A Program to Collect Massive Activity Data in Northern California: Phase 2 Instrumented Vehicle Study

FINAL REPORT

prepared for the

California Environmental Protection Agency
California Air Resources Board
CARB Contract No. 94-733

Bourns College of Engineering
Center for Environmental Research and Technology
University of California, Riverside

January, 1998

Executive Summary

Estimating vehicle activity is a critical component for producing an accurate emissions inventory. Several studies have been carried out by the US Environmental Protection Agency (EPA), the California Air Resources Board (CARB), and others to better characterize vehicle driving patterns and overall vehicle activity. These studies used techniques such as on-board vehicle dataloggers, chase cars, and sophisticated instrumented vehicles.

The College of Engineering-Center for Environmental Research and Technology (CE-CERT) at UC Riverside and CARB have conducted a vehicle activity research program to provide significantly more vehicle activity data. A total of 199 in-use vehicles were instrumented with simple dataloggers over a 17-month period starting in April 1996 and ending in September 1997. The dataloggers were used primarily to record time-tagged second-by-second speed data. The vehicles were randomly selected from all registered vehicles in the Sacramento, California region. The Sacramento region contains urban, suburban, and rural roadways. In addition, the area has great geographical diversity extending from the Sierra Nevada foothills to the flat delta farmlands around the city. The study area extended from Yuba City on the north to Walnut Grove on the south and from Shingle Springs in the east to Winters in the west. The study area provided an ethnically diverse, large (over 1.1 million residents) population demographically.

The vehicles that were instrumented came from 139 different households that had as few as one vehicle to as many as five vehicles. This study provides a unique data base of over 13,500,000 seconds of data collected from over 22,000 starts over 3,520 vehicle-days. This vehicle activity study is unique in several ways: 1) it captured *household vehicle usage patterns* by instrumenting all vehicles in multiple-vehicle households; 2) it captured *seasonal effects* by instrumenting vehicles over many months; and 3) a subset of data was collected on *air conditioning usage*.

Preliminary analysis has been carried out on this large database leading to a number of conclusions:

- Overall there were an estimated average of 5.93 starts per vehicle for all days.
- Overall there were an average of 6.30 starts per vehicle-driven-day.
- Significant differences were found in the number of starts per vehicle driven day between vehicles from different numbers of household vehicles. Vehicles in single car households had

the highest number of starts while those in the five car household had the lowest average starts per vehicle-driven-day.

- Significant differences in starts per vehicle driven day were found between months with February the lowest and April the highest, excluding January because of the small amount of data collected.
- The mean trip distance was 4.86 miles.
- The mean speed was 27.43 mph.
- The average trip time was 646.4 seconds (10.8 minutes).
- Significant differences in average trip distance, speed, and time were found between months.
- Air conditioner compressors were turned on in 69.1% of the trips monitored for AC use in late August through mid October. The compressor was on an average of 64% of the time during the trip.

This huge database can be further analyzed in greater detail to provide new information on: family vehicle interaction, air conditioner usage, seasonal changes in driving behavior, variations in typical driving patterns, average soak times, etc.

Table of Contents

List of Tables

List of Figures

Figure Number — Page

Preface

This final report has been prepared for the California Air Resources Board, contract number 94-733, entitled "A Program to Collect Massive Activity Data in Northern California: Phase 2 Instrumented Vehicle Study." This report covers the work that has been performed during the contract period, January 1996 to October 1997. Contributions to this report have been made from Theodore Younglove, Adam Sherman, Matthew Barth, Janusz Gruszecki, Matthew Smith, Mac McClanahan, and Carrie Levine. It is also important to acknowledge Gordon W. Taylor from Instrumental Solutions Inc. for providing assistance on the Autologger dataloggers, and Augustus Pela, Dr. Pranay K. Avlani, and Ed Yotter from CARB who have provided valuable assistance and information used in the planning and execution of this study.

1 Introduction

Modeling mobile source emissions plays an important role in the formation and modification of mitigation strategies for air pollutants. However, it is generally agreed within the technical community that current mobile source emission model estimates often differ when compared with emission measurement studies [CRC 94, 95, 96]. While there are several reasons for the inadequacies of the current models, one of the major problems can be attributed to the non-representativeness of the standardized FTP (Federal Test Procedure) driving cycle from which most of the emissions data are derived [FTP 89]. The FTP was established over two decades ago, and it has been shown in a number of recent studies (e.g., see material in [CRC 94, 95, 96]) that it does not accurately represent present-day vehicle emission control performance and vehicle activity.

As a result, the United States Environmental Protection Agency has recently carried out a comprehensive Federal Test Procedure Revision Program (see, e.g., [Markey 93, 94]). One of the key findings of this program was that there are significant discrepancies between vehicle activity represented in the FTP driving cycle and vehicle activity measured today. Some of the key parameters of vehicle activity that differ include vehicle speeds, accelerations, aggressiveness in driving behavior, average in-use trip lengths, and frequencies of stops.

The California Air Resources Board (CARB) has also been active in characterizing modern vehicle activity in California. For example, CARB was the first to sponsor "chase-car" studies (performed by Sierra Research, Inc.) where an instrumented vehicle equipped with a forward-looking radar range sensor was used to follow random vehicles and measure their speed patterns on different roadway facility types under different congestion levels [Austin 93].

In 1994, CARB initiated a new research program to provide significantly more vehicle activity data in Northern California. Under contract with CARB, the College of Engineering-Center for Environmental Research and Technology (CE-CERT) at UC Riverside initially created specifications for a new datalogger-based vehicle activity study in Northern California. This initial work reviewed previous vehicle activity studies and made recommendations for carrying out a long-term study using dataloggers in multiple vehicles from randomly selected households (see [CE-CERT 95]).

Subsequently, CE-CERT carried out the datalogger-based vehicle activity study in Sacramento for a period of 21 months. The primary goal of the research project was to collect a large amount of second-by-second speed data on all vehicles within numerous households across an extended time period. Vehicles were selected randomly from the DMV database of registered vehicles in the Sacramento region to ensure statistical validity of the results. During the study time period, approximately 100 dataloggers were installed into several hundred vehicles, recording over 21,000 trips and over 13 million seconds of data. This vehicle activity study is unique in several ways:

1) it captured *household vehicle usage patterns* by instrumenting all vehicles in multiple-vehicle households; these data provide a unique insight into household driving interactions.

2) it captured *seasonal effects* by instrumenting vehicles for long periods of time (i.e., on the order of several months); this has produced a database that can provide valuable information of driving behavior changes over time.

3) in addition to standard vehicle activity data (e.g., number of starts, average speeds, trip length, etc.), a limited set of data was collected on *air conditioning* usage. This initial AC activity data can be combined with AC-related emissions data to help determine the impact air conditioning has on the overall emissions inventory.

This report presents in detail the study methodology (Section 2), the data processing and analysis performed (Section 3), and the results (Section 4). Conclusions and recommendations are given in Section 5.

2 Study Methodology

2.1 STUDY AREA GEOGRAPHY AND DEMOGRAPHICS

The vehicle activity study was conducted in the Sacramento region, which contains urban, suburban, and rural roadways. In addition, the area has great geographical diversity extending from the Sierra Nevada foothills to the flat delta farmlands around the city. Initially the study area extended from Yuba City on the north to Walnut Grove on the south and from Shingle Springs in the east to Winters in the west (see Figure 2.1)* . Later in the project the study area was reduced to cut down on travel time between participants' households. The study area encompassed all postal ZIP codes which were enclosed or intersected a 20-mile radius around the I-5/I-80 interchange.

The Sacramento study area provided an ethnically diverse, large (over 1.1 million residents) population demographically. The city of Sacramento is a large urban state capital with extensive suburbs and a diverse work force. The surrounding region, however, remains largely rural with a great deal of farming activity within the study area.

The racial makeup of the population in the study area is primarily white with a significant Hispanic minority population (Table 2.1).

Racial/Ethnic Group	Population	Population Percent
White	743,600	66.5%
Hispanic	140,400	12.6%
Asian/Pacific Islander	114,200	10.2%
Black	108,000	9.7%
Native American	11,450	1.0%
Total	1,117,700	100%

Table 1.1 Racial distribution of the Sacramento region July, 1995(1990 Census Data Server).

* It appeared that a higher percentage of the participants in the outlying areas were retired.

2.2 STUDY AREA VEHICLE PROFILE

A complete list of all registered cars and light-duty trucks within the study area was compiled from the California Department of Motor Vehicles (DMV) database of all registered vehicles. Within the ZIP codes encompassing the study region there were a total of 1,118,800 cars and light-duty trucks. Over half of the registered vehicles were less than 11 years old, and over 30% 1990 model year (MY) or newer (see Table 2.2). Trailers, motorcycles, motor-homes, and business-operated (i.e., fleet) vehicles were excluded from this count.

Model Year	Frequency	Percent of Total	Cumulative Percent
Pre-1977	161,048	14.4	14.4
1977	23,611	2.1	16.5
1978	27,009	2.4	18.9
1979	29,089	2.6	21.5
1980	24,353	2.2	23.7
1981	25,520	2.3	26.0
1982	28,193	2.5	28.5
1983	33,136	3.0	31.5
1984	49,857	4.5	35.9
1985	56,290	5.0	40.9
1986	64,992	5.8	46.8
1987	64,631	5.8	52.5
1988	63,438	5.7	58.2
1989	68,032	6.1	64.3
1990	63,283	5.7	69.9
1991	66,742	6.0	75.9
1992	55,317	4.9	80.8
1993	59,280	5.3	86.1
1994	57,825	5.2	91.3
1995	60,742	5.4	96.7
1996	35,326	3.2	99.9
1997	1,086	0.1	100.00

Table 2.2 Model Year Frequency Distribution for Study Area ZIP Codes as of January, 1997.

2.3 SAMPLING STRATEGY AND PLANNING

Random selection was chosen as the most suitable recruitment method for this study from six alternatives, previously examined in [CE-CERT 95]. For the results of this study to be representative of a wider vehicle population, it was necessary to select participants randomly. Previous vehicle activity studies have introduced potential bias in two areas:

1) The first is through the use of sampling methods which are biased toward higher income drivers. Telephone surveys are frequently biased toward higher incomes because of the greater number of upper income multiple phone households and the lack of households without telephones in any but the lowest income groups.

2) A second potential bias arises from the sub-population who have intentionally modified their vehicles. The drivers of these modified (i.e., tampered) vehicles do not wish to have their modifications brought to the attention of any authorities and are much more likely to refuse installation of a datalogger. Previous studies have not included methods which are likely to induce drivers with modified vehicles to participate, nor have they included means of checking for differences in refusal to participate for modified vehicles.

2.3.1 DMV Database

A computer generated random sample of vehicles was generated from the DMV vehicle registration database for the Sacramento region. The vehicle registration database provides a precise listing of the population to be sampled and is easily used to generate mailing labels. Other methods of selection such as license renewal target the driver for selection with the vehicle indirectly chosen through the driver. Multiple listings for people who own more than one vehicle were reduced to one listing prior to random selection to keep the equal probability of selection property necessary for a random sample. An initial random sample of 1500 was taken from the participants from the 1991 Statewide Travel Survey Final Report for the start of this project. For the second part of the project a random sample of 10,000 people was taken from the current DMV database for all vehicles registered in ZIP codes within a 20-mile radius of Sacramento. This method will not include the unregistered vehicles in the sample frame. Recent remote sensing studies have shown that the number of unregistered vehicles is approximately 6%. No cost effective method of including these vehicles could be found.

2.3.2 Vehicle Stratification

Study participants were stratified into two categories, multiple-vehicle households and single-vehicle households. The target allocation was for 65% dataloggers to be installed in multi-vehicle households and 35% to be installed in single-vehicle households. Overall, 35.5% of households owning registered vehicles in the region have only one vehicle. The proportion of renters with one vehicle is greater than the proportion of homeowners who only own one vehicle (Table 2.3). These are recruiting targets and because of the necessity of having "floating" dataloggers for swapping, new installations, and expected scheduling complications, it was anticipated that the dataloggers would be distributed with roughly 35% in single-vehicle households but that the number would vary throughout the study.

	Home-owners				Renters			
	0 vehicles	1 vehicle	2 vehicles	3 or more	0 vehicles	1 vehicle	2 vehicles	3 or more
SACOG	.019	.140	.267	.161	.059	.188	.126	.040
CALIF.	.020	.135	.243	.158	.069	.197	.134	.043

Table 2.3 Percentage of households having 0,1,2,3+ vehicles for home owners and renters in the study region (SACOG) and California.

Multiple Vehicles—Samples from the DMV database were not selected based on number of vehicles in the household with the expectation that additional mailings would be made if additional participants were needed in the multiple-vehicle category. Sampling was intended to match the population proportion of multiple vehicle households (65% of the dataloggers targeted for multiple vehicle households). If a large difference in response rate to the solicitation letters was observed, stratification of the DMV data would be necessary.

Single Vehicles—Single-car households were not separated from the DMV database for mailings during the course of the project. The selection was done at the recruiting stage instead, with a modified letter specific to single vehicle households. Because it was planned to rotate single-vehicle households out of the study after one month of participation, a steady supply of single-vehicle participants was necessary throughout the study.

Downloading— Vehicles were instrumented in multi-vehicle households for a term of 6 months, after which new 6-month participants were recruited and added to the study. To prevent the dataloggers from filling memory, resulting in data loss, regular downloading of data was planned. Downloading of the dataloggers was conducted every four to five weeks in typical families to prevent the datalogger from filling memory. The downloading of a full or nearly full Autologger required 5 to 6 hours. To minimize the time required of participants, units were to be swapped with fresh dataloggers rather than downloading on site. Every effort was made to minimize the inconvienence to the participants.

Vehicles in single-vehicle households were to be included in the study for a period of one month. The downloading of one-month vehicles was conducted after removal of the datalogger with the exception of the participants who had air conditioner compressor monitoring. The extra data recorded on these vehicles cut the data storage time in half. These vehicles were downloaded once at mid-month by swapping in a fresh datalogger and again after removal from the study.

2.4 VEHICLE RECRUITMENT

The recruitment of participants for the study was done by bulk mailing to the vehicle owners randomly selected from the DMV database. Copies of the cover letter and information sheet are included in Appendix A. Since the multiple-vehicle households participate in the study for a period of six months, they were recruited at the start of the installation phase and at the halfway point. The initial mailing list was taken from the list of vehicle owners surveyed in the 1991 Statewide Travel Survey Final Report vehicle use survey by randomly selecting 1484 people from the list which CALTRANS had randomly selected from the DMV records. A second mailing was done to a subset of the first mailing to determine whether follow-up letters would increase the response rate. The follow-up mailing was not successful, producing more angry phone calls than new participants. All later mailings were randomly taken from the DMV list of registered vehicles in the study area by CARB personnel.

2.4.1 Incentives

Recruitment incentives are an integral part of the recruitment process because of the inconvenience and perceived risk of participation in the study. The multiple vehicle household incentive was higher, $100 per vehicle, because of the extra inconvenience caused by the need to download the dataloggers every month (see Table 2.4). For the 4- and 5-vehicle households in particular the scheduling was at times difficult. The relatively low $50 incentive for the single-vehicle households was considered sufficient because of the relative ease of scheduling one 2-hour installation and one 30-minute removal. At the end of the project, 10 vehicles were set up with a status channel to monitor air conditioner compressor operation. This cut the data storage in half and required bi-weekly downloading of the dataloggers. The participants were offered an additional $50 per vehicle for the extra inconvenience.

# Vehicles in Household	Participation Time	Incentive
2 or more	6 months	$100 per vehicle
1	1 month	$50
AC monitoring	1 month	Additional $50 per vehicle

Table 2.4 Incentive Schedule

2.4.2 Multiple-Car Mailing

A single large mailing of 1500 letters was done to start the project (Appendix A). As vehicle owners responded to the mailing, they were queried about the number of vehicles they owned and recruited for the appropriate part of the study. For this initial mailing, a project cover sheet was included to give vehicle owners a general description of the equipment and goals of the study (Appendix A).

2.4.3 Single-Car Mailing

Single-vehicle households were included in the study for one month and then rotated out. A steady supply of single-vehicle households was needed. People have a tendency to loose interest in participating as time passes from receipt of the recruiting letter, so for single-vehicle households multiple small mailings were conducted.

2.4.4 Response/Returned Letter Rate

The overall response rate ran about 9% for the general mailing directed at single- and multiple-vehicle families. The mailing specific to single-vehicle families had a response rate of between 3% and 4%, which corresponds to the single-vehicle population proportion of the 9% response rate found in the general mailing. The returned undeliverable mail rate was 148 of 1484 (10%) on the first mailing. The rate ranged from 9.8% to 3.1% on the secondary mailings (see Table 2.5). The difference in returned letter rates is accounted for by the age of the DMV data used to generate the lists, with the first mailing conducted from a 3-year-old database and the following mailings from a list less than a year old. The response rate to the mailings is approximate because some respondents failed to leave a name or phone number. In general the reposes started 3 to 4 days after mailing with the majority responding within 10 days. However, some of the responses to the first mailing occurred several months after the letters were sent so it may be assumed that some of the responses are from prior mailings to the time period in which they were received.

Date	Letters	Undeliverable	Responses	Notes
5/96	1,484	148	64	First mailing, all households
10/96	100	9	3	Repeat mailing to subset of first
2/97	520	16	57	All households, updated DMV database
5/97	275	10	12	Letter asking for single vehicle households only
7/2/97	182	8	0	Business card included, single vehicle only
7/21/97	50	3	4	Letter asking for single vehicle households only
8/97	300	21	14	Letter asking for single vehicle households only

Table 2.5. Mailing summary.

The only mailing to have no response was the mailing which included a CE-CERT business card. In similar mailings in Southern California inclusion of the business card had helped to assure the public that the project was not a sham and resulted in roughly twice the response rate of the mailings without business cards. The difference may be due to the Southern California address on the business card, which could have made the project management appear too remote.

2.4.5 Participant Concerns

The primary concern of the potential participants was whether the letter was actually an attempt to steal their vehicle or steal from them in some other manner. Business cards and University of California ID cards were essential for setting the participants at ease once an appointment was made. The relatively low response rate for the mailings can in part be accounted for by general distrust and fear of crime. Care was taken to not mention monitoring of speed in the cover letters and project description because of perceived customer fear of being reported if they exceeded the speed limit. Participants were assured that the project was strictly for research and not for enforcement of any pollution or driving laws. Further participant concerns are addressed in Appendix C.

2.5 DATA ACQUISITION EQUIPMENT DESCRIPTION

2.5.1 Hardware

For this study, CARB purchased 100 dataloggers from Instrumental Solutions of Ottawa, Canada. The particular model used was the Autologger Model 2/128KB which is capable of recording various second-by-second signals from a vehicle such as speed, engine RPM, AC compressor on/off, etc. A time/date-stamp is also recorded with each data record. For this study, vehicle speed was the primary vehicle parameter that was recorded. With 128 KB of on-board data storage (RAM), each unit can hold approximately 30 hours of second-by-second speed data. The data collection period varied greatly from vehicle to vehicle but typically covered 4 to 6 weeks in most situations. The Autologger dimensions are 10.5 x 3.5 x 1.5 inches and could fit in the engine compartment of most domestic and foreign vehicles.

Each Autologger consists of an assembly of four printed circuit boards which are connected together with pins and sockets or an edge connector. There are two main boards, one analog component board and one digital computer board, a small printed circuit (PC) card which stores the Autologger software on non-volatile RAM, and an end cap PC board which connects the analog board to the sensor and vehicle battery wires.

In most applications the speed data were collected using an add-on inductive coil speed sensor and magnets typically used in after market cruise-control vehicle accessory additions. Depending upon the vehicle, the magnets were placed on the drive-line close to the front universal joint or on one of the CV joints on the transaxle side. No holes were drilled in the participants vehicle to mount the sensor. Any bolts that are loosened or removed to mount the sensor were performed by a qualified automotive engineer or mechanic in order to prevent any problems to the vehicle, and consequently, the participant. The magnets were glued to the drive shaft at three equal points and the speed sensor was attached to the underside of the car adjacent to the magnets with a gap allowance of approximately 1-1.3 cm between the sensor center and the magnet.

The Autologger requires 2 power connections and one ground connection (see Table 2.6) The ground connection was connected to a clean chassis ground or ideally to the negative terminal of the battery.

Vehicle Operation OFF/ON/START	Autologger (Pin 1) MAIN POWER	Autologger (Pin 6) VEHICLE IN USE
Engine off/ Key Off	+12 V of Batt. (+)	0 V Open Circuit
Engine Starting (Engaging starter)	+12 V of Batt.(+)	+12 V
Engine Running	+12 V of Batt.(+)	+12 V

Table 2.6. Autologger wiring connections.

Most vehicle accessories such as the radio are temporarily disconnected when the key is turned into the start position to allow maximum current for the starter motor. Special consideration was required for the key-on signal of the Autologger. This signal was usually tapped from the fuse box and there are usually very few available options for the appropriate power connection. It is important that the voltage does not drop below 10 volts when the vehicle starter motor is engaged or else the Autologger logs this as two trips or experience errors in it normal function.

Two people were required to monitor the power on a meter while depressing the clutch and turning the key to properly select the source power for Autologger key-on signal. All wires were carefully routed and secured with nylon cable ties or tape to allow the participants full access for regular maintenance and to avoid any problems due to entanglement or short circuits. Wiring then was run to the Autologger's front panel.

In some applications the Autologger could pick up the speed signal directly from the vehicle wiring from either the transmission pulse signal or the factory or after market cruise control wiring. The Autologgers pulse input wire could be spliced into the vehicles stock wiring harness. This method however, proved to be more trouble than its offset time savings for several reasons:

1) The cruise control signal was usually only available on older vehicles and because of this it was frequently non-operational.

2) Often the baud rate from the vehicle's signal would exceed the Autologgers allowable input frequency and as a result the speed data would then be truncated.

3) When removing the equipment, the vehicle's wiring harness insulation would require repair to prevent corrosion of the original wiring.

When problems were encountered with the vehicles pulse signal, the installation would inevitably resort to the magnetic sensor and magnets causing more wasted time rather than a time savings.

Any wasted time is perceived as an inconvenience to the participant. Because of the frequent problems using the vehicle's speed proportional pulse signal, it was preferred to use the magnetic sensors because it worked consistently and with limited problems.

2.5.2 Hardware Modifications

The long-term underhood use proved to be a difficult environment for the Autologger. CE-CERT engineers made modifications to the units at the halfway point of the project. Each Autologger had eight modifications to improve the integrity and reliability of the connections among the 4 boards, and an additional backup battery was added for the RAM storage. These modifications were made primarily to strengthen the robustness of the Autologger and are described in detail in Appendix B.

Further, the Autologgers were designed to have two operational modes. The "active" mode occurs during a trip when the vehicle ignition is energized. When the vehicle stops, and the ignition key is removed, the Autologger senses the power-off condition and, after storing the current data set, executes a "sleep" mode subroutine in the software. The Autologger draws approximately 10 times more current during the active mode (~250 mA) than it does during the sleep mode (~10 to 25 mA). This current draw is insignificant while the vehicle is operating and the battery is constantly being recharged. However, when the vehicle engine is off and the alternator is not charging the battery, the current consumed by an active Autologger is substantial. This condition is exacerbated when the vehicle's battery has not been well maintained or is nearing the end of its useful life.

It was discovered early in the study that both software and hardware problems could force an Autologger to lock up in the active mode, which would drain the vehicle battery. To help eliminate this problem, a "reset circuit" was designed and added to the Autologger installations between the Autologger and the battery. When a participant completed a vehicle trip and turned off the ignition switch, the reset circuit timer was activated. The Autologger was allowed to consume power for a short time, sufficient to properly archive the latest trip data and statistics. After this time period had elapsed, the circuit opened a switch, limiting the current the Autologger could sink from the vehicle battery.

This limited current would be sufficient to keep the Autologger memory alive while in the sleep mode. However, if the Autologger experienced a temporary failure due to a hardware or software problem, the current limitation allowed the Autologger to reset. Prior to this modification, an Autologger that experienced an error would remain in its active high-power consumption mode until the power connector was momentarily disconnected or the unit replaced. The addition of the reset circuit served two purposes: it allowed the Autologger to recover from temporary hardware problems or software crashes in the participants trip, and it prevented the Autologger from draining the vehicle battery. The prototype reset circuit schematic is shown in Figure 2.2. A diagram showing the wiring position of the reset circuit relative to the battery and Autologger appears in Appendix B.

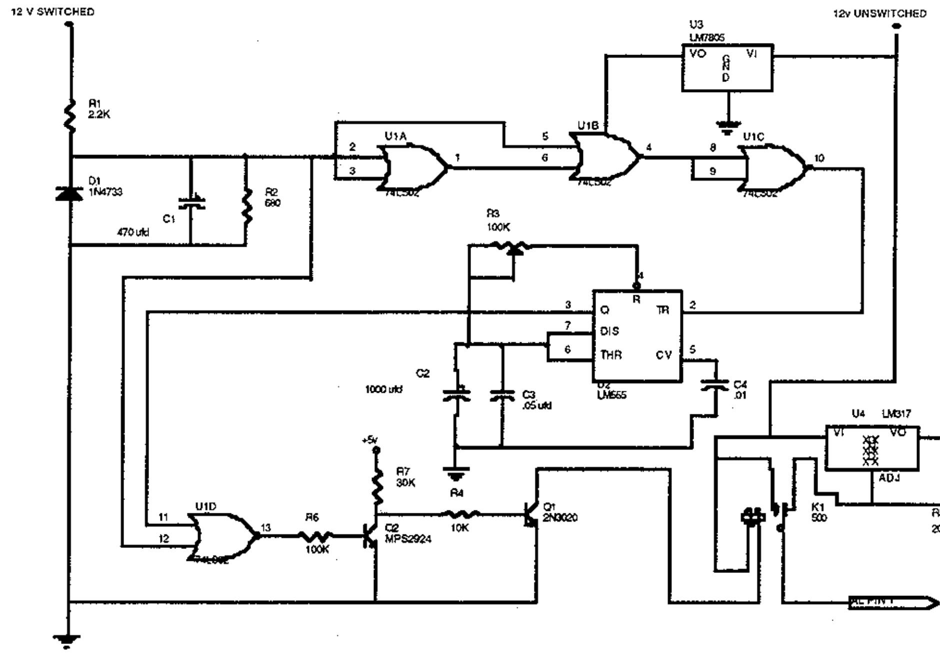


Figure 2.2. Autologger Reset Circuit

2.5.3 Software

The software underwent several revisions during the initial part of the installation phase of this project because of problems encountered in the field. The "trace" program collects second-by-second speed data and the "trctrp" program collects both second-by-second speed data and trip summary data. The "sacto" program was a modification of the "trctrp" program to include collection of oxygen sensor and air conditioner compressor data in binary (ON/OFF) format. The software versions are listed in Table 2.7.

Version Name	Release Date	Notes
trace2m.3	11/7/95	Original Accel error - Freeze error RTD
trcnw.txt	5/3/96	Bugs in Apr. 6 Counter Reset/Sleep/RTD
tra233f.txt	5/6/96	Version 2.34
tractrip.txt	5/6/96	Trace + trip archiving Bad argument errors
trctrp2.txt	6/4/96	
trctrp3.txt	6/7/96	Fix Counter Reset freeze & RTD - Underflow
trctrp5.txt	6/12/96	Fix underflow - Total archiving error=no data
trctrp6.txt	6/21/96	Never Used - Archiving Freeze
trctrp7.txt	6/26/96	Replacement for 1.06 Fix Freeze prob.
trace2m.37	7/22/96	Backup Version of trace2m.3 - Bad download
extract.txt	7/22/96	To redump stored data - Did not work
trctrp8.txt	7/29/96	Supposed fix for data dump in 1.07
trc237.txt	7/29/96	Backup program for 2m.3 w/ failsafe
sacto2.txt	8/7/96	Repl. For bad Sacto1 TRCTRP +O2 and A/C
extrac2.txt	8/13/96	Fail Same Results as original download
trace2m.38	9/26/96	To fix memory page error - Fail
trace2m.381	10/1/96	Won't Record or reset

Table 2.7 Software revisions.

2.6 DATALOGGER INSTALLATION AND DATA CALIBRATION

The Autologgers were calibrated in the field by taking a test drive while monitoring the Autologger using a laptop computer. Rear wheel and 4-wheel drive vehicles were outfitted with magnets on the driveline; front wheel drive vehicles received magnets on the CV joints or on the front axle. Once traveling at a steady speed no less than 60 km/hr, the Autologger was locked in for a particular calibration factor in [m/pulse] corresponding to the average number of meters traveled per magnet passing the sensor. These factors ranged from 0.129 to 0.69 m/pulse (Appendix D) depending upon the magnet location, either drive-line or axle and number of magnets attached.

Callibration procedure:

1. Install the Autologger and verify that the unit powers up when the vehicle is started.
2. Connect the Autologger to the laptop computer using the Instrumental Solutions cable.
3. Start the vehicle and run the tracetrip program on the laptop computer.
4. Select the callibration mode.
5. The program will show second-by-second speed.
6. Drive the vehicle at a steady 60 km/hr.
7. Press the Enter key, then type in the vehicle speed. The program will return the calibration factor.
8. Keep a record of the calibration factor so that it can be entered directly on future installations on the vehicle to eliminate this procedure.

This method of speed calibration is only as accurate as the speedometer in the participant's vehicle. For the few vehicles where the speedometer was broken, the driver and engineer operating the laptop computer would agree on a best estimate for the present speed and calibrate the Autologger accordingly.

2.7 DATA RETRIEVAL

All data retrievals were conducted with the Autologger out of the vehicle. The lengthy download time (over six hours for most datasets) made downloading impractical in the participants vehicle because of the drain on the vehicles battery and the inconvenience to the participant. Several Autologgers had to be kept available for rotation of the units in the six-month participant vehicles.

Downloading procedure:

1. Connect Autologger to a 12 volt power source.
2. Connect Instrumental Solutions data cable to IBM compatible PC.

3. Connect cable to Autologger.

4. Turn on power to Autologger.

5. Turn on PC.

6. Run tracetrip program.

7. Select download data option (Number 5 on most versions of the software).

8. Save file at end of download.

9. Edit file and add vehicle information.

Two used IBM compatible 286 PC's were used for the majority of the downloading to keep the laptop free for use in installations. Because of the slow speed of the Autologger downloads the system requirements for the downloading computers are minimal. A sample download is presented in Appendix E.

3 Data Processing and Analysis

3.1 DATA SMOOTHING

The environment under the hood of an in-use vehicle is difficult for computer equipment because of the heat, vibration, and interference from the vehicle electrical equipment. One or two second speed spikes occur on occasion and were smoothed out of the data prior to calculating the trip speed statistics. Typically, electromagnetic noise from the vehicle electrical coil would introduce spikes of unreasonable speed. These suspect data values were filtered out by an algorithm based upon a reasonable maximum allowable acceleration. From zero speed, the maximum allowable acceleration was limited to 25 km/hr/sec (corresponding to a 0.7 g acceleration). As the vehicle speed increases, the maximum acceleration decreases because more engine power is consumed overcoming rolling resistance and aerodynamic drag. To compensate for the decrease in available power, the acceleration limitation was sloped down linearly from 25 km/hr/sec at zero speed to 10 km/hr/sec at a vehicle speed of 120 km/hr. The maximum deceleration was fixed at –25 km/hr/sec for the entire speed range. This generic acceleration filtering was effective in removing the majority of the bad data points which were quite large relative to neighboring speed values. The bad values were replaced with interpolated values so that the trip could be included in the analysis. A more specific speed filter could be developed taking each vehicles weight and horsepower into account, and accurately determining the vehicle's maximum acceleration/deceleration values at all speeds.

3.2 DATA FILTERING

Data filtering was necessary for several reasons: to remove spikes in the speed and to eliminate bad trips from the analysis of the data. The datalogger callibration trips were eliminated from the analysis. Some data problems were corrected, such as the speed spikes noted above, while others caused elimination of the trips from some or all of the statistics. Further, portions of data sets where the Autologgers clock froze were removed from the analysis. Any trips where the Autologger reported a date or time that was nonsense were also removed from analysis. Data were not included in the analysis without confidence that the information was complete. There were approximately 500,000 seconds of data where the time or the speed were questionable because of possible hardware problems, date/time problems, memory overwrite problems, data archiving problems, software problems which caused the Autologger to sample data every two seconds, and speed truncation. In addition, 72 Autologgers were recovered with little or no data recoverable even after substituting parts for working Autologgers to get to the memory on the dead units. This resulted in approximately 7 million additional seconds of data lost if we assume most of these units would have had about 100,000 seconds typically recovered.

3.2.1 Trip Time

Similar to the three-cities study [DeFries and Kishan 92], all trips of less than 18 seconds were eliminated from the trip speed statistics. These trips, however, were counted in the starts per day statistics. Data sets also were eliminated if trips exceeded 20,000 seconds. Under certain conditions the Autologgers experienced failures, which caused overwriting of the memory. No cause of this type of failure was determined. However, datasets with this problem were easily identified because it resulted in false trips of 20,000 seconds or more with most seconds having zero speed. Downloads exhibiting this problem were not included in the final analysis because once the memory has been overwritten it is not possible to determine with any certainty where good data ends and bad data begins.

The internal clock on the Autologger froze in some units, resulting in multiple trips having identical time stamps or impossible time stamps. These trips had apparently valid speed data but were not included in the analysis because the speed data were disassociated from corresponding start and soak data. In addition, because the cause of the malfunction could not be determined with certainty, it was not known if the problem could also have affected the speed data.

3.2.2 Starting or Ending Non-Zero Speed

Trips which started or ended in non-zero speeds >10 kph were not included in average speed calculations. These trips were assumed to have experienced an error which stopped data recording at some unknown time during the trip, making the average speed data useless. However, these trips were counted in the trip start calculations because the time and date are recorded at the beginning of the trip prior to the error. Valid trips which start with non-zero speeds could occur with drivers who start driving quickly after the motor starts. In these cases a small delay in the changing of the Autologger from low-power mode to high-power mode could cause non-zero initial speeds. The non-zero trip end speeds could occur on valid trips when the driver shuts off the ignition prior to the vehicle coming to a complete stop. These trips should be counted in the inventory, however datalogger failures and vehicle stalls should be excluded. The 10 kph limit was chosen to ensure that the speed was well above the 3 to 5 kph limit where the Autologger lost resolution in most applications.

3.2.3 Different Software Versions

As mentioned previously, some problems with the software were identified during the course of the study and several revisions were made. One version of the software took the data at 2 second intervals instead of 1 second. These trips are not included in the speed calculations because of the difference in time resolution with half the number of sample points for an equal time interval. Additional datasets were not included from a version of the software which truncated speed values (Figure 3.1) because the maximum speeds and average speeds could not be determined accurately.

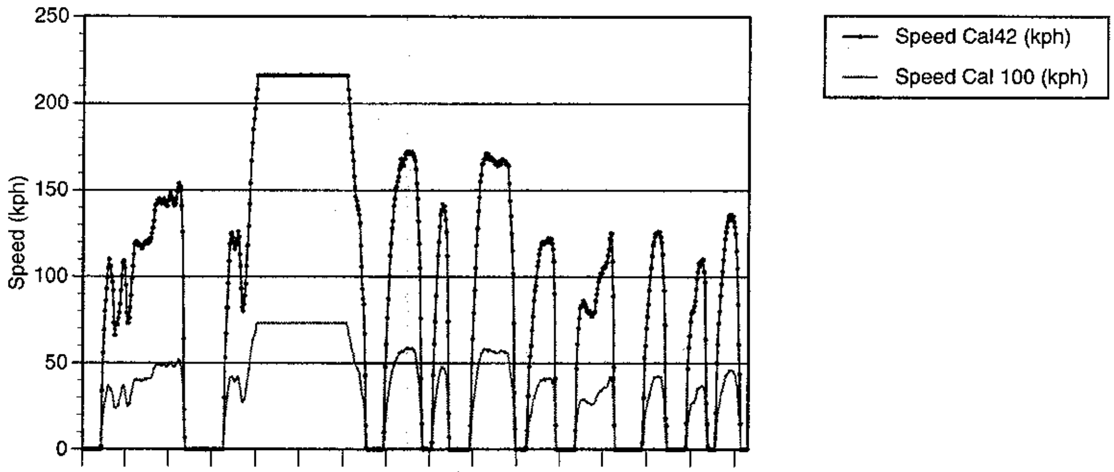


Figure 3.1. Example of speed truncation data set.

Extensive data loss occured due to Autologgers which were recovered inoperable and which could not be saved. Project engineers opened all Autologgers recovered nonfunctional and substituted NVRAM cards from good units as well as checking all internal connections in order to recover as much data as possible. While the time to disassemble these units was not planned for, the data recovered made the effort worthwile.

Data Quality Check	Filter Used
Speed Spike	Filter decreases linearly from 25km/hr/sec at 0 kph to 10 km/hr/sec at 120 km/hr. Maximum deceleration set at -25 km/hr/sec Bad speed points replaced with interpolated values.
Trip Time	Trip Time <18 seconds not used in trip speed analysis.
	Downloads containing trips >20,000 seconds eliminated.
Internal Clock Frozen	Trips where all times are the same were eliminated from the analysis because they could not be assigned to any day. Data collected prior to the clock freeze were used.
Non-Zero Start or End Speed	Trips starting or ending in speeds >10 kph were not included in speed averages.
Speed Truncation	Speed truncated data were not included in the analysis

Table 3.1 Data Quality Check Summary.

4 Results

4.1 GENERAL RESULTS

This study has produced a large real-world vehicle activity data set with over 13,400,000 seconds of vehicle speed data recorded on 22,165 total starts and 21,155 trips (a trip is considered to be greater than 17 seconds). A total of 385 installations were completed on 199 individual vehicles. After filtering out all questionable data a total of 204 data sets containing valid data were collected. A total of 3,520 vehicle/days of data were collected in this study. The data collected from multi-vehicle households (a 110 vehicle subset) provide a unique data set for analyzing household vehicle interactions. A second unique data set produced focused on air conditioning monitoring which was completed on 1,036 trips covering a total of 718,575 seconds.

4.2 SPEED DATA VALIDATION

The Autologger's accuracy in measuring speed was verified at CE-CERT using a state-of-the-art dynamometer as well as using a GPS-equipped CE-CERT instrumented vehicle. The dynamometer-based speed validation was performed on a 1993 Ford Aerostar van. Two Autologgers were set up on the van and the time scales were synchronized. One unit was set up using the magnetic sensor and the other unit was setup using the pulse signal from the transmission. Each Autologger received a different calibration factor to test for linear response across calibration values. After a test on the dynamometer, the recorded data were compared with the data from the reference dynamometer speed record. Both speed traces were linear and proportional to the speed trace of the reference dynamometer trace with the unit having the correct speed calibration factor differing from dynamometer measured speed by 6%.

In addition, a comparison test was conducted on the road to validate the accuracy of the speed data collected by the Autologger units under real driving conditions. This was done by installing an Autologger on CE-CERT's instrumented vehicle. The Autologger data was then compared with data collected by the highly accurate GPS velocity measurements. The Autologger was installed in the CE-CERT instrumented vehicle using the speed sensor and magnets on the drive unit. The instrumented vehicle was then taken on a test drive on small roads and one larger higher-speed road to cover the driving conditions found in the Sacramento study. This speed was compared with the Autologger and the traces were proportional and linear with the GPS data. (Figure 4.1). The average speed for the test run was 50.82 kph with a maximum speed of 119.9 kph. On the validation test run, a high correlation (R-square = 0.992) was found between the Autologger speed data and the GPS speed data (Figure 4.2). The Autologger speed was slightly higher across the range (6%) but the Autologger is calibrated to the speedometer, which can be off up to 10%. The only real difference between the two speed monitoring methods occurred at speeds below 5 kph where the Autologger resolution drops with the small number of pulses while the GPS speed gets more accurate with the closer spacing of the data points.

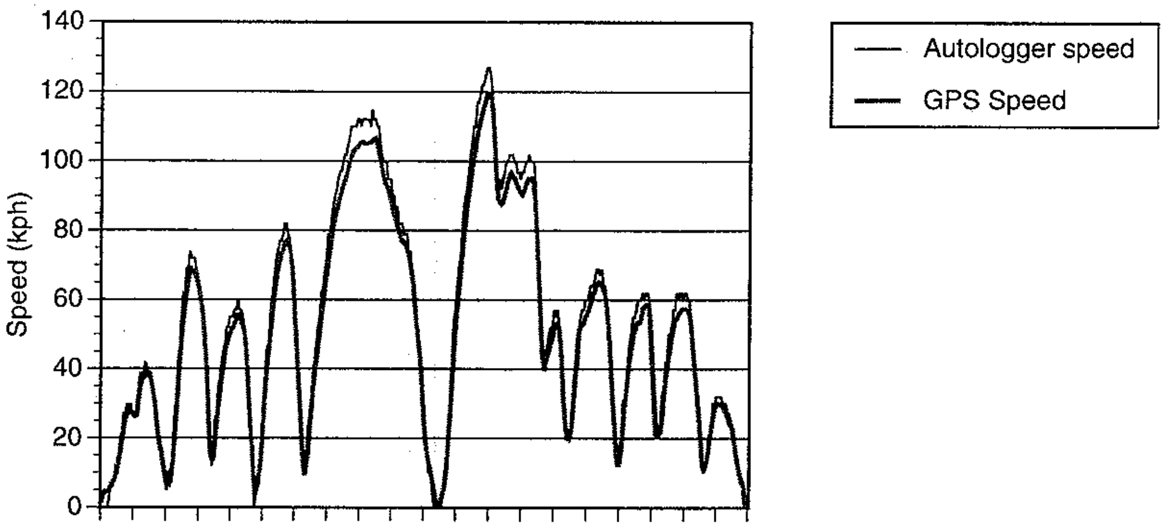


Figure 4.1 Validation test run second-by-second speed trace.

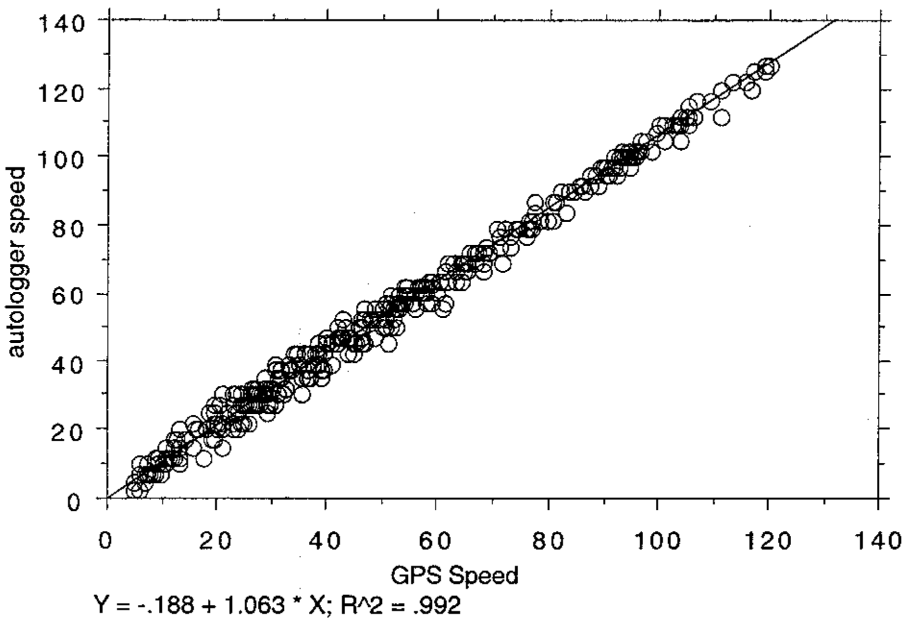


Figure 4.2 Validation test run regression plot of second-by-second speed data.

4.3 PARTICIPANT CAR COMPARISON WITH REGIONAL DATA

The vehicle age profile of the vehicle activity study (Figure 4.3a) was similar to the profile for the vehicles in the study area, shown in Figure 4.3b excluding the pre-1964 vehicles and presented in tabular form in Table 2.2.

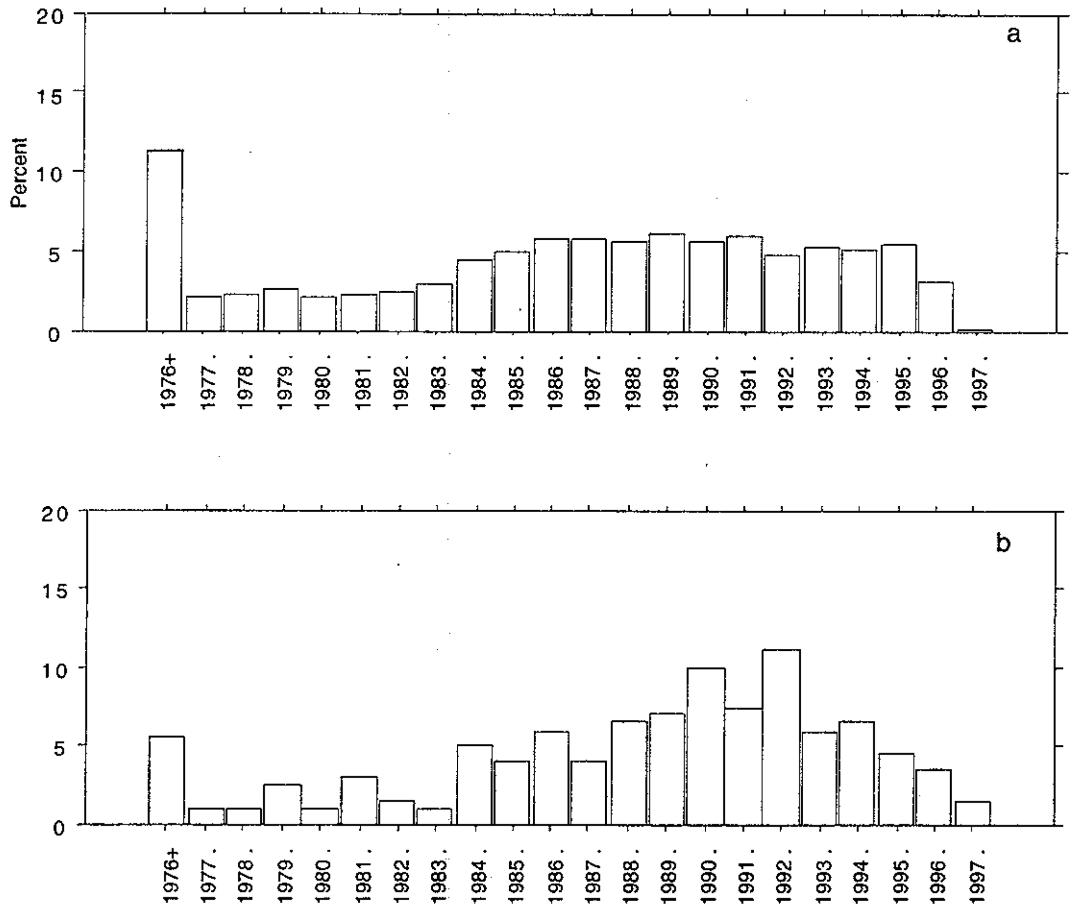


Figure 4.3 a) Study region DMV vehicle age profile b). Sacramento Vehicle Activity Study vehicle age profile

The Kolmogorov-Smirnov one sample test [Siegel, 1956] was used to test for differences between the sample vehicle fleet and the DMV model year profile. The K-S test is a test for any differences in distribution which does not assume any statistical distribution in advance. The two-tailed 5% significant critical value is calculated as: $1.53/(\mathrm{sqrt}(n)) = 10.84$.

Examination of the DMV registration data revealed that 6.1% of the vehicles registered in the region were cars from 1963 and earlier. It is likely that the owners of these classic vehicles do not want to make them available for instrumentation because of concern for the vehicle and in some cases probably due to modifications to the emissions equipment. For the 199 vehicles in our sample (model years 1964 to 1997) the two-tailed critical value is 10.84. The largest observed percent difference is 10.80, indicating that our study sample distribution does not differ significantly from the DMV registration in the region for cars newer than 1963. The three cities study vehicle sample distributions are presented for comparison (Figure 4.4).

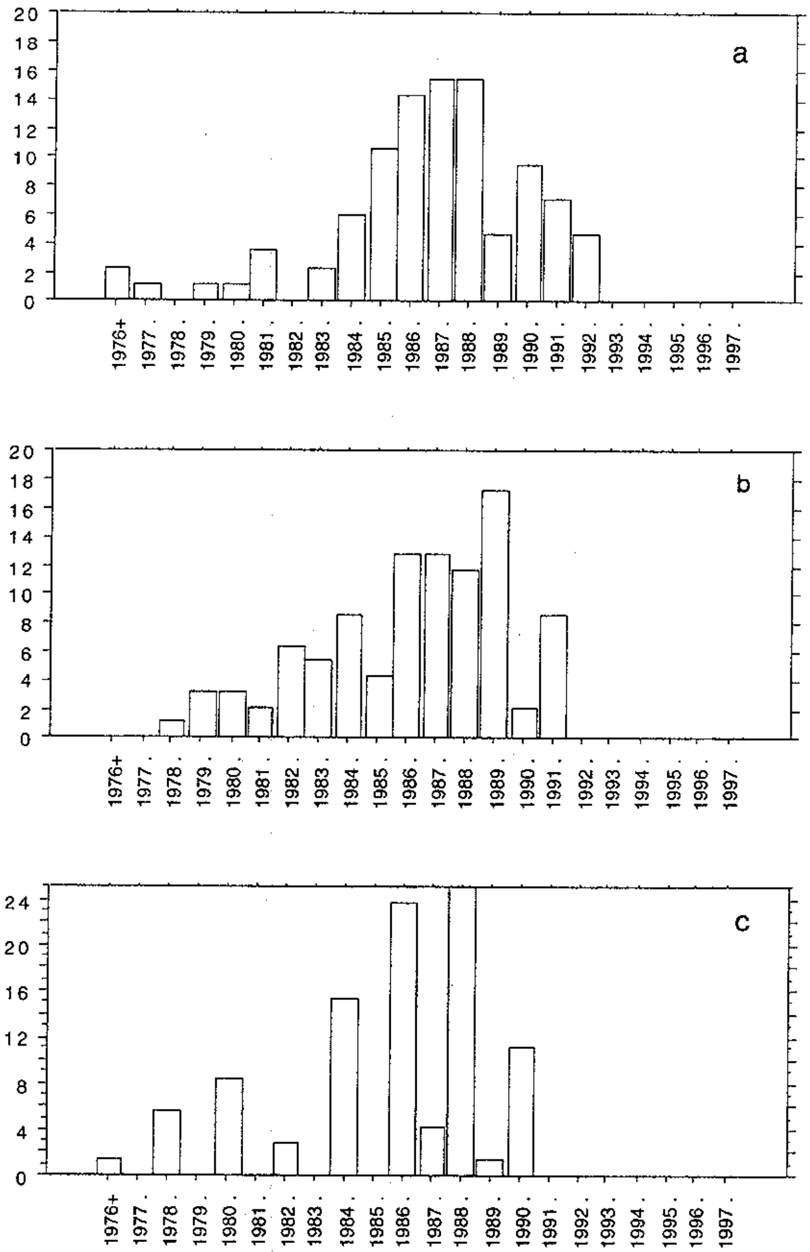


Figure 4.4. Vehicle Age Distribution For a) Atlanta, GA, b) Baltimore, MD, and c) Spokane, WA Datalogger Studies [Markey, 1994]

4.4 VEHICLE START CHARACTERISTICS

The current definition of a trip start with datalogger output is relatively simple. If there is a break in the time count for greater than 18 seconds, the time after the break is considered to be the start of the next trip. Cold starts are identified by calculating the soak time since the engine was shut down. Trips of less than 18 seconds duration are included in the number of starts, but are not included in trip speed statistics. All daily starts data are reported as average starts per vehicle because of the different number of vehicles having data collected on different days.

4.4.1 Starts Per All Days

Starts per all days are estimated as the average number of starts per vehicle for all vehicle data collection days. Because of sporadic problems with the dataloggers it is difficult to determine this number exactly.

$$\text{Starts per all days} = \sum \text{Starts}/\sum \text{Data Collection Days} = 22{,}165/3737 = 5.93$$

Single days where vehicles did not record any trips but which had trips recorded on the pre and post days were considered to have been recording data and simply not driven. A conservative estimate of vehicle driven days was calculated by excluding the days where more thatn one zero day in a row were observed. Vehicles which were not driven over the weekend were not included in this total. Vehicles that were recording data but which were not driven need to be included in the calculation of the averages, however days where the datalogger was not recording data are not distinguishable from days where the vehicle was not driven. A more detailed analysis examining individual vehicle use patterns, household status etc. should be conducted in the future to determine the data collection days more accurately. The count of Data Collection Days used here is conservative and the actual number is likely to be higher.

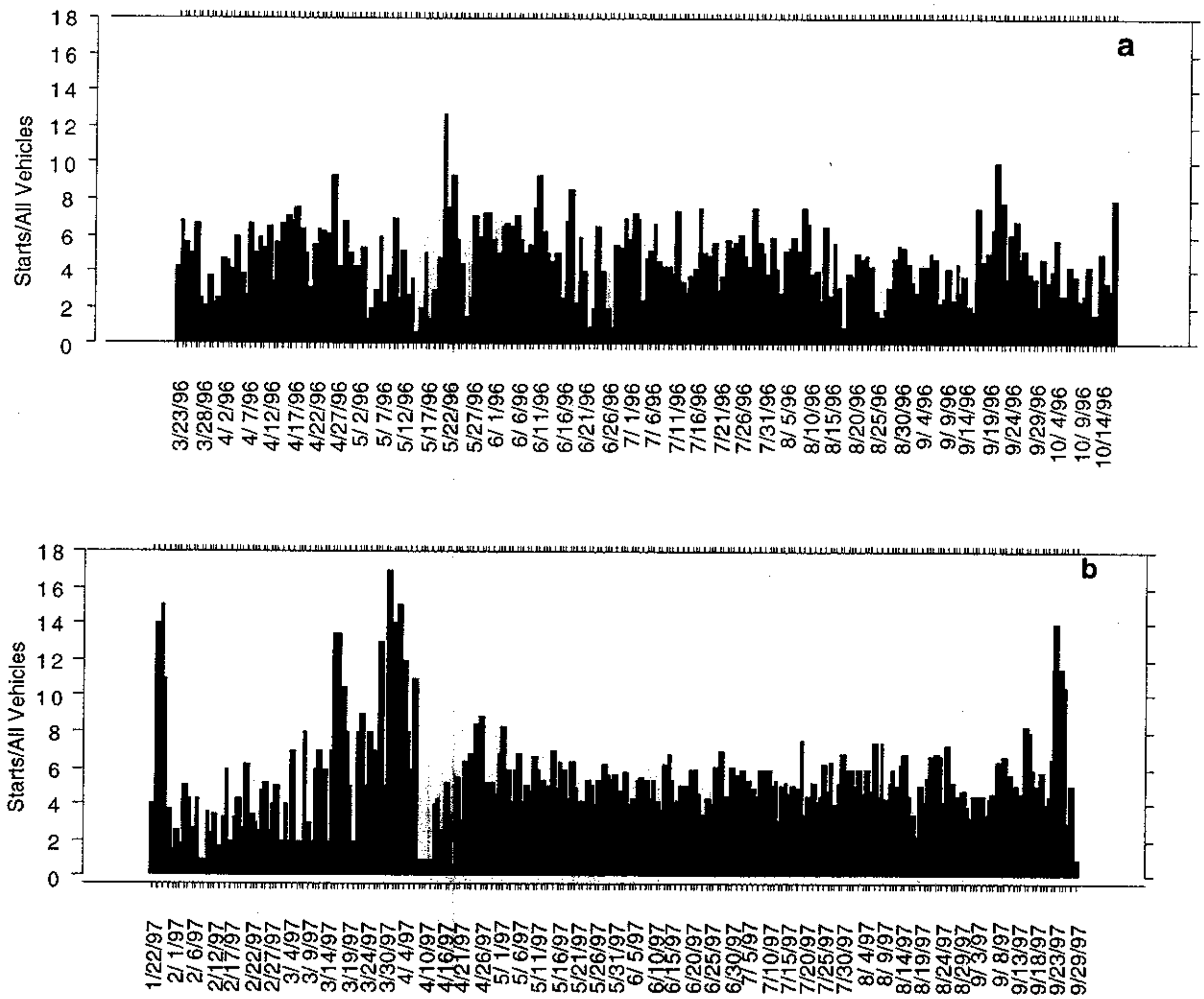


Figure 4.5 Daily Mean Starts/All-Vehicles for a) 1996 and b) 1997.

4.4.2 Starts Per Vehicle-Driven-Days

Starts per vehicle-driven-days are calculated as the average number of starts for only the vehicles which were driven. Unlike the Starts/All Days this statistic is determined exactly.

$$\text{Starts per vehicle driven days} = \sum \text{Starts}/\sum \text{Vehicle Driven Days} = 22{,}165/3520 = 6.30$$

Vehicles that were not recording data and vehicles that were not driven are not included in the calculations. The daily average starts/vehicle numbers were also somewhat variable, with a standard deviation of 2.361 (Figure 4.6).

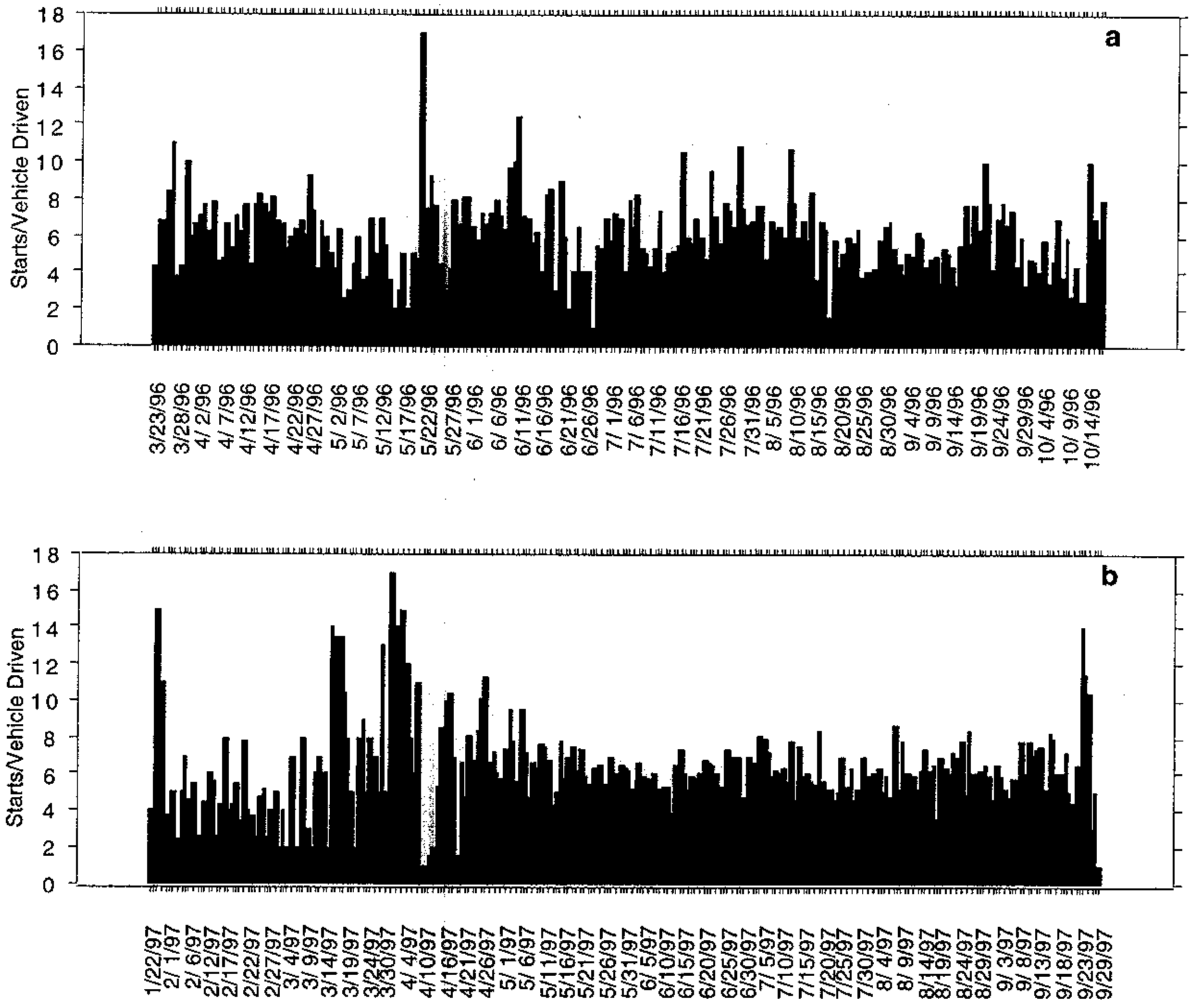


Figure 4.6 Daily Mean Starts/Vehicle for a) 1996 and b) 1997.

4.4.2 Starts/Vehicle Driven Day by Day of Week

An Analysis of Variance (ANOVA) was conducted on the daily starts per vehicle driven day to test for differences between days of the week. The P-value for this test was .7404 (Table 4.1), well above the .05 (5%) significance level indicating no significant difference in mean number of starts per vehicle driven day between the days of the week.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
day of week	6	19.756	3.293	.587	.7404
Residual	443	2483.054	5.605		

Model II estimate of between component variance: •

Table 4.1 ANOVA Results for Starts/Vehicle-Driven-Day by Day of Week.

Small differences in the mean number of starts per vehicle driven day were found between days of the week (Table 4.2 and Figure 4.7), however the high within-day variability makes these differences non- significant in the ANOVA. The high day-to-day variability observed was in part due to the problems associated with the dataloggers which resulted in the daily statistics sometimes being calculated from a small number of vehicles.

	# Days	Mean	Std. Dev.	Std. Err.
Sunday	64	5.904	2.221	.278
Monday	66	6.121	2.658	.327
Tuesday	64	6.633	2.650	.331
Wednesday	63	6.322	2.018	.254
Thursday	64	6.111	2.480	.310
Friday	65	6.295	2.002	.248
Saturday	64	6.203	2.437	.305

Table 4.2 Mean, Standard Deviation, and Standard Error for Mean Starts/Vehicle Driven Day by Day of Week

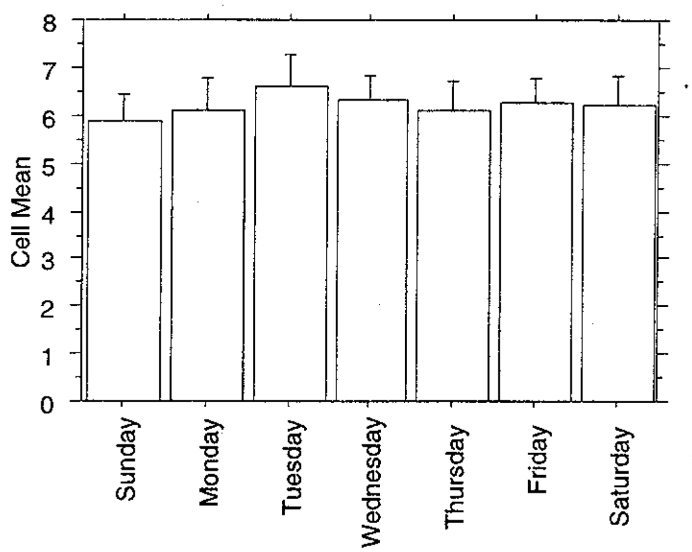


Figure 4.7 Mean Starts/Vehicle Driven Day with 95% Confidence Limits by Day of Week.

4.4.4 Starts By Weekdays/Weekends

Starts by weekdays are calculated as the average number of starts per vehicle for all vehicles having data collected on weekdays during the study period. Starts/vehicle were calculated by day-of-week as described above and the mean number of starts/vehicle was 6.295 for the weekdays (Monday to Thursday). The mean number of starts/vehicle for weekends (Friday, Saturday, Sunday) was 6.135 (see Table 4.3).

	# Days	Mean	Variance	Std. Dev.	Std. Err
Weekend	193	6.135	4.931	2.221	.160
Weekday	257	6.295	6.067	2.463	.154

Table 4.3 Mean Data for Number of Trips/Vehicle Driven Day

An un-paired t-test was used to test for a difference between weekdays and weekends for the entire study (Table 4.4) and no significant difference was found with a P-value of .4753.

	Mean Diff.	DF	t-Value	P-Value
Weekend, Weekday	-.161	448	-.715	.4753

Table 4.4. T-test for difference in mean Starts/Vehicle Weekday vs. Weekend

4.4.5 Starts By Vehicle Age Distribution

An analysis of variation (ANOVA) was run on the daily data for all data collected to check for significant differences in the average number of starts per vehicle-driven-day between model years. Significant differences ($p<.0001$) were found between model years (shown in Table 4.5) indicating that the mean number of starts per vehicle-driven-day is not uniform across model years.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model Year	23	3095.742	134.597	7.924	<.0001
Residual	3116	52928.208	16.986		

Model II estimate of between component variance: .926

Table 4.5 ANOVA Results by Model Year.

The number of vehicles within each model year was random so the number of days and vehicles within each group varies. There was a general trend for older model year vehicles to have fewer average starts per day than the newer vehicles, as shown in Table 4.6. A regression was run on mean starts per vehicle driven day over model year and a significant linear fit was found ($p=.0003$). The regression is shown in Figure 4.8.

	Count	Mean	Std. Dev.	Std. Err.
1964	30	3.000	2.767	.505
1967	31	3.581	1.979	.356
1970	10	5.400	2.875	.909
1975	29	6.103	2.833	.526
1977	8	2.500	1.690	.598
1978	21	5.476	3.234	.706
1979	125	5.232	4.058	.363
1981	145	4.359	3.164	.263
1982	51	5.686	4.474	.627
1983	15	6.067	4.217	1.089
1984	176	6.659	5.918	..446
1985	88	3.977	2.354	.251
1986	198	6.737	4.047	.288
1987	102	6.480	4.014	.397
1988	330	5.730	3.858	.212
1989	234	7.047	4.869	.318
1990	213	7.859	4.082	.280
1991	298	6.148	3.829	.222
1992	395	7.114	4.461	.224
1993	76	5.737	3.300	.379
1994	245	6.759	4.029	.257
1995	104	6.606	4.248	.417
1996	123	6.724	4.092	.369
1997	93	5.817	3.352	.348

Table 4.6 Mean, Standard Deviation, and Standard Error for Starts/Vehicle-Driven-Day by Model Year.

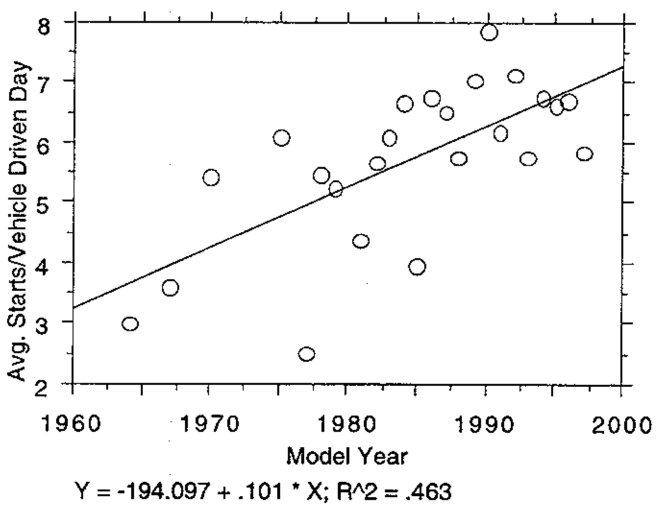


Figure 4.8 Regression Plot for Starts/Vehicle-Driven-Day by Model Year.

4.4.6 Starts By Household-Vehicle

An ANOVA test was run to determine if there were significant differences in the number of starts per vehicle across household vehicle sizes. For this analysis each vehicle in the study was assigned a group code based on the number of vehicles in the household. The daily number of trips per vehicle driven day were calculated and used for the one-way ANOVA with FamVeh (number of vehicles within a household) as the grouping variable. Daily averages were used instead of vehicle averages to incorporate the high day-to-day variability within individual vehicles. Significant differences were found (Table 4.7) indicating that the average number of starts per vehicle-driven-day was not uniform across households with different numbers of vehicles.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
FamVeh	4	428.330	107.082	5.978	<.0001
Residual	3476	62259.674	17.911		

Model II estimate of between component variance: .152

Table 4.7 ANOVA Results for Starts/vehicle-driven-day by Household Vehicles.

The highest average number of starts per vehicle driven day were in the single vehicle households (Table 4.8 and Figure 4.9) while the lowest was in the three vehicle households vehicles. The Scheffe paired comparison test was run to identify significant differences between groups. The Scheffe test is a conservative paired comparison test. In this case the 3 vehicle households had a significantly lower number of starts per vehicle than the 1 and 2 vehicle households, but not significantly different than the 4 and 5 vehicle households.

	# Veh. Days	Mean	Std. Dev.	Scheffe Group*
1 Vehicle	1011	6.651	4.604	b
2 Vehicles	1636	6.292	4.179	b
3 Vehicles	434	5.493	3.537	a
4 Vehicles	225	6.480	4.351	a b
5 Vehicles	175	6.017	3.899	a b

* Groups having the same letter code are not significantly different.

Table 4.8 Mean, Standard Deviation, and Standard Error of Starts/Vehicle-Driven-Day by Household Vehicles.

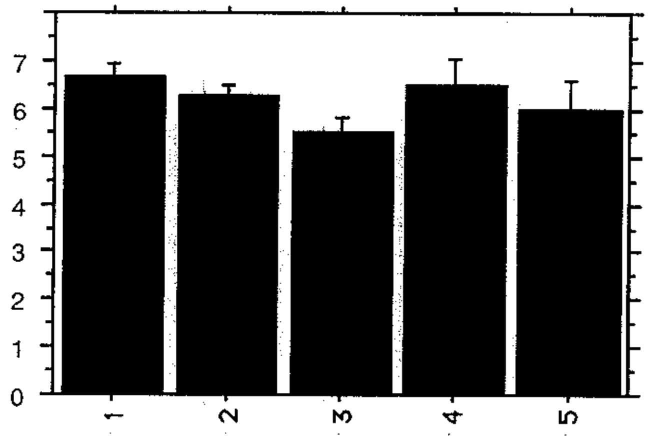


Figure 4.9 Bar Chart of Mean Starts/Vehicle-Driven-Day by Household Vehicles with 95% Confidence Limits.

4.4.7 Seasonal Effects

In order to estimate seasonal effects the daily average number of starts per vehicle were calculated. A total of 450 days of data were used for this analysis. Each day was then assigned a categorical variable for the month for analysis with a one-way ANOVA. Monthly average starts/vehicle were calculated by averaging the daily results across the entire study. A one-way ANOVA does not require equal sample size within treatments, an impossibility with months. Significant differences in the mean monthly starts per vehicle-driven-day were observed ($p<.0001$) between months, as shown in Table 4.9. January was the highest and February the lowest (Table 4.10 and Figure 4.10). The high standard deviation was observed during January because of the small number of days reporting data. Because of the length of the study, the April to September time period had data available in both 1996 and 1997. January was included for completness, however it has much higher confidence limits because of the smaller amount of data.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
trip month	9	213.880	23.764	4.568	<.0001
Residual	440	2288.930	5.202		

Model II estimate of between component variance: .422

Table 4.9 ANOVA Starts/Vehicle-Driven-Day by Month.

Effect: trip month

	# Days	Mean	Std. Dev.	Scheffe Groups
Jan	5	9.550	5.386	b
Feb	27	4.463	1.575	a
Mar	39	6.740	3.845	b
April	58	7.053	2.880	b
May	62	6.111	2.245	a
June	60	6.158	1.798	a
July	62	6.367	1.428	a
Aug	62	6.112	1.431	a
Sep	58	6.075	2.132	a
Oct	17	5.133	2.050	a

Table 4.10 Starts/Vehicle Mean, Standard Deviation and Standard Error by month.

The Scheffe paired comparison test was run to identify significant differences between groupsIn this case the months fell into two groups with January, March, and April not significantly different and February, May, June, July, August, September, and October not significantly different.

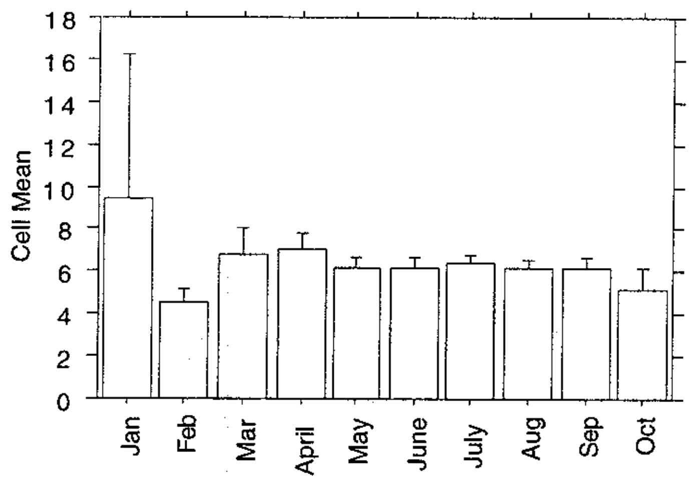


Figure 4.10 Average Starts/Vehicle-Driven-Day by Month with 95% Confidence Limits.

4.5 TRIP CHARACTERISTICS

For the trip characteristics analysis, the trips with duration's of less than 18 seconds were excluded from the calculations. There were 1,010 trips less than 18 seconds (out of a total of 22,165), of which 399 had some distance traveled, indicating that the vehicle was moved.

The key trip characteristics of interest include distance traveled, average trip speed, and trip time, described below.

4.5.1 Trip Distances

Trip distance was calculated by assuming that the speed for a second is constant for the entire second. The total distance is then the sum of the kilometers/second for the entire trip. The majority of trips (97%)were less than 38.53 kilometers (23.94 miles) (Table 4.11).

From (≥)	To (<)	Count
0.000	38.525	20598
38.525	77.049	359
77.049	115.574	69
115.574	154.098	74
154.098	192.623	35
192.623	231.148	11
231.148	269.672	5
269.672	308.197	3
308.197	346.721	0
346.721	385.246	1
	Total	21155

Table 4.11 Frequency Distribution of Trip Distance (km).

The mean trip distance was 7.82 kilometers(4.86 miles), with a standard deviation of 16.30 kilometers (10.13 miles) (Table 4.12). The high standard deviation relative to the mean indicates high trip-to-trip variability of trip distance.

Mean	7.82
Std. Dev.	16.30
Std. Error	.11
Count	21155
Minimum	0.00
Maximum	385.25
# Missing	0

Table 4.12 Descriptive statistics for Trip Distance.

Mean trip distance by model year showed a general decline in trip distance with older model years (Figure 4.11). Model years having fewer vehicles have higher error bars because of the smaller amount of data and are more easily affected by outliers.

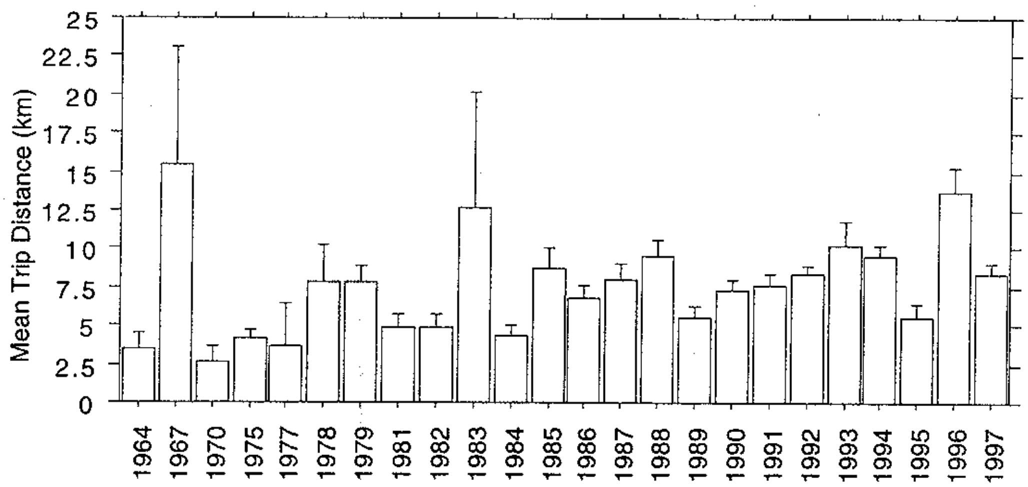


Figure 4.11 Mean Trip Distance with 95% Confidence Limits Plotted by Model Year.

The mean trip distance was calculated for each of the participants home ZIP codes and is illustrated in Figure 4.12. The dataloggers collect only trip time and speed data without any location data. However, the location of the household where the vehicle activityoriginates is known. The location of any particular trip cannot be determined, but the randomly selected participants are representative of the population in their area because they were randomly selected from all registered vehicle owners within the region. The participant vehicles were grouped using ZIP code as the grouping variable in order to identify regional differences in average trip distance. In general, the longer average trip distances occurred in the Davis, Winters, Newcastle, Rancho Cordova and Fair Oaks Zip codes.

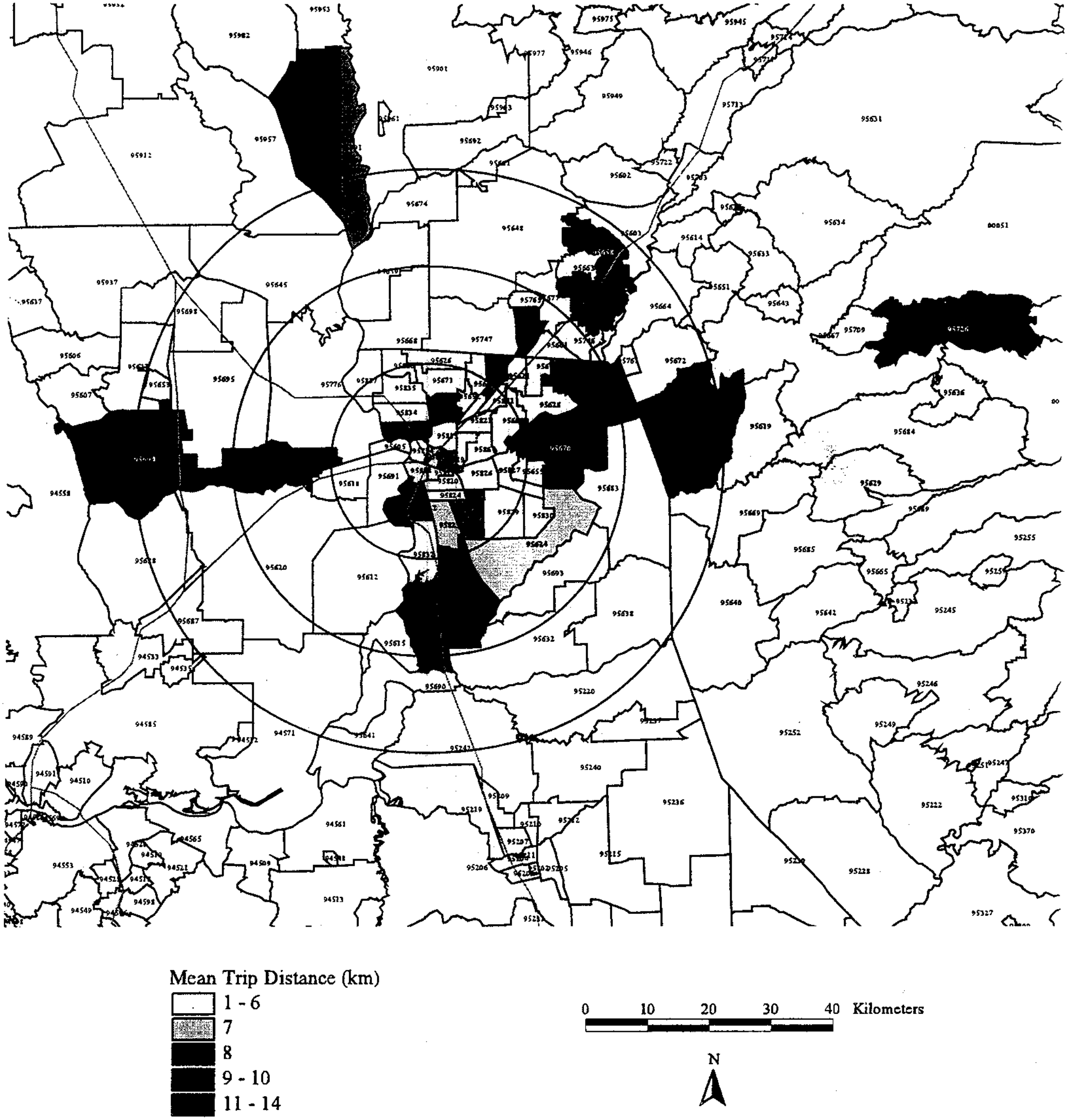


Figure 4.12 Map of Mean Trip Distance over ZIP Codes for the Sacramento Region.

4.5.2 Trip Speeds

Average Speed, the average speed over all vehicles and all seconds of data collected in this study is calculated as:

Average Speed = ΣAll speed data/number of seconds of data

= 44.11 kilometers per hour (27.41 miles per hour)

Average Speed excluding trips <18 seconds = ΣAll speed data >17 sec./n

= 44.13 kilometers per hour (27.43 miles per hour)

Average Trip Speed, the average speed for a trip is calculated by adding up the speeds for all seconds of the trip, then dividing by the number of seconds in the trip. The largest number of the trips have average speeds in the 17.054 to 34.108 kph range (Tables 4.13 and 4.14).

From (≥)	To (<)	Count
0.000	17.054	4918
17.054	34.108	7768
34.108	51.162	5398
51.162	68.216	1817
68.216	85.270	930
85.270	102.325	261
102.325	119.379	53
119.379	136.433	8
136.433	153.487	0
153.487	170.541	2
	Total	21155

Table 4.13. Frequency Distribution of Average Trip Speed (kph).

The average trip speed distribution is skewed towards the higher trip speeds (Figure 4.13) and truncated at zero kph.

Mean	31.53
Std. Dev.	20.34
Std. Error	.14
Count	21155
Minimum	0.00
Maximum	170.54
# Missing	0

Table 4.14. Descriptive Statistics for Average Trip Speed (kph).

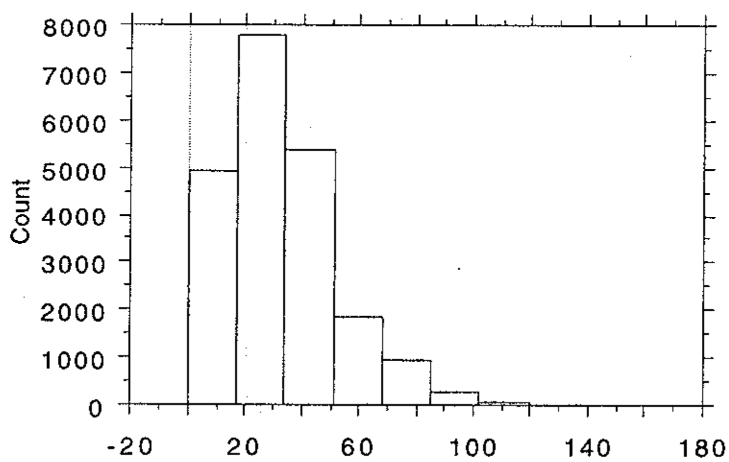


Figure 4.13. Histogram of Average Trip Speed.

Mean trip speed declined with increasing vehicle age (Table 4.15). Mean trip speed by model year showed a general decline in trip speed with older model years. Model years having fewer vehicles have higher error bars because of the smaller amount of data and are more easily affected by outliers.

	Count	Mean	Std. Dev.	Std. Err.
1964	80	25.018	22.464	2.512
1967	106	26.605	18.772	1.823
1970	54	11.873	8.661	1.179
1975	163	17.134	10.982	.860
1977	16	15.643	18.068	4.517
1978	106	36.164	21.290	2.068
1979	622	28.980	16.540	.663
1981	866	26.160	18.991	.645
1982	280	21.102	22.288	1.332
1983	89	31.775	19.692	2.087
1984	1208	25.048	18.720	.539
1985	521	29.885	18.644	.817
1986	1325	31.032	20.481	.563
1987	765	31.117	16.895	.611
1988	1974	35.456	20.530	.462
1989	1639	30.223	18.395	.454
1990	1859	32.775	19.075	.442
1991	1999	32.291	18.466	.413
1992	2733	33.295	21.537	.412
1993	432	33.860	22.017	1.059
1994	1748	35.236	21.255	.508
1995	957	23.305	18.502	.598
1996	1086	38.245	25.374	.770
1997	527	35.151	17.294	.753

Table 4.15 Mean, Standard Deviation, and Standard Error for Trip Speed by Model Year.

Model year was regressed against average trip speed and a significant correlation was found ($p=.0011$) with older vehicles having lower average trip speeds (Figure 4.14). The higher variability in the older model years is due to the small number of vehicles in each model year for older vehicles. The newer model years averages are based on several vehicles and generally about 1,000 trips.

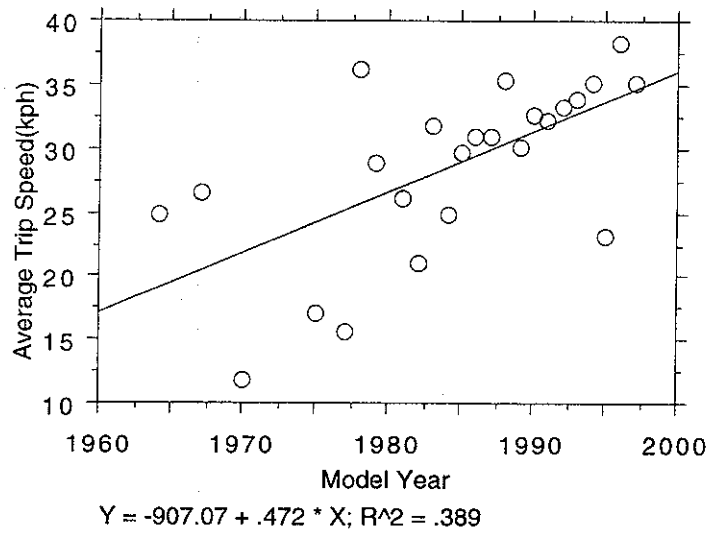


Figure 4.14. Regression of Mean Trip Speed with Model Year.

Average trip speed was calculated by home ZIP code of the participant and is presented in Figure 4.15. In general the areas farther from the urban center had higher average trip speeds. This was consistent with the longer average trip distribution found in the previous section.

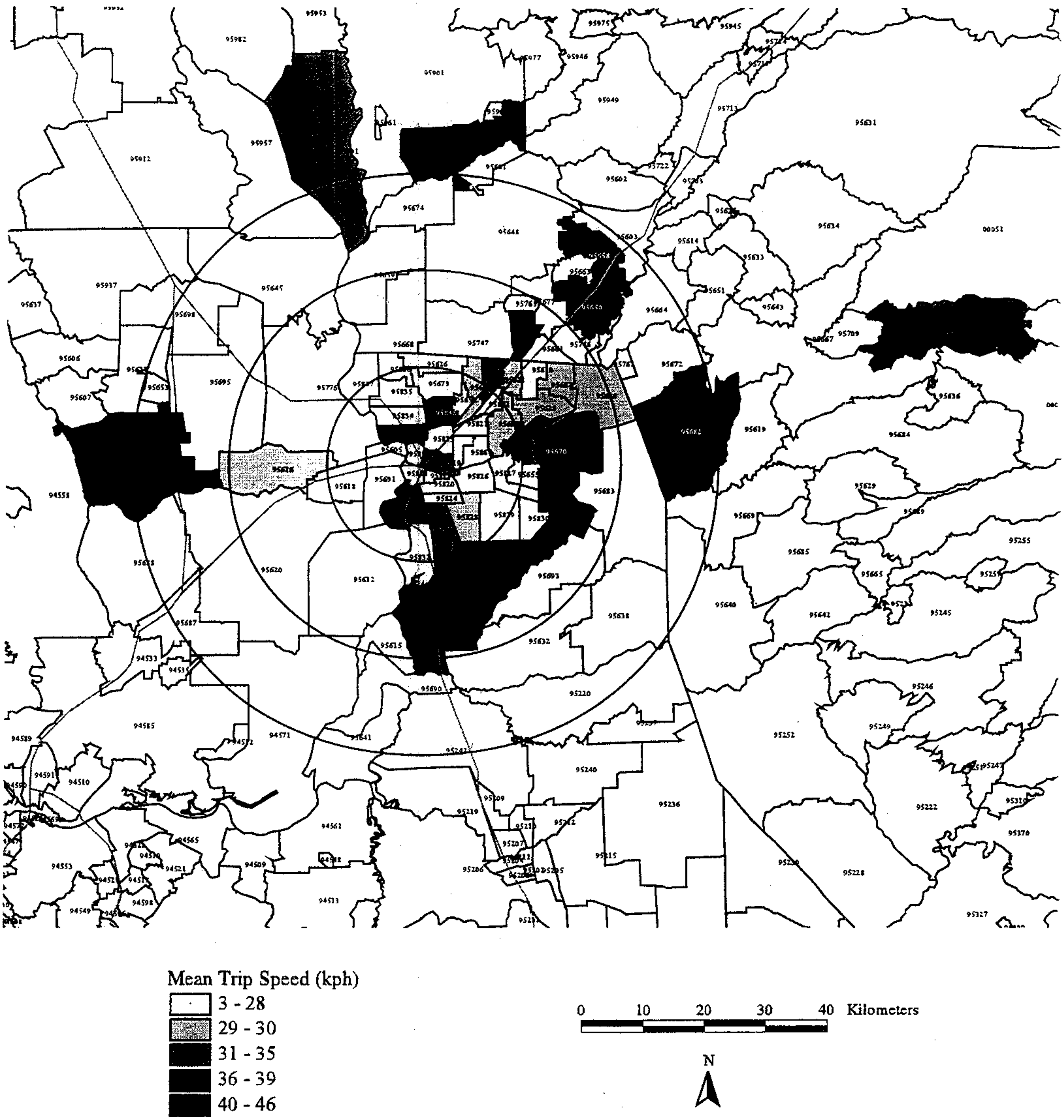


Figure 4.15 Map of Mean Trip Speed by ZIP Code for the Sacramento Region.

4.5.3 Trip Time Distributions

Trip time was calculated as the total time in seconds from key-on to key-off. Trips of less than 18 seconds are not included in these calculations. The majority of the trips took less than 3253 seconds (.9 hours) with 20,886 trips in this range (Table 4.16). The standard deviation of trip time was higher than the mean (Table 4.17) indicating high variability trip-to-trip.

From (≥)	To (<)	Count
18.000	3253.800	20886
3253.800	6489.600	211
6489.600	9725.400	46
9725.400	12961.200	10
12961.200	16197.000	1
16197.000	19432.800	1
19432.800	22668.600	0
22668.600	25904.400	0
25904.400	29140.200	0
29140.200	32376.000	6
	Total	21161

Table 4.16. Frequency distribution of Trip Time.

Mean	646.43
Std. Dev.	926.79
Std. Error	6.37
Count	21161
Minimum	18.00
Maximum	
# Missing	0

Table 4.17. Descriptive Statistics for Trip Time.

The mean trip time declined slightly with older model years (Table 4.18), however the regression across model years was not significant with a P-value of .2611 (Figure 4.16).

	Count	Mean	Std. Dev.	Std. Err.
	80	322.775	324.802	36.314
1967	106	966.292	1910.896	185.603
1970	54	553.185	467.317	63.594
1975	163	721.123	438.755	34.366
1977	16	471.625	461.761	115.440
1978	106	579.189	681.525	66.196
1979	622	763.289	809.785	32.469
1981	866	469.807	641.099	21.785
1982	280	555.425	483.842	28.915
1983	89	948.708	1407.131	149.156
1984	1208	463.031	527.117	15.166
1985	521	780.075	841.891	36.884
1986	1325	591.447	736.410	20.231
1987	765	672.013	695.876	25.159
1988	1974	674.840	882.435	19.861
1989	1639	467.924	610.773	15.087
1990	1859	579.116	684.118	15.867
1991	1999	632.744	779.953	17.445
1992	2733	637.928	760.658	14.550
1993	432	755.051	906.066	43.593
1994	1748	713.547	922.427	22.063
1995	957	638.222	593.086	19.172
1996	1086	928.035	1030.403	31.267
1997	527	745.600	707.007	30.798

Table 4.18. Mean, Standard Deviation, and Standard Error of Trip Time by Model Year.

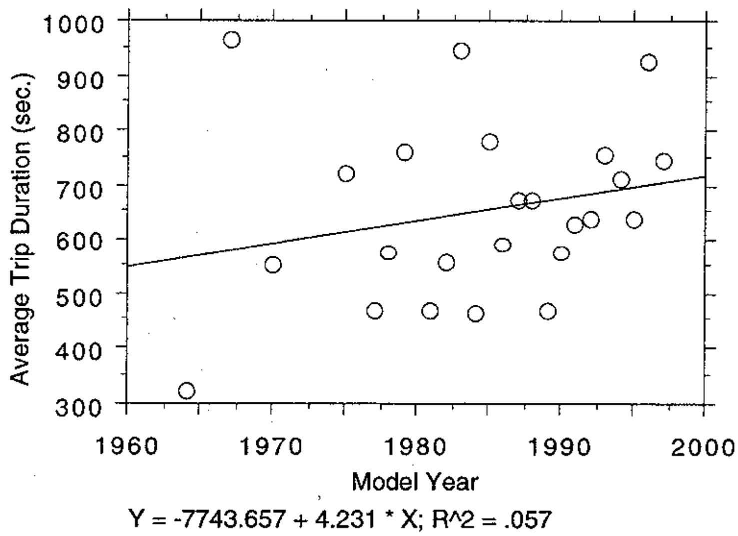


Figure 4.16. Regression of Mean Trip Duration by Model Year.

Mean trip time was calculated for home ZIP codes of the participants and is presented in Figure 4.17. In general, the longer trip times correspond to the longer trip distances, as would be expected. The ZIP codes to the south of Sacramento had shorter average trip times relative to trip distance, more characteristic of the Carmichael area. The majority of the participants in the two southern ZIP codes were from the city of Elk Grove.

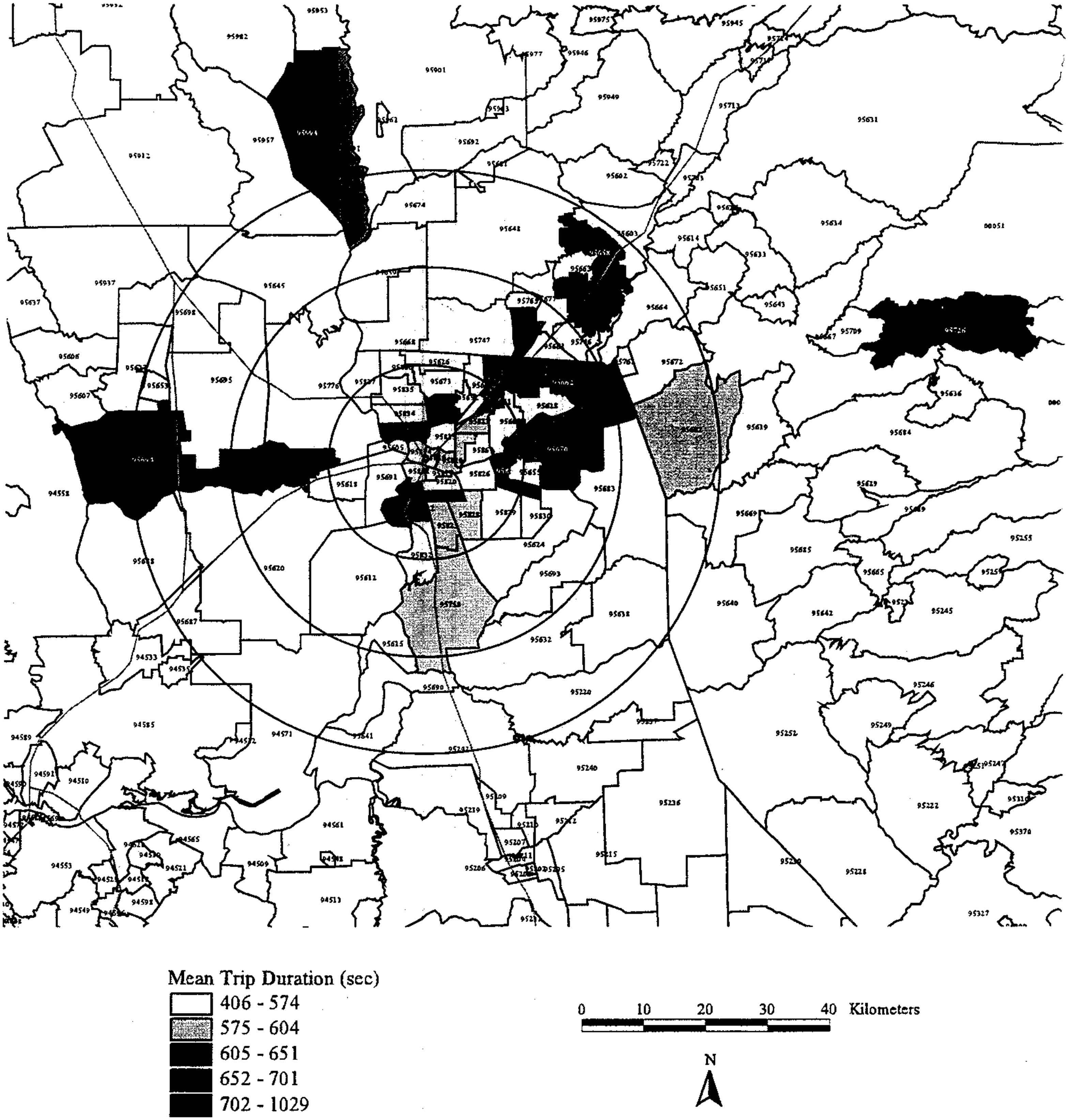


Figure 4.17 Map of Mean Trip Time by ZIP Code for the Sacramento Region.

4.5.4 Seasonal Effects

An ANOVA was run on mean trip distance by month (Table 4.19) and significant differences were found with $p<.0001$. Thus there are significant differences in average trip distance between the months of the year.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Month	9	13273.930	1474.881	5.564	<.0001
Residual	21145	5604960.976	265.073		

Model II estimate of between component variance: .611

Table 4.19 ANOVA Results for Mean Trip Distance by Month.

The lowest average trip distances occurred in January (Table 4.20, Figure 4.18), however this time period has very few total trips, as noted previously. The Scheffe paired comparison test was run to identify significant differences between groups. The Scheffe test identified significant differences between August and March, June, and July.

	# Days	Mean	Std. Dev.	Scheffe Groups
Jan	59	2.792	2.846	a b
Feb	375	8.144	15.138	a b
Mar	455	6.942	9.187	a b
April	2714	7.665	13.264	a b
May	4045	7.197	14.513	b
June	4433	7.479	16.151	b
July	3048	7.310	15.003	b
Aug	3418	9.292	19.085	a
Sept	2389	8.464	20.586	a b
Oct	219	8.302	15.560	a b

Table 4.20 Mean Monthly Trip Distance with Standard Deviation and Standard Error.

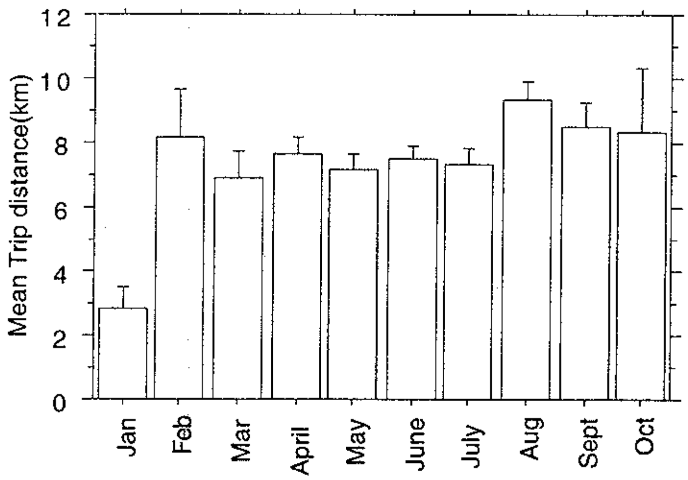


Figure 4.18 Mean Trip Distance by Month.

An ANOVA test was run on mean trip speed by month (Table 4.21) and significant differences were found with p<.0001. Thus there are significant differences in average trip speed between the months of the year.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Month	9	32598.891	3622.099	8.788	<.0001
Residual	21145	8715480.339	412.177		

Model II estimate of between component variance: 1.621

Table 4.21 ANOVA Results for Mean Trip Speed by Month.

The lowest average trip speeds occurred in January (Table 4.22, Figure 4.19), however this time period has very few total trips, as noted previously.

	# Days	Mean	Std. Dev.	Scheffe Groups
Jan	59	21.863	10.212	a
Feb	375	30.977	16.533	a
Mar	455	29.636	19.714	a
April	2714	31.754	19.090	a b c
May	4045	31.171	19.469	a b
June	4433	31.630	19.586	a b c
July	3048	30.264	21.411	a
Aug	3418	33.573	22.373	d
Sept	2389	30.717	20.356	a
Oct	219	35.751	22.705	b c d

Table 4.22 Mean Monthly Trip Speed with Standard Deviation and Standard Error.

The Scheffe paired comparison test was run to identify significant differences between groups. The Scheffe test did not produce clear groups in this case.

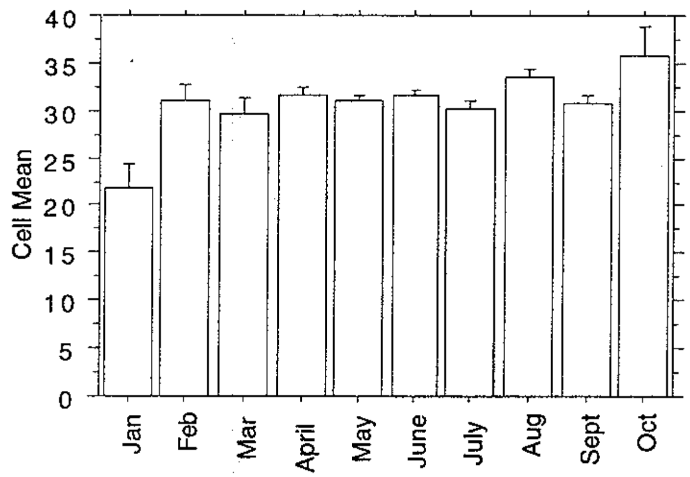


Figure 4.19 Mean Trip Speed by Month.

An ANOVA test was run on mean trip time by month (Table 4.23) and significant differences were found with p<.0001. Thus there are significant differences in average trip times between the months of the year.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Month	9	20405281.690	2267253.521	3.701	.0001
Residual	21145	12952554515.883	612558.738		

Model II estimate of between component variance: 835.498

Table 4.23 ANOVA Results for Mean Trip Time by Month.

The lowest average trip times occurred in January (Table 4.24, Figure 4.20), however this time period has very few total trips. The Scheffe paired comparison test was run to identify significant differences between groups. The Scheffe test identified significant differences between August and June without any other pairwise differences.

	Count	Mean	Std. Dev.	Scheffe Groups
Jan	59	377.593	247.323	a b
Feb	375	663.459	784.906	a b
Mar	455	599.802	543.312	a b
April	2714	650.651	651.918	a b
May	4045	619.716	694.521	a b
June	4433	611.358	738.636	a
July	3048	628.317	770.533	a b
Aug	3418	692.047	957.750	b
Sept	2389	648.961	926.085	a b
Oct	219	643.886	572.376	a b

Table 4.24 Mean Monthly Trip Time with Standard Deviation and Standard Error.

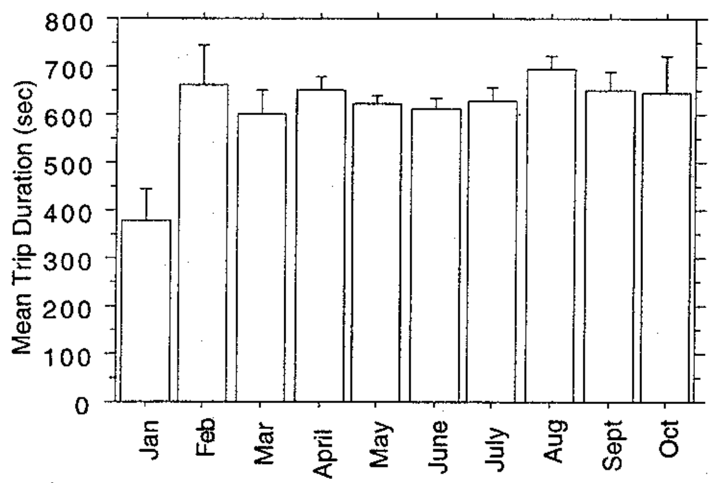


Figure 4.20 Mean Trip Time by Month.

4.6 VMT CHARACTERISTICS

Vehicle Miles Traveled represents the total miles traveled by vehicles in the study area during a time period. For this study, the number of vehicles recording data varied from day to day, depending upon the number of functioning units, and installation and removal scheduling. For this reason, VMT was calculated as the total miles traveled by the vehicles recording data divided by the number of vehicles recording data. Dividing VMT by the number of vehicles normalizes the data between days wher different numbers of vehicles have active data recorders. Without this normalization the daily VMT numbers would be highly dependent on the number of functioning Autologgers. When VMT is calculated for large populations such as all vehicles in a city, the small daily changes in actual numbers of vehicles make little difference. In a small population (such as the study vehicles), the day to day changes in numbers can skew total VMT considerably. As with the start data, days with fewer vehicles recording data will be more variable than days with larger numbers of vehicles recording. The daily VMT/vehicle are presented in Figure 4.21 and Figure 4.22.

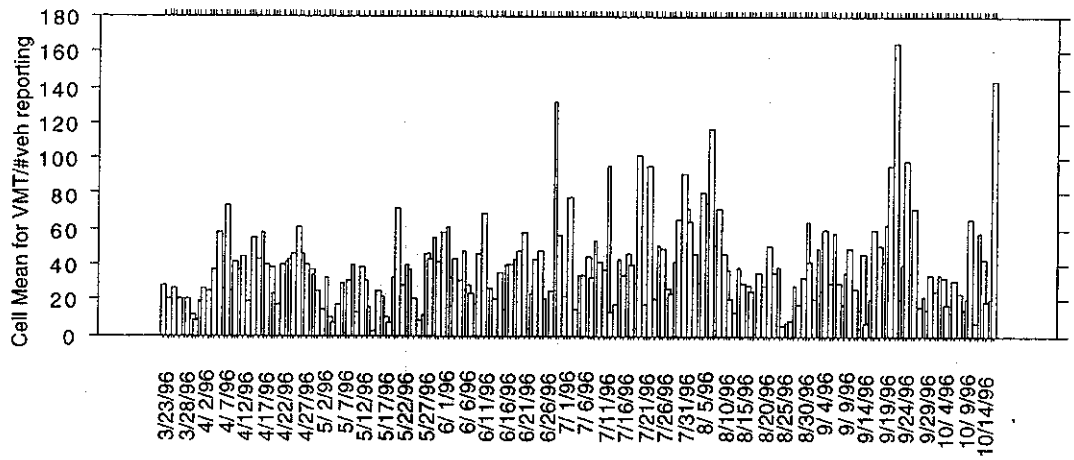


Figure 4.21 Daily VMT/Vehicle for 1996.

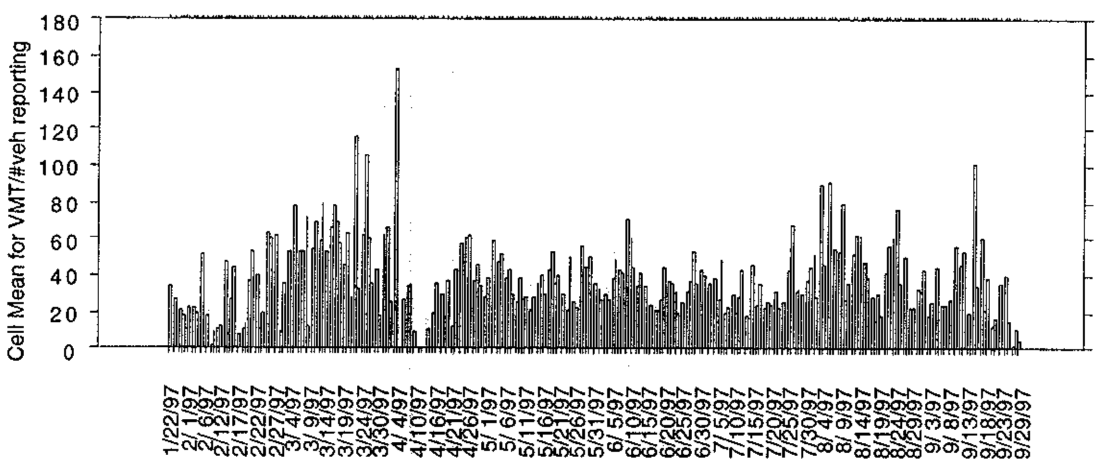


Figure 4.22 Daily VMT/Vehicle for 1997.

An ANOVA test was run on the daily VMT/vehicle results to test for differences in the day of week. No significant differences were found with a p-value of .2109, well above the .05 significant level (Table 4.25). High day-to-day variability again lowers the power of the ANOVA to detect differences between days of the week. The highest VMT/Vehicle occurred on Friday, with the lowest on Sunday (Table 4.26 and Figure 4.23).

	DF	Sum of Squares	Mean Square	F-Value	P-Value
day of week	6	4304.848	717.475	1.405	.2109
Residual	443	226185.638	510.577		

Model II estimate of between component variance: 3.219

Table 4.25 ANOVA of VMT/Vehicle by Day.

	# Days	Mean	Std. Dev.	Std. Err.
Sunday	64	31.990	24.463	3.058
Monday	66	34.241	19.178	2.361
Tuesday	64	40.201	21.521	2.690
Wednesday	63	37.353	22.030	2.776
Thursday	64	39.683	20.826	2.603
Friday	65	41.184	21.761	2.699
Saturday	64	37.775	27.511	3.439

Table 4.26 Mean, Standard Deviation and Standard Error of VMT/Vehicle by Day.

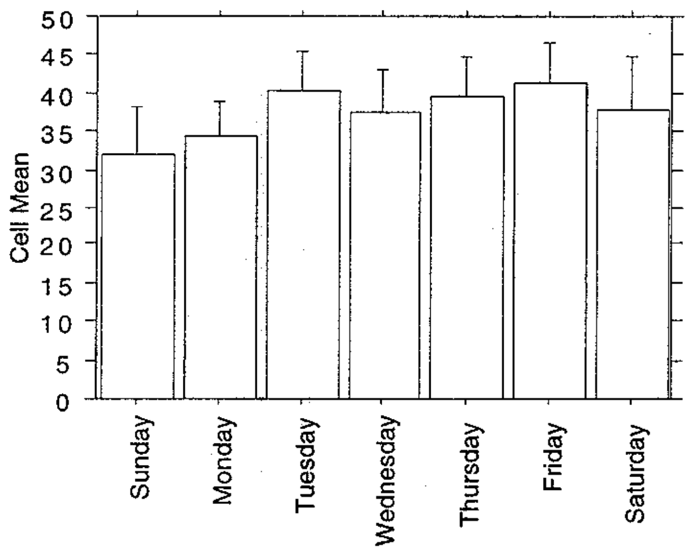


Figure 4.23 Daily VMT/Vehicle by Day with 95% Confidence Limits.

An ANOVA test was run on the daily VMT/vehicle results to test for differences in weekday against weekend. No significant differences were found with a p-value of .6980, well above the .05 significant level (Table 4.27). High day-to-day variability again lowers the power of the ANOVA to detect differences between weekday and weekend, however the actual difference is quite small (Table 4.28 and Figure 4.24).

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Weekday/Weekend	1	77.530	77.530	.151	.6980
Residual	448	230412.955	514.315		

Model II estimate of between component variance: •

Table 4.27 ANOVA of VMT/Vehicle by Weekday/Weekend.

	# Days	Mean	Std. Dev.	Std. Err.
Weekend	193	37.005	24.840	1.788
Weekday	257	37.843	20.911	1.304

Table 4.28 Mean, Standard Deviation and Standard Error of VMT/Vehicle by Weekday/Weekend.

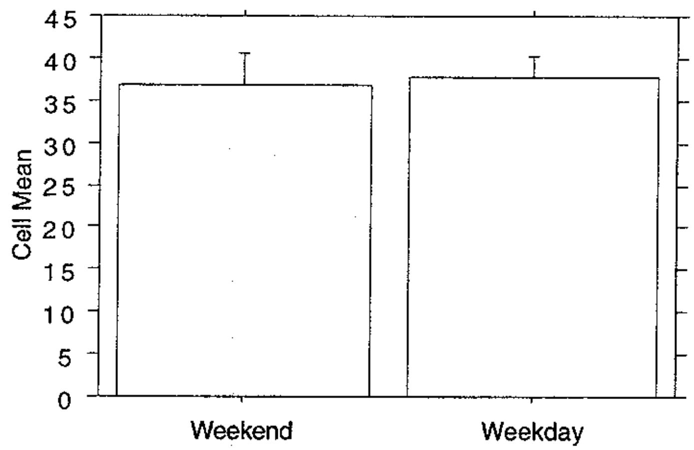


Figure 4.24 Daily VMT/Vehicle by Day with 95% Confidence Limits.

4.6.1 Seasonal Effects

An ANOVA test was run on the daily VMT/vehicle results to test for differences in month. Significant differences were found with a p-value of .0046, well below the .05 significant level (Table 4.29). The highest VMT/Vehicle occurred in March, followed by August with VMT/Vehicle following a curve with the low in the winter months and the high in the summer (with the exception of February) (Table 4.30, Figure 4.25).

	DF	Sum of Squares	Mean Square	F-Value	P-Value
trip month	9	12049.647	1338.850	2.697	.0046
Residual	440	218440.838	496.456		

Model II estimate of between component variance: 19.159

Table 4.29 ANOVA of VMT/Vehicle by month.

The Scheffe paired comparison test was run to identify significant differences between groups. The Scheffe test found no significant pair-wise differences between months.

	# Days	Mean	Std. Dev.	Std. Err.
Jan	5	22.021	9.511	4.254
Feb	27	26.877	19.060	3.668
Mar	39	47.783	25.962	4.157
April	58	36.423	23.436	3.077
May	62	31.995	14.997	1.905
June	60	37.602	18.824	2.430
July	62	37.974	20.032	2.544
Aug	62	42.608	23.013	2.923
Sep	58	38.229	27.749	3.644
Oct	17	35.452	32.029	7.768

Table 4.30 Mean, Standard Deviation and Standard Error of VMT/Vehicle by month.

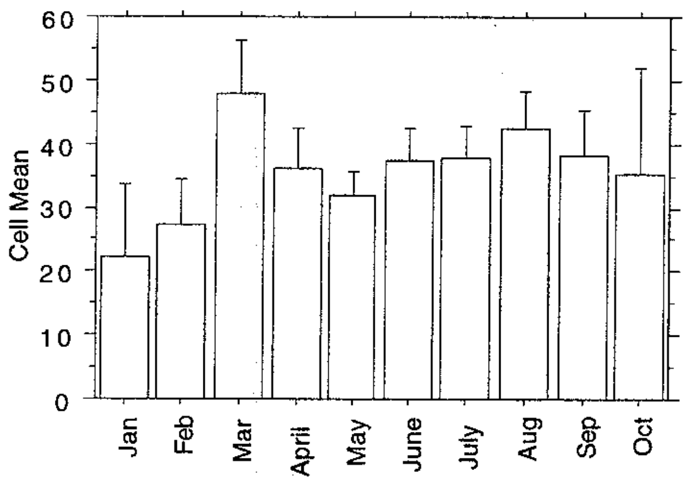


Figure 4.25 Daily VMT/Vehicle by month with 95% Confidence Limits.

4.7 COMPARISON WITH OTHER STUDIES

While direct comparison with other vehicle activity studies is difficult because of differences in equipment, methodologies, and changes due to time, some qualitative comparisons can be made. In terms of average trip speed, length, and duration, the Sacramento data most resembles the Baltimore-Exeter data set. The higher trip speeds, lengths, and duration's found in the ARB Los Angeles study are probably due to methodological differences. The Los Angeles study was a "chase car" study. Using this methodology, the vehicle is acquired on the road and thus does not include any of the start up idle time or potential small street driving time which is included in the datalogger-based studies. This probably accounts for the some of the higher speed, but would not account for the observed difference in trip duration or distance. The longer distances and times may be due to differences in which vehicles are included in the studies and due to real driving behavior differences between Los Angeles and Sacramento.

Trip Behavior Measure	Baltimore (Both)	Baltimore Exeter	Baltimore Rossville	Spokane	Atlanta	Los Angeles	Sacramento
Speed (kph)	39.4	33.6	45.2	37.4	46.3	45.6	31.5
Length (kilometers)	7.82	6.42	9.48	5.73	9.72	12.52	7.8
Duration (minutes)	12.03	11.55	12.56	9.18	12.59	16.45	10.8
Total Time (seconds)	3.4 million	1.7 million	1.7 million	2.1 million	3.0 million	0.1 million	13.5 million

Table 4.31 Trip Behavior Averages for Baltimore, Spokane, Atlanta, Los Angeles, and Sacramento (Source: Markey, 1993. Federal Test Procedure Review Project: Preliminary Technical Report, US EPA)

The Average Trip Speed and Average Trip Distance for the six locations are plotted in Figure 4.26. The six locations fall into two groups, with Sacramento in the slower and shorter trip distance group.

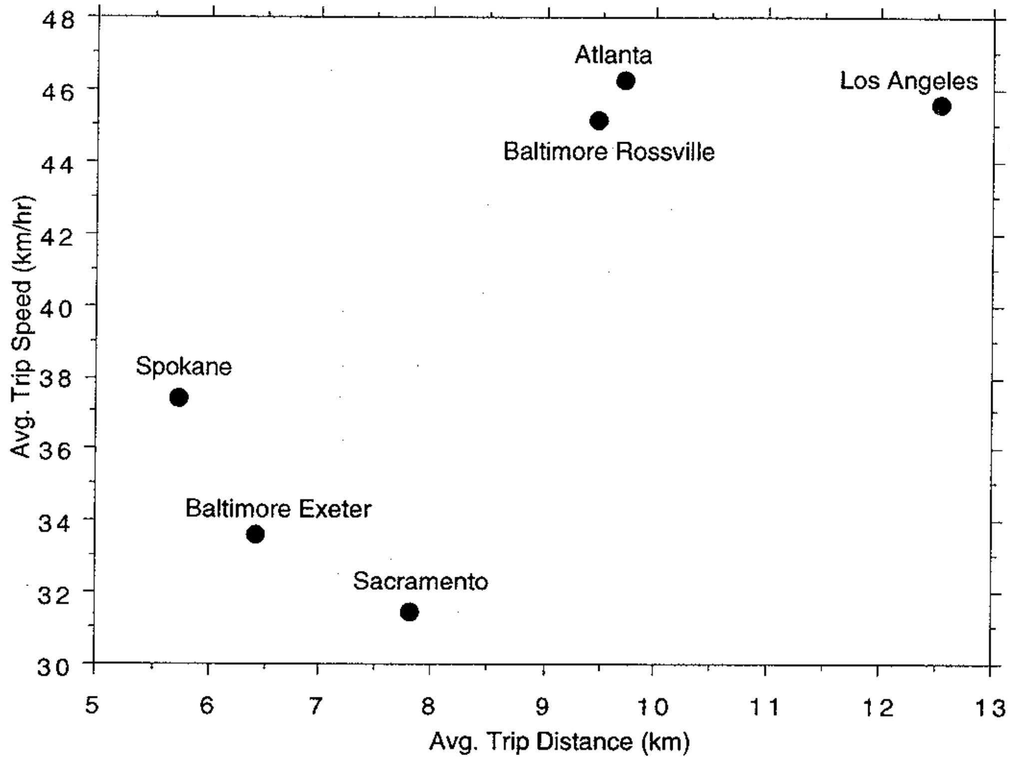


Figure 4.26 Average Trip Distance and Average Trip Speed for Baltimore, Spokane, Atlanta, LA, and Sacramento.

4.8 BRIEF AIR CONDITIONING RESULTS

A subset of the vehicles instrumented in this study were also wired for monitoring of air conditioning compressor usage. A status channel on the datalogger was used to monitor the compressor clutch switching on or off. This was done on ten vehicles and effectively cut the data storage in half on these participants because the datalogger was storing both speed and AC data. This was compensated for by swapping and downloading the dataloggers for these participants every two weeks, instead of every four weeks. Participants in the AC part of the study were paid an additional $50 for the added inconvenience.

1036 trips were recorded with AC data. Of the 1036 trips, 999 of them were greater than 17 seconds long. Of these 999 trips, 309 (30.9%) never had the AC compressor on. Of the 690 trips where the compressor was on at least one second of the trip, the average percent of trip time that the compressor was on was 64.7% (Table 4.32). The compressor was on 90 to 100% of the time in over 30% of the trips where AC was used (Figure 4.27).

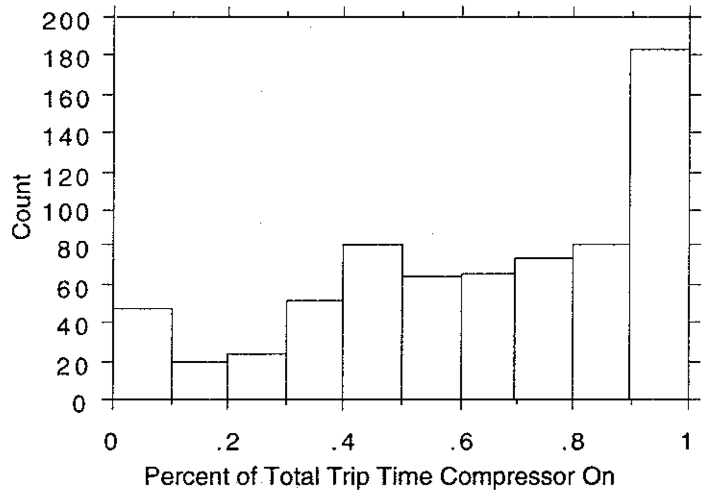


Figure 4.27 Histogram of Percent of Trip Time AC Compressor was On

The distribution of percent time compressor is on is skewed towards the upper end of the range so the average time is misleading to some extent. The 50th percentile, that is the middle value of all trips is 68.5% while the 90th percentile is 99.3% (Table 4.32). This indicates that in fully 10% of the trips where the AC compressor was engaged it was on over 99.3% of the trip time.

10	.231
25	.435
50	.685
75	.924
90	.993

Table 4.32 Percentiles of Percent of Trip Time AC Compressor was On

To determine if the percent of trip time that the AC compressor was on varied by trip length the data set was split into two groups, trips under 10 minutes and trips over 10 minutes. There was a difference in average trip time compressor was on, with the average for trips under 10 minutes at 70.9% and the average for trips over 10 minutes at 54.7% of the time (Table 4.33)

	Count	Mean	Variance	Std. Dev.	Std. Err
Under 10 Minutes	426	.709	.068	.260	.013
Over 10 Minutes	264	.547	.099	.314	.019

Table 4.33 Mean, Variance and Standard Deviation of %Time Compressor On by Trip Length.

The difference in time was tested using an unpaired t-test (Table 4.34) and significant differences were found (p<.0001) indicating that the average percent time the compressor is on is significantly different for trips under 10 minutes against trips longer than 10 minutes. This difference is probably due to compressor cycling strategies.

	Mean Diff.	DF	t-Value	P-Value
Under 10 Minutes, Over 10 Minutes	.162	688	7.327	<.0001

Table 4.34 T-test of %Time Compressor On by Trip Length.

5 Conclusions and Recommendations

The Sacramento Vehicle Datalogger Study was a pilot study and thus produced two types of conclusions, those dealing with the study methodology and those dealing with Sacramento regional vehicle activity. In a long term study such as this, the human element produced interesting problems such as how to classify a two-vehicle household after a split into two households or what to do if one member of a household vacates during the time of instrumentation.

5.1 STUDY METHODOLOGY CONCLUSIONS:

The study methodology proved to be workable, but required a great deal of hard work and collaborative effort to overcome several difficulties. In general:

- Random sampling from the DMV in combination with large scale mailings proved to be a cost effective method of acquiring a representative participant group.
- The response rate to the mailings of less than 10% indicates that the incentive may need to be raised, however no non-response bias was found in the respondents in terms of vehicle model years or population demographics.
- Participants had many concerns, many of which were not anticipated. These are summarized in Appendix C and should be addressed in future studies.
- Reliable hardware and software are critical to the success of a vehicle activity study. Several hardware/software problems did occur during this project, however most problems were overcome. For future studies, it is important to note that datalogger technology is rapidly evolving in terms of hardware, software, and parameters which can be monitored.

5.2 SACRAMENTO VEHICLE ACTIVITY CONCLUSIONS:

Vehicle activity (specifically driving behavior) is quite variable from one individual to another, however general statistics can summarize the regional behavior for comparison with other areas. The vehicle activity statistics covered in this report fall into four areas: Start statistics, trip characteristics, VMT statistics, and AC usage statistics:

5.2.1 Starts/Day

- Overall, there were an average of 5.93 starts per vehicle for all days.
- Overall, there were an average of 6.30 starts per vehicle-driven-day.
- No significant difference in starts per vehicle-driven-day was found between days of the week.
- No significant difference in starts per vehicle-driven-day was found between weekdays (M-Th.) and weekends (F-Su).
- Significant differences were found in the number of starts per vehicle-driven-day between model years with the older vehicles tending to have fewer starts than the newer vehicles.
- Significant differences were found in the number of starts per vehicle-driven-day between vehicles from different numbers of household vehicles.
- Vehicles in single car households had the highest number of starts while those in the five car household had the lowest average starts per vehicle-driven-day.
- Significant differences in starts per vehicle-driven-day were found between months with February the lowest and April the highest, excluding January because of the small amount of data collected.

5.2.2 Trip Characteristics

General trip characteristics such as speed, time duration, and distance provide useful summaries of trips, however the actual trips can vary considerably from the average statistics.

- The mean trip distance was 7.82 kilometers (4.86 miles) with a standard deviation of 16.30 kilometers (10.13 miles).
- Significant differences in mean trip distance were found between model years with older vehicles having shorter trip distances than newer vehicles in general.
- Average trip distance was not uniform across ZIP codes with participants living in the Sacramento city area having shorter average trips than those in the outlying areas.

- The mean driving speed was 44.13 kilometers per hour (27.43 miles per hour).
- Significant differences in trip speed were found between model years with older vehicles having generally slower average trip speeds.
- Average trip speeds were not uniformly distributed across ZIP codes with participants living in the Sacramento city area having slower average trips than those in the outlying areas.
- The average trip time was 646.4 seconds (10.8 minutes) with a standard deviation of 926.8 seconds.
- Significant differences in trip time were found between model years with older vehicles having generally shorter average trip times.
- Average trip times were not uniformly distributed across ZIP codes with participants living in the Sacramento city area having shorter average trips than those in the outlying areas.
- Significant differences in average trip distance, speed, and time were found between months.

5.2.3 VMT

Daily VMT statistics were calculated on an average per vehicle basis because of the variability day to day in the number of vehicles included in the study. However, these statistics provide an estimate of the daily changes in regional VMT.

- No significant difference was found in VMT between days of the week.
- No significant difference in VMT was found between weekday and weekends.
- Significant differences in VMT were found between months with March the highest and February the lowest, excluding January because of the small amount of data collected in January.

5.2.4 Air Conditioning Usage Results

AC usage increases the horsepower necessary to keep the vehicle rolling at a constant speed and thus is a factor in determining emissions. This study collected over 700,000 seconds of trip data with AC compressor use monitored.

- Air conditioner compressors were turned on in 69.1% of the trips monitored for AC use in late August through mid October.

- The compressor was on an average of 64% of the time during the time period the AC was estimated to be set to on.

- In trips under 10 minutes the compressor was on an average of 70.9% of the trip.

- In trips over 10 minutes the compressor was on an average of 54.7% of the trip.

5.2.5 Comparison With Other Studies

The Sacramento study was run across several seasons as opposed to previous datalogger studies which were conducted over shorter time periods. However, some general comparisons can be made between studies:

- The Sacramento vehicle activity was similar to the Baltimore Exeter driving profile in terms of average speed and trip duration.

- The Sacramento average trip speed data was slower than the LA study average trip speed at least in part due to methodological differences.

- The LA study trips had higher average trip duration and length, with methodological difference effects unknown.

5.3 RECOMMENDATIONS

The large, household inclusive, multi-season database produced by this study provides a wealth of information on many aspects of vehicle activity. Only preliminary data analysis has been carried out thus far, much more detailed analysis can be performed in the following areas:

- ***Analysis of family use patterns***—it would be interesting to determine if vehicles within households exhibit positive or negative correlation to overall vehicle activity. That is, are household vehicles driven approximately the same, or are there significant differences in trip distances and trip durations between vehicles.

- ***GPS-based dataloggers***—There are significant differences in how vehicles are driven on different roadway facility types. For example, freeway driving will consist of much higher speeds and less stops than driving on arterials. In order to capture these differences, location information is crucial along with the other vehicle activity parameters. The location information can be integrated with a digital roadway database to identify which portions of trips occur on which roadway facility type. Global Positioning System (GPS) receivers make location identification possible at a reasonable price.

- ***Analysis of AC usage data***—Only a preliminary analysis was performed on the AC data that was collected. Much more detailed analysis can be performed in determining the correlation of AC with ambient temperatures. Emissions due to AC usage are not well understood at this time, however it is felt that they are a significant fraction of the total emissions inventory.

- ***Cold start effects***—It is possible to determine average soak times of vehicles from the accumulated database. The soak times are important for determining the impact of cold and warm starts. Emission models have recently started using a "continuum" of starts rather than classifying starts as either cold or warm.

- ***Identification of trip patterns***—Analysis can be performed to determine general trip patterns of drivers. It is assumed that many trips are home-to-work and work-to-home. Variations in the day-to-day patterns are of interest from a driving behavior point-of-view.

6 References

[CRC 94] Proceedings of the Fourth CRC On-Road Vehicle Emissions Workshop, San Diego, CA, April, 1994.

[CRC 95] Proceedings of the Fifth CRC On-Road Vehicle Emissions Workshop, San Diego, CA, April, 1995.

[CRC 96] Proceedings of the Sixth CRC On-Road Vehicle Emissions Workshop, San Diego, CA; March, 1996.

[FTP 89] Code of Federal Regulations, Title 40, Parts 86-99 (portion of CFR which contains the Federal Test Procedure), Office of the Federal Register, 1989.

[Markey 94] J. Markey, "Federal Test Procedure Review Project", Technical Report Report #420-R-93-007, U.S. Environmental Protection Agency, 1993.

[Markey 95] J. Markey, "The FTP Review Project: Preliminary Findings on Emissions from "Off Cycle" Operation", in *Fourth CRC-APRAC On-Road Vehicle Emission Workshop*, San Diego, CA, pp. 3-109 3-133, 1994.

[Austin 93] T. C. Austin and e. al., "Characterization of Driving Patterns and Emissions from Light-Duty Vehicles in California, Draft Final Report", Report California Air Resources Board, 1993.

[CE-CERT 95] College of Engineering-Center for Environmental Research and Technology, "A Program to Collect Massive Activity Data in Northern California: Preliminary Instrumented Vehicle Study, Technical Report prepared for CARB, January, 1995.

[DeFries 92] T. H. DeFries and S. Kishan, "Light-Duty Vehicle Driving Behavior: Private Vehicle Instrumentation", Final Report Report #DCN 92-254-036-90-04, Radian Corporation, 1992.

[Siegel 56] S. Siegel, "Nonparametric Statistics for the Behavioral Sciences", McGraw-Hill Book Company, New York, 1956.

[1990 Census] 1990 Census Data Lookup Server, Located at Laurence Berkeley Lab, Berkely, CA. Web site http://parep2.ibi.gov/cdrom/lookup

Appendix A

Recruitment Letters

Cover letter

February 1, 1996

Dear Fellow Californian,

We would like to invite you to participate in the fight to help clean the air in California. The University of California, Riverside in conjunction with the California Air Resources Board, the California Department of Transportation, and the Sacramento Area Council of Governments will be conducting a vehicle activity study in the Sacramento area. Your family has been randomly selected from the list of participants in the 1991 CALTRANS vehicle activity survey for temporary installation of a small computer in each vehicle that you own. The computer records trip statistics such as the number of starts per day, start time, and travel distance. The trip data collected from the study participants will be used to help understand how cars are typically driven. This will help in better defining vehicle activity patterns for use in estimating emissions.

If you choose to participate, the installation of the computer will take about one hour and will not affect the operation of your vehicle in any way. For your participation you will receive $25.00 for each vehicle in your household included in the study. After a period of six months the computer(s) will be removed and you will be paid an additional $25.00 per vehicle. In addition, a technician will visit you once every month to retrieve from the computer the information collected in the previous month. This visit will take about one hour and will be scheduled at your convenience. You will receive $10.00 for each data retrieval visit.

You will be contacted by telephone within two weeks to provide more information on the study and to answer your questions. If you decide to participate, we will set up a preliminary schedule for installation. If you do not hear from us by ??/??/??, please call us as we may not have your current telephone number. If you wish additional information please call (916)445-2151.

Sincerely,

Ted Younglove
College of Engineering, Center for Environmental Research and Technology
University of California, Riverside

Project Description

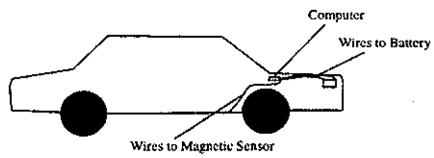
ARB Sacramento Datalogger Project

This project is a 15 month long vehicle activity study that the University of California, Riverside is conducting for the California Air Resources Board. 100 dataloggers (small computers which record and store data) will be installed in privately owned vehicles in the Sacramento area.

The owners of vehicles participating in this project will be required to sign a written agreement. Vehicle owners must carry at least the minimum limits of automobile liability insurance as prescribed under the California Financial Responsibility Laws on each vehicle in order to participate in this Project. Owner will be required to show proof of insurance prior to the computer being installed.

Data Confidentiality - The driving data collected on your car for this study will be identified by the type of vehicle but will not contain any information which will identify you personally.

The installation of the equipment is simple, but the vehicle does need to be driven briefly (10 minutes or less) to calibrate the speed the computer is recording. The vehicle owner will be required to drive during the calibration test while the UCR Engineer operates a laptop computer from the passenger seat. The datalogger installation is performed by an experienced team of UCR Engineers and will take about one and a half hours. An illustration of a typical installation is shown below.



Instrumenting Your Vehicle - Our computer monitors your vehicle and saves data. It is a passive observer that should not affect the normal operation of your vehicle The instruments will record the time your trip starts and ends and the number of rotations of the drive shaft and/or the motor.

Potential Problems - All units are thoroughly tested by UCR engineers prior to installation. The computer has no moving parts and draws about the same amount of power as a car radio when the vehicle is running.

All wires to the computer are fused and the equipment presents no danger to you, however you should not touch or disturb the equipment in any way. The computer must not be removed by anyone but UCR Engineers.

For more information or to schedule your installation please call Adam Sherman at (916)445-2151. Please have the Make, Year, and Model of your vehicles available, as well as several times which would be convenient for you to have us do the installation.

Single Vehicle Household Cover Letter

July 1, 1997

Dear Fellow Californian,

We would like to invite you to participate in the fight to help clean the air in California. The University of California, Riverside in conjunction with the California Air Resources Board, the California Department of Transportation, and the Sacramento Area Council of Governments are currently conducting a vehicle activity study in the Sacramento area. You have been randomly selected for temporary installation of a small computer in your vehicle. The computer records trip start times, end times, and distance. **For this phase of the study, we are only interested in participants who own and use a single vehicle.**

If you choose to participate, the installation of the computer will take about one and a half hours and will not affect the operation of your vehicle in any way. We would like to install the computer in your vehicle for a period of one month. For your participation you will receive a check for $50. Removal will be scheduled at your convenience and will take about one half hour.

In conjunction with this project, the California Department of Transportation (Caltrans) will be conducting a survey regarding the driving trips of local residents in the wider Sacramento Region. If you choose to participate, a Caltrans representative may contact you to acquire relevant information on your household member's driving trips for one day of travel. Your cooperation will verify and enhance the information automatically measured by the instrument in your vehicle, as well as helping in planning for improved air quality and travel in the Sacramento region.

If you wish to participate or if you want additional information please call Adam Sherman at (916) 445-2151. If you are interested in participating, please have the make, model, and model year of your vehicle available when you call. In addition, it would be helpful if you had approximate times when you would be available at home for us to come and install the computer. We look forward to hearing from you.

Sincerely,

Ted Younglove
CE-CERT, U.C. Riverside
Riverside, CA 92521
Phone:(909)781-5047

Appendix B

Autologger Modifications

The long-term use of the Autologger dataloggers in the high vibration underhood environment resulted in many problems which the project engineers believed could be solved by modifications to the Autologgers to make them more durable in long term use. Each Autologger had eight modifications to improve the integrity and reliability of the connections among the 4 boards and the backup battery for the RAM storage.

To improve the connection between the NVRAM card and the edge connector in the digital board, the PC card was notched and affixed with silicone and nylon cable ties (Figure B.2 - E, G). Closed-cell foam was substituted for the plastic end cup and packed around the NVRAM PC card to support and cushion the card in the edge connector (Figure B.2 - F). The foam also helps to apply pressure on the 3-board assembly towards the front end cap PC board where the external connections are located.

The digital computer and analog component boards communicate through 1 inch long pins at the end and along the sides. Silicone was applied at the top of the pin sockets to hold the pins in the socket maintaining a more stable connection (Figure B.1- A). The Autologgers analog board (bottom) is held firmly by internal ribbing inside the enclosure, however the digital board is more narrow and is not supported by the enclosure. Cylindrical standoffs and machine screws were added to each of the 4 corners to support the digital board on top of the Analog board (Figure B.1 - B and Figure B.2 - H). Most units had an original single standoff at one corner but is was usually too long or short and caused the digital board to bend up or down loosening the connections of the long pins in the sockets between the two main boards.

The component wires which protrude through the bottom board were trimmed shorter to prevent the components from shorting out on the interior of the aluminum enclosure (Figure B.1 - D). Many of the original units had clear transparency film to prevent the component shorts but it was found to be too fragile and the component pins sometimes penetrated the film. This film was replaced with a thicker and more durable clear vinyl (Figure B.1 - C).

The Autologger software is stored on Non-Volatile RAM memory, however the data recorded while driving is held intact by a coin style lithium battery. The clip which holds the battery did not appear very secure so an additional backup battery and more reliable clip were attached in parallel with the original (Figure B.2 - I). Loose components were affixed with silicone.

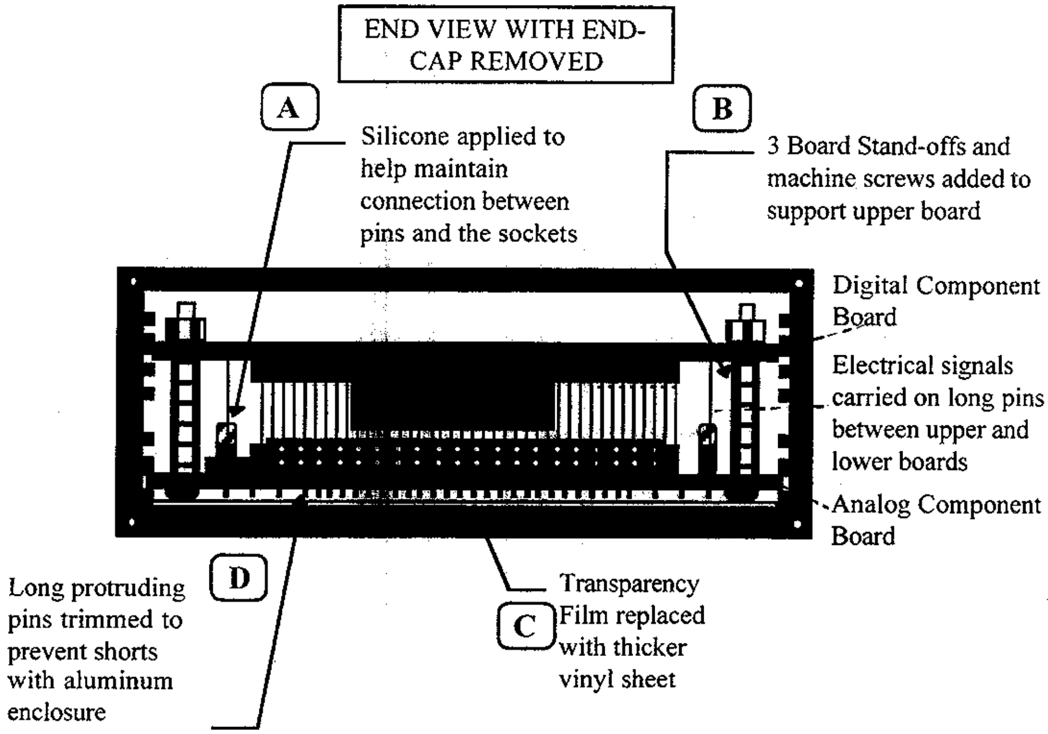


Figure B.1 Autologger end view.

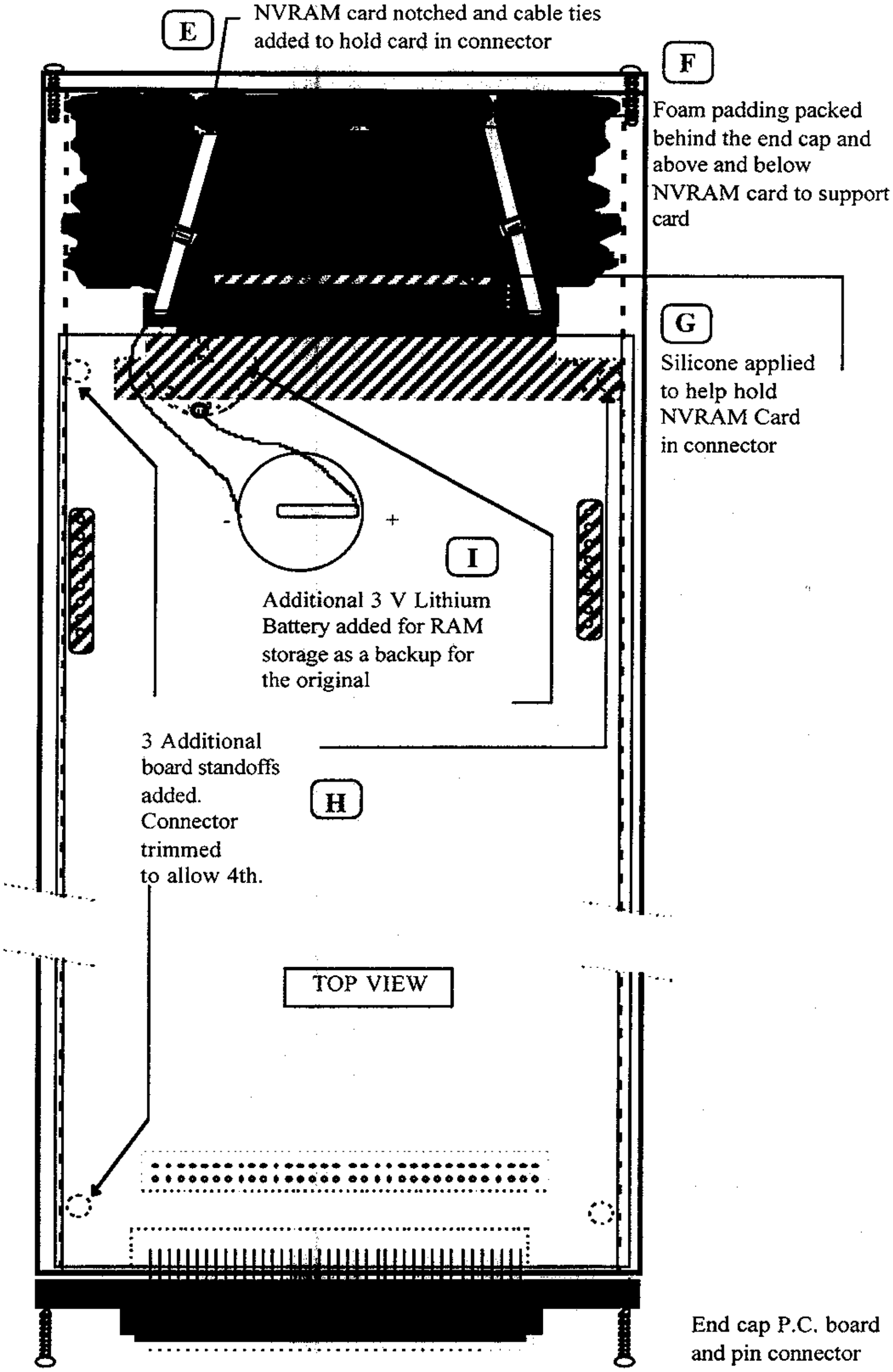


Figure B.2 Autologger top view

Appendix C

Participant Concerns

It cannot be stated with enough emphasis that a study like this is primarily about customer relations much more than it is related to engineering and statistics. All of the participants have individual concerns but the most common concerns have been outlined below to serve as a guide for designing future studies. The quantity of data collected form a family is most often related to the relationship between the organization and the participant. If the relationship is beneficial, the people are much more likely to make the extra effort to meet at a specific time and place and have all of the vehicles ready and waiting. They are more likely to call you and offer a convenient time if they have a good working relationship with the organization who is performing the study. If they feel that they have been let down in any way or that they are unpleasantly surprised by any step in the study, they will drag their feet, postpone appointments, and generally resist helping the study without overtly causing problems.

When the people have little apprehension about the study and feel they have been treated professionally and fairly they are less likely to call complaining about some unrelated vehicle problem.

Vehicle problems

Everyone wants to know what the equipment will do to their car and how they will be protected if there are problems. There appears to be no correlation between the estimated vehicle value and the participants concern for the well being of the vehicle. In general all participants own and maintain the best car that they can afford and they have equal concern for the vehicle they use most frequently. If they have apprehension about volunteering the use of their vehicle, they will always allow the use of the more inexpensive vehicle but not the more expensive. Unfortunately this usually means that the primary use vehicle is not instrumented or at the very least, all family trips are not counted. As an example, the participants will volunteer their '85 Mustang but not the '96 Lincoln. If all vehicles are needed to effectively measure the family vehicle activity, then the solicitation letter should say that all registered vehicles must be instrumented. Even if the letter targets single car participants, they often disregard the letter, call, volunteer and then pretend that they didn't realize that they need to volunteer all of the vehicles. In other cases participants apparently lied about the number of vehicles they owned to get the $50 incentive fee.

Why do we need the data

Participants rarely understand why vehicle activity information is needed. They are very surprised to find out that the equipment is in no way involved with measuring the actual emissions from their tail pipe. There is a tremendous lack of understanding about mobile source pollution. Much of the time spent on the phone or at their house is spent educating the people about emissions, cold starts, and smog checks. Very few participants realized that the cold starts are the major contributor to a single trip's emissions. In addition, people have no understanding that some cars produce more pollution than others. They are surprised to find out that their 64 Barracuda produces more pollution than their Geo Metro even though "both cars passed their smog check."

Payment

Rich or poor, everyone wants the incentive payment. In general the people with the least money are taking part in the study more for the purpose of payment rather than for the purposes of reducing pollution. However often the ones who need the money the least, want the money the most. The incentive payment often represents closure to the relationship between the participant and the instrumenting organization. The contract that the participants sign states that they will be compensated. If the equipment is removed and they have not yet received their payment, they are angry, even if the contract states that they will receive the check in the mail after the equipment is removed.

Every step should be taken to try to compensate the participants for their time and effort through every step of the study.

Ideally, the person should receive a partial payment (perhaps 40% of the total payment) in hand after the installation. It would be a tremendous advantage if they were compensated along the way for each appointment and for each vehicle's data-logger serviced. When the equipment is removed, the people feel that their obligation is completed and they should therefore be completely compensated monetarily that day, not three to five weeks later. If compensation was offered for each datalogger swap for each vehicle, the people would make more effort to have all of their vehicles present and ready. (Example offer $10 for each data-logger swapped within a 3-5 week period with a maximum of 6 swaps over the 6 month period)

When will the check get there? Why is the payment taking so long? Why can't they get paid after they have the installation

People feel that they are owed something once you show up at their house and work on their cars. If the reader could imagine receiving or placing two or three phone calls to setup an appointment for a Saturday, signing an agreement to volunteer their vehicles, spending half of the day watching two people work on their prized possessions and then being left empty handed. Even when the letter explains when they will get paid, they feel that they should get paid earlier. If they are promised a check by a certain date, they sometimes will call anyway and ask why it is taking so long.

As we all know, large bureaucratic organizations have internal checks and processes which slow the payment schedule but the participants do not care and cannot relate. In future studies, every effort should be made to pay the people in a timely manner.

How long will it take?

Some participants feel they need to be present while the installation is completed. Some feel confident that you know what you are doing and have no fears that you will harm their vehicles. When the people are promised that the installation is to take 1.5 hours they get apprehensive if it takes any longer. They sometimes feel guilty that their vehicle is somehow posing a problem to the people installing the equipment. If the engineers are having trouble with any of the equipment involved in the installation, they will feel apprehensive about having the equipment remain in the vehicle which may ultimately bias the driving behavior.

Obligations

Despite the fact that most details are outlined in the solicitation letter, the participants do not always read the letter carefully and have questions concerning their obligations to the study. The fact that the data-loggers need to be swapped out rather than downloaded on site often surprises them. The people feel their obligations are outlined in the legal agreement and usually disregard the solicitation letter once they have volunteered.

In general, any obligations that appear in the legal document signed by the participant are met without problems. However, any surprises are not well accepted. Much of the friction caused by the adjunct Caltrans study was alleviated once it was outlined in the solicitation letter at a later point in the study.

Keep in mind that in most cases the participants will do whatever they can to help but it must be outlined in detail prior to any involvement. We always made a point to briefly summarize each paragraph of the legal document in one English sentence so they felt that they understood all of their obligations and responsibilities.

Will information be shared with them or others?

Although the address for the solicitation letter is randomly selected, participants often feel that they have been singled out for some reason. They often have apprehension that they will be obligated to participate in additional studies or that their personal information will be shared with other organizations. People fear that the information, particularly their social-security and phone numbers will be shared with other organizations freely.

Will they have to test drive?

The participants most often allow the engineers to test drive the vehicle for the calibration run but some people would rather drive it themselves. It is always better to have the engineers perform the test drive themselves because they are familiar with the procedure and generally get more accurate calibrations faster when the participants are not involved in the process. If any problems are encountered in the test drive, the participants feel inconvenienced to have to stop, let the engineers make adjustments or changes, then re-test. If the participants are removed from this part of the installation they are oblivious to any problems and generally feel more confident in the study further reducing future service calls.

In future studies it is highly recommended to have an umbrella insurance policy that covers every vehicle that the engineers drive. All automotive mechanics have such a policy for test driving their customer cars and future studies should dot the same.

How long will it be in?

Participants always want to know how long they are obligated to continue the study. In general the participants appear to be relieved once the equipment is removed and that their obligation is completed. Many participants soon forget that the computer is installed in their vehicle however repeated appointments are bound to remind them that the equipment is always present. Even the most friendly participants are somewhat burnt out on the project after the 4th or 5th appointment and begin to ask when the equipment will be removed. We often bargain with them asking if we can swap the data-logger one more time and then remove it the following month.

Weekend Vs Weekday Scheduling

People often feel that they are too busy to be bothered on weekdays and prefer weekend appointments even if they are retired. If a weekend appointment is offered, 9 out of 10 times, the participant will choose it over a weekday. However if no offer of a weekend time is made, than the participants always seem to find a time window on a weekday. Weekend installations to setup two or three cars over a 5 hour period will lead the participant to expect a weekend appointment to perform fifteen minutes to swap three data-loggers. For the latter half of the study, postcards were given so that the participants could schedule their own swap times. This was often very useful but not all participants would send them in or some would rather make the appointment on site for the following month.

Workload

Equipment installation requires a minimum of 2 people for several reasons: Testing the vehicle for proper power connections and test drive calibration requires one person to operate the vehicle and another to operate and monitor the equipment. Passing materials, tools and feeding wires is best done with two people. All installations performed with a single engineer always took more than double the time to complete.

Any time that the vehicle is to be elevated on ramps one person had to drive and the other to monitor the position of the vehicle on the ramp. It is important to note that the participants should have no part in this phase of the installation. Participant interaction could cause errors that could severely damage the vehicle or be lethal to those nearby.

Tremendous time was wasted in this study playing phone tag with the participants making and re-scheduling appointments, answering questions and make field service calls when there were problems with the vehicles.

Once the equipment is installed and the paperwork is signed most emergency calls were totally unrelated to the study or the equipment in any way. However, the participants are more likely to suspect that the field engineers caused the problem even if it is totally unrelated. Important NOTE, It is not sufficient that the engineers can rule out the effects of the data-loggers or sensors. The participants demand a full explanation of their vehicles problem not just the fact that the equipment has been ruled out for the problem with the vehicle. It is a study requirement that a highly skilled automotive engineer or mechanic be available for service calls when there are problems.

In addition, It is a strict recommendation that a qualified person should be available full time to monitor the phone for new and current participants and for emergency calls. Despite the fact that the portable cellular phone number was provided on the voice mail, many participants would not make the second call to the field engineers.

Appendix D

Vehicle Information

City	zip	VIN	Model Year	Make	Model	Calibration Factor	Drive Type	Household Type
CARMICHAEL	95608	2FAPP36X1MB164237	1991	Ford	Tempo	0.198	Rear/4 Wheel	Single
CARMICHAEL	95608	YV1DX8840F2211371	1985	Volvo	740	0.162	Rear/4 Wheel	Single
CARMICHAEL	95608	1FTDE14N5HHA50520	1987	Ford	Econolin van	0.183	Rear/4 Wheel	Single
CARMICHAEL	95608	2HGED6346LH534570	1990	Honda	Civic	0.556	Front Drive	Single
CARMICHAEL	95608	1G4BP37Y8FHA28868	1985	Buick	LeSabre	0.278	Rear/4 Wheel	Single
CARMICHAEL	95608	2FAPP36X1MB164237	1991	Ford	Tempo	0.198	Rear/4 Wheel	Single
CARMICHAEL	95608	1G1JD69P8FJ216671	1985	Chevrolet	Cavalier	0.575	Front Drive	Single
CARMICHAEL	95608	1C1AC69P5EK100291	1984	Chevrolet	Cavalier	0.595	Front Drive	Multiple
CARMICHAEL	95608	1G1JD69P8FJ216671	1985	Chevrolet	Cavalier	0.575	Front Drive	Single
CITRUS HTS	95610	1G1JC1249SM103732	1995	Chevrolet	Cavalier	0.694	Front Drive	Single
CITRUS HTS	95610	1HGCA5646JA064929	1988	Honda	Accord	0.617	Front Drive	Multiple
CITRUS HTS	95610	1B4GK44R1MX588266	1991	Dodge	Grand Voyager	0.235	Rear/4 Wheel	Multiple
CITRUS HTS	95610	JHMSN5228CC040589	1983	Honda	Prelude	0.579	Front Drive	Multiple
CITRUS HTS	95610	1B4GK44R1MX588266	1991	Dodge	Grand Voyager	0.235	Rear/4 Wheel	Multiple
CITRUS HTS	95610	JM1BA1412S0130170	1996	Mazda	Protege	0.579	Front Drive	Multiple
CITRUS HTS	95610	JM1BA1412S0130170	1996	Mazda	Protege	0.579	Front Drive	Multiple
CITRUS HTS	95610	1HGCA5646JA064929	1988	Honda	Accord	0.617	Front Drive	Multiple
CITRUS HTS	95610	1087G9L557914	1979	chevy	Camaro	0.267	Rear/4 Wheel	Multiple
CITRUS HTS	95610	1G4AL19E9E6479406	1984	Buick	Century	0.554	Front Drive	Multiple
CITRUS HTS	95610	2P4FH51G9FR214426	1985	Plymouth	Voyager LE	0.641	Front Drive	Multiple
CITRUS HTS	95610	1GCCS1447TK102074	1996	Chevrolet	S10 Pickup	0.188	Rear/4 Wheel	Multiple
CITRUS HTS	95610	1GCCS1447TK102074	1996	Chevrolet	S10 Pickup	0.188	Rear/4 Wheel	Multiple
CITRUS HTS	95610	2P4FH51G9FR214426	1985	Plymouth	Voyager LE	0.641	Front Drive	Multiple
CITRUS HTS	95610	1G4AL19E9E6479406	1984	Buick	Century	0.554	Front Drive	Multiple
CITRUS HTS	95610	HLF30386667	1977	Datsun	280Z	0.483	Front Drive	Multiple
CITRUS HTS	95610	1G8ZG5288VZ273977	1997	Saturn	Sedan 4D	0.617	Front Drive	Multiple
DAVIS	95616	1FTCF10E9BRA13213	1981	Ford	Pickup F150	0.694	Front Drive	Multiple
DAVIS	95616	1G4CW52L9RH626107	1994	Buick	5th. Ave.	0.617	Front Drive	Multiple
DAVIS	95616	9248204534	1978	Porche	924	0.526	Front Drive	Multiple
DAVIS	95616	2P4FH55J9KR310086	1989	Plymouth	Voyager Van	0.219	Rear/4 Wheel	Multiple
DAVIS	95616	JT2SK12E7N0050136	1992	Toyota	Camry - LE	0.407	Front Drive	Multiple
CITRUS HTS	95621	JHMCA5621HCO66940	1987	Honda	Accord	0.427	Front Drive	Multiple
CITRUS HTS	95621	1G4AL51W3H6429715	1987	Buick	Century	0.626	Front Drive	Multiple
CITRUS HTS	95621	JHMCA5621HCO66940	1987	Honda	Accord	0.427	Front Drive	Multiple
CITRUS HTS	95621	1FABP40AXKF255622	1989	Ford	Mustang	0.000	Rear/4	Single

							Wheel	
CITRUS HTS	95621	1G4AG55M3S6400168	1995	Buick	Century	0.000	Rear/4 Wheel	Single
ELK GROVE	95624	1FMDU34X8TUA75861	1996	Ford	Explorer	0.000	Rear/4 Wheel	Single
FAIR OAKS	95628	WBAAE6404G0992489	1986	BMW	325 e	0.172	Rear/4 Wheel	Multiple
FAIR OAKS	95628	1FABP44E9KF133055	1989	Ford	Mustang	0.201	Rear/4 Wheel	Single
FAIR OAKS	95628	WBAAE6404G0992489	1986	BMW	325 e	0.172	Rear/4 Wheel	Multiple
FAIR OAKS	95628	WVWFB4317LE251265	1990	VW	Passat	0.476	Front Drive	Multiple
FAIR OAKS	95628	1G4AM47A0BH265421	1981	Buick	Regal	0.245	Rear/4 Wheel	Single
FOLSOM	95630	2G4WB52L3S1423134	1995	Buick	Regal	0.694	Front Drive	Single
FOLSOM	95630	JHMCB7566LC126541	1990	Honda	Accord	0.427	Front Drive	Multiple
FOLSOM	95630	JHMAE5330ES005358	1984	Honda	CRX	0.463	Front Drive	Multiple
FOLSOM	95630	3VWRR21H0PM038488	1993	VW	Jetta	0.617	Front Drive	Multiple
FOLSOM	95630	1G6KY52918U817624	1993	Cadillac	Seville STS	0.650	Front Drive	Single
FOLSOM	95630	JHMAE5330ES005358	1984	Honda	CRX	0.463	Front Drive	Multiple
LOOMIS	95650	JM3LV522XN0409745	1992	Mazda	MPV Van	0.133	Rear/4 Wheel	Multiple
NEWCASTLE	95658	1GCCSL4ZOK8L18754	1989	Chevrolet	S10 Pickup	0.281	Rear/4 Wheel	Multiple
NEWCASTLE	95658	1G1LT51W8JE568160	1988	Chevrolet	Corsica	0.447	Front Drive	Multiple
N HIGHLANDS	95660	1MECM50U4MG628446	1991	Mercury	Sable	0.216	Rear/4 Wheel	Multiple
N HIGHLANDS	95660	1FTCR10A8NPB02632	1992	Ford	Ranger	0.193	Rear/4 Wheel	Multiple
N HIGHLANDS	95660	1G4AH54N3L6460816	1990	Buick	Century	0.617	Front Drive	Multiple
N HIGHLANDS	95660	1MECM50U4MG628446	1991	Mercury	Sable	0.216	Rear/4 Wheel	Multiple
N HIGHLANDS	95660	1FTCR10A8NPB02632	1992	Ford	Ranger	0.193	Rear/4 Wheel	Multiple
SACRAMENTO	95662	TE31388737	1979	Toyota	Corolla	0.096	Rear/4 Wheel	Multiple
ORANGEVALE	95662	2FMDA5141SBB72158	1995	Ford	Windstar	0.463	Front Drive	Multiple
ORANGEVALE	95662	2FMDA5141SBB72158	1995	Ford	Windstar	0.463	Front Drive	Multiple
ORANGEVALE	95662	1FMDU34X7RUB2817	1994	Ford	Explorer	0.149	Rear/4 Wheel	Multiple
ORANGEVALE	95662	1GNCS13Z1M2218876	1991	Chevrolet	Blazer	0.154	Rear/4 Wheel	Multiple
SACRAMENTO	95662	JT4VN13G7M5066270	1991	Toyota	Pickup 4wd	0.132	Rear/4 Wheel	Multiple
ORANGEVALE	95662	JT2SK12EXP0120005	1993	Toyota	Camry	0.617	Front Drive	Multiple
ORANGEVALE	95662	ZFABS00A2B8142213	1985	Fiat	Bertone X-19	0.595	Front Drive	Multiple
ORANGEVALE	95662	ZFABS00A2B8142213	1985	Fiat	Bertone X-19	0.595	Front Drive	Multiple
ORANGEVALE	95662	1B3BL18D2KC486116	1989	Dodge	Omni	0.181	Rear/4 Wheel	Multiple
SACRAMENTO	95662	JT4VN13G7M5066270	1991	Toyota	Pickup 4wd	0.132	Rear/4 Wheel	Multiple
ORANGEVALE	95662	1FMDU34X7RUB2817	1994	Ford	Explorer	0.149	Rear/4 Wheel	Multiple
RNCHO CORDOVA	95670	JN1HZ04S7BX266410	1981	Nissan	280ZX	0.479	Front Drive	Multiple
RNCHO CORDOVA	95670	1GCBS14E5K8106446	1989	Chevy	S10 Pickup	0.163	Rear/4 Wheel	Multiple
RNCHO CORDOVA	95670	1GCDM19WOTB111921	1996	Chevy	Astro van	0.235	Rear/4 Wheel	Multiple

RNCHO CORDOVA	95670	1FMEU15H2KLA74404	1989	Ford	Bronco	0.234	Rear/4 Wheel	Single
RNCHO CORDOVA	95670	JN1HZ04S7BX266410	1981	Nissan	280ZX	0.479	Front Drive	Multiple
RNCHO CORDOVA	95670	1GCDM19WOTB111921	1996	Chevy	Astro van	0.235	Rear/4 Wheel	Multiple
RNCHO CORDOVA	95670	1GCDM19WOTB111921	1996	Chevy	Astro van	0.235	Rear/4 Wheel	Multiple
RNCHO CORDOVA	95670	250S04087	1967	Mercedes	250S	0.000	Rear/4 Wheel	Single
RNCHO CORDOVA	95670	1GCBS14E5K8106446	1989	Chevy	S10 Pickup	0.163	Rear/4 Wheel	Multiple
GOLD RIVER	95670	JT2AE82L4E3022268	1984	Toyota	Corolla	0.595	Front Drive	Single
ROSEVILLE	95678	JN6ND11Y0GW003876	1986	Nissan	4x4	0.143	Rear/4 Wheel	Multiple
SHINGLE SPGS	95682	WBAAJ9310MEJ02060	1991	BMW	318i	0.483	Front Drive	Multiple
SHINGLE SPGS	95682	1P3XLI8XLC731654	1990	plymouth	Horizon	0.214	Rear/4 Wheel	Single
WHEATLAND	95692	1FTDF15Y1MLA03501	1991	Ford	150 Pickup	0.198	Rear/4 Wheel	Multiple
POLLOCK PINES	95726	6069S99203614	1979	Cadilac	Sedan De Ville	0.242	Rear/4 Wheel	Multiple
POLLOCK PINES	95726	1B7HW14T1ES295536	1984	DODGE	Pickup	0.174	Rear/4 Wheel	Multiple
RNCHO CORDOVA	95742	2FMDA5146SBA03897	1994	Ford	Windstar	0.694	Front Drive	Single
RNCHO CORDOVA	95742	2FMDA5146SBA03897	1994	Ford	Windstar	0.694	Front Drive	Single
ELK GROVE	95758	1P4GH44R3NX190801	1992	Plymouth	Voyager	0.617	Front Drive	Single
ELK GROVE	95758	1HGED3654LA092843	1990	Honda	Civic	0.538	Front Drive	Single
ELK GROVE	95758	1HGED3654LA092843	1990	Honda	Civic	0.538	Front Drive	Single
ELK GROVE	95758	1HGED3654LA092843	1990	Honda	Civic	0.538	Front Drive	Single
ELK GROVE	95758	CKL187Z159397	1977	Chevy	Blazer	0.238	Rear/4 Wheel	Multiple
SACRAMENTO	95815	JF2AT53B7CE500106	1984	Subaru	Brat	0.579	Front Drive	Multiple
SACRAMENTO	95816	JN1PB11SBEU111959	1984	Nissan	Sentra	0.604	Front Drive	Single
SACRAMENTO	95819	3N69R8C115579	1989	Oldsmobile	Delta 88	0.278	Rear/4 Wheel	Single
SACRAMENTO	95819	1C3BC56D1HF236046	1988	Chysler	Lebaron	0.608	Front Drive	Multiple
SACRAMENTO	95819	1FAPP36XXLLK152334	1990	Ford	Tempo	0.198	Rear/4 Wheel	Multiple
SACRAMENTO	95819	1NXAF04F0PZ054229	1993	Toyota	Corolla	0.575	Front Drive	Single
SACRAMENTO	95819	JT2EL43B1N0173253	1992	Toyota	Tercel	0.556	Front Drive	Single
SACRAMENTO	95821	4S4BJ65C2N7909668	1992	Subaru	Legacy 4wdWag	0.439	Front Drive	Multiple
SACRAMENTO	95821	JT2MX73EXG0076017	1986	Toyota	Cressida	0.119	Rear/4 Wheel	Multiple
SACRAMENTO	95821	2G4WB14W9K1444697	1989	Buick	Regal	0.000	Rear/4 Wheel	Single
SACRAMENTO	95822	1FMDU34X7SZB02386	1991	Ford	Explorer	0.201	Rear/4 Wheel	Multiple
SACRAMENTO	95822	4S3BC6321N1622981	1992	Subaru	Legacy TC	0.490	Front Drive	Multiple
SACRAMENTO	95822	1G8ZK8272SZ382213	1995	Saturn	Wagon	0.556	Front Drive	Multiple
SACRAMENTO	95822	1HGCD7254RA026144	1994	Honda	Accord EX	0.617	Front Drive	Single
SACRAMENTO	95822	1FMDU34X7SZB02386	1991	Ford	Explorer	0.201	Rear/4 Wheel	Multiple
SACRAMENTO	95822	1FBHE2114FHA60398	1985	Ford	Van Diesel	0.160	Rear/4 Wheel	Multiple

SACRAMENTO	95822	JT2AE98C1J3070446	1988	Toyota	Corolla	0.617	Front Drive	Single
SACRAMENTO	95822	1HGCD7254RA026144	1994	Honda	Accord EX	0.617	Front Drive	Single
SACRAMENTO	95822	YS3AC35D1G2021875	1986	Saab	900S	0.490	Front Drive	Multiple
SACRAMENTO	95822	1FMDU34X7SZB02386	1991	Ford	Explorer	0.201	Rear/4 Wheel	Multiple
SACRAMENTO	95822	1FBHE2114FHA60398	1985	Ford	Van Diesel	0.160	Rear/4 Wheel	Multiple
SACRAMENTO	95822	4S3BC6321N1622981	1992	Subaru	Legacy TC	0.490	Front Drive	Multiple
SACRAMENTO	95823	JM1GB411GC0628698	1982	Mazda	626	0.000	Rear/4 Wheel	Single
SACRAMENTO	95823	1Y1SK5361RZ029818	1994	Geo	Prizim	0.608	Front Drive	Single
SACRAMENTO	95823	2B4FK45JALR540300	1990	Dodge	Caravan	0.667	Front Drive	Single
SACRAMENTO	95824	1FDEE14N6MHB38874	1991	Ford	F150 Van	0.187	Rear/4 Wheel	Multiple
SACRAMENTO	95825	2HGEJ1121SH538750	1995	Honda	Civic-ex	0.617	Front Drive	Single
SACRAMENTO	95826	1P3BP46C5EC151421	1984	Plymouth	Reliant	0.604	Front Drive	Multiple
SACRAMENTO	95826	1GCDC14K7MZ177723	1991	Chevrolet	1500 Pickup	0.214	Rear/4 Wheel	Multiple
SACRAMENTO	95826	1P3BP46C5EC151421	1984	Plymouth	Reliant	0.604	Front Drive	Multiple
SACRAMENTO	95827	3P3AA4637RT274984	1994	Plymouth	Acclaim	0.667	Front Drive	Multiple
SACRAMENTO	95828	JHMCB7552PC008113	1993	Honda	Accord	0.595	Front Drive	Multiple
SACRAMENTO	95828	2P4FP2534TR637161	1996	Plymouth	Voyager	0.725	Front Drive	Multiple
SACRAMENTO	95828	2P4GH2537NR602523	1992	Plymouth	Voyager	0.214	Rear/4 Wheel	Multiple
SACRAMENTO	95828	WBAAG3305B8000963	1981	BMW	318i	0.125	Rear/4 Wheel	Multiple
SACRAMENTO	95828	JN1PS26S9GW087159	1986	Nissan	200SX	0.150	Rear/4 Wheel	Single
SACRAMENTO	95828	JN1PS26S9GW087159	1986	Nissan	200SX	0.150	Rear/4 Wheel	Single
SACRAMENTO	95828	V442695562	1964	Plymouth	Baracuda	0.224	Rear/4 Wheel	Single
SACRAMENTO	95828	WBAAG3305B8000963	1981	BMW	318i	0.125	Rear/4 Wheel	Multiple
SACRAMENTO	95831	JT2SK12E3N0027002	1992	Toyota	Camry	0.631	Front Drive	Single
SACRAMENTO	95831	4T1VK13E6PU093862	1994	Toyota	Camry	0.379	Front Drive	Multiple
SACRAMENTO	95831	1G2NE4U5MC654602	1991	Pontiac	Grand Am	0.641	Front Drive	Single
SACRAMENTO	95831	JT2SK12E3N0027002	1992	Toyota	Camry	0.631	Front Drive	Single
SACRAMENTO	95833	JM1BG232XN0466538	1992	Mazda	323 Hatchbck	0.538	Front Drive	Multiple
SACRAMENTO	95833	F10GRFE0669	1979	Ford	F-100 Pickup	0.186	Rear/4 Wheel	Multiple
SACRAMENTO	95833	1N6HD16Y1JC318300	1988	Nissan	4x4 King Cab	0.186	Rear/4 Wheel	Multiple
SACRAMENTO	95833	1N6HD16Y1JC318300	1988	Nissan	4x4 King Cab	0.186	Rear/4 Wheel	Multiple
SACRAMENTO	95842	JB3XD44S7MY014590	1991	Dodge	Stealth	0.670	Front Drive	Single
SACRAMENTO	95842	1B4FK403XJX351185	1988	Dodge	Gran Caravan	0.667	Front Drive	Multiple
SACRAMENTO	95842	1B4FK403XJX351185	1988	Dodge	Gran Caravan	0.667	Front Drive	Multiple
SACRAMENTO	95864	YV1AX4946C1795707	1982	Volvo	240 DL	0.165	Rear/4 Wheel	Single
SACRAMENTO	95864	2MECM75W7NX680560	1992	Ford	Grand Marquis	0.198	Rear/4 Wheel	Single
YUBA CITY	95991	1FACP524XNG223480	1992	Ford	Taurus	0.196	Rear/4 Wheel	Multiple

YUBA CITY	95991	2MEBM75F8HX691552	1987	Mercury	Grand Marquis	0.187	Rear/4 Wheel	Multiple
YUBA CITY	95993	1MEPM36X6RK603561	1994	Mercury	Topaz	0.198	Rear/4 Wheel	Multiple
YUBA CITY	95993	1G4AG55M2R6460324	1994	Buick	Century	0.641	Front Drive	Multiple
YUBA CITY	95993	1G4AG55M2R6460324	1994	Buick	Century	0.641	Front Drive	Multiple
YUBA CITY	95993	2C1MR2469R6706287	1994	Geo	Metro	0.556	Front Drive	Multiple
YUBA CITY	95993	2GTFC29K9J1581487	1988	GMC	Pickup	0.146	Rear/4 Wheel	Multiple
YUBA CITY	95993	TE31297959	1978	Toyota	Corolla	0.107	Rear/4 Wheel	Multiple
YUBA CITY	95993	2GTFC29K9J1581487	1988	GMC	Pickup	0.146	Rear/4 Wheel	Multiple

Appendix E

Download Example, Speed(v1), and AC Status(s1)

```
+++++++++++++++++++++++++++++++++++++++++++
+    AUTOLOGGER System Developed By       +
+ Instrumental Solutions (613) 832-0039  +
+  DATA TRACE PROGRAM (    128 Kb memory) +
+           Version   2.386              +
+++++++++++++++++++++++++++++++++++++++++++

Hit <<enter>> key at any time to bring up menu...

     ** AUTOLOGGER MENU**
Instrumental Solutions - Woodlawn,ON, Canada
  Data Trace Program - Version   2.386

0  normal operation
1  set/view time & date
2  set up channels
3  calibrate sensor
4  realtime data display
5  download data
6  clear data area
enter selection: 5

Program Version - Trace  2.386

trip #  1 of  90
```

mm/dd/hh/mn/ss 7 30 10 6 29

Sec, v1, s3,

1 , 7 , 0
2 , 0 , 0
3 , 0 , 0
4 , 0 , 0
5 , 0 , 0

trip end

trip # 2 of 90

mm/dd/hh/mn/ss 7 30 10 18 19

Sec, v1, s3,

1 , 0 , 0

trip end

trip # 3 of 90

mm/dd/hh/mn/ss 7 30 10 18 34

Sec, v1, s3,

1 , 0 , 0

trip end

trip # 4 of 90

mm/dd/hh/mn/ss 7 30 10 18 56

Sec, v1, s3,
1 , 10 , 0

2,	0,0
3,	0,0
4,	0,0
5,	7,0
6,	12,0
7,	14,0
8,	16,0
9,	16,0
10,	18,0
11,	16,0
12,	14,0
13,	12,0
14,	12,0
15,	12,0
16,	10,0
17,	10,0
18,	3,0
19,	6,0
20,	14,0
21,	20,0
22,	22,0
23,	28,0
24,	34,0
25,	36,0
26,	38,0
27,	42,0
28,	43,0
29,	43,0

.
.
.
.