Final Report

Heavy-Duty Truck Activity Data

prepared for

Office of Highway Information Management
Office of Technology Applications
Federal Highway Administration
400 Seventh St. S.W.
Washington, D.C. 20590

by

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505 King Avenue
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April 30, 1999

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ACKNOWLEDGMENTS

Battelle served as the prime contractor for this program, managed the hardware and software development, and executed the field data collection activities and subsequent analyses. This program involved Battelle staff in Columbus, Ohio and Irvine, California.

Acumen Building Enterprises of Oakland, California; The Adept Group of Los Angeles, California; and AFA Construction of Novato, California provided installation technicians and participated in the field data collection activities.

Battelle appreciates the cooperation and support of the many trucking firms and their employees that permitted the use of their vehicles during the field data collection activities.

Battelle developed the user interface software. Software used for map-matching of GPS data points and GIS map elements was developed by TransCore, an SAIC Company.

This research program was sponsored by the Office of Highway Information Management and the Office of Technology Applications, Federal Highway Administration, U.S. Department of Transportation; the Planning and Technical Support Division, California Air Resources Board; and Battelle's internal research and development program.

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EXECUTIVE SUMMARY

This report documents a sample of heavy-duty truck activity data collected in California using an automated data collection device that incorporated Global Positioning System (GPS) technology. This research effort was originated by the Planning and Technical Support Division of the California Air Resources Board (CARB) and jointly supported by the Federal Highway Administration (FHWA). The data collection equipment and techniques were developed in previous work for FHWA and were modified for this application with support from Battelle's internal research and development program.

The Federal Highway Administration's objective was to describe truck travel patterns in urban and rural areas for several vehicle classes and to analyze characteristics of heavy-duty truck travel by producing speed profiles, trip patterns, and start patterns and other data summaries. The California Air Resources Board's objective was to improve the heavy-duty truck activity data that are used in forecasting on-road emissions.

The GPS approach offers advantages in this data collection because of the ability to record the actual location of the heavy-duty trucks while in operation. Incorporating GPS data allows the truck activity data to be properly allocated to specific geographic regions such as California air basins, counties, and urban areas during data post-processing.

Battelle performed data collection activities using automated equipment that included Global Positioning System technology to record and subsequently describe truck travel activity within the state of California. The project collected activity data from 140 heavy-duty trucks drawn from a volunteer sample from the California trucking industry.

Hardware. The hand-held computer employed in the data collection activity was deployed in a service environment that was generally more severe than envisioned by the equipment vendors. While the Sony MagicLinks performed reasonably well, they periodically "froze" and thus did not record data as intended. Since the MagicLinks were first purchased in 1995 (they are no longer manufactured) a number of newer personal digital assistant and palm-computer products have become available that could perform in this type of application.

The GPS receivers were the best performing piece of equipment, as expected, because they were essentially designed for the service environment. Other failures that were experienced included cabling failures that were replaced with heavier duty material during the course of the field activities and one data set was lost due to a failed battery within the PCMCIA memory card.

Sampling Process. The response rate for the sampling process was low and additional effort is required to achieve an improved response rate. Future applications, especially if a large, representative sample is desired, should include a pre-test to refine the recruitment strategy and to fine-tune the data collection equipment prior to large-scale deployment. While a pre-test may consume resources without promising fully useful data, lessons learned in the pre-test should result in resource savings during the later data collection period, allowing more data to be obtained. At a minimum, the pre-test activity will help focus the planning process and recruiting strategy for improved results.

Incentives. Overall, both drivers and, to a lesser extent, owners seemed somewhat mistrustful of the project objectives. These concerns were generally voiced as uncertainties over enforcement issues (such as hours of service, compliance to route, and unscheduled stops) and the ultimate use of the data (e.g., additional regulations that may impact their business).

Incentive offers to fleet owners, operators, and heavy-duty truck drivers help assure a more broad-based data sample and increase the recruiting success rate. Driver compliance improved when additional efforts were taken to explain the data collection activity and also included a non-cash incentive that was well received by the drivers.

Equipment Installation. The approach to equipment installation required an installation technician to visit the site and calibrate the data collection equipment for each truck. The individual calibration was necessary based on data collection equipment design and the wide variation in voltage response of different trucks as seen through the accessory power port. This approach is not optimal. Technicians cost money and drive time to the sites was significant, especially if an appointment was missed or cancelled. Redesigning the power management circuit to eliminate the calibration process and the need for the technician should improve the success of the data collection and reduce the costs.

GPS Data Analysis Incorporating GIS. The GPS/GIS data integration involved (1) tagging the GPS data points to specific geographic areas, such as counties or urban areas, and (2) map-matching the GPS data points to the roadway network represented in the GIS map. Tagging the GPS data points to geographic areas is a straightforward process supported by the GIS software once geographic areas are defined.

The map-matching process has improved since its application in the Lexington study; however, the sheer size of the HDT database challenged the software capacity. Several modifications to the software were made during the map-matching process to address issues observed during the matching process.

Data Collection Costs. Cost comparison to traditional survey methods such as telephone surveys is inappropriate because the method and results of the data collection are vastly different. However, FHWA's Lexington study offers a basis of comparison since the methods, equipment, and resultant data are similar. The Lexington and HDT data collection costs are compared for selected activities on a "per installation" basis as the most appropriate measure of the activity required to collect an individual sample.

Participant recruiting and overall study planning and management were more expensive per installation in the Lexington study, while field activities and data analysis were more expensive in the HDT study. In general, the Lexington study recruiting effort was more successful and the HDT study recorded substantially more data with additional analysis requirements. Overall, HDT study cost per installation was approximately 80 percent of the Lexington cost per installation, ignoring equipment purchase and software development costs. This reduction is progress in the right direction; however, study planning and pre-collection activities likely should have been emphasized more in the heavy-duty truck study to enhance the recruiting and data collection success.

The HDT Sample and Analyses. The resultant sample and accompanying data base are best described as an opportunity sample. Explicit coverage of vehicle classes, geographic coverage, business use, or other data characteristics is problematic when voluntary contributors drive the sample composition. The resulting data base described in this report therefore is descriptive only of the sample itself, and may or may not be descriptive of HDT travel activity in the state of California.

The descriptive analyses of the sample data prepared in this project demonstrate that this data collection and analysis process is useful for describing HDT activity data. Analyses based on vehicle classes, geographic areas (e.g., air basins), highway functional classes, and other factors are possible and were performed. The analyses presented in Chapters 4 and 5 offer insights into the HDT activity included in the sample and a level of detail never captured before in an HDT activity data base.

Overall, the resultant data base from the HDT Activity Data Project addresses the objectives defined for the project. A substantial amount of HDT activity data was collected throughout the state of California and described to support the project objectives. These data therefore represent a new knowledge base for FHWA, CARB, and other researchers engaged in the task of describing HDT activity.

Future Applications. Future use of this technology for travel data collection will benefit from the lessons learned in this application. The key issues are hardware durability and education of the sample population to ensure successful recruiting and compliance with sample objectives. Hardware issues are being addressed as newer, more capable equipment becomes commercially available. Potential sample populations will become more receptive to these data collection techniques as researchers gain a better understanding of the issues involved and the general use of global positioning system technology becomes more commonplace. As these issues are resolved, global positioning system-based travel data will provide a more robust and detailed source of data for better understanding of personal travel characteristics and vehicle on-road emissions.

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ACRONYMS

Caltrans	California Department of Transportation
CARB	California Air Resources Board
CFCC	Census Feature Class Code
DGPS	Differential Global Positioning System
DLG	Digital Line Graph
DMV	Department of Motor Vehicles
FC	Functional Class
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
GVW	Gross Vehicle Weight
GVWR	Gross Vehicle Weight Rating
HDT	Heavy Duty Truck
HPMS	Highway Performance Monitoring System
JFA	Jack Faucett and Associates
MVEI	Motor Vehicle Emissions Inventory
NPTS	National Personal Transportation Survey
SAIC	Science Applications International Corporation
TIUS	Truck Inventory and Use Survey
UZA	Urban Zone Area
VIN	Vehicle Identification Number
VMT	Vehicle Miles of Travel

Heavy-Duty Truck Activity Data Collection and Analysis Using Global Positioning Systems

1. INTRODUCTION

This report describes the application of an automated data collection device that includes Global Positioning System (GPS) technology for the collection of heavy-duty truck activity data. This research effort was originated by the Planning and Technical Support Division of the California Air Resources Board (CARB) and jointly supported by the Federal Highway Administration (FHWA). The data collection equipment and techniques were developed in previous work for FHWA[1] and were modified for this application with support from Battelle's internal research and development program.

This approach to collecting travel activity data offers a more robust data source for defining travel activity than current methods, which rely on telephone interviews, travel diaries, or data loggers that provide no geographic references. While this technology is not expected to supplant current data collection methods, this application demonstrates that this approach has merit with respect to more clearly defining travel activity.

1.1 Background

Vehicle travel and how it changes is of continuing concern to transportation planners, air quality modelers, and policy makers. Information about daily travel patterns, engine starts and stops, time of day decisions, and highway choice decisions are generally captured using telephone interviews, travel diaries, data loggers, or other self-reported information.

Transportation and air quality professionals and other users of the collected data surmise that data based on self-reported methods includes the tendency to round travel times and travel distances, likely omits very short trips, and contains inaccuracies related to engine starts and stops and time between engine starts (soak time). Overall, vehicle miles of travel (VMT) reporting may be fairly complete using current methods, however other data related to engine operation and the highway class actually used for the travel are incomplete.

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[1]Lexington Area Travel Data Collection Test – Global Positioning Systems for Personal Travel Surveys, Office of Highway Information Management, Office of Technology Application, Federal Highway Administration, US Department of Transportation, Final Report, September 15, 1997.

This project used an automatic data collection device that collected truck activity data including automatically recording GPS position and speed information. In addition to the GPS information, the truck data consist of basic information such as vehicle configuration, body type, fuel type, and gross vehicle weight rating (GVWR). Additional data collected include the vehicle's primary business use, whether or not the vehicle has a catalytic converter, vehicle identification number (VIN), and starting and ending odometer readings. This report describes the equipment and activities associated with the California Heavy Duty Truck Activity Survey and the data that were retrieved during the field data collection activities.

1.2 Objectives

The overall objectives of the research program were stated as follows.

- Collect truck travel activity data to describe truck travel patterns in urban and rural areas to support congestion modeling activities. These data include several truck vehicle classes, trip definition based on engine start and stop, trip time and distance, and highway functional classification.

- Characterize the collected data by producing speed profiles, trip patterns, start patterns, and other data summaries by vehicle class, urban area types, highway functional class, and California counties and air basins.

1.3 Project Organization

This project required the coordination of several organizational elements to organize, recruit, collect, and manage the data in the heavy duty truck activity survey. The three principal activities were as follows.

- Participant Recruiting - Participant recruiting focused on trucking companies that would provide three or more vehicles at one site for instrumentation. Recruiting was accomplished through a series of mailings and telephone contacts with trucking company management. Once a recruit agreed to participate, information on the company and appropriate contact information was transferred to a field installation technician.

- Field Data Collection Operations - Field data collection was managed by several installation technicians. Once a participant was identified, the installation technician contacted the trucking company to arrange final details including dates for installation and retrieval of the data collection equipment. After the equipment was retrieved, the raw data were downloaded for inclusion in the project data base.

- Data Base Management - All raw data were collected at a central location and incorporated into the project data base. This process included tagging the data points to geographic features in a Geographic Information System (GIS) and quality control checks of the data files. The completed data base was used in the subsequent analyses.

1.4 Organization of this Report

Section 2 provides an overview of the sampling strategy employed for the collection of the heavy duty truck activity data, and describes the actual sample obtained from the field data collection activities.

Section 3 describes the activities associated with the field data collection, including recruiting trucking company participants and data collection device placement and retrieval. Anecdotal data are provided to illustrate the challenges in recruiting participants and problems encountered in the field data collection.

Section 4 presents the heavy duty truck activity data and the analysis approach and results. The sample of trucks included in the data are described. Data base management activities and the analysis approach are discussed in detail. Analysis results include descriptions of the location of truck travel and comparisons of accumulated truck travel activity.

Section 5 presents the analysis of trip start patterns and the contrast of urban area and non-urban area results.

Section 6 provides a brief summary of the findings of the project and overall conclusions from this research project.

Appendix A contains a description of the HDT activity data base resulting from the project, including gross statistics on the amount and quality of the collected data. A discussion of the process employed to construct the data base from the raw data is included, as well as information on initial data screening procedures and GIS data tagging to prepare the data files for the analyses.

Appendix B provides a general description of the data collection equipment, hardware, and software used for the heavy duty truck activity data collection, including the technical specifications of commercially available components and features of the software interface used in the data collection.

Appendix C provides a description of the map-matching process used to identify highway functional class from the collected GPS data points.

2. SAMPLING STRATEGY

The data collected in this project serves two purposes. First, FHWA has an interest in HDT travel activity in urban and rural areas. This includes data that describe HDT trip patterns, VMT, and speeds segregated by urban and rural travel. These data should be useful in subsequent studies focusing on the contribution of HDT traffic to congestion in urban areas.

The second purpose of this project is to collect data in order to improve CARB's heavy-duty truck (HDT) activity data that are used in estimating on-road vehicle emissions. This effort includes improvement of data on speed profiles, starts/trip patterns, VMT, and fuel usage by truck weight class and geographic location. The scope of the data collection is essentially state-wide.

Collection of a state-wide sample of truck activity represents several challenges. California occupies approximately 156,700 square miles containing over 170,000 miles of urban and rural roadways, with a truck population in excess of 661,000 vehicles. In addition, there are 14 air basins defined by CARB and approximately 38 urban areas as defined by FHWA and the U.S. Census Bureau. Given these factors, obtaining a representative sample of truck activity in California is a challenge.

In this project, GPS technology was used to collect the HDT activity data. The GPS approach offers advantages in this data collection. The most important advantage is the ability to record the location of a vehicle equipped with the device at all times the vehicle is in operation. This capability is particularly valuable in estimating activity parameters in various geographic regions (e.g., air basins or counties). Data can be post-processed to determine *where* vehicles traveled. Thus the same vehicle can be used to represent activity in multiple areas. These data on vehicle position can be used to evaluate this activity information *after the fact*.

This section describes the sampling strategy employed during participant recruitment and data collection activities.

2.1 Geographic Regions and Truck Weight Classes

A probability-based random sampling of HDTs in California was not attempted. This decision was necessary because of (1) the difficulty in identifying and locating each truck in California, (2) practical restrictions in sampling associated with voluntary participation in the study, and (3) the resource constraints of the project.

The goal of this project was to collect information to characterize activity of HDTs in California for use in estimating the emissions inventory. Of course, only a small sample of HDTs was obtained, and it is difficult to make inferences to the broad population of HDTs in the state. Because a random sampling of vehicles was infeasible, at best, one could use a statistical model to incorporate the effects of primary and secondary factors and various sources of variability to characterize HDT activity across the state. Due to the small (and perhaps biased) sample, Battelle did not attempt to develop or use such a statistical model.

Nonetheless, several factors influence HDT activity, such as weight class, geographic region, business usage, range of use, and type of fuel. The factors of primary importance to this data collection effort, based on discussions with FHWA and CARB, are weight class and geographic area. The HDT activity data collection focused on five truck weight classes as defined in Table 1[2].

Table 1. Truck Weight Classes Defined for the Data Collection Effort

Truck Class Description	Gross Vehicle Weight (GVW) (lbs.)
Light, Heavy-Duty (LHDT) – T4	8,501 – 10,000
Light, Heavy-Duty (LHDT) – T5	10,001 – 14,000
Medium, Heavy-Duty (MHDT) – T6	14,001 – 33,000
Heavy, Heavy-Duty (HHDT) – T7	33,001 – 60,000
Super, Heavy-Duty (SHDT) – T8	> 60,000

The intent of the weight class designation was to identify the Gross Vehicle Weight (GVW), or maximum legal weight, of the trucks included in the sample. The actual operating weight of the truck at a given time will vary depending on the cargo carried and whether the truck is fully loaded, partially loaded, or empty at that time. Thus the GVW was intended as a consistent measure of the truck weight for assignment to a specific weight class.

The approach to identifying truck weight class was to collect the manufacturer-specified maximum gross weight rating as indicated on the truck identification plate. For a combination vehicle, the values from both the tractor and the trailer are required to define the maximum weight. In practice, this information was not available for every truck included in the sample. In these cases, the driver or another designated contact with the trucking company was asked to provide the GVW for the truck.

Four geographic regions were defined for purposes of recruiting participants for data collection. The regions were defined based on geographic similarities and the estimated truck populations in the air basins. Anticipated challenges in the recruitment effort were also considered in the decision process for defining data collection regions. The ability of the GPS approach to identify more specific locations (such as individual air basins, counties, or urban areas) also supports a broader definition of the recruiting regions. More specific partitioning of the data, if desired, can be performed during data post-processing. The four geographic regions, as illustrated in Figure 1 and listed in Table 2, include one or more California air basins with similar characteristics.

[2] The lowest two weight classes differ from those in CARB's statement of work based on discussions conducted during the development of the sample strategy. The medium duty category (6,000 - 8,500 lbs.) was dropped, and the light heavy-duty category was divided as shown in Table 1.

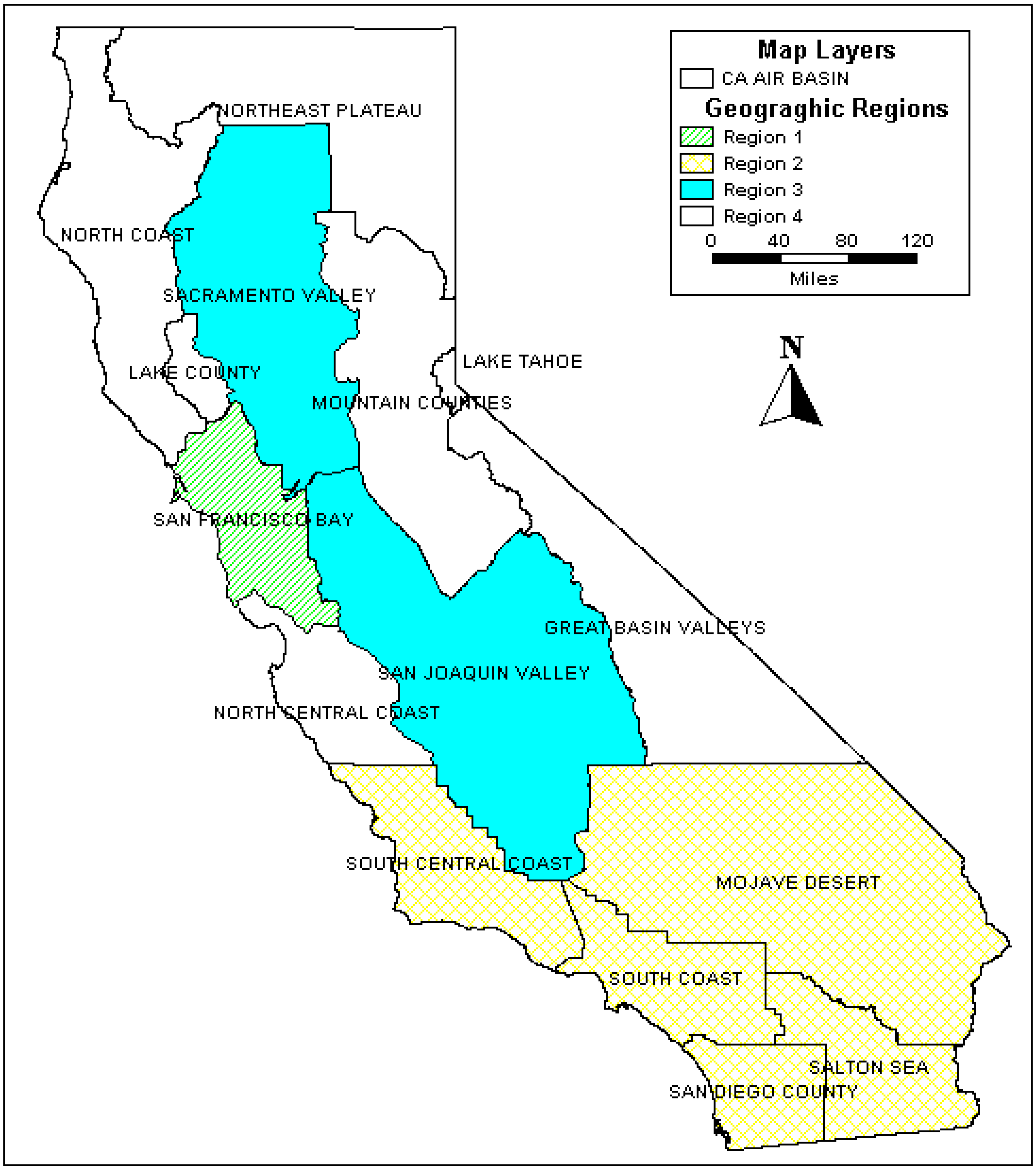


Figure 1. Geographic Regions

Table 2. Geographic Regions Defined for the Data Collection Effort

Data Collection Region	California Air Basins
1	San Francisco
2	San Diego County, South Central Coast, South Coast, and Southeast Desert (Mojave Desert and Salton Sea)
3	San Joaquin Valley and Sacramento Valley
4	Great Basin Valleys, Lake County, Lake Tahoe, Mountain Counties, North Central Coast, North Coast, and Northeast Plateau

Based on these two factors of primary interest to FHWA and CARB, heavy-duty trucks in California were divided into 20 strata (5 weight classes x 4 geographic areas) for the data collection strategy. These strata, and the planned recruiting targets, are illustrated in Table 3.

