-back travel surveys with multiple response waves reveal more reasons for underreporting trips. One is certainly the increasing memory gap in later waves and, moreover, respondents tend to under-report trips that they make once they realize the amount of time involved in recording each trip (Richardson, 2000). These results are applicable to callback travel surveys as well, since the respondent might not be reached immediately after the travel day, or, when they are reached, they quickly learn how much time is required to report an individual trip. Richardson also found that non-reported trips were significantly correlated with the purpose of the trip and the position within the day.

Correction methods for missing trip details, such as trip purpose and travel mode, have focused on data expansion procedures. These procedures include different kinds of imputation (i.e., deductive imputation, class mean imputation, hot-deck and cold-deck imputation), regression analysis, weighting procedures and item substitution (Armoogum, 1997; Zmud, 1997; Polak, 1997, Richardson, 1995). In addition, gaps in trip data can be “repaired” through manual or automatic corrections by applying a set of diagnostic repair rules which detect and repair inconsistencies and missing data (Richardson, 1995; Arentze, 1999). These methods have also been applied to correcting for omitted socio-economic data as well to missed trips.

During the past decade, researchers have tried to calculate several trip correction weights and factors in order to address the trip under-reporting problem. Hassounah (1993) calculated the underreporting of non-informant trips by using informant data from a Canadian telephone interview travel survey from 1986. The morning peak-period underreporting trip factor from the dataset and cordon line counts were estimated and applied to other periods of day. The result estimated correction factors that ranged between 1.03 and 1.85, based on the period of the day and the trip types.

Other Canadian data from the greater Toronto area collected in 1996 was used to calculate trip adjustment factors. Based on the same procedure as in Hassounah’s study, the researchers brought the non-informant trip-rate to the level of the informant trip-rate. Thus, adjustment factors, defined
as the ratio of the informant trip-rate to the non-informant trips-rate, were estimated. These factors were used to determine the additional number of trips required to raise the non-informant trip-rate to that of the informant’s. The results were in the range of 1.07 to 2.7 for non home-based discretionary trips based on other variables such as driver’s license and vehicle availability and extended up to 4.08 for non home-based trips (Badoe, 1999).

Other studies were done based on the German KONTIV (Kontinuierliche Erhebung des Verkehrsverhaltens – A Continuous Survey of Travel Behavior) survey design. Based on the dataset, Richardson calculated a non-reporting correction factor by dividing the sum of the original stops, the expected stops, and the unexpected added stops by the original stops (Richardson 1995, 1996). Expected extra stops were those where, during data entry, it had been identified that it was likely that an extra stop should have been reported and unexpected stops were those that had not been identified in this way but that respondents reported during the validation interview checking. The resulting factors were between 1.000 and 1.449, depending on the trip purpose. All together, an increase of trip rate per person of 14.2% was reported, based on the equation.

Finally, in another survey, researchers used two survey instruments to find a weighting method for underreported short trips for French National Personal Transportation Surveys (Armoogum 1998). They compared results from car diaries and interview results and found differences of up to 32 percent depending on the length of the trip, especially on weekend days. This was mostly due to the fact that the previous weekend was too far in the past to ensure accurate memory of the trips taken for the interviewed people. Nevertheless, they suggested a weighting method to compensate for the underreporting of short weekend trips.

Although all of these studies did attempt to derive trip correction factors for unreported trips, the techniques developed were entirely dependent upon self-reported information. Now that several large-scale travel surveys are implementing GPS data collection for sub-samples, it is possible to develop GPS-based trip correction factors based on an independent, observed approach – one that should provide more accurate results.

With respect to air quality impacts, it is worthwhile to note that GPS data collection offers researchers and analysts the opportunity to examine differences in reported and measured trip rates simultaneously with differences in reported and measured trip lengths, travel times, and cold starts. This type of examination should reveal the impact of misreporting behaviors on overall vehicle miles traveled (VMT) and cold start activities, two variables which serve as major predictors of mobile source emissions within air quality models. It is entirely possible that these GPS-based studies prove that people underreport trips, yet overall VMT and cold start levels remain fairly constant.

3. PREVIOUS GPS STUDY RESULTS
Several pilot studies were conducted in the 1990’s that examined the use of GPS as a supplemental source for household travel behavior data collection. The FHWA-sponsored Lexington study was the first study to collect in-vehicle GPS data for a six-day period and then to compare the data with trips recalled for a chosen travel day. The results of this process identified several issues with the attempt to match GPS data with recall data, including respondent rounding inaccuracies with respect to trip start times, travel times, and travel distances; variations in methodologies to process the GPS data; and possible omission or malfunction of equipment use (Wagner, 1996). As a result of these issues, the study was unable to match more than 61% of the recall trips with GPS-recorded trips. Consequently, it was not possible to perform a thorough trip rate analysis.
In 1997, the first household travel survey conducted with a GPS subcomponent occurred in Austin, Texas. In this study, 117 households were instrumented with GPS data loggers and reported their travel via CATI retrieval. A total of 186 vehicles were instrumented. Researchers have been analyzing the data with respect to defining appropriate dwell times for trip end identification within the GPS data streams (Pearson, 2001). Dwell time, as defined by Pearson, is the minimum amount of time allowed for a stop between trips. This has been challenging since the data were collected while Selective Availability (the intentional degradation of GPS signal accuracy) was active. After reviewing other study results as well as a variety of dwell times, 45 seconds was found to be an appropriate dwell time for this study.

Comparisons of reported and GPS-detected trips in the Austin study showed that 50% percent of all reported trips started within 2 minutes of the GPS-recorded trip starts and 80% were within 5 minutes of the GPS start time. The average underreporting trip rate was calculated as 31.1%, based on a 45-second dwell time. A trip dwell time of 120 seconds produced an underreporting rate of 12.4 % for all trips. The amount of underreported trips was found to be independent of income level and of total reported trips by household.

In her dissertation work, Wolf (2000) examined the use of GPS data loggers as a replacement to travel diaries. In this research effort, procedures were developed for processing second-by-second GPS data collected in Atlanta to create trip-level details. As a result of this research, Wolf found that most trips made in an instrumented vehicle could be identified in the GPS data stream, including some trips that are often forgotten or omitted in paper diary recording, such as trips of short duration that occur as part of a trip chain or those that are short ‘out-and-back’ round trips. Trips that could not easily be identified in the GPS data stream were those with stops of very short duration that did not involve the vehicle leaving the travel path – for example, stopping at a controlled intersection and dropping someone off while waiting for the signal to change. However, if these types of passenger pickup or drop-off occur out of range of the predicted travel path, then they can be detected within a GIS environment as a questionable route that can then be used for respondent follow-up. Trips made that are not taken in a GPS-instrumented vehicle, including those that are part of a tour that occur at a single vehicle stop and those made strictly by other modes (walk, bike, transit), would not be captured by the in-vehicle GPS system. Wolf has suggested that these trips either be recorded manually by the participant or collected using a personal GPS data logger.

In both the Austin and Atlanta GPS data analyses, which were based on GPS data collection performed with no user interface to ‘mark’ trip ends, researchers were faced with thousands of GPS records logged sequentially throughout the study days. Since the GPS data loggers in both studies were powered by the vehicle’s power supply, it was fairly straightforward to detect trip ends for vehicles that only provided power to the loggers when the engine was powered on. However, for vehicles that provide continuous power even when the engine is powered off, the detection of trip ends within the GPS data stream could only be determined based on the detection of non-movement within the data stream for a minimum amount of time (i.e., the dwell time). Consequently, the determination of an appropriate dwell time for the preliminary detection of trip ends was one of the first tasks undertaken by both Pearson and Wolf. It is interesting to note that while Pearson found 45 seconds to be a reasonable dwell time for GPS-based trip end detection, Wolf found that 120 seconds proved to be a better first pass dwell time; anything less than that tended to find many false trip ends that were attributed to heavy congestion or signal delays experienced within the Atlanta region.
Finally, the GPS pilot studies to date confirmed that GPS points are not always captured at the start of some trips. This occurs when GPS receivers experience a cold start signal acquisition delay after a loss of signal due to power off or signal blockage conditions that last more than 30 minutes. As a result, it is possible that the first 20 to 120 seconds of a trip start may not be captured by a GPS data logger. However, these studies have also shown that it is likely that the previous trip’s destination coordinates are the origin coordinates for the current trip and can be used accordingly.

4. SAMPLING AND DEPLOYMENT PLANS

The initial deployment goal for the California Statewide Travel Survey GPS Study was 500 households that were to be recruited from within the 16,500 households participating in the statewide household travel survey. Early on, it was realized that 500 deployments would most likely produce between 300 and 400 complete households, factoring in household travel survey dropouts, GPS study dropouts, and vehicle cigarette lighter power failures (more on this later). Given such a small sample size (as compared to the statewide sample) and to allow for deployment efficiencies, a sampling plan was developed for three geographic regions (San Diego, Sacramento, and Alameda County). This focused plan was designed to allow for an in-depth analysis of trip reporting behaviors while controlling for household, person, and travel characteristics evident in the three regions.

The set of household characteristics to be evaluated within this study include the size of household, the number of vehicles, the number of children, the proportion of adults in the household with either a full-time job and/or school attendance, the presence of only one adult in household, and the presence of multi-activity adults. Travel and trip characteristics to be examined include trip chaining behaviors, trip lengths, trip times of day, and trip purposes. Once the trip rate correction factors are developed for this sample, it is expected that the rates can then be applied to other households with the same demographic characteristics statewide. This approach should also provide much insight into the suspected determinants of trip underreporting.

A deployment firm was contracted to deliver and pick up the GeoStats GeoLoggers (passive in-vehicle GPS data loggers, see Figure 1) to and from each household recruited into the GPS study. A GeoLogger would be provided for up to three vehicles in each household and would be delivered to each household one to two days prior to the assigned travel day (note that the household travel survey is a one-day study). During the GPS study recruitment call, the household would be asked to verify that each household vehicle had a functioning (i.e., working) cigarette lighter. This question was necessary to confirm that an adequate power source was available in each vehicle for the GPS receiver. In addition, the delivery of the GeoLogger would also be scheduled during the recruitment call.

Once the assigned travel day passed, the equipment would be picked up within one or two days; the pickup would be scheduled by the deployment firm during equipment delivery. Each household would also fill out the standard paper travel diary provided for the household travel survey and would report the household travel information via traditional CATI-retrieval methods. The GPS Study was scheduled to start in February 2001 and to conclude in June 2001. Weekend GPS sampling was not scheduled due to the small weekend sample size for the household travel survey.
5. DATA COLLECTION

In order to perform a trip rate comparison between GPS-measured trips and CATI-reported trips, data were required from both sources. First, the GeoLoggers were delivered to each household with instructions to install the devices in each household vehicle prior to the start of the first trip of the survey date. The installation instructions were very simple – the respondent only needed to plug the power connector into the cigarette lighter and to place the GPS receiver/antenna on the roof of the vehicle.

When adequately powered, each GeoLogger was programmed to store date, time, position, and speed information for each second that the vehicle was in motion. Once the GeoLoggers were retrieved after the study dates, the deployment firm downloaded the GPS data from each device and transferred the GPS files to the GeoStats office in Atlanta. The GPS files were then logged according to the study region and household ID.

Although the recruitment call did ask for confirmation of working cigarette lighters in each household vehicle, it became evident upon retrieval of the equipment and downloading of the data loggers that it was probable that some of the cigarette lighter sockets were not working. However, an ‘empty’ data logger could also indicate that the respondent chose not to install the GeoLogger into a particular vehicle. The true reason for total GPS data loss for a particular vehicle would become clearer once the household reported travel data was examined later in the process.

Attempts to retrieve the household travel survey information occurred concurrently via CATI methods. Once these data were collected, additional data verification and location geocoding procedures occurred prior to the delivery of the CATI trip files for the GPS households to the GeoStats office. At this point in time, both data streams were ready for processing.
6. **Data Processing Overview**

Figure 2 depicts the key steps developed to process both the GPS-measured data and the CATI-retrieved data. The GPS second-by-second data, once received, are first converted into GIS-compatible formats and then reviewed for potentially bad or poor data points. Then, a program is run on the GPS data stream to identify potential trip ends based on time intervals between consecutively logged points. For this study, 120 seconds was defined as the appropriate time gap between GPS trip ends. Next, each potential trip is evaluated within an interactive GIS-based application to allow the project analyst to identify both missing and false trip ends. Once this step is complete, the updated GPS-based trip file for a given household vehicle is ready for comparison.

When the CATI-retrieved household trip files arrive at the GeoStats office, the first processing step is to convert the files into a vehicle-based format to provide a standard unit against which GPS trips can be compared. Once this conversion is complete, both the GPS vehicle-based trip files and the CATI-retrieved vehicle-based trip files are ready for comparison. A program is run using the two files as input – comparing the individual trip records within each based on departure times and producing several output files containing the individual trip-level results of the comparison process as well as the aggregate vehicle-level results per household. The comparison results are then examined in tabular form, with questionable items reviewed. Once the comparisons are finalized, trip rate correction factors can be calculated.

![Figure 2: Data Processing Flow Chart](image-url)
7. TRIP COMPARISON AND REVIEW

Once the GPS and CATI data from the first fifteen completed households in the California GPS Study were received, a total of 123 GPS trips were identified, along with 104 CATI-reported trips for the same vehicles. Next, the CATI-reported trips for each vehicle in each household were compared with the GPS-derived trip data. This comparison was performed automatically via a program designed to compare individual trip records in each vehicle file using only the departure time as the significant variable for matching. A match rate of 67% was attained using a plus or minus 10-minute departure time buffer as the only match criteria.

The results of the matching process for each vehicle were then reviewed and analyzed, with matching corrections made based on the type of discrepancy found. A final match rate of 80% was achieved upon completion of the review process, along with the identification of four additional GPS stops that were less than two minutes in duration and that occurred along the vehicle’s travel path.

Matching results and discrepancies fell into the following categories:
1) Trips detected and reported (i.e., a correct match)
2) Trips detected but reported with poor accuracy in trip start time, resulting in either: a) an unmatched trip or b) a mismatched trip (which then causes problems in adjacent trip matching)
3) Trips detected but not reported (i.e., underreported or missed trips)
4) Trips not detected but reported

Graphical examples for each category of matching results can be seen in the following figures. Note that for these examples, a match is defined as one in which the departure times of the GPS-detected trip and CATI-reported trip are within +/- 10 minutes of each other, without considering trip end locations. The matching program is currently being enhanced to add this spatial dimension into the matching process.

Figure 3 shows an example of a perfect match of GPS-measured and CATI-reported trips. Matched trips are represented in gray. All reported trip start times fell within plus or minus ten minutes of the recorded GPS departure times. Therefore, it is very likely that the respondents in this household reported their trip times very accurately. Of the trips made in 25 vehicles, 5 had perfect matches of GPS-detected and CATI-reported trips without any corrections needed. Three others had no trips recorded or reported (which is also an exact match).
In this example (Figure 4), it seems likely that the 30-minute trip reported between 8:00 and 8:30 by the respondent actually happened 1.5 hours earlier. For whatever reason, the respondent failed to record, report, or remember the departure time correctly.

In the case shown in Figure 5, a CATI trip that started at 14:30 was incorrectly matched with a GPS-measured trip starting at 14:28, and, as a result, the CATI trip could not be matched to the correct GPS trip. In this case, the GPS-measured trip starting at 14:15 should have been matched to the reported CATI trip starting at 14:30, which would have then allowed the second GPS and CATI trips in the sequence to match correctly as well.

For both types of matching discrepancies that are caused by poor reporting of trip times, matching corrections can be applied based on trip end locations.
As shown in Figure 6, the GPS data logger detected a trip (identified in black) that was not reported by the respondent, although the trips prior to and after this trip were recorded and reported correctly. This is a classic example of a missed trip within a trip chain.

Figure 7 shows an example of a reported trip that was most likely a sequence of trips (i.e., a trip chain) since the gaps between consecutively recorded GPS trip end and start signals are 3 and 13 minutes. It is possible that these gaps could also represent signal gaps due to driving through sheltered areas like tunnels, but it is highly unlikely that the second gap of 13 minutes is a signal gap. These GPS gaps were reviewed and confirmation was made that no change in location occurred between the consecutive trip end and trip start locations.

In addition to individual and multiple links in trip chains, round trips are also easily detected within the GPS data yet are often forgotten by study respondents. In this study, a total of 104 trips were reported via CATI; another 23 trips were detected by GPS but not reported by respondents.
In this example, there is no recorded GPS trip for the first CATI trip reported for this vehicle (as seen in Figure 8). It is very probable that the GeoLogger was not powered for the first trip of the day. There were only a few occurrences of this type of discrepancy among the first 15 households evaluated; the review process indicated that these resulted from either a lack of power to the GPS data logger or to a household trip incorrectly assigned to this vehicle within the CATI trip file.

In numerous GPS trip traces, it was obvious that the beginning GPS points of the trip were missing. This was attributed to the cold start acquisition delay experienced by GPS receivers when left unpowered for more than 30 minutes. In no case, however, was the cause of a missing GPS trip identified as a signal acquisition delay.

Finally, there were three vehicles within the first 15 households that did not have any GPS data recorded during the assigned travel day. When the GeoLoggers were downloaded and it was determined that no data were logged, the cause was not obvious. A total lack of GPS data could result from a broken cigarette lighter, a decision to not install the equipment, or the absence of travel in that vehicle on the assigned travel date. Comparisons with the CATI-retrieved data, however, confirmed that each of the three vehicles was not used on the travel day.

8. SUMMARY OF TRIP COMPARISON RESULTS
A summary of the results of the trip comparison and review processes for the first 15 completed households can be seen in Table 1. The trips reported and recorded for each vehicle within a household have been aggregated at the household level. For each household, the table shows the number of vehicles instrumented in the study (# Veh), the total number of GPS-identified trips for all instrumented vehicles (# GPS Trips); the total number of CATI-retrieved trips associated with all household vehicles (# CATI Trips); the total number of exact trip matches between the GPS trip file and the CATI file (# Match); the percent match rate (% Match), and the number of missed trips detected (# Missed Trips). The match rates are calculated based on the assumption that the number of GPS trips is the correct total of household trips made in household vehicles.
Table 1: Summary of Trip Comparisons (First 15 Households)

<table>
<thead>
<tr>
<th>Household</th>
<th># Veh</th>
<th># GPS Trips</th>
<th># CATI Trips</th>
<th># Match</th>
<th>% Match</th>
<th># Missed Trips</th>
</tr>
</thead>
<tbody>
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<tr>
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<td>9</td>
<td>9</td>
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<tr>
<td>4</td>
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<td>9</td>
<td>8</td>
<td>8</td>
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</tr>
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<td>8</td>
<td>6</td>
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<td>3</td>
</tr>
<tr>
<td>Totals</td>
<td>25</td>
<td>127</td>
<td>104</td>
<td>101</td>
<td>80%</td>
<td>23</td>
</tr>
</tbody>
</table>

For these 15 households, the average GPS trip rate for all vehicle trips made on the assigned travel day was 8.47; whereas the equivalent CATI-reported trip rate was 6.93. The appropriate trip correction factor for these households is 22.1%.

9. NEXT STEPS

By the end of June 2001, GPS and CATI data collection activities will conclude for the California Statewide Household Travel Survey GPS Study. Once all data have been collected and transferred to the GeoStats office, the data will be processed through all steps presented in this paper.

Trip rate correction factors will be developed at several reporting levels, including all household vehicle trips and all household trips. A statistical examination of underreporting trip behaviors will be conducted based on household, travel, and trip characteristics. The set of household characteristics to be evaluated include the size of household, the number of vehicles, the number of children, the proportion of adults in the household with either a full-time job and/or school attendance, the presence of only one adult in household, and the presence of multi-activity adults. Travel and trip characteristics to be examined include trip chaining behaviors, trip lengths, trip times of day, and trip purposes.

Once the trip rate correction factors are developed for this sample, it is expected that the rates can then be applied to other households with the same demographic characteristics statewide. This approach should also provide much insight into the suspected determinants of trip underreporting.
10. REFERENCES