Table 3. Strata and Target Numbers of Trucks for the Recruiting Effort

Geographic Region		Weight Class					
		T4 8.5-10K	T5 10-14K	T6 14-33K	T7 33-60K	T8 >60K	Region Totals
Region 1	Target	12	10	15	21	19	77
	%	4.5%	3.8%	5.7%	7.9%	7.2%	29.1%
Region 2	Target	10	12	16	19	21	78
	%	3.8%	4.5%	6.0%	7.2%	7.9%	29.4%
Region 3	Target	12	10	15	21	19	77
	%	4.5%	3.8%	5.7%	7.9%	7.2%	29.1%
Region 4	Target	7	6	7	7	6	33
	%	2.6%	2.3%	2.6%	2.6%	2.3%	12.5%
Weight Class Total	Target	41	38	53	68	65	265
	%	15.5%	14.3%	20.0%	25.7%	24.5%	100.0%

Trucks recruited from each of the 20 strata ensure statewide coverage as well as representation across weight classes to characterize HDT activity.

The recruiting strategy called for approximately equal size samples from each of the first three regions, and fewer vehicles from the fourth region, where only about five percent of the California trucking population is registered[3]. This allocation of vehicles to the different regions was designed to provide the best ability to make comparisons between the strata of primary interest. Allocation of the sampling effort in proportion to the population of vehicles in each weight class and region would be the optimal approach to estimate statewide averages of activity parameters. However, a primary goal of this project was to estimate differences between regions and weight classes – not to obtain statewide average estimates[4].

[3]Based on fax communication from CARB to Battelle (February 28, 1997).

[4]Obtaining statewide average estimates was the goal of a separate effort performed by another contractor.

Approximately half of the recruiting effort was targeted at the two heaviest weight classes (greater than 33,000 lbs.), as opposed to equal allocation among the five weight classes. Obtaining more precise characterizations of activity for these weight classes is important because these heavier trucks would be the most likely targets of future vehicle emission regulation changes.

The recruitment effort focused on fleets that allowed equipping three or more trucks at a time, ideally fleets that have operations in different geographic regions and/or vehicles in different weight classes. Approximately 85 to 90 percent of the recruitment effort was targeted at these larger fleets for efficiency. The remainder of the recruitment effort was targeted at smaller, one- or two-truck fleets, referred to as "independents." Although a large proportion of the California trucking population is made up of independents[5], this segment of the truck population proved to be much harder to recruit into the survey and consumed a larger portion of the project's limited resources on a per unit basis. Without representation, assumptions would have to be made regarding activity for these vehicles relative to vehicles in larger, multi-truck fleets.

2.2 Urban Areas in California

Travel activity within urban areas is of high interest to both FHWA and CARB. FHWA's interest focuses on truck travel activities, principally in urban areas, as a component of congestion modeling and trip patterns. CARB's interest in urban area travel activity relates directly to the HDT vehicle emissions in these areas. Approximately 38 urban areas are located in California as defined by FHWA and the U.S. Census Bureau. These urban areas are described in Table 4 and shown geographically in Figure 2.

Table 4 divides the urban areas into three types of areas as follows: (1) Large Urban Areas with a population greater than 200,000, (2) Urbanized Areas with a population between 50,000 and 200,000, and (3) Small Urban Areas with a population between 5,000 and 50,000. All areas outside these defined urban areas are considered rural for these analyses. Travel activity analyses provide information on trips, travel time and distances, speed profiles, and other measures within these four area types.

2.3 Sample Description

As expected, the actual sample collected differs from the planned sample defined at the beginning of the project and described in the previous sections. The recruiting process depended entirely on voluntary participation from the California trucking industry, which increased the difficulty in satisfying the plan on a bin-by-bin basis. Some significant differences in the actual sample achieved versus the plan are described below.

[5] Some estimates indicate that nearly 45 percent of the trucking population in California is made up of vehicles in fleets with only one truck.

Table 4. Urban Areas Defined in California

Area Type	Urban Area	Estimated Population
Large Urban Areas 200,000 < population	Los Angeles	11,299,899
	San Francisco-Oakland	3,710,676
	San Diego	2,327,189
	San Jose	1,440,176
	Riverside-San Bernardino	1,147,688
	Sacramento	1,075,562
	Fresno	459,415
	Oxnard-Ventura	401,173
	Bakersfield	301,621
	Stockton	263,103
	Modesto	220,969
Urbanized Areas 50,000 < population < 200,000	Lancaster-Palmdale	179,372
	Antioch-Pittsbug	149,833
	Santa Rosa	143,762
	Santa Cruz	136,331
	Hesperia-Apple Valley	131,132
	Seaside-Monterey	129,265
	Salinas	124,729
	Simi Valley	113,110
	Palm Springs	107,060
	Santa Barbara	106,342
	Fairfield	86,997
	Visalia	83,555
	Santa Maria	82,391
	Hemet-San Jacinto	80,652
	Redding	80,132
	Chico	74,069
	Yuba City	65,068
	Merced	65,009
	Vacaville	64,440
	Napa	62,886
	Indio-Coachella	51,513
	Lodi	50,549
Small Urban Areas 5,000 < population < 50,000	Watsonville	49,069
	Davis	45,010
	Lompoc	41,079
	San Luis Obispo	39,533
	Yuma	5,670

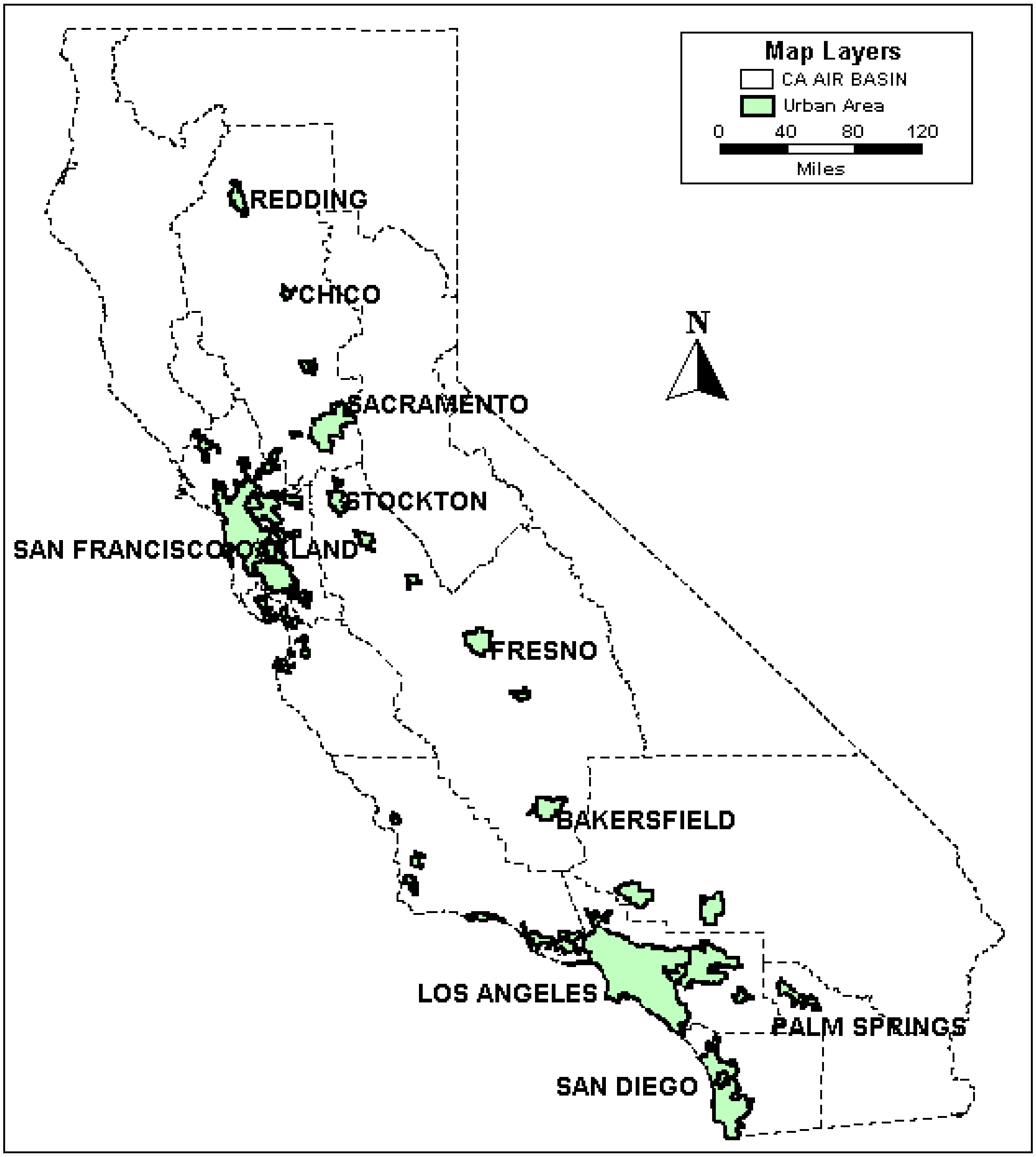


Figure 2. California Urban Areas

- The total sample size is smaller than the plan, 140 versus 265. A total of 167 trucks were recruited and instrumented, with 27 vehicles (16 percent) returning no usable data due to data collection equipment or installation problems early in the project, or other interruptions of the data collection.

- Review of the truck weight assignments revealed some inconsistencies in the weight values versus the GVW that would be expected based on truck configuration and number of axles. First, some of the verbal responses received are more likely to approximate a typical operating weight rather than the GVW. Second, some of the T7 trucks appear to be assigned to weight categories based on the tractor GVW alone and no information about the trailer weight. The net effect of these inconsistencies is that approximately half of the trucks designated as T7s may be T8s based on a maximum weight estimated from the axle count. The impact of these inconsistencies is expected to be minimal, since the current models use the T7 and T8 weight classes defined here as a single weight group. Also, the project data base contains sufficient information on truck configuration to allow reassignment of the truck weight classes for future analyses, if desired.

- In general, each fleet participant contributed from one to six trucks to the sample. The plan specified a target of three trucks per fleet. Some fleets have fewer than three trucks represented due to data collection equipment difficulties or because fewer trucks were available at the time of equipment installation. Some fleets contributed more than three trucks because the recruiting scope was enlarged as the recruiting progressed. This scope enlargement resulted for two reasons: (1) some companies offered larger numbers of trucks and (2) since recruiting was proving to be a difficult process, this option offered the opportunity to expand the overall sample in terms of number of vehicles.

- The largest single participant provided 17 trucks garaged at a single site. However, these vehicles covered diverse routes that contribute activity to several air basins.

- A significant portion of the sample (50 vehicles) represents a single business use (package pickup and delivery). This resulted from a large fleet operator that provided several trucks at multiple sites throughout the state.

- The sample includes no “independent truckers.” As expected, independents were difficult to recruit, and the project resources provided for only limited incentives to encourage participation. However, independents were a very small part of the recruitment plan, and this difference has little impact on the subsequent analyses.

Table 5 describes the sample obtained versus the sample plan in terms of the 20 strata defined for the recruiting effort. The geographic region designation in Table 5 relates only to the sites where the trucks were garaged, not the geographic areas where travel activity occurred. As can be seen in the table, 5 of the 20 strata show no trucks garaged in that bin.

The majority of the trucks contained in the sample are diesel-fueled trucks (69 percent). Approximately 23 percent are gasoline-fueled and the remainder are alternatively fueled vehicles. Table 6 shows the distribution of the sample and activity among the various fuel types.

Table 7 describes the sample data in terms of the truck activity (VMT) collected in the 20 strata. The sample includes nearly 87,000 total miles, with approximately 84,000 miles of truck activity in California. Truck activity was observed in all but three of the 20 sample strata.

The data are more evenly distributed between urban and rural locations within California. Table 8 shows the truck activity (VMT) distributed across the truck weight classes and the defined urban and rural areas.

Table 5. Sample Collected Versus Plan

Geographic Region		Weight Class					
		T4 8.5-10K	T5 10-14K	T6 14-33K	T7 33-60K	T8 >60K	Region Totals
Region 1	Target	12	10	15	21	19	77
	Actual	--	--	1	9	--	10
Region 2	Target	10	12	16	19	21	78
	Actual	9	12	17	11	5	54
Region 3	Target	12	10	15	21	19	77
	Actual	9	4	3	25	20	61
Region 4	Target	7	6	7	7	6	33
	Actual	2	--	11	2	--	15
Weight Class Total	Target	41	38	53	68	65	265
	Actual	20	16	32	47	25	140

Table 6. Distribution by Fuel Type

	Sample Size	Miles	Trips	Days
Diesel	97	75,324	5,991	455
Gas	32	4,432	2,969	131
Other	11	7,028	516	51
Total	140	86,784	9,476	637

Table 7. Truck Activity (VMT) Contained in the Sample Data

	Weight Class					
Geographic Region	T4 8.5-10K	T5 10-14K	T6 14-33K	T7 33-60K	T8 >60K	Region Totals
Region 1	-- 0%	- 0%	666 1%	11,012 13%	3,454 4%	15,132 18%
Region 2	626 1%	869 1%	4,988 6%	6,624 8%	4,580 5%	17,687 21%
Region 3	1,428 2%	612 1%	581 1%	19,577 23%	18,661 22%	40,859 49%
Region 4	384 0%	-- 0%	3,938 5%	5,163 6%	982 1%	10,467 12%
Weight Class Total	2,438 3%	1,481 2%	10,173 12%	42,376 50%	27,677 33%	84,145 100%

Table 8. Sample Truck Activity Data (VMT) in Urban and Rural Areas

	Weight Class					
Urban Area Class	**T4 8.5-10K**	**T5 10-14K**	**T6 14-33K**	**T7 33-60K**	**T8 >60K**	**Totals**
Large Urban (200,000+)	24 0%	-- 0%	1 0%	325 0%	119 0%	469 1%
Urbanized (50,000 to 200,000	953 1%	527 1%	2,459 3%	2,785 3%	1,516 2%	8,240 9%
Small Urban (5,000 to 50,000	740 1%	847 1%	5,176 6%	18,486 21%	9,649 11%	34,897 40%
Rural	739 1%	110 0%	2,547 3%	23,239 27%	16,544 19%	43,179 50%
Weight Class Total	2,456 3%	1,484 2%	10,182 12%	44,834 52%	27,828 32%	86,784 100%

Truck activity was recorded in all but one of the California air basins. Table 9 lists the sample truck activity data (VMT) for each of the California air basins. Only Lake County has no truck activity recorded in the sample data.

Table 9. Truck Activity Data in the California Air Basins

Air Basin	VMT Totals	Percentage
Great Basin Valley	243	0.3
Lake County	0	0.0
Lake Tahoe	116	0.1
Mountain Counties	3,439	4.0
North Central Coast	5,613	6.5
North Coast	291	0.3
Northeast Plateau	765	0.9
Sacramento Valley	19,889	22.9
Salton Sea	1,524	1.8
San Diego County	2,531	2.9
San Francisco Bay	15,131	17.4
San Joaquin Valley	20,972	24.2
South Central Coast	810	0.9
South Coast	11,698	13.5
Southeast Desert	1,124	1.3
Outside of CA	2,639	3.0
Total	**86,784**	**100.0%**

As stated earlier, a large fraction (approximately 41 percent) of the sample resulted from a single business use – postal/parcel. Other business uses with substantial representation in the sample include retail, for-hire, and agriculture. Figure 3 provides the distribution of the sampled trucks by business use.

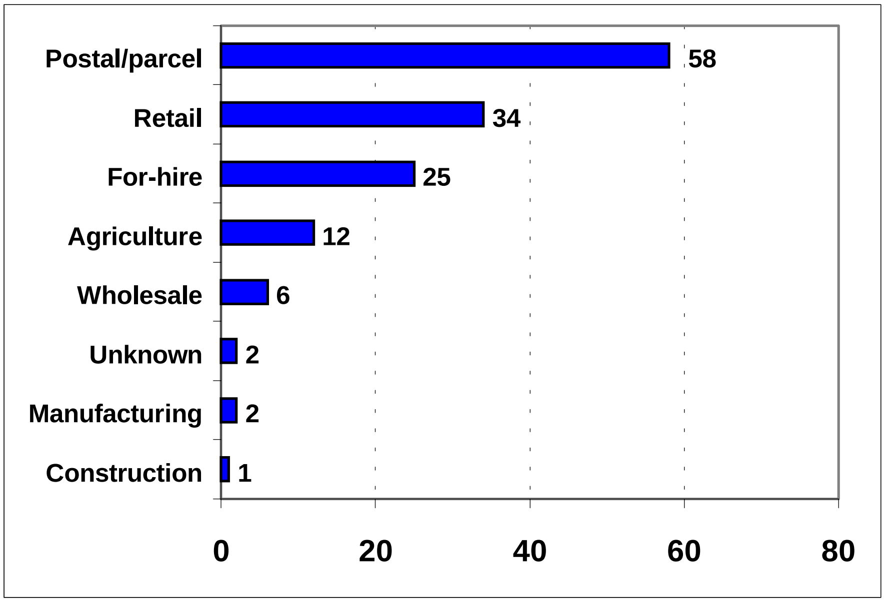


Figure 3. Distribution of Sample Trucks by Business Use

Figure 4 and Figure 5 provide illustrative examples of the sample collected for two trucks. Figure 4 represents a trick that made mostly long-distance trips, and Figure 5 represents a truck that operated in a local environment. Both figures show the truck cumulative travel over the full data collection period.

2.4 Use of the Collected Data

Due to the nature and size of the sample obtained, statewide inferences cannot be made regarding the activity of heavy-duty trucks in California based on these data. It would be unfounded, and perhaps misleading, to make comparisons across weight classes or across geographic boundaries, and assume that these comparisons are representative. Even with a statistical model, and estimates of subpopulation sizes, the data obtained could not support such inferences. Thus, no statistical inferences have been made based on these data.

Nonetheless, a substantial amount of useful activity data was obtained on more than one hundred heavy-duty trucks in California. Information not previously obtained was collected on speed profiles, starts, and soak times, by time of day, functional class, and geographic location (e.g., region, air basin, urban area) for vehicles in five weight classes.

Therefore, in the following sections, summaries of this activity data are provided which can be used to:

- Describe the nature of the specific sample collected
- Characterize activity of a specific vehicle class under restricted definitions (leaving responsibility to the user for the inferences made)
- Demonstrate the value of the technologies used to collect the activity parameters obtained in this sample
- Provide guidance to support future data collection efforts.

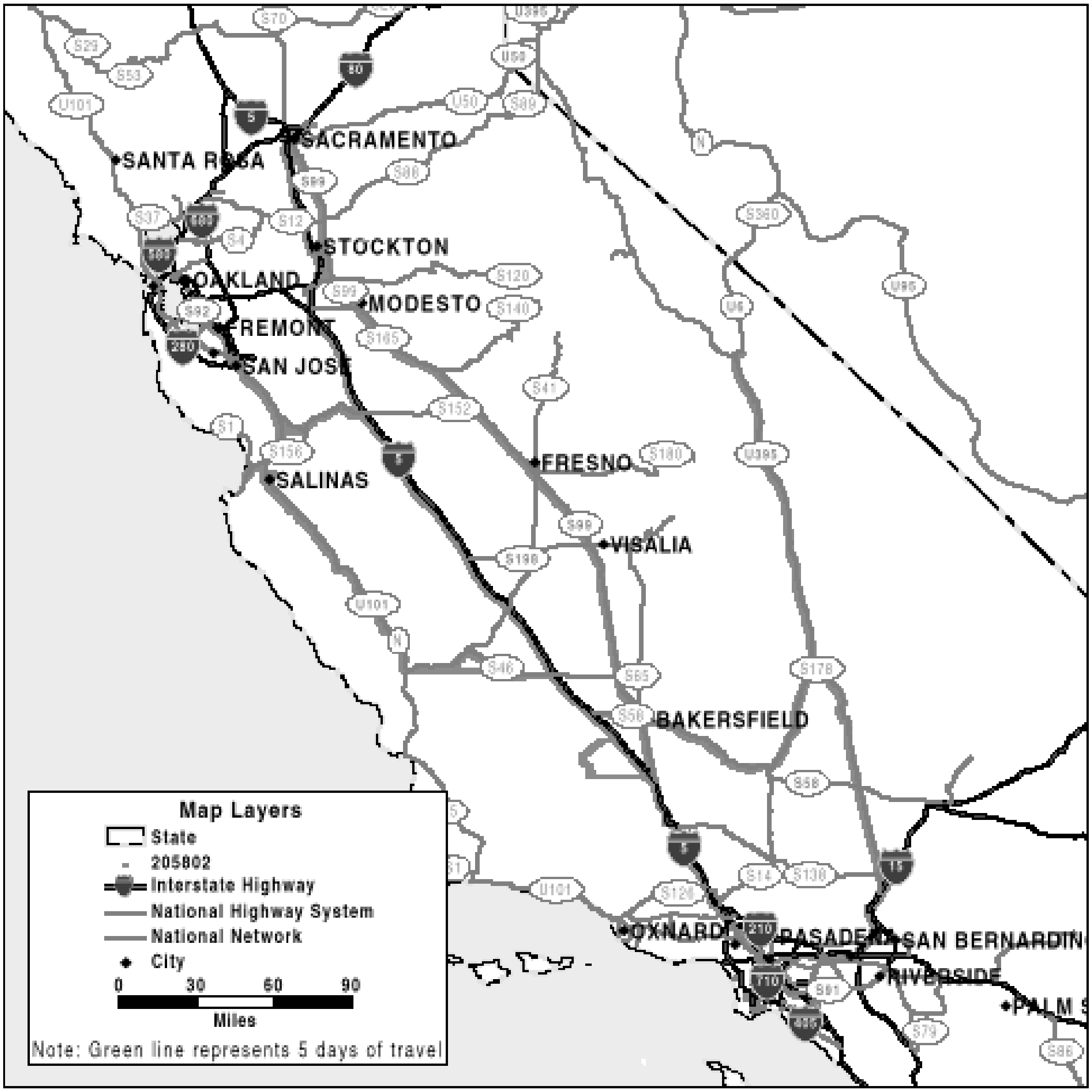


Figure 4. Example of Truck Activity Data Resulting from Long Distance Trips

Figure 5. Example of Truck Activity Data Resulting from Local Travel

3. RECRUITING AND FIELD DATA COLLECTION

The recruiting and field data collection activities consisted of several steps and involved several project participants. Figure 6 illustrates the general project process flow beginning with the recruiting process and continuing through the data downloading task that concluded the "field activities" related to an individual HDT participant.

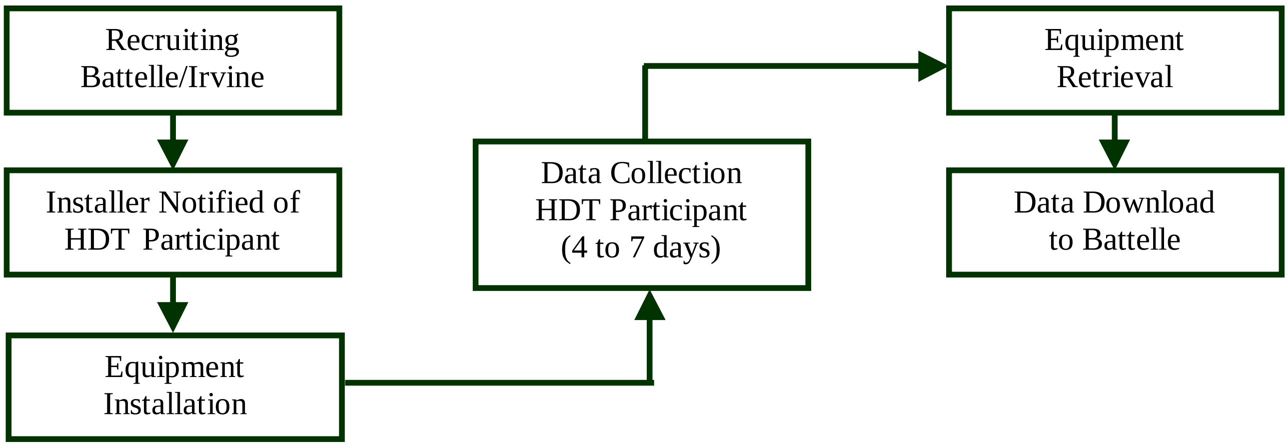


Figure 6. The HDT Activity Data Project Field Operations Process

3.1 Recruiting Participants

The recruiting process comprised several activities. There was no pre-recruitment publicity or expressions of interest from the trucking firms prior to the recruiting effort. Essentially all of the organizations contacted had no prior knowledge of the project.

Recruiting was focused through a general list of trucking firms that were active in California. Groups of 25 to 50 firms were selected and a presolicitation letter was sent to these firms. The letter generally explained the nature of the project and announced that there would be a follow-up telephone call to ascertain the trucking firm's interest in participating in the project.

Follow-up telephone calls were made to trucking firms that received the presolicitation letter. If the trucking firm indicated interest in participating, more detailed information about the project was provided in a subsequent mailing. Several telephone calls were usually necessary to (1) identify the decision maker within the trucking firm and (2) conduct the follow-up discussions to assure participation in the project. Once the trucking firm's participation was confirmed, contact information was provided to a project installation technician to schedule the installation of the data collection equipment.

No cash incentive was offered to encourage participation by trucking firms. However, each trucking firm that participated in the project received a summary report of the data that were collected on their trucks. Of the trucking firms that were engaged in the detailed telephone follow-up, about one in four agreed to participate in the project. Table 10 provides a summary of the recruiting activity conducted for the project. Some of the reasons trucking firms gave for declining to participate are summarized in Table 11.

Table 10. Recruiting Activity

Activity	Number
Trucking firms contacted by mail	236
Detailed telephone follow up (potential participants)	84
Agreed to participate	24
Declined	47
Still undecided at conclusion of data collection activities	13
Large fleet operators contacted	3
Agreed to participate	2

Table 11. Stated Reasons for Declining to Participate in the Project

For *fleets* the reasons for not participating were:

- Not interested and/or too busy (15)
- Would not return follow-up phone calls, reason unknown (4)
- No reason given (3)
- Corporate approval was needed which they could/would not obtain (3)
- No value to participating, operate on static daily schedules and routes (3)
- Dislike of CARB objectives (2)
- Only would be interested if the data provided were "real-time" (2)
- Already have data tracking systems they are happy with (2)
- Concerns about "technical difficulties" with the equipment (2)
- Manager approval obtained but owner would not sign consent form (1)
- Computers are able to give more information than they want to know (1)
- Driver is paid 8 hours for doing a route, don't care what else he or she does or where he or she goes (1)
- Trucks run 24/7 schedule and don't want them stopped for 20 minutes. Tried a tracking system in the past which didn't work (1)

For *independents* the reasons for not participating were:

- Only own two trucks - husband/ wife or husband/son teams, no need for data (3)
- Local set routes, always know where their trucks are (4)
- No working cigarette lighters (1)

3.2 Equipment Installation and Retrieval

Once a participant was recruited, the closest field technician was contacted and provided with the participant contact information so a follow-up call could be made immediately. The field technician would typically set up an installation date at this juncture, answer any technical questions the party may have had, and obtain directions to the installation site. The field technician called again a day or two before the installation date and reminded the participant of the appointment. Because the fleet owners/operators could not always predict when their vehicles would be in use, cancellations or changes were common. Some participants seemed to simply forget and failed to make arrangements or notify their personnel. The field technicians averaged approximately 90 minutes to reach each site, so cancellations without a forewarning were time consuming and expensive. In all, there were approximately 17 installations that did not occur because of cancellations, miscommunication, or unavailability of the vehicles.

Once on-site, the installer made contact with the fleet operator or owner or a designated employee. Typically, company employees and drivers asked questions, and the technician explained the purpose of the study as clearly as possible. Answering their questions and leaving a description of the project was important to minimize the potential for driver tampering due to mistrust of the project objectives.

The installer verified which vehicles were to be equipped and reaffirmed permission to start the vehicles (moving the vehicle was not necessary) during the installation process. The first step was to confirm that power was accessible through the power accessory port (cigarette lighter port in most cases), since these ports were not always installed or functioning properly. The installation technician then verified that the equipment ignition detection circuit operated properly on each vehicle. A multimeter and power accessory adapter was used to measure the electrical system characteristics during engine-on and engine-off states. A power connection was then made. Securing this connection was a matter of using the best fitting adapter and, when appropriate, fortifying it with tape. In cases where the accessory power port was unavailable, a banana jack adapter was used to connect to CB plugs or a fuse tap to connect to the fuse box. The power connection was fused to prevent electrical damage to both the equipment and the vehicle in the case of an electrical short.

The GPS receiver was then mounted in a position that was both secure and provided the least obstruction of the sky. Since non-differential GPS is most accurate with a full view of the sky, the goal was to use either a magnetic roof-top mount or a mirror mount. The latter was the most secure even though there were no reported problems with the roof-top mount. In a few cases, a window suction mount was used but with very poor results. The interior window suction mount has poor satellite visibility in heavy-duty trucks and is the mount that is most accessible for possible tampering. When using the roof-top or mirror mounts, the GPS power/serial cable was routed through the door jam and into the cab, preferably from the passenger side.

The hand-held computer, a Sony Magic Link, was used to store the truck descriptors, i.e., vehicle configuration, GVWR, business use, and odometer readings. Once all the vehicle information was entered via the touch screen interface, the computer was connected to the power supply and serial cable.

The power management/ignition detection circuit was calibrated using the voltage characteristics measured through the power connection to detect when the engine was running. Calibrating the circuit consisted of turning a potentiometer on the circuit box until the appropriate response was achieved. This step proved to be the most difficult in the installation process. Testing the circuit response to the engine-on and off states was critical to the success of the data collection.

Once the power connection and GPS receiver were secured, truck descriptors entered into the computer, and the power management/ignition detection circuit calibrated, the data collection function in Battelle's Magic Link software was activated. The engine was then started to simulate a trip start. This allowed the technician to verify the equipment was activated, the software was running, and GPS data were being collected. If this test was successful, installation was complete, and all the equipment was stowed securely away. The entire installation averaged about 20 minutes per truck. A full description of the data collection equipment can be found in Appendix B.

The data collection period was typically scheduled for one week. There were many cases when retrieval of the equipment was not possible because one or more trucks were unavailable at the end of the week. No-shows and cancellations occurred as frequently for retrieval appointments as installation appointments. Upon retrieval, the field technician would normally simulate a trip by starting the engine and noting whether or not all components were functioning properly. These first and final simulated trips were later removed from the data set.

3.3 Data Download

Data were delivered to Battelle in one of two ways. The most common option was to replace the PC memory card in the hand-held computer with a blank memory card and mail the memory cards. The other option was to upload the data to a PC at the installation technician's office and transmit via e-mail to Battelle staff.

A thorough discussion of the data processing and quality screening can be found in Appendix A. The processing included tagging all GPS records with the county, air basin, and urban area in which that activity occurred. Identification of the roads in which activity occurred was made possible through the use of map-matching software developed by TransCore , an SAIC company (described in Appendix C).

3.4 Performance of the Data Collection Equipment

Data collection occurred in two distinct time periods: August through November 1997 and December 1997 through July 1998. These two data collection periods resulted from equipment performance issues as described below.

During the initial phase of the study, from August through November 1997, data collection efforts produced very few usable data sets. Much of the data collected had inaccurate start and stop times due to both poor calibration and malfunction of the power management/ignition detection circuit. Evidence also showed that 6 of the 25 truck samples collected in this period were disconnected either selectively or completely. The combination of poor equipment performance, lack of experience of the field technicians, and insufficient driver education resulted in 13 data sets with questionable engine start time accuracy and 12 unusable data sets. Equipment installation and data collection was therefore suspended until corrective measures could be implemented in the data collection activity.

Several adjustments were made. The power management/ignition detection circuit was redesigned to (1) improve durability, (2) lessen the sensitivity to voltage noise, and (3) improve the ease of calibration. A Battelle staff member also visited a participant site with each field technician to review the installation process and better train the technicians. Finally, a driver incentive program was instituted, whereby each truck operator was given a laminated card describing the project and a post card thanking him/her for his/her participation and offering the choice of a baseball cap or T-shirt. Feedback from the field technicians revealed that the vehicle operators often assumed the government and/or company management was seeking to use the GPS receivers to track their activity and enforce government or company policy. The cards left with the drivers explained clearly and concisely the project intentions and the level of confidentiality of the data. About three-fourths of the truck operators responded to the incentive offer.

The data collected during the second data collection period were placed in a data base separate from the initial samples. The initial samples are described as Phase I data, and most of the data collected between December 1997 and July 1998 are described as Phase II data. However, any data sets having questionable engine start times were removed from the Phase II data base and incorporated into the Phase I data base. The use of these Phase I and Phase II data sets is described in Chapters 4 and 5 with the applicable analyses.

During Phase II the data collection was greatly improved. Of the 142 installs made during Phase II, 100 produced high quality samples. This data collection accumulated over 53,000 miles and 9,400 trips. Fifteen installs resulted in no usable results, and the other 27 had limited usefulness due to poor calibration of the ignition detection circuit or hardware failure. The resulting Phase I database has a total of 40 truck samples and more than 33,000 miles of data.

Table 12 describes the suspected problems related to the data collection efforts in three classifications: lost/unusable, Phase I, and Phase II data. Phase II data are included in this discussion because 55 of the 100 installs did not collect a full week of data. Most of these 55 samples collected about one-half of the week, which resulted in significant loss of overall activity. The reason for the partial loss of data was often difficult to determine when there was not an obvious hardware failure. As explained, the primary reasons were believed to be an intermittent power cycle problem in many of the hand-held computers, a poor power connection, or selective driver tampering.

Table 12. Problems Experienced During the Data Collection Efforts

Lost/Unusable Data (27 total)	
Number of Data Sets	**Cause of Lost/Unusable Data**
5	Hardware failure other than circuit performance (e.g., GPS, Magic Link, cable failure)
6	Poor calibration and/or circuit performance
4	PC card on write-protect (human error)
2	Trucks were not used (no activity to collect)
10	Little or no data; suspected driver tampering
Phase I Data (40 total)	
Number of Data Sets	**Cause of Inaccurate Starts/Stops or Data Inconsistencies**
7	Hardware failure other than circuit performance (e.g., GPS, Magic Link, cable failure)
16	Human error related to installation (e.g., poor calibration, power connection)
17	Undetermined: poor calibration and/or hardware malfunctions
Phase II Data (100 total/55 incomplete)	
Number of Data Sets	**Cause of Incomplete Data Sets**
9	Hardware failure other than Magic Link failing to turn on (e.g., GPS, cable failure)
46	Hand-held computer failed to consistently activate or power connection not secure or tampering

Table 13 provides an overall summary of the data collection efforts. These efforts resulted in approximately 9,500 individual truck trips (Phase II only), nearly 87,000 vehicle miles of travel, and over 8 million GPS data points.

Table 13. Summary of Data Collection Activity

Activity	Number
Total attempted installations	184
Missed installs due to truck unavailability or cancellations	17
Actual number of installs	167
Installs with no data collected	27
Phase I data sets	40
Phase II data sets	100
Total data sets available for Analysis (Phase I and Phase II)	140

4. TRUCK TRAVEL ACTIVITY DATA

Truck travel occurred throughout the state of California. The GPS equipment provided records of vehicle latitude, longitude, and speed for each second of activity successfully recorded. Errors are present in these measures, and errors in recorded speed are generally regarded as much smaller than errors in latitude and longitude.

Measures of accumulated travel are provided in terms of trip length and trip duration, for each truck weight class. For all analyses, a trip is defined as the period between “engine on” and “engine off”. Thus the trip duration description as a measure of accumulated travel includes any idle time experienced while the engine was on. Idle time is defined as a recorded speed less than 2.5 mph due to errors present in the GPS measure. These measures of accumulated travel are presented in a format consistent with National Personal Transportation Survey (NPTS) reporting.

This section presents several descriptions of the HDT activity data. First, accumulated travel measures (trip duration and trip distance) are presented. Secondly, HDT travel by highway functional class is reviewed, including travel by time of day, with measures for both urban and rural travel. Lastly, several speed profile descriptions are included by truck weight class, including profiles for various geographic areas and highway functional class.

4.1 Description of Trucks Included in the Analysis

The measures of accumulated travel rely on accurate recording of trip start and trip stop. Early in the data collection period, the data collection equipment experienced reliability problems resulting in a number of samples where trip start and stop times were uncertain. The measures of accumulated travel presented here are based on the Phase II data samples where the trip start and stop times were reliable.

A tremendous amount of data was generated from which to determine speed profiles because GPS data were recorded on a second-by-second basis while vehicles were being monitored. Due to the difficulties in identifying trip start and stop time in some of the Phase I samples, data from parts of several trips were lost. Nonetheless, speed data from incomplete trips were used in defining the speed profiles, under the assumption that the lost data was a random exclusion. Both Phase I and Phase II data are used in the speed profile analyses.

4.2 Analysis Approach

Accumulated travel measures are presented as the fraction of total trips, within each truck weight class, in each trip duration or trip distance category. The trip duration and trip distance categories are consistent with NPTS reporting categories. Splits between urban and rural travel are presented in the same format for each truck weight class. All trips with definitive start and stop times are included in these summaries (Phase II data).

Travel distributions by highway functional class are presented as average speed in several classifications. These classifications include percent time of total travel by highway functional class, by urban or rural area, and by weight class. The highway functional class summaries are based on the map-matched results resulting from the process described in Appendix C. Both the Phase I and the Phase II data were used in the map-matching analysis.

Speed summaries are presented as “profiles” based on percentage of VMT in each speed bin, with speed bins defined in 5-mph intervals as 2.5 to 7.5 mph, 7.5 to 12.5 mph, up to 72.5 to 77.5 mph, and greater than 77.5. (These are the bins used in the Burden program.) VMT is quantified using the point-to-point GPS-measured (latitude-longitude) positions. The 0 to 2.5 speed bin is excluded because, even when vehicles had GPS speed measurement equal to zero, errors in the position measurement can result in substantial cumulative point-to-point displacement. In general, GPS data points with speeds less than 2.5 mph are assumed to be engine idling. Any VMT accumulated at these speeds is expected to be a small contribution to the overall speed profile.

These results should not be interpreted as representative of a particular weight class and geographic location combination. The results should be regarded as an “opportunity sample,” including only those vehicles belonging to organizations that were contacted and were willing to participate in this study. The results are descriptive of the sample collected in this project and may not be descriptive of HDT activity in California.

4.3 Location of Travel

The location of the travel was inferred by mapping the GPS position data on the GIS maps. By identifying the location (latitude and longitude) of the activity, the travel information can be described in terms of the individual geographic regions, air basins, urban areas, or any other geographic quantity defined in the GIS. The principal limitation is the amount of activity data collected within the geographical area.

Additional location information was developed by matching the GPS data points to specific roadways in the GIS maps[6]. This process allows summary information, such as speed profiles, to be developed for each highway functional class (as defined within the GIS) in addition to a defined geographic area as described above.

4.4 Comparisons of Accumulated Travel

4.4.1 Travel Time

Travel time and distance are obviously related, but differing drive cycles and idle patterns make a separate discussion of travel duration and distance worthwhile. Figure 7 shows the distribution of the travel distance and duration for the Phase II data set (only trips of less than 300 miles and

[6]Appendix C describes the map-matching process and defines the values used in analyses based on highway functional class.

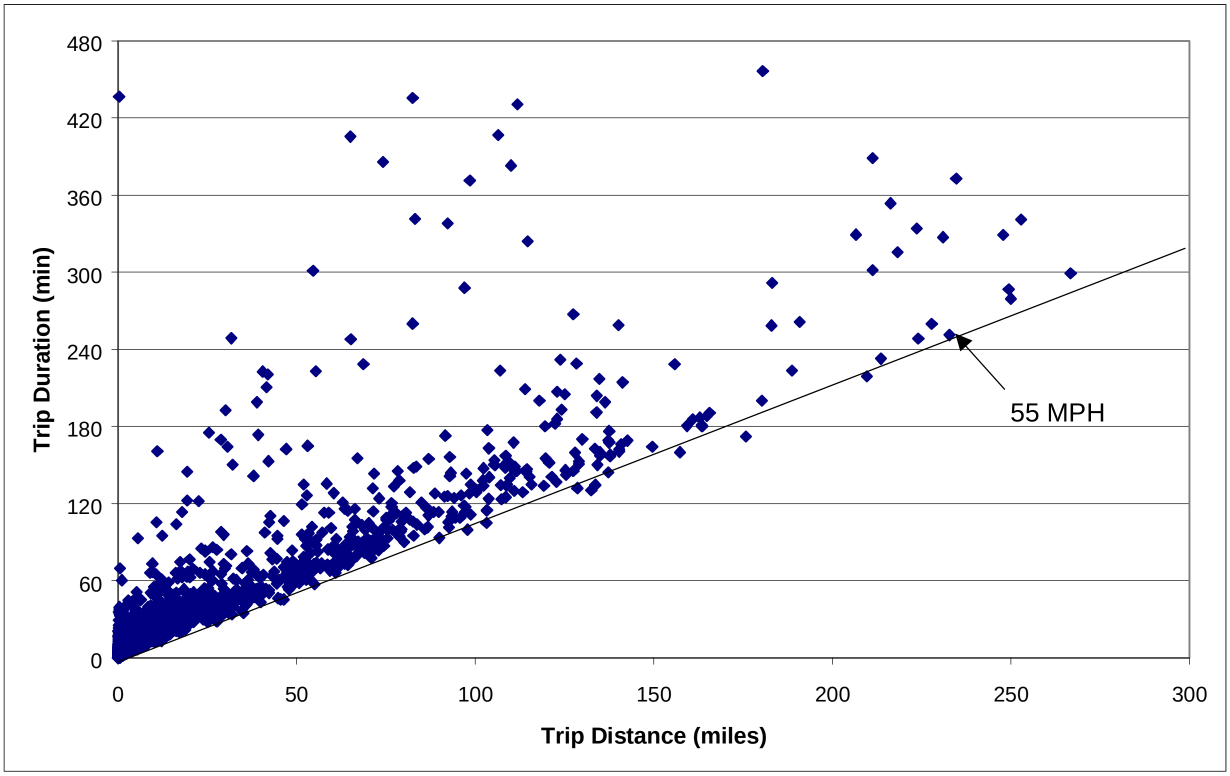


Figure 7. Trip Distance Versus Duration

8 hours are shown). Each point represents the distance and duration of a single trip. The trip duration is from the engine start time to the engine off time. The line shown corresponds to an average trip speed of approximately 55 mph. Since the number of postal/parcel vehicles in the T4 to T6 weight classes are significant in this sample, there is a high concentration of trips with a relatively short distance and duration.

Most of the travel activity involved trips less than 150 miles. In general, the longest trips (greater than 150 miles) can be attributed to vehicles in the T7 and T8 weight classes. However, trips less than 150 miles contain substantial contributions from all truck weight classes.

Figure 8 shows the trip duration by 10 minute bins and the trip count as a percentage of the total number of trips for each truck weight group. The figure indicates similar patterns between the first three weight groups. T7s and T8s are similar and more widely distributed among the bins with approximately 40 percent of all trips having a duration of less than 10 minutes, and nearly thirty percent of all trips lasting longer than 50 minutes.

Separating each trip by its starting location can make a further distinction. Figure 9 shows the contribution of urban and rural trips in each bin. Each chart in the figure represents a different weight class. This figure shows that trips beginning in urban areas are a majority of all trips except in two cases – T7 and T8 weight classes for trips exceeding 50 minutes in duration. In these two instances, trips beginning in rural areas are the majority.

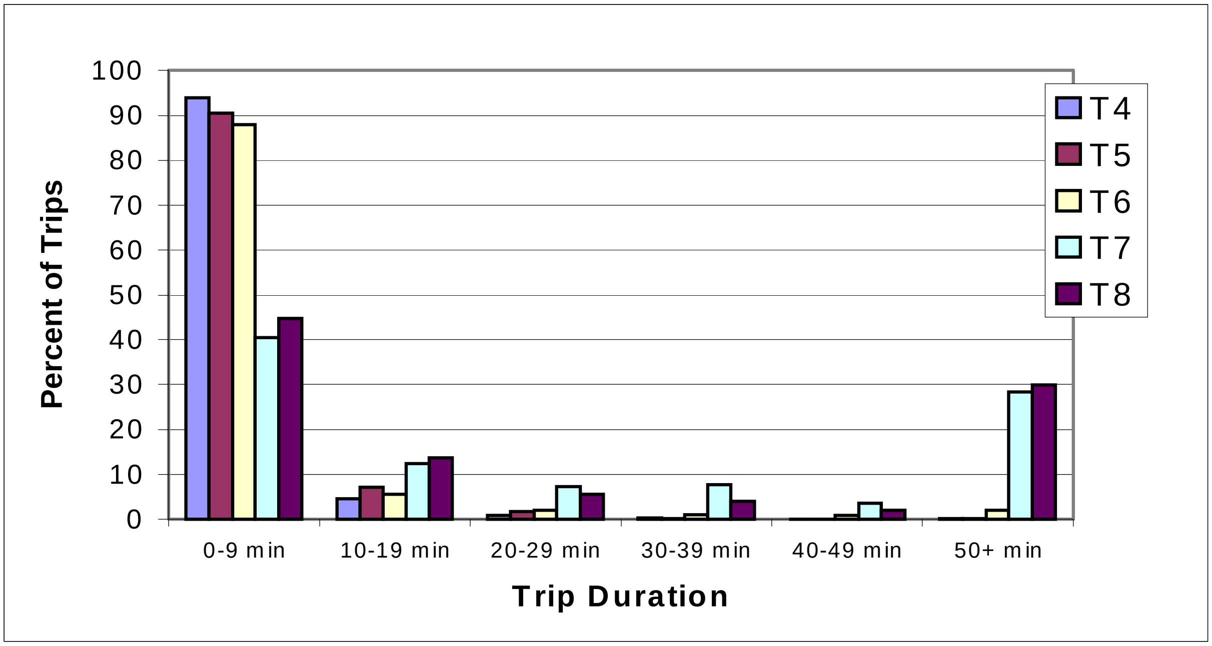


Figure 8. Distribution of Trip Duration by Weight Class

The distribution is weighted by the total number of trips accumulated in each truck weight class. Therefore those business uses (i.e., postal/parcel – T4, T5, and T6 distributions) that constitute a larger portion of the number of trips clearly dominate the distributions for their weight class. These durations also include idle time incurred during the trip. (Idle time includes all 0-2.5 mph activity, which includes very short idle contribution from on-road driving.) The inclusion of idle time may also skew the trip duration results since trips initiated in an urban area could be expected to incur more idle time than a trip initiated in a rural area.

4.4.2 Trip Distance

Figure 10 shows the trip distance contribution as a percent of all trips for each truck weight class. This distribution displays characteristics very similar to the trip duration distribution (Figure 8). This result is expected based on the strong correlation between trip distance and duration displayed in Figure 7.

4.4.3 Travel by Highway Functional Class

The highway functional classes (FC), as defined in the GIS base map, include:

- FC 1 – Primary Highway, Including Limited Access Highways
- FC 2 – Primary Road, Without Limited Access Highways
- FC 3 – Secondary and Connecting Roads
- FC 4 – Local, Neighborhood, and Rural Roads
- FC 5 – Access Ramps
- FC 6 – Other and Undefined Roads.

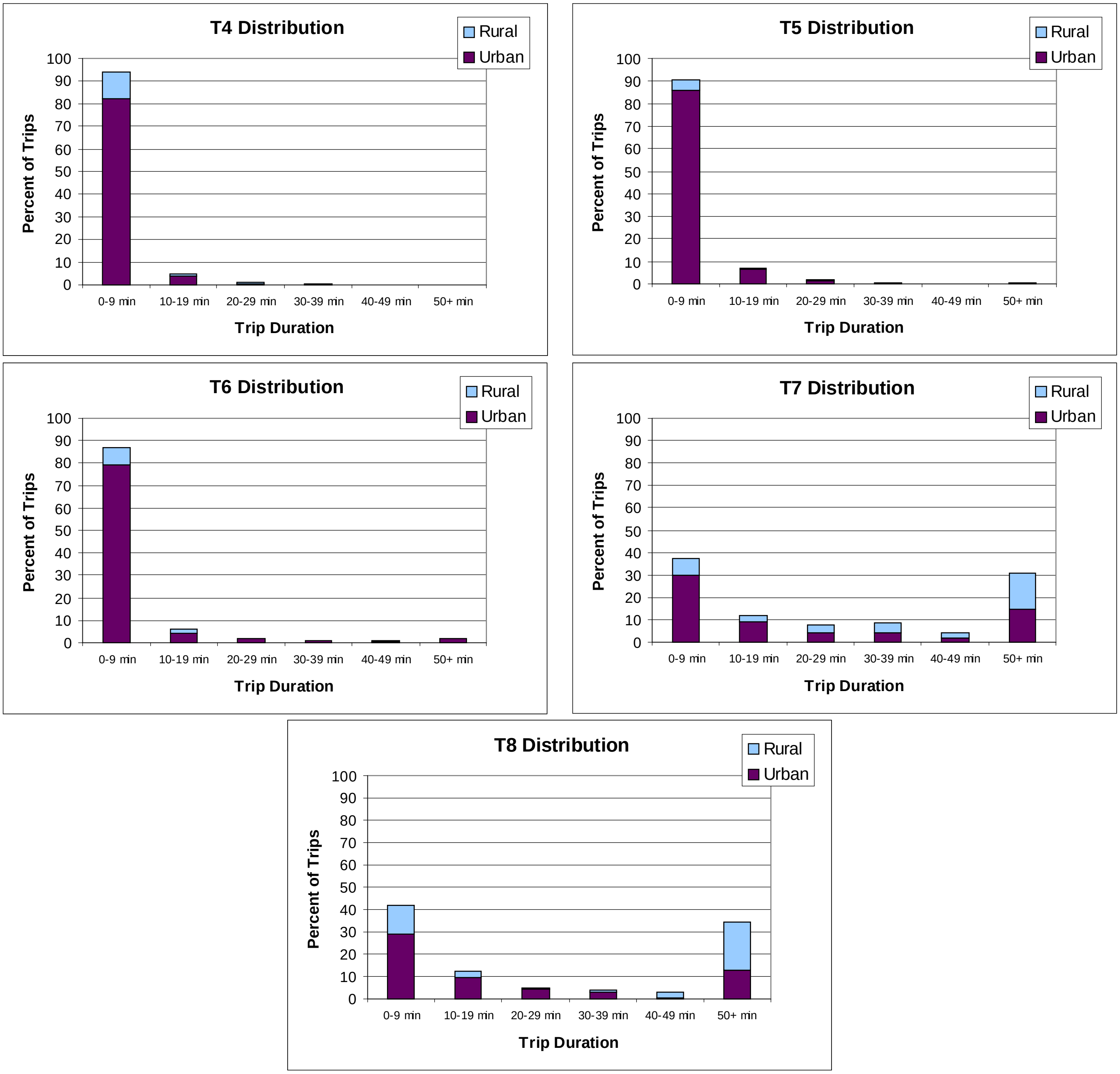


Figure 9. Trip Duration by Weight Class Distribution with Urban/Rural Starting Points

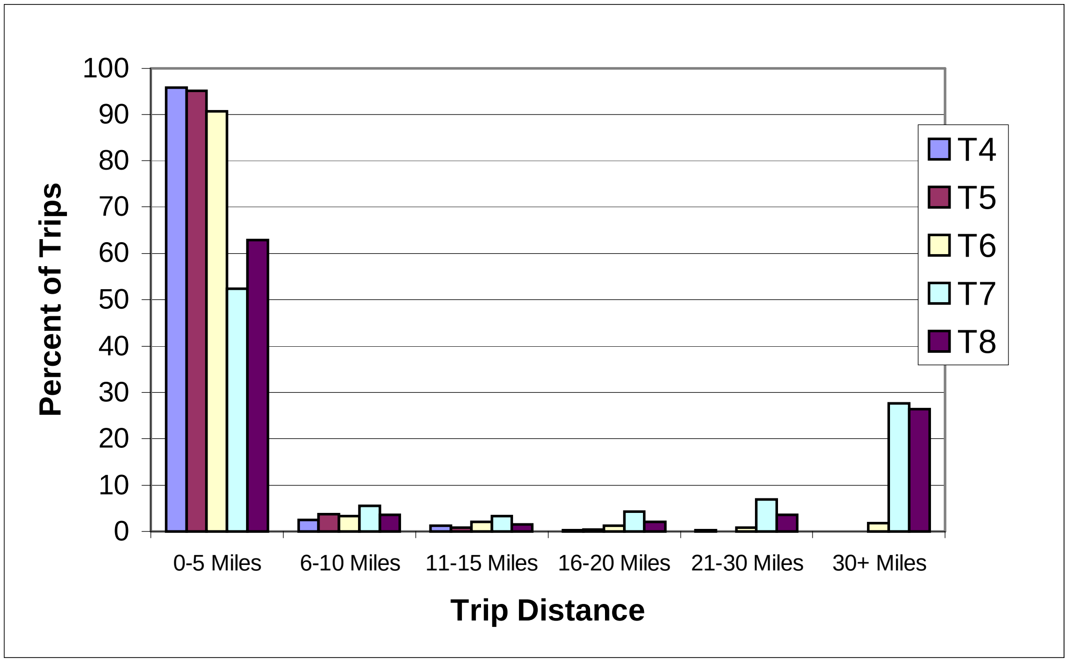


Figure 10. Distribution of Trip Distance by Weight Class

The base map used in this analysis was a subset of the Census Bureau's TIGER® data base. The highway functional classes, as referred to in this report, were defined by the Census Bureau Census Feature Class Codes (CFCCs). These classifications are different than the Federal Highway Administration definition of highway functional class. FC2, FC5 and FC6 are omitted in the subsequent analyses whenever the total VMT accumulated in one of these classifications is small (less than 100 miles). These three classifications are a small percentage of the total highway mileage included in the base map. Appendix C provides further discussion of the base map and the highway functional class definitions.

A further distinction to the functional classes is whether the travel occurred in urban or rural designations. While the highway functional class was defined via the map-matching analysis, the urban and rural designations were determined from the geographic features defined in the GIS base map.

The first comparison is average speed by functional class and weight group. Figure 11 shows there is significant variation across functional classes, but no obvious pattern between weight groups. The average speed is lower for the lower functional classes, as expected. In addition, the average speeds estimated for the highest functional class (FC1) are somewhat lower than expected. This result may be due to the inclusion of idle time in the trip duration used in the calculation.

CARB currently uses six time periods, called planning periods, to account for changes in ambient temperatures and activity levels when modeling engine emissions. Figure 12 shows average speed for these six planning periods (time of day). All truck weight classes are combined in Figure 12. FC1 varies only approximately 5 mph overall, with the higher average speeds between 6 a.m. and 3 p.m. FC2 shows its lowest speed in 6 a.m. to 9 a.m. and its highest

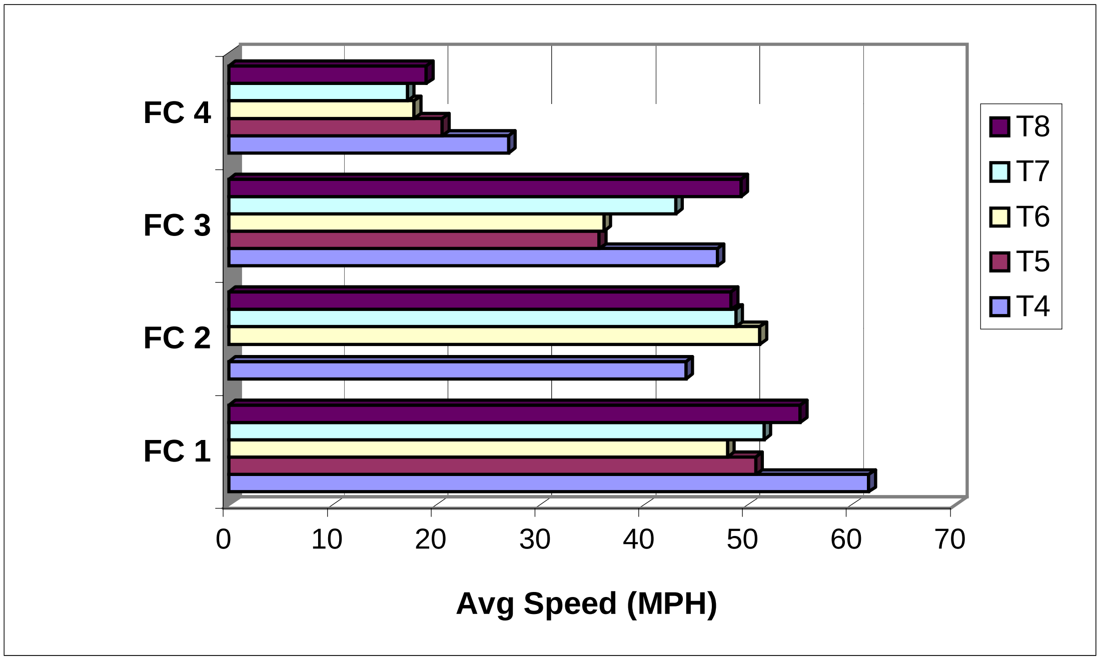


Figure 11. Average Speed by Functional Class and Weight Class

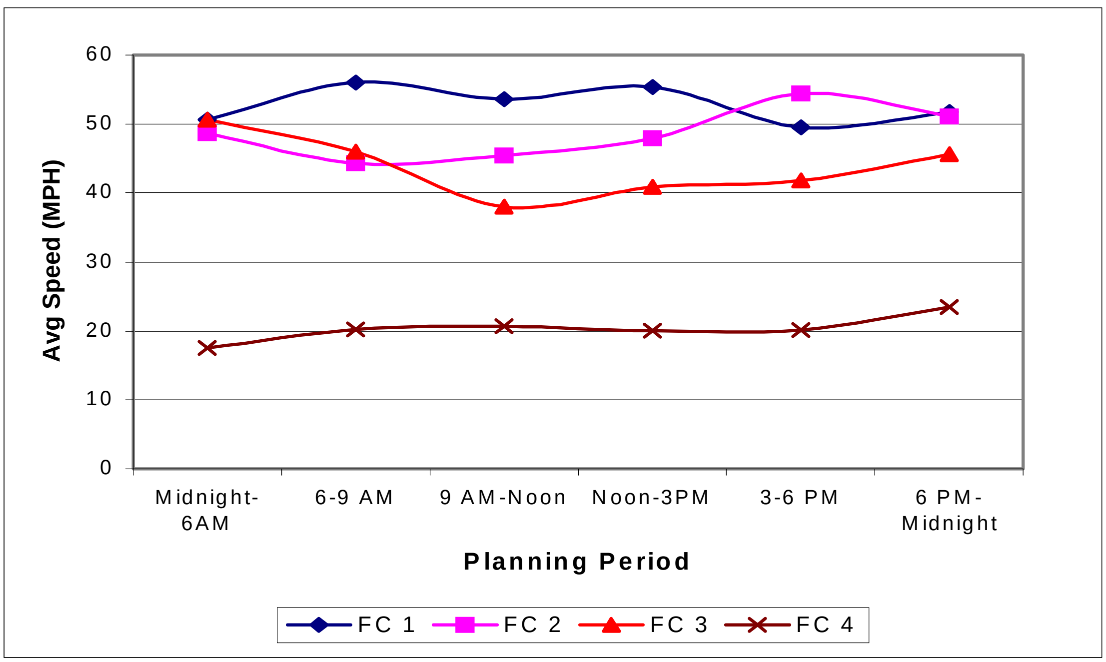


Figure 12. Average Speed by Functional Class
For All Weight Classifications by Period of Day

speed in 3 p.m. to 6 p.m. FC3 shows the widest variation in average speeds, approximately 12-15 mph. The highest speed is midnight to 6 a.m. and lowest speeds occur during 9 a.m. to 6 p.m. FC4 average speeds are relatively steady throughout the day, with a slight increase shown between 6 p.m. and midnight.

Figure 13 presents the percent time of travel per highway functional class (urban and rural) for each weight class. The sample in the lower weight classes (T4, T5, and T6) is dominated by parcel/postal delivery trucks, thus their travel time is predominantly urban and on local roads (FC4). The heavier weight classes (T7 and T8) spend approximately one-half of their travel time on rural roads and their total travel time is more widely distributed over the highway functional classes.

4.5 Speed Profiles of Travel (5 mph bins)

Vehicle speed affects emissions. In the past, due to lack of data, the same vehicle speed profiles have been assumed for all vehicle classes. Recently, CARB emissions models (Burden/EMFAC) have been updated with the capability to incorporate speed profiles that vary by vehicle class and county.

In the past, Caltrans has used a combination of traffic counts on some urban freeways and the Highway Performance Monitoring System (HPMS) Model to estimate average vehicle speed. In this project, GPS recorded the speed of each vehicle monitored – wherever it traveled. This chapter summarizes the speed profiles observed by weight class and by geographic location. Location was categorized by region, air basin, and urban area. Using a map-matching algorithm, speed profiles are also summarized by highway functional class or roadway type. The GPS data permit characterization of the speed profiles by county; however, it is not summarized here due to the small amounts of data collected in each county.

4.5.1 Speed Profiles by Weight Class

Figure 14 shows the speed profiles for the combined Phase I and Phase II sample data, by truck weight class. In general, the speed profiles agree with intuitive knowledge of truck activity. The heavier trucks (T7 and T8) accumulate a large fraction of their mileage at higher speeds (50 to 65 mph). Lighter trucks (T4 and T5) show a more evenly distributed profile with significant portions of their mileage accumulated at speeds less than 45 mph.

4.5.2 Speed Profiles by Region

Table 14 displays the speed profiles by truck weight class as percentages of VMT in each region, and aggregated across regions. The different regions are defined in Section 2. Only combinations of weight class and region for which at least 200 miles were recorded are presented in Table 14. For example, insufficient data were collected on T4 trucks in Region 1, and T5 trucks in Regions 1 and 4, and are not reflected in these results.

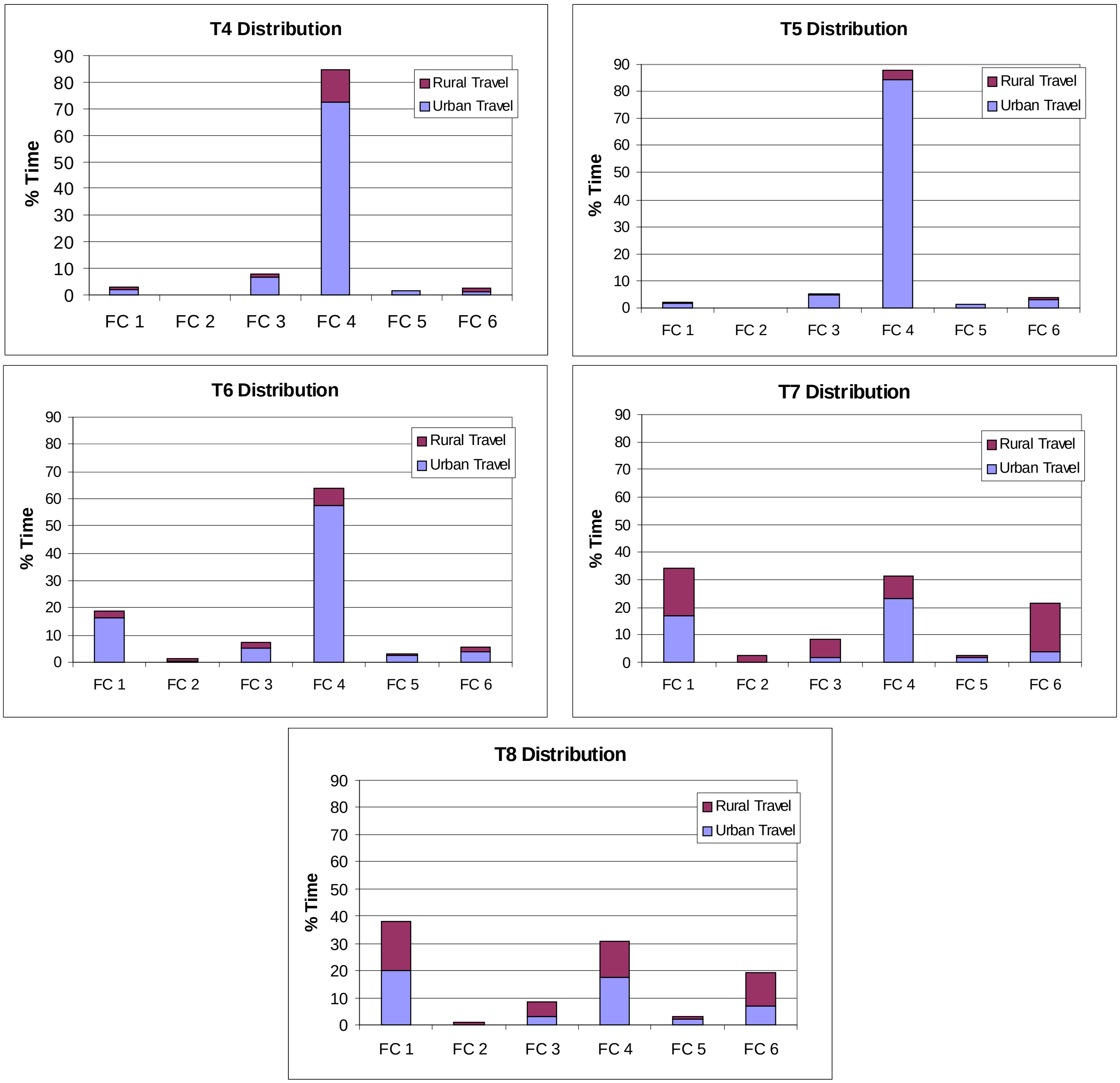


Figure 13. Travel Time Distribution by Functional Class And Weight Class for Urban and Rural Travel

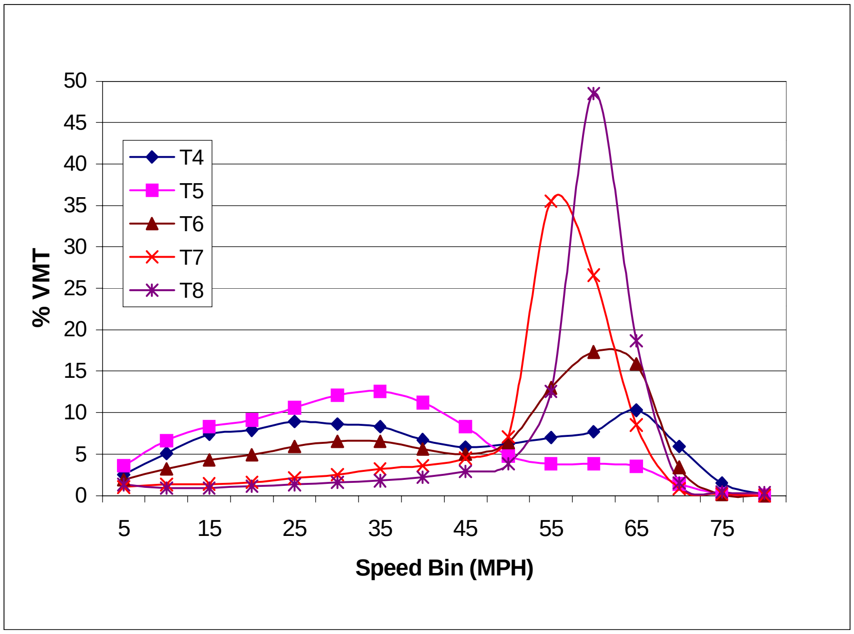


Figure 14. Speed Profiles by Weight Class

For illustration, Figure 15 and Figure 16 display this information for Regions 1 and 2. These figures display percentages of VMT recorded in each of several speed bins, separately for each of the five truck weight classes (where sufficient data was recorded to warrant display). Figure 16 shows that for higher weight classes, greater percentages of miles were traveled at higher speeds. However, Figure 15 illustrates that in Region 1, T7 vehicles exhibited lower percentages of VMT traveled at highway speeds than the T6 and T8 vehicles.

For T4 trucks, data were recorded for Regions 2, 3, and 4 (insufficient data were obtained in Region 1). The most notable distinction in these speed profiles was that trucks in Region 3 traveled a greater percentage of VMT at higher speeds (Table 14). Specifically, the percentage of VMT recorded between 62.5 and 72.5 mph in Region 3 was well over three times that observed in Regions 2 and 4. Since Region 3 represents the San Joaquin Valley and Sacramento Valley, this observation makes intuitive sense.

Travel by T5 vehicles was only recorded in Regions 2 and 3, and there was little notable difference in speed profiles across these regions.

The greatest percentage of "high-speed" travel (across all weight classes) was observed in Region 1 (San Francisco area) on T6 vehicles. In this region, 47 percent of the T6 VMT was traveled at speeds between 62.5 and 67.5 miles per hour. However, the total number of trucks associated with this observation is small and may not be representative.

There is a clear difference between the speed profiles of the lighter heavy-duty trucks (T4 and T5) and the heavier ones (T6, T7, and T8). The heavier vehicles travel more miles at greater speeds. This would generally be expected, but it is even less surprising because the majority of the lighter trucks represented in this sample are delivery trucks (postal/parcel business use).

Table 14. Speed Profiles by Weight Class and Geographic Region

Weight Category	Region	Total # Trucks	Total # Trips	Total VMT	2.5-7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5	27.5-32.5	32.5-37.5	37.5-42.5	42.5-47.5	47.5-52.5	52.5-57.5	57.5-62.5	62.5-67.5	67.5-72.5	72.5-77.5	>77.5
T4	2	9	771	626	3.0	6.4	9.6	10.2	11.1	10.8	10.9	8.1	6.1	5.0	4.7	4.8	4.8	3.6	0.8	0.1
	3	9	810	1,428	2.1	4.1	5.8	6.2	7.5	7.3	7.1	6.2	5.8	6.3	7.8	9.5	14.6	8.0	1.5	0.2
	4	3	542	384	2.9	6.8	9.8	10.4	10.4	9.4	8.6	6.3	5.2	7.7	8.2	6.1	3.7	2.2	2.5	0.1
T4 TOTAL		19	2,124	2,456	2.5	5.1	7.4	7.9	8.9	8.6	8.3	6.7	5.8	6.2	7.0	7.7	10.3	5.9	1.5	0.1
T5	2	12	1,009	869	4.3	7.1	9.2	10.0	11.1	12.3	12.8	10.9	7.1	4.9	3.4	3.0	2.0	1.4	0.3	0.0
	3	4	514	612	2.5	5.8	7.1	7.9	9.9	11.7	12.4	11.7	10.0	4.8	4.3	4.9	5.7	1.4	0.0	0.0
T5 TOTAL		16	1,523	1,484	3.6	6.6	8.3	9.1	10.6	12.1	12.6	11.2	8.3	4.8	3.8	3.8	3.5	1.4	0.2	0.0
T6	1	3	22	666	6.3	2.6	2.3	1.9	2.2	2.2	2.4	2.3	2.2	2.3	5.7	14.1	46.9	6.0	0.0	0.7
	2	17	1,139	2,988	1.4	2.5	3.3	3.9	5.0	6.1	6.8	5.8	4.8	6.0	15.9	22.7	13.8	1.9	0.2	0.0
	3	3	185	581	0.7	2.1	3.1	3.9	3.8	3.8	3.4	2.9	3.1	8.8	14.5	21.2	23.8	5.0	0.0	0.0
	4	12	2,770	3,937	1.8	4.2	6.2	6.7	7.9	8.1	7.5	6.3	6.1	7.3	10.3	10.5	12.1	4.7	0.1	0.0
T6 TOTAL		32	4,100	10,182	1.9	3.2	4.3	4.9	5.9	6.5	6.5	5.6	5.0	6.4	13.0	17.3	15.9	3.4	0.1	0.0
T7	1	27	518	11,012	2.3	2.1	2.2	2.4	2.7	2.8	3.3	3.7	4.5	7.9	31.7	25.0	7.7	1.1	0.3	0.1
	2	13	253	6,624	0.7	1.1	1.1	1.3	1.8	2.3	2.8	3.3	4.8	8.6	26.6	41.8	3.6	0.1	0.0	0.0
	3	36	985	19,581	0.7	1.2	1.3	1.5	2.0	2.4	3.1	3.5	3.9	5.4	44.4	24.2	6.0	0.3	0.0	0.0
	4	25	199	5,163	0.4	0.5	0.6	0.9	1.6	2.5	4.0	5.0	7.1	11.7	32.4	26.8	6.2	0.2	0.0	0.0
T7 TOTAL		47	1,760	44,838	1.0	1.3	1.4	1.6	2.1	2.5	3.2	3.6	4.5	7.1	35.5	26.6	8.5	0.8	0.2	0.0
T8	1	12	182	3,454	1.5	1.7	1.7	1.8	2.3	2.6	2.9	3.1	4.3	6.3	17.8	35.7	17.1	0.8	0.2	0.0
	2	7	57	4,580	1.0	0.6	0.7	0.9	1.4	1.6	2.0	2.7	3.6	5.6	17.0	46.9	14.1	1.6	0.2	0.0
	3	25	452	18,661	1.3	0.8	0.8	0.9	1.1	1.3	1.5	1.9	2.3	2.7	10.3	52.6	19.9	1.7	0.6	0.5
	4	5	21	982	0.4	0.4	0.9	1.3	1.8	4.1	4.1	3.7	6.1	8.6	17.2	28.9	21.2	1.4	0.0	0.0
T8 TOTAL		25	620	27,828	1.3	0.9	0.9	1.1	1.3	1.6	1.8	2.2	2.9	3.8	12.6	48.5	18.7	1.8	0.4	0.3

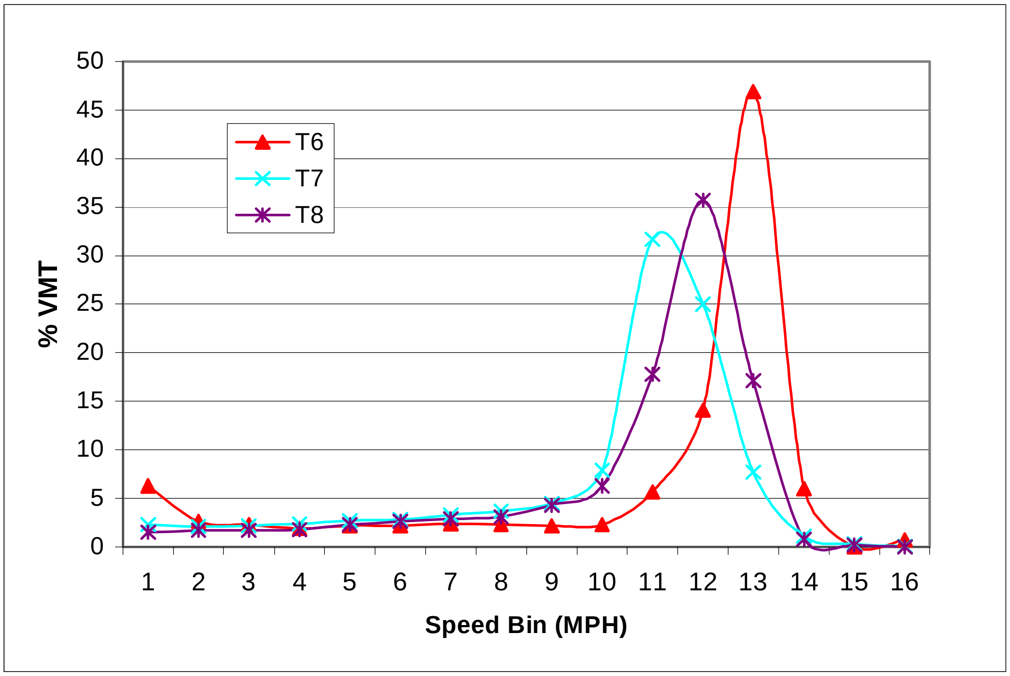


Figure 15. Speed Profiles by Weight Class in Region 1

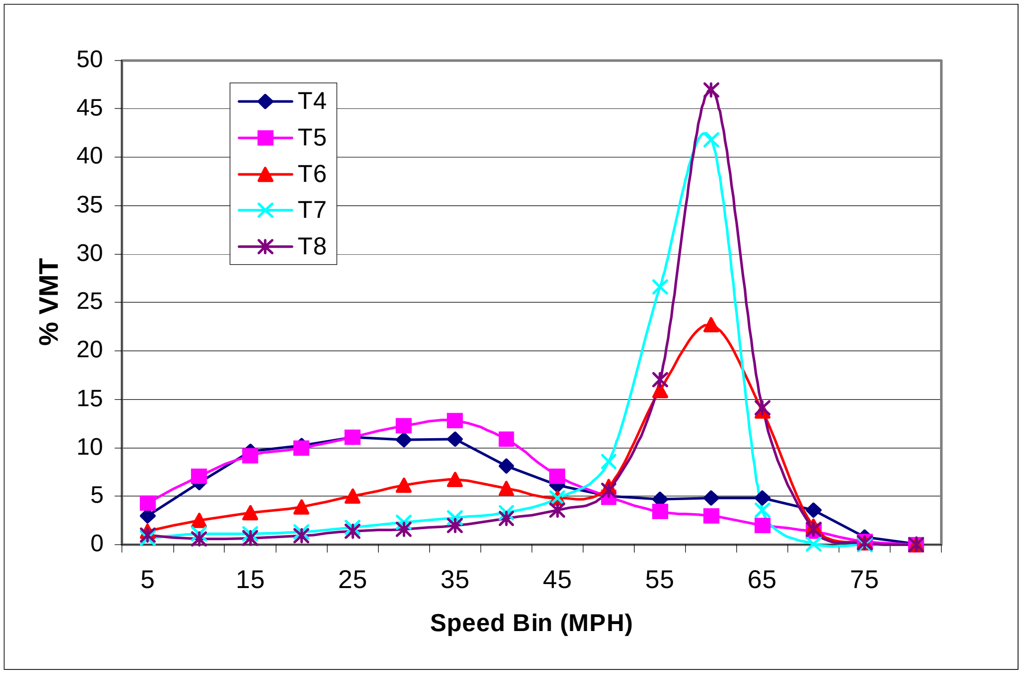


Figure 16. Speed Profiles by Weight Class in Region 2

4.5.3 Speed Profiles by Air Basin

Table 15 is similar in structure to Table 14, but with region replaced by air basin. Only combinations of vehicle weight class and air basin containing more than 200 VMT are included in Table 15. For each air basin, vehicles in the T4 and T5 weight classes traveled the majority of their VMT under 42.5 miles per hour, and there was little distinction in these speed profiles across air basins. In contrast, more than half of the miles traveled by T7 and T8 vehicles occurred between 52.5 and 62.5 miles per hour.

Figure 17 and Figure 18 illustrate these speed profiles across air basins for T4 and T5 vehicles, respectively, for the air basins where more than 200 VMT were collected. Interestingly, these figures show there was little variation in the speed profiles from one air basin to another.

4.5.4 Speed Profiles by Urban Area and Urban Versus Rural

Table 16 displays speed profiles by urban area. Disaggregating the data to this level results in substantial thinning of the data. Only those urban areas for which 200 VMT were accumulated were included in this table. For example, although T4 vehicles were monitored in 12 urban areas, profiles are provided for only two of these urban areas, where greater than 200 VMT were recorded.

Figure 19 shows the recorded speed profiles observed on T4 and T6 vehicles, respectively, in the urban areas with the most VMT recorded. There are differences between the speed profiles in these urban areas. In particular, for T6 vehicles, greater percentages of VMT were observed at speeds between 10 and 45 mph in Salinas and Monterey than in the other urban areas (Los Angeles and San Diego), where greater percentages of VMT were observed at highway speeds.

Table 17 shows the difference in speed profiles between travel conducted in urban and rural areas. Travel through all urban areas is included, whether 200 VMT were recorded or not, and aggregated to obtain the "urban" speed profile. Figure 20 shows aggregated speed profiles for urban and rural travel observed on T4 and T6 vehicles. The graphs indicate that a greater percent of activity is at higher speeds when traveling in rural areas.

4.5.5 Speed Profiles by Functional Class

Table 18 displays speed profiles by vehicle weight class and highway functional class[7]. The highway functional classes (FC), as defined in the GIS base map, include:

- FC1 – Primary Highway, Including Limited Access Highways
- FC2 – Primary Road, Without Limited Access Highways
- FC3 – Secondary and Connecting Roads
- FC4 – Local, Neighborhood, and Rural Roads
- FC5 – Access Ramps
- FC6 – Other and Undefined Roads.

[7]Appendix C describes the map-matching process and defines the values used in analyses based on highway functional class.

Weight Category	Air Basin	Total # Trucks	Total # Trips	Total VMT	2.5-7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5	27.5-32.5	32.5-37.5	37.5-42.5	42.5-47.5	47.5-52.5	52.5-57.5	57.5-62.5	62.5-67.5	67.5-72.5	72.5-77.5	>77.5
T4	North Central Coast	3	541	384	2.9	6.8	9.8	10.4	10.4	9.4	8.6	6.3	5.2	7.7	8.2	6.1	3.7	2.2	2.5	0.1
	Sacramento Valley	9	810	1,118	2.3	4.6	6.4	6.9	8.7	8.5	8.2	7.3	6.8	7.4	8.4	7.6	9.1	6.4	1.1	0.1
	San Diego County	4	610	464	2.6	6.0	9.7	10.1	10.1	9.3	8.6	6.3	6.7	6.4	6.1	6.1	6.0	4.7	1.1	0.2
	San Joaquin Valley	2	3	310	1.5	2.7	3.5	3.4	3.1	2.8	2.7	2.1	2.0	2.4	5.8	16.5	34.4	13.6	3.2	0.3
T5	Sacramento Valley	4	514	612	2.5	5.8	7.1	7.9	9.9	11.7	12.4	11.7	10.0	4.8	4.3	4.9	5.7	1.4	0.0	0.0
	San Diego County	6	446	342	4.0	8.1	10.3	9.7	9.7	9.6	9.9	7.8	7.2	6.4	5.5	4.1	3.3	3.4	0.8	0.1
	South Coast	6	563	528	4.6	6.4	8.5	10.2	12.0	14.1	14.7	13.0	7.1	3.8	2.0	2.2	1.2	0.1	0.0	0.0
T6	North Central Coast	11	2,725	3,601	2.0	4.5	6.7	7.2	8.4	8.6	8.0	6.8	6.6	7.7	10.8	10.4	10.1	2.2	0.1	0.0
	Northeast Plateau	1	45	337	0.5	1.6	1.5	1.5	2.2	2.9	2.6	1.1	1.3	2.6	5.6	11.0	33.4	31.8	0.5	0.0
	Sacramento Valley	3	185	581	0.7	2.1	3.1	3.9	3.8	3.8	3.4	2.9	3.1	8.8	14.5	21.2	23.8	5.0	0.0	0.0
	San Diego County	9	663	1,423	1.7	3.3	4.2	4.4	5.1	5.8	6.3	5.6	5.1	6.5	16.1	18.4	12.0	4.9	0.6	0.0
	San Francisco Bay	3	22	666	6.3	2.6	2.3	1.9	2.2	2.2	2.4	2.3	2.2	2.3	5.7	14.1	46.9	6.0	0.0	0.7
	South Coast	11	480	3,476	1.3	2.2	2.9	3.8	5.1	6.3	6.9	5.9	4.7	5.8	15.7	24.3	14.2	0.7	0.0	0.0
T7	Great Basin Valley	1	5	243	0.3	0.3	0.3	0.5	0.9	1.1	0.9	1.0	1.9	2.0	10.3	52.7	27.4	0.3	0.0	0.0
	Southeast Desert	2	12	538	0.1	0.1	0.2	0.2	0.5	0.6	0.7	1.6	4.1	6.4	32.5	44.6	8.4	0.2	0.0	0.0
	Mountain Countries	14	86	2,683	0.3	0.3	0.4	0.7	1.7	3.0	4.6	6.6	10.5	16.4	32.9	18.4	3.9	0.3	0.0	0.0
	North Central Coast	13	81	1,580	0.6	0.8	1.0	1.3	1.7	2.0	3.0	3.0	3.6	7.4	26.0	40.2	9.4	0.1	0.0	0.0
	North Coast	2	9	211	0.2	0.4	0.5	0.5	0.5	1.0	1.0	0.8	1.3	4.2	57.4	31.0	1.2	0.0	0.0	0.0
	Northeast Plateau	3	12	330	0.3	0.7	0.4	0.5	0.6	0.5	1.6	2.1	1.9	6.1	67.3	17.9	0.2	0.0	0.0	0.0
	Sacramento Valley	32	767	12,035	0.9	1.6	1.8	2.1	2.6	3.1	4.0	4.5	5.0	6.8	49.5	14.2	3.8	0.2	0.0	0.0
	Salton Sea	2	27	759	0.5	0.6	0.5	0.6	0.9	1.5	2.0	3.3	8.3	12.5	32.6	34.6	2.2	0.0	0.0	0.0
	San Diego County	2	6	283	0.4	0.2	0.3	0.4	0.6	0.6	1.3	1.0	3.1	8.3	33.7	45.4	4.6	0.1	0.0	0.0
	San Francisco Bay	27	518	11,012	2.3	2.1	2.2	2.4	2.7	2.8	3.3	3.7	4.5	7.9	31.7	25.0	7.7	1.1	0.3	0.1
	San Joaquin Valley	25	274	7,546	0.4	0.5	0.5	0.7	1.0	1.4	1.8	2.0	2.3	3.0	36.3	40.3	9.5	0.5	0.0	0.0
	South Central Coast	3	17	415	0.5	0.4	0.5	0.5	1.1	1.0	1.6	1.9	2.3	9.7	37.9	38.5	3.7	0.2	0.0	0.0
	South Coast	12	209	4,629	0.8	1.4	1.5	1.6	2.3	2.8	3.5	3.8	4.7	8.1	23.4	42.7	3.2	0.1	0.0	0.0
T8	Southeast Desert	4	12	586	0.2	0.2	0.4	0.5	1.0	1.6	2.7	2.7	4.0	6.4	18.6	53.2	7.8	0.6	0.0	0.1
	Mountain Counties	3	12	756	0.3	0.2	0.7	0.9	1.4	3.4	2.4	2.4	5.2	7.6	17.3	30.5	26.1	1.7	0.0	0.0
	Sacramento Valley	16	185	5,542	0.7	0.6	0.6	0.7	1.0	1.1	1.4	1.4	1.7	2.2	8.9	50.1	27.6	2.1	0.0	0.0
	Salton Sea	4	12	766	0.3	0.3	0.4	0.5	0.6	0.8	1.4	1.4	1.8	3.1	19.9	49.4	19.0	1.0	0.0	0.0
	San Francisco Bay	12	182	3,454	1.7	1.7	1.7	1.8	2.3	2.6	3.1	3.1	4.3	6.3	17.8	35.7	17.1	0.8	0.2	0.0
	San Joaquin Valley	23	316	13,119	1.6	0.9	0.8	1.0	1.1	1.4	2.1	2.1	2.5	2.9	11.0	53.6	16.6	1.5	0.8	0.7
	South Central Coast	2	6	306	1.3	0.9	1.1	1.2	1.3	1.6	1.8	1.8	5.4	6.8	12.8	40.2	22.2	1.8	0.0	0.00
	South Coast	7	42	2,903	1.3	0.8	0.9	1.1	1.7	1.9	3.2	3.2	3.8	6.0	16.4	45.4	13.3	1.9	0.3	0.1

Table 15. Speed Profiles by Weight Class and Air Basin

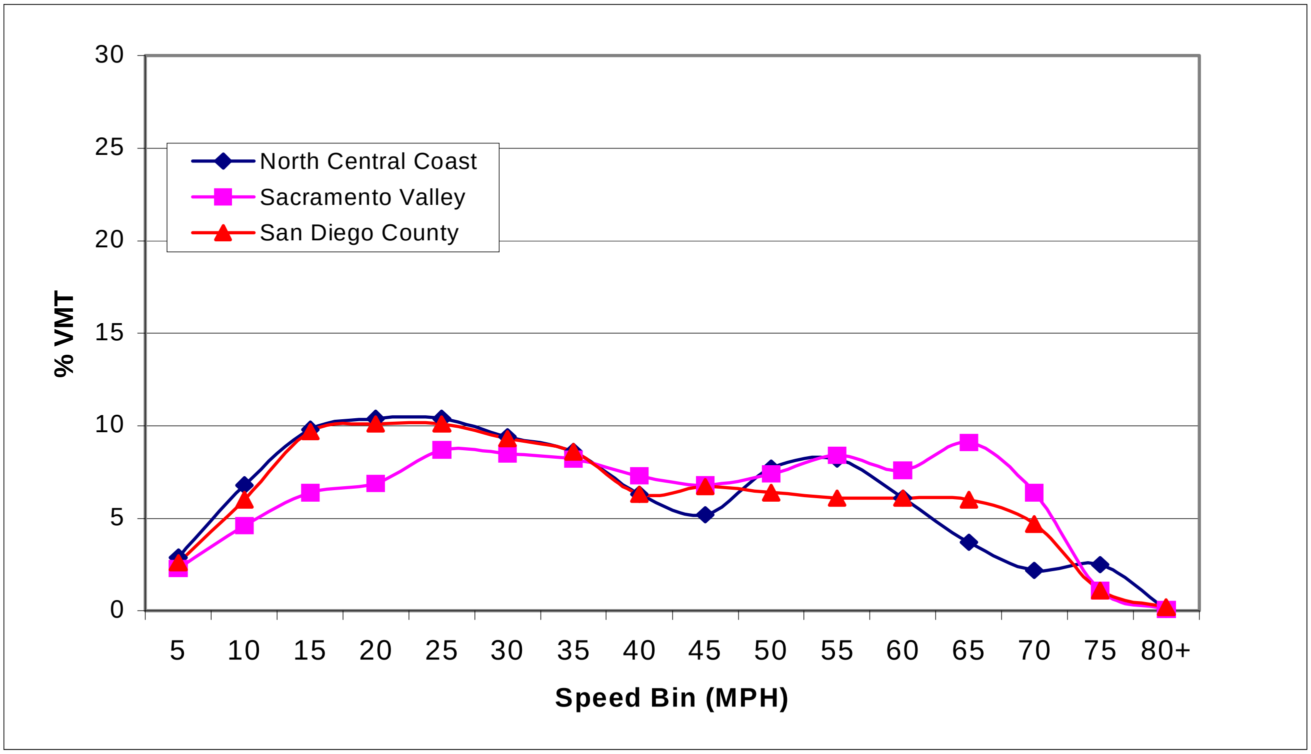


Figure 17. Speed Profiles for T4 Vehicles (8,501 to 10,000 lbs.) in Three Air Basins

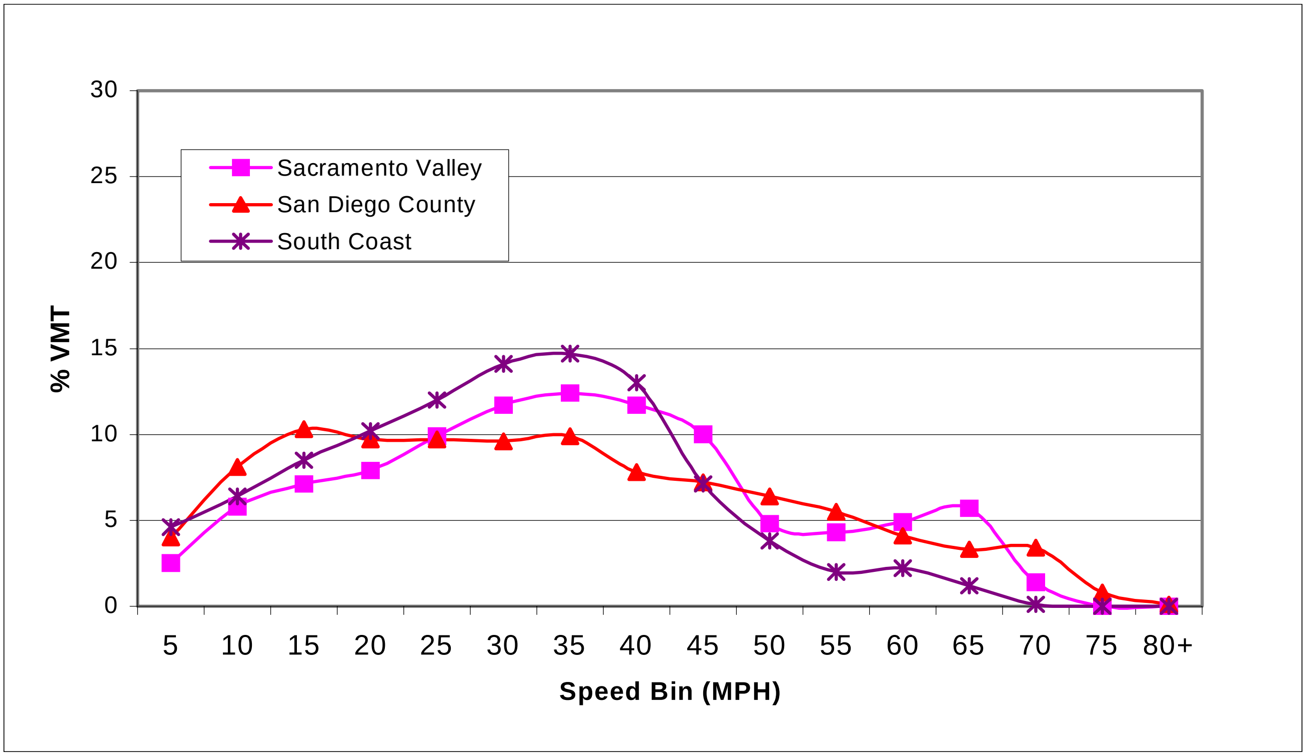


Figure 18. Speed Profiles for T5 Vehicles (10,000 to 14,000 lbs.) in Three Air Basins

Weight Category	Urban Area	Total # Trucks	Total # Trips	Total VMT	2.5-7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5	27.5-32.5	32.5-37.5	37.5-42.5	42.5-47.5	47.5-52.5	52.5-57.5	57.5-62.5	62.5-67.5	67.5-72.5	72.5-77.5	>77.5
T4	San Diego	4	607	456	2.6	6.2	10.0	10.4	10.3	9.6	8.5	6.2	6.4	5.8	5.8	6.2	6.1	4.7	1.1	0.2
	Redding	4	359	427	2.8	5.6	7.5	7.6	9.0	8.6	7.5	6.1	7.0	8.5	9.3	8.9	8.5	2.6	0.4	0.0
T5	Los Angeles	6	563	528	4.6	6.4	8.5	10.2	12.0	14.1	14.7	13.0	7.1	3.8	2.0	2.2	1.2	0.1	0.0	0.0
	San Diego	6	420	319	4.1	8.2	10.4	9.7	9.8	9.8	9.9	7.4	6.7	6.3	5.2	4.3	3.6	3.7	0.9	0.1
	Chico	2	307	285	3.4	8.1	9.2	9.4	11.3	14.2	14.5	9.4	5.5	3.1	4.9	5.3	1.7	0.0	0.0	0.0
	Redding	2	195	242	1.9	4.5	5.7	6.6	8.9	10.2	10.1	10.8	9.5	6.0	4.2	5.7	12.3	3.5	0.0	0.0
T6	Los Angeles	11	445	2,976	1.4	2.4	3.2	4.2	5.5	6.9	7.5	6.5	5.1	6.3	15.9	22.4	11.9	0.8	0.0	0.0
	San Diego	9	626	1,255	1.8	3.6	4.6	4.7	5.5	6.4	6.8	5.9	5.2	6.2	15.7	17.0	10.9	5.2	0.6	0.0
	San Jose	2	17	431	1.1	1.6	1.9	1.8	2.4	2.8	3.0	2.5	2.2	2.6	5.4	14.3	50.7	7.6	0.0	0.0
	Riversice-San Bernardino	2	49	396	1.2	1.3	1.2	1.7	3.0	3.7	4.2	3.2	2.7	3.6	13.5	31.2	29.2	0.4	0.0	0.0
	Salinas	5	734	780	2.5	6.6	9.6	9.6	11.5	12.1	10.0	8.2	6.5	5.2	4.5	5.7	7.1	0.9	0.0	0.0
	Seaside-Monterey	11	1,948	1,415	3.1	6.6	10.0	10.8	12.0	11.9	10.2	7.8	6.5	6.3	6.9	4.5	2.8	0.3	0.1	0.0
T7	Los Angeles	12	193	3,446	0.9	1.6	1.8	1.9	2.5	3.1	3.6	3.6	4.2	7.3	22.0	44.4	3.1	0.1	0.0	0.0
	San Fran.-Oakland	27	388	5,869	3.7	3.2	3.3	3.4	3.7	3.8	4.1	4.1	4.5	7.8	25.6	22.9	7.8	1.5	0.5	0.2
	San jose	21	92	1,368	0.9	1.1	1.3	1.7	2.2	2.2	2.5	2.3	2.4	5.3	34.0	34.2	9.8	0.2	0.0	0.0
	Sacramento	31	680	5,674	1.6	2.8	3.2	3.7	4.7	5.4	6.6	7.2	7.1	8.6	32.0	12.7	4.4	0.2	0.0	0.0
	Riverside-San Bernardino	7	22	402	0.4	0.6	0.5	0.6	1.2	1.3	1.2	1.8	2.9	7.7	38.5	41.4	2.0	0.1	0.0	0.0
	Fresno	6	19	289	0.7	1.4	1.7	1.9	2.5	3.2	3.9	5.2	5.9	4.4	33.0	34.7	1.4	0.0	0.0	0.0
	Stockton	19	64	832	0.4	0.3	0.4	0.4	0.5	0.4	0.5	0.6	1.4	3.3	55.3	28.2	8.3	0.0	0.0	0.0
	Modesto	6	19	233	0.4	0.6	0.8	0.9	1.3	2.2	4.6	3.1	1.7	1.1	45.8	31.0	6.0	0.2	0.0	0.0
	Santa Rosa	4	34	284	0.7	1.8	1.5	2.0	2.2	2.0	1.9	2.5	3.8	6.0	52.3	21.6	1.7	0.0	0.0	0.0
	Seaside-Monterey	6	37	220	1.4	1.7	2.2	3.0	4.2	4.7	5.0	4.1	4.0	5.0	22.7	34.6	7.5	0.0	0.0	0.0
	Fairfield	17	81	715	0.9	0.8	0.7	0.8	0.7	0.9	1.2	1.9	3.3	7.8	52.1	22.0	5.0	1.5	0.3	0.0
	Vacaville	16	60	470	0.9	0.5	0.4	0.4	0.4	0.9	1.0	1.0	0.8	2.6	64.7	21.8	3.9	0.7	0.0	0.0
T8	Los Angeles	5	34	1,652	2.2	1.3	1.4	1.5	1.7	1.9	1.8	2.2	3.1	5.8	16.6	47.1	11.8	1.4	0.3	0.0
	San Fran.-Oakland	12	174	2,205	1.8	2.3	2.4	2.4	3.1	3.4	3.7	3.5	4.6	7.0	19.4	32.1	13.5	0.5	0.1	0.0
	Sacramento	14	139	1,910	1.2	1.1	1.0	1.4	1.7	2.1	2.5	2.2	2.4	2.7	10.1	50.5	21.1	0.2	0.0	0.0
	Fresno	10	57	595	6.9	1.7	0.9	0.8	1.2	1.1	1.1	1.5	0.9	1.0	6.5	51.7	21.7	1.8	0.9	0.2
	Bakersfield	8	111	1,132	7.0	3.5	2.6	2.5	2.6	3.4	3.4	4.6	4.9	4.9	11.6	42.4	5.6	0.5	0.1	0.2
	Stockton	16	65	913	0.4	0.4	0.4	0.7	0.5	0.4	0.4	0.6	1.5	3.2	15.2	57.1	18.7	0.5	0.0	0.0
	Modesto	12	59	778	0.3	0.6	0.8	0.9	1.4	1.7	2.6	4.0	4.8	3.0	8.2	58.1	12.2	1.3	0.0	0.0
	Fairfield	8	41	445	0.7	0.4	0.5	0.6	0.6	0.6	1.3	1.5	4.0	4.4	12.0	42.3	30.5	0.5	0.0	0.0
	Merced	11	38	280	0.4	0.6	0.3	0.5	0.4	0.6	0.9	1.0	1.0	2.2	12.8	66.6	12.0	0.7	0.0	0.0
	Vacaville	7	40	368	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.6	48.3	46.6	0.2	0.0	0.0

Table 16. Speed Profiles by Urban Areas

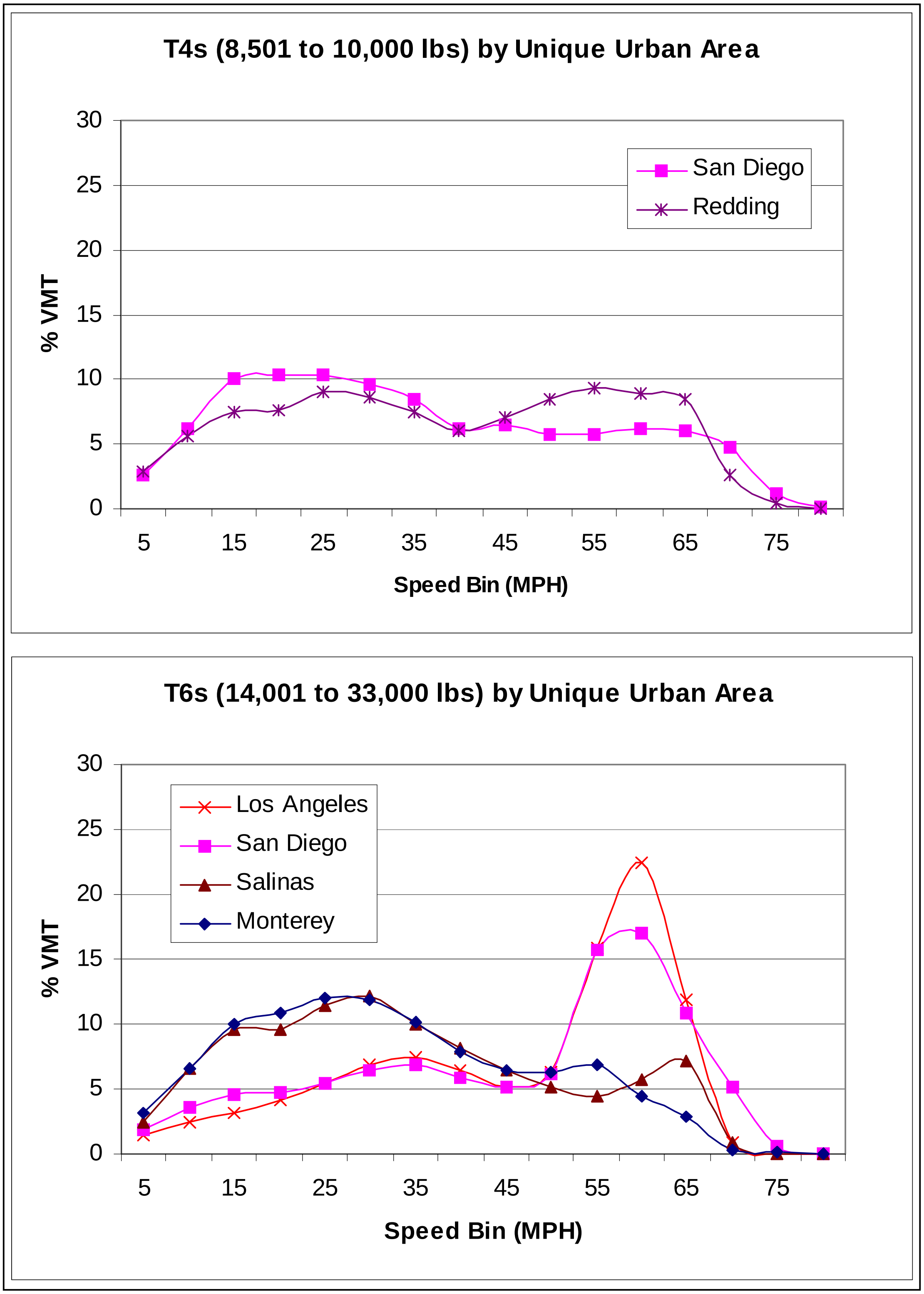
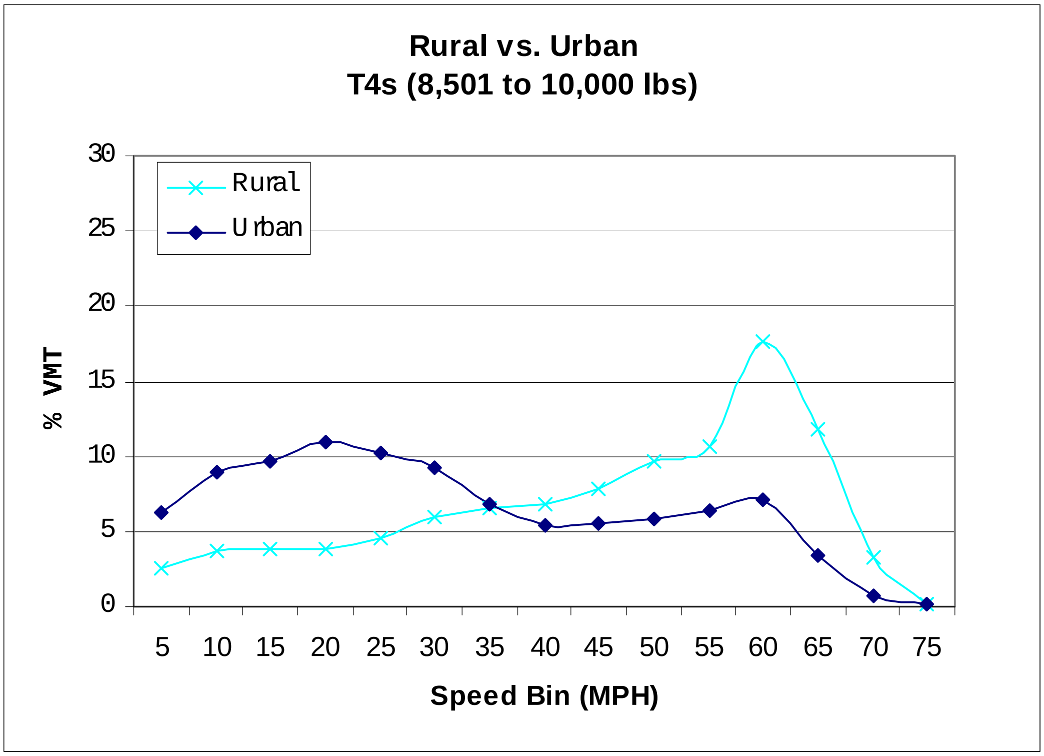


Figure 19. Examples of Travel in Unique Urban Areas

Weight Category	Urban/ Rural	Total # Trucls	Total # Trips	Total VMT	2.5-7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5	27.5-32.5	32.5-37.5	37.5-42.5	42.5-47.5	47.5-52.5	52.5-57.5	57.5-62.5	62.5-67.5	67.5 72.5	72.5-77.5	>77.5
T4	Urban	19	1,951	1,717	3.1	6.3	9.0	9.6	11.0	10.2	9.3	6.8	5.4	5.5	5.9	6.4	7.1	3.4	0.7	0.1
	Rural	10	271	739	1.0	2.5	3.7	3.8	3.9	4.6	6.0	6.5	6.8	7.8	9.7	10.7	17.6	11.8	3.3	0.2
T5	Urban	16	1,485	1,374	3.8	6.8	8.6	9.3	10.8	12.4	12.7	10.6	7.1	4.6	3.7	4.0	3.8	1.5	0.2	0.0
	Rural	4	86	110	1.2	3.1	5.1	7.1	8.4	7.6	11.3	19.3	23.8	7.3	4.2	1.5	0.0	0.0	0.0	0.0
T6	Urban	32	3,908	7,636	2.3	3.8	5.3	5.8	7.0	7.7	7.6	6.3	5.2	5.9	12.2	16.2	12.7	1.8	0.1	0.1
	Rural	22	461	2,547	0.5	1.1	1.6	2.1	2.7	2.8	3.3	3.4	4.5	8.0	15.3	20.8	25.5	8.4	0.0	0.1
T7	Urban	47	1,502	21,599	1.8	2.2	2.4	2.6	3.2	3.6	4.2	4.4	4.7	7.2	31.9	25.6	5.5	0.5	0.1	0.1
	Rural	45	765	23,239	0.3	0.5	0.5	0.7	1.1	1.5	2.2	2.9	4.3	7.1	39.0	27.5	11.3	1.0	0.3	0.0
T8	Urban	25	497	11,284	2.2	1.4	1.4	1.5	1.8	2.1	2.3	2.6	3.2	4.3	13.2	46.1	17.1	0.8	0.1	0.0
	Rural	25	349	16,544	0.7	0.5	0.6	0.8	1.0	1.3	1.5	2.0	2.7	3.5	12.2	50.2	19.8	2.0	0.7	0.5

Table 17. Speed Profiles by Weight Class and Urban/Rural



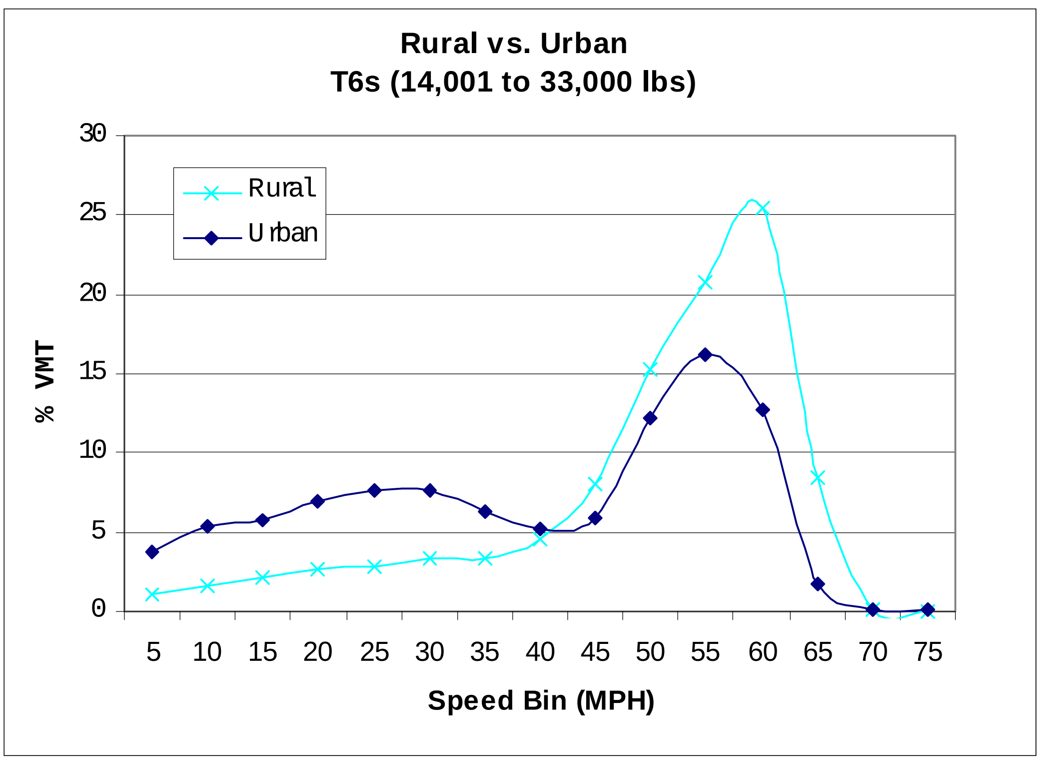


Figure 20. Examples of Rural vs. Urban Travel

Weight Category	Highway Functional Class	Total # Trucks	Total # Trips	Total VMT	2.5-7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5	27.5-32.5	32.5-37.5	37.5-42.5	42.5-47.5	47.5-52.5	52.5-57.5	57.5-62.5	62.5-67.5	67.5-72.5	72.5-77.5	>77.5
T4	Primary Hwy. w/Limited Access	13	80	322	0.1	0.2	0.6	0.3	0.6	0.8	1.2	1.4	1.3	2.2	6.0	16.4	36.0	27.0	5.4	0.4
	Secondary & Connecting Roads	14	228	433	0.5	1.8	2.2	1.7	2.8	4.1	5.8	5.9	6.1	8.0	12.2	19.0	19.7	7.8	2.5	0.0
	Local/Nbrhood/ Rural Roads	20	2,056	1,904	3.6	9.7	11.8	10.8	11.9	11.2	10.3	7.6	5.9	5.4	4.5	2.4	2.6	1.6	0.6	0.1
T5	Local/Nbrhood/Rural Roads	16	1,423	1,357	1.3	3.5	2.6	2.6	1.1	1.1	1.3	2.1	3.1	7.1	6.3	12.8	31.7	19.8	3.4	0.2
	Access Ramp	11	72	–	1.9	3.8	4.8	3.4	4.7	7.5	11.7	8.0	6.9	7.0	8.5	15.8	14.8	1.1	0.0	0.0
	Other/Undefined	14	255	–	4.8	11.5	12.0	10.0	10.9	12.5	12.2	10.9	7.7	3.7	2.3	1.2	0.2	0.1	0.0	0.0
					2.0	3.2	2.5	3.7	6.4	5.4	5.9	5.8	8.6	13.2	17.2	11.9	9.6	4.6	0.0	0.0
					3.7	10.6	14.6	13.4	9.9	8.7	9.1	7.2	5.7	4.5	4.7	5.3	2.2	0.2	0.0	0.0
T6	Primary Hwy. w/Limited Access	22	298	4,565	0.4	0.7	0.7	0.9	1.1	1.2	1.5	1.7	2.9	6.4	21.0	31.4	24.8	5.3	0.2	0.0
	Primary Rd. w/o Limited Access	6	124	332	0.7	1.3	1.8	0.9	1.0	0.8	1.0	1.0	1.7	4.1	15.4	23.0	40.4	6.9	0.2	0.0
	Secondary & Connecting Roads	24	772	1,252	0.6	1.8	2.4	2.5	3.5	4.9	6.3	7.4	9.1	12.4	20.6	16.9	9.7	1.6	0.1	0.0
	Local/Nbrhood/ RuralRoads	32	3,824	4,890	4.0	9.3	10.5	9.8	11.1	12.0	11.6	9.1	5.8	4.7	4.2	4.4	3.1	0.5	0.0	0.0
	Access Ramp	31	531	475	1.3	2.4	3.0	3.7	4.6	5.5	5.6	6.0	6.1	8.0	18.5	22.3	11.7	1.2	0.1	0.0
	Other/Undefined	32	621	1,282	0.9	2.0	2.4	3.0	3.2	3.0	2.8	2.7	2.8	5.0	13.9	27.4	27.0	3.9	0.0	0.0
T7	Primary Hwy. w/Limited Access	47	749	23,378	0.2	0.4	0.5	0.6	0.8	1.0	1.4	1.9	3.4	7.1	42.7	31.8	7.4	0.7	0.1	0.0
	Primary Rd. w/o Limited Access	18	91	1,261	0.1	0.3	0.4	0.6	1.9	2.6	4.3	4.7	6.9	10.2	24.2	35.5	8.1	0.1	0.0	0.0
	Secondary & Connecting Roads	44	433	4,710	0.4	0.6	0.9	1.0	1.7	2.8	4.7	6.0	8.3	12.1	34.8	22.2	4.4	0.1	0.0	0.0
	Local/Nbrhood/ Rural Roads	47	1,579	7,760	6.5	8.1	6.5	6.2	7.0	8.0	9.1	9.2	8.0	7.3	12.9	9.0	1.9	0.1	0.0	0.0
	Access Ramp	47	748	1,261	1.1	1.9	2.2	3.0	3.6	3.8	4.6	5.1	6.7	10.8	28.4	23.1	4.8	0.8	0.2	0.0
	Other/Undefined	46	776	10,108	0.4	0.6	0.9	1.0	1.2	1.3	1.6	1.8	2.6	4.6	35.7	26.0	18.6	2.7	1.1	0.0
T8	Primary Hwy. w/Limited Access	24	250	15,155	0.1	0.2	0.2	0.5	0.7	0.9	0.9	1.2	2.0	3.2	12.1	52.3	23.7	1.7	0.2	0.0
	Primary Rd. w/o Limited Access	5	11	288	0.1	0.2	0.3	0.3	0.6	1.3	2.4	2.5	4.8	9.5	20.3	51.2	5.9	0.7	0.0	0.0
	Secondary & Connecting Roads	24	227	5,645	0.5	0.4	0.4	0.5	0.8	1.2	1.8	2.2	2.8	4.4	13.6	55.9	15.1	0.4	0.0	0.0
	Local/Nbrhood/ Rural Roads	25	541	5,429	8.8	5.3	3.8	3.6	4.	4.6	4.9	5.4	5.7	5.7	12.4	28.5	7.2	0.3	0.0	0.0
	Access Ramp	25	274	1,083	1.1	1.0	1.5	1.8	2.0	1.9	2.3	2.5	3.6	5.4	13.7	44.3	17.2	1.5	0.1	0.0
	Other/Undefined	25	316	5,376	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.9	1.2	2.0	10.0	60.1	21.4	0.7	0.1	0.0

Table 18. Speed Profiles by Weight Class and Highway Functional Class

Each row of the table shows the percentage of VMT recorded on that functional class by vehicles in each speed bin. Only combinations with more than 200 VMT are included in this table. Figure 21 shows the speed profiles by highway functional class for the total sample (all vehicle weight classes combined). As expected, higher speeds of travel are shown for the higher class of roadway.

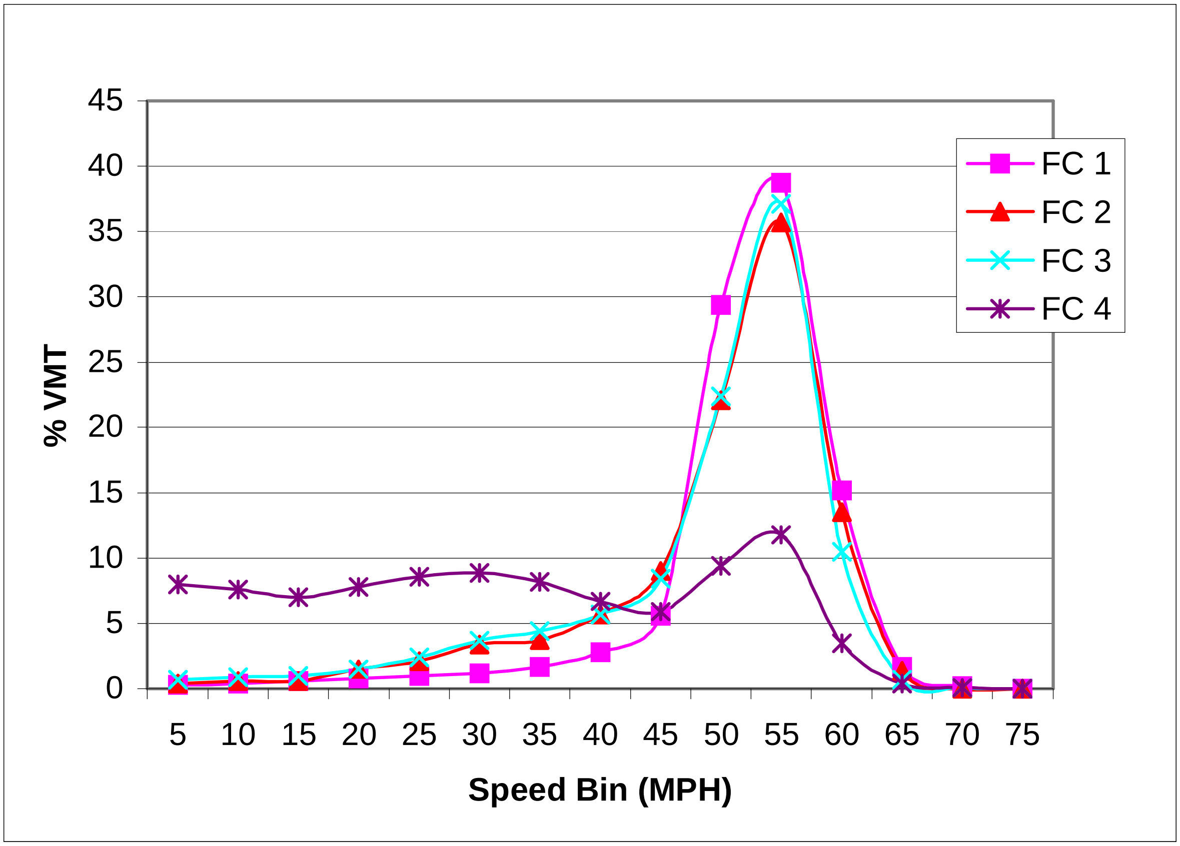


Figure 21. All Activity Summarized by Functional Class

Figure 22 shows speed profiles for two highway functional classes (FC1 – Primary Highway and FC4 – Local Roads) separated for urban and rural travel for the T6 and T8 vehicle weight classes. The T6 activity clearly shows that the urban travel takes place at lower speeds for both highway functional classes. The T8 activity shows a different response. Travel on local roads is consistent with the T6 activity, showing lower speeds for travel on urban local roads. The primary highway travel for T8s, however, shows no difference between the urban and rural travel speeds.

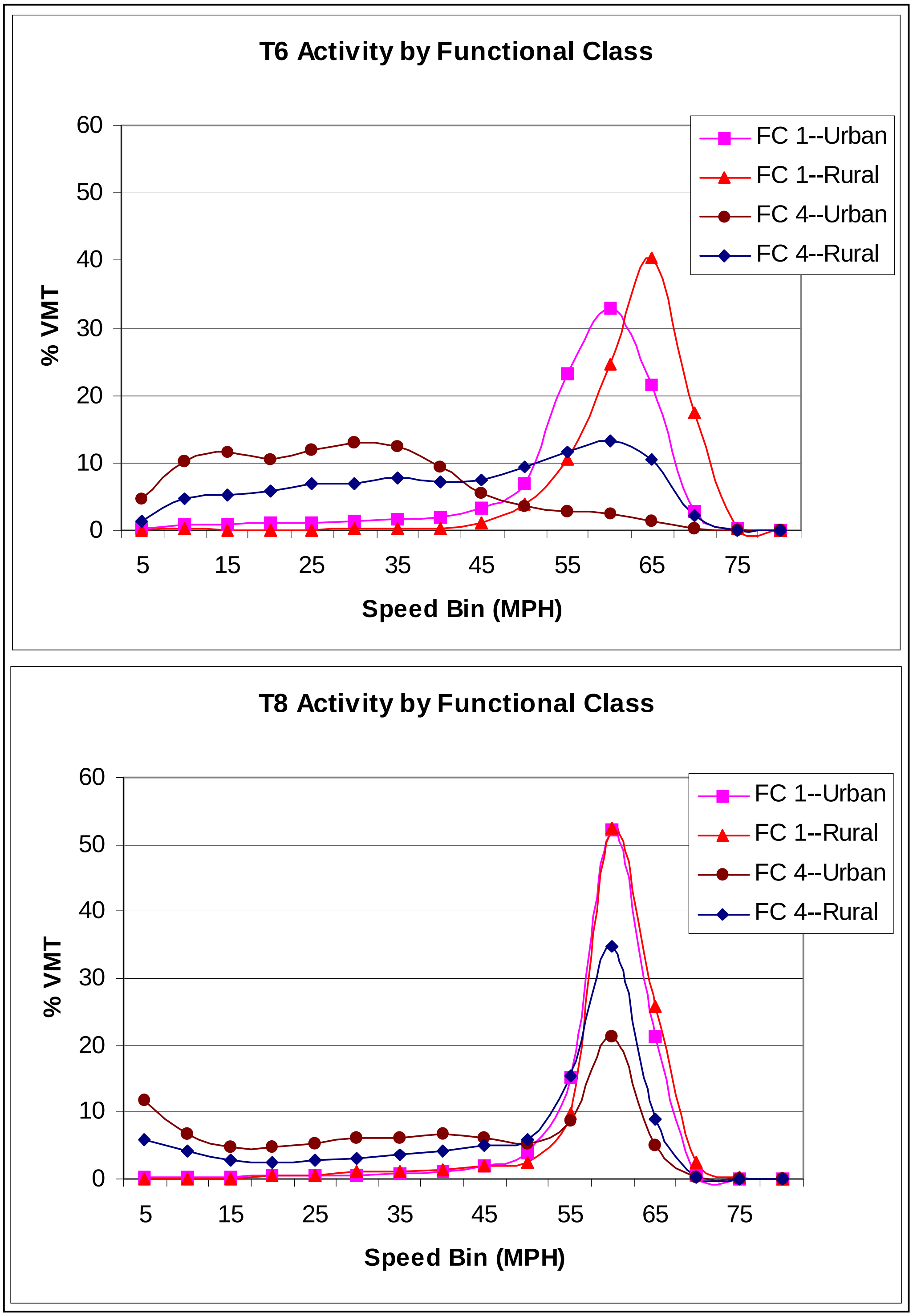


Figure 22. Example of Functional Class Separated by Rural and Urban Travel

5. TRIP START PATTERNS AND IDLE TIME BY TRUCK CLASS

Vehicle start rates represent the average number of times a vehicle starts in an average day. Vehicle starts are an indication of daily travel activity in terms of the number of trips started per day. Also, vehicle starts are used in conjunction with population distributions to develop the starts distributions used in vehicle emission inventory models.

Engine temperature at the time of ignition affects emissions. Engine temperature at start-up depends on the length of time since the engine was last turned off. This duration is referred to as "soak time." Because soak time is easier to measure than engine temperature, the emission inventory models use soak time distribution as input rather than engine temperature.

Vehicle idle time is another consideration of truck activity. Since heavy-duty trucks spend significant portions of their travel time idling, the idling percentage is an important contributor to emissions estimates, trip duration, and average speed. Due to the nature of the data, idle time is included with start patterns in the following discussions.

5.1 Description of Trucks Included in the Analysis

The data collection equipment recorded engine starts and stops based on changes in the voltage characteristics of the vehicle electrical system when the engine was started or stopped. Early in the data collection, this approach was not highly reliable and resulted in a number of samples where trips start and stop times were uncertain. As the data collection equipment and procedures improved, measurement of trip start and stop times became more reliable. Only Phase II data sets are used in the trips and start patterns analyses.

Even with reliable measurement of trip start and stop times, intermittent equipment failures continued to result in occasional data losses. Many of these data losses resulted in data that are only representative of a partial day's activity. In estimating characteristics about numbers of starts per day and soak time distribution, these "partial-day" data were excluded from the analysis. Only data representative of a full day of activity were included in this analysis to avoid biasing the results. Thus, in particular, if part of a day's data were lost in the middle of a week of data collection on a vehicle, the starts recorded on this day are excluded. However, data from the full day activity on either side of the partial day of data are included in the analysis.

There were some trips for which valid start and stop information was recorded, but no valid GPS data were obtained. The number of these trips was not significant (less than 3 percent) and almost all were very short in duration. These trips are included in these analyses.

5.2 Analysis Approach

Information in this chapter related to "location" refers to the location of trip origin. For example, when discussing numbers of starts per day, while summarizing information by region, the numbers of starts are presented for trips *originating* in a particular region. This is in contrast to the information presented in the previous chapter on speed profiles, where individual trips were parsed into the miles traveled across regions (or air basins, or urban areas, or highway functional class).

5.3 Truck Starts Per Day

The average number of starts per day and duration of engine idle times varied by truck weight class and other factors. Temporal and spatial variations in these parameters are presented in this section, as well as variations across business usage. Business usage variations are presented first to remind the reader of the fact that this was an opportunity sample, and this sample should be considered whenever making inferences based on the data.

Temporal variations are illustrated by displaying information about idle times and numbers of starts by planning period (time of day) and by day of week. Spatial variations are illustrated by providing summary statistics separately for each region, for each air basin, and for urban and rural areas.

5.3.1 Starts and Idle Time by Business Use

Trucks representing several different business uses are included in the sample. Table 19 and Figure 23 summarize the starts and idle time information obtained by business use for each of the five weight classes. For each business use/weight class combination, Table 19 shows the number of vehicles represented and the number of trips recorded, along with the average number of starts, the total idle time in minutes, and the average time per day spent idling. The denominator used to estimate the number of starts per day includes those days in which there were no starts – typically weekends. The number of starts per week day would be greater for all business uses.

Figure 23 indicates that the number of starts per day can vary significantly by business use within a given weight class. Variation between weight classes for certain business uses is also shown.

All of the T4 and T5 vehicles for which information on starts and idle time were obtained were postal/parcel delivery trucks. The T6 vehicles were also dominated by postal/parcel delivery trucks. This fact should be taken into account before trying to make inferences to the entire population of heavy-duty trucks in California. T7 vehicles had the broadest representation, but were dominated by vehicles involved in retail trade.

Postal/parcel trucks had a large number of starts per day (more than 25), whereas all other types of trucks averaged less than 10 starts per day (with the exception of two T8 vehicles classified as “For-hire Transportation”).

Table 19. Summary of Number of Starts and Idle Time Per Day, by Business Use

Weight Class	Business Use	Total # Trucks	# Days w/GPS Device	Total # Starts	Average # Starts/ Day	Total Idle Time (Min.)	Average Idle Time (Min.)	% of Time Spent Idling
T4	Postal/Parcel	13	53	1,892	35.7	1,425	26.9	25
T5	Postal/Parcel	14	54	1,391	25.8	1,566	29.0	31
T6	Postal/Parcel	23	136	3,756	27.6	3,477	25.6	23
	Wholesale Trade	2	16	99	6.2	466	29.1	16
	Retail Trade	6	27	121	4.5	3,535	130.9	51
T7	Agriculture	3	5	47	9.4	520	104.0	20
	Construction	1	6	14	2.3	581	96.8	41
	Wholesale Trade	2	9	36	4.0	561	62.4	18
	Retail Trade	21	110	928	8.4	6,560	59.6	19
	For-hire Transp.	4	36	76	2.1	3,834	106.5	37
T8	Agriculture	4	19	54	2.8	1,399	73.6	22
	For-hire Transp.	2	10	143	14.3	941	94.1	26

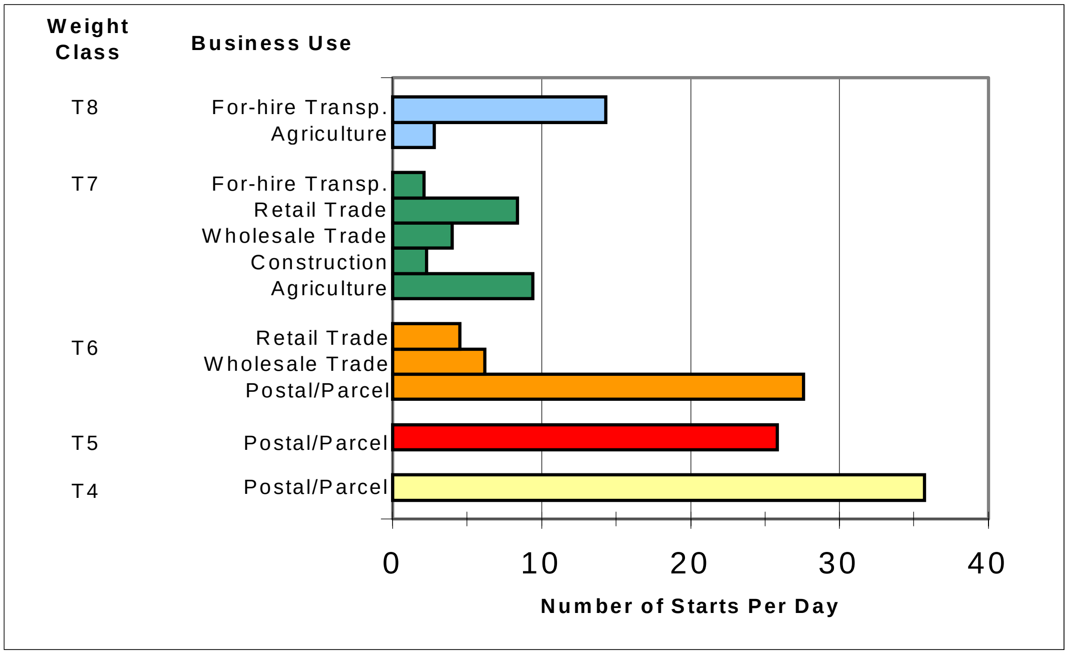


Figure 23. Number of Starts per Day by Weight Class and Business Use

The percentage of time spent idling did not seem to vary markedly across business uses. On average, the vehicles were observed to idle around 25 percent of the time. The major exceptions were the six T6 vehicles involved in Retail Trade. They were observed to be idling over 50 percent of the time that they were recorded.

5.3.2 Starts and Idle Time by Planning Period

Because emission rates depend on ambient temperatures, and because activity varies throughout the day, the EMFAC/BURDEN model currently uses six time periods when modeling engine emissions. These are referred to as "planning periods" and are defined as follows:

Period 1: Midnight to 6:00 am
Period 2: 6:00 am to 9:00 am
Period 3: 9:00 am to 12:00 noon
Period 4: 12:00 noon to 3:00 pm
Period 5: 3:00 pm to 6:00 pm
Period 6: 6:00 pm to Midnight.

Table 20 displays information on total number of starts, average number of starts per day, total engine idle time, and average idle time per day for each weight class. This information is provided for each planning period and aggregated across planning periods. As an indication of the data quality on which these summary statistics are based, the table shows the number of distinct trucks observed during each planning period and the total number of truck-days observed for each weight class.

Table 20. Summary of Number of Starts and Idle Time Per Day, by Planning Period

Weight Class	# Days w/ GPS Device	Planning Period	Total # Trucks	Total # Starts	Average # Starts/ Day	Total Idle Time (Min.)	Average Idle Time/ Day	% of Time Spent Idling
T4	53	Midnight-6 am	1	1	0.0	0	0.0	0
		6-9 am	13	49	0.9	95	1.8	19
		9 am-noon	13	9439	17.7	548	10.3	25
		Noon-3 pm	13	554	10.5	403	7.6	26
		3-6 pm	13	334	6.3	368	7.0	25
		6 pm-Midnight	5	15	0.3	12	0.2	44
		TOTAL	13	1,892	35.7	1,425	26.9	25
T5	54	Midnight-6 am	3	6	0.1	10	0.2	79
		6-9 am	14	73	1.4	241	4.5	35
		9 am-noon	14	678	12.6	538	10.0	28
		Noon-3 pm	13	314	5.8	249	4.6	25
		3-6 pm	14	293	5.4	431	8.0	36
		6 pm-Midnight	9	27	0.5	98	1.8	42
		TOTAL	14	1,391	25.8	1,566	29.0	31
T6	179	Midnight-6 am	10	27	0.2	1,400	7.8	54
		6-9 am	29	189	1.1	1,325	7.4	37
		9 am-noon	28	1,978	11.1	1,635	9.1	23
		Noon-3 pm	30	980	5.5	1,943	10.9	28
		3-6 pm	28	736	4.1	994	5.6	23
		6 pm-Midnight	21	66	0.4	181	1.0	53
		TOTAL	31	3,976	22.2	7,478	41.8	30
T7	166	Midnight-6 am	24	187	1.1	2,994	18.0	26
		6-9 am	28	172	1.0	2,904	17.5	30
		9 am-noon	30	259	1.6	2,368	14.3	23
		Noon-3 pm	27	184	1.1	1,391	8.4	19
		3-6 pm	26	140	0.8	1,145	6.9	22
		6 pm-Midnight	20	159	1.0	1,252	7.5	18
		TOTAL	31	1,101	6.6	12,055	72.6	23
T8	29	Midnight-6 am	5	27	0.9	499	17.2	18
		6-9 am	6	62	2.1	728	25.1	25
		9 am-noon	4	47	1.6	482	16.6	25
		Noon-3 pm	5	29	1.0	306	10.5	22
		3-6 pm	4	24	0.8	190	6.6	29
		6 pm-Midnight	2	8	0.3	136	4.7	43
		TOTAL	6	197	6.8	2,340	80.7	24

Figure 24 shows the starts per day by planning period for each vehicle weight class. The lighter trucks average many more trips per day than the heavier trucks. The difference observed was five-fold. For the lighter trucks (T4, T5, and T6), most of the starts occurred during normal business hours (between 9:00 am and 6:00 pm). In fact, for the lighter trucks, almost twice as many starts were recorded between 9:00 am and 12:00 noon than in any other planning period. The heavier trucks tended to have their starts more uniformly scattered throughout the day.

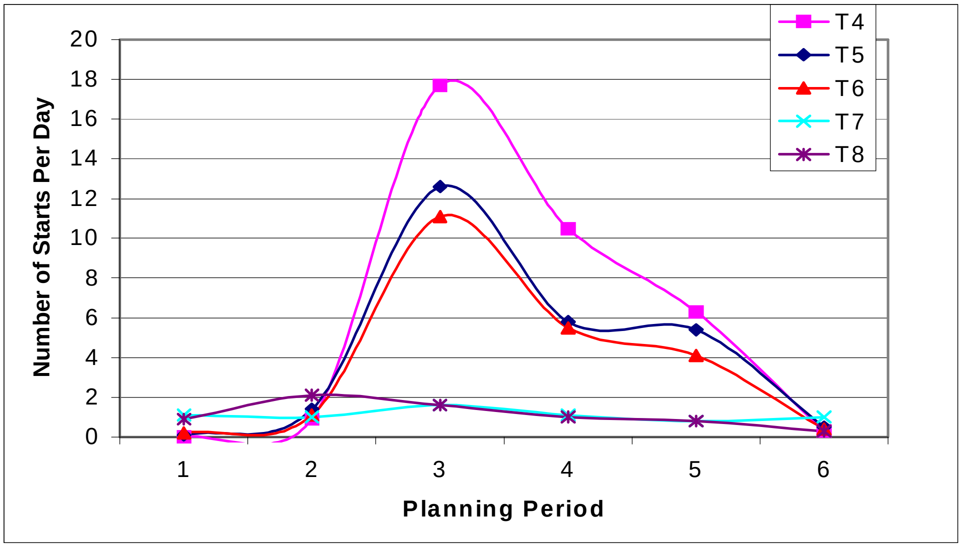


Figure 24. Number of Starts per Day by Planning Period for Each Vehicle Weight Class

Figure 25 illustrates the percent time spent at idle by planning period. Idle time was generally lowest between 9:00 a.m. and 3:00 p.m. on all trucks. Percent idle time was not included in Figure 25 when the total number of starts observed was less than ten. For example, T5 trucks in Period 1 recorded only six starts.

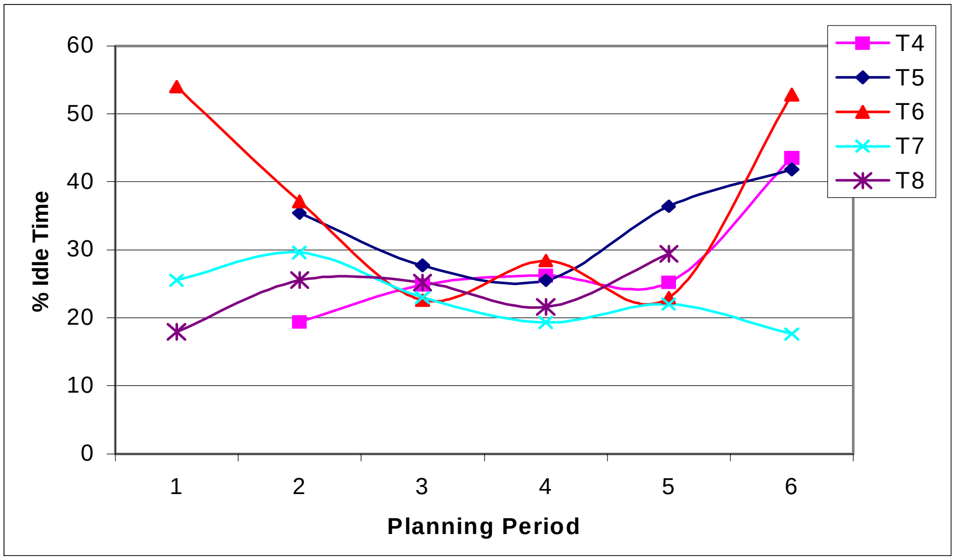


Figure 25. Percent Idle Time by Planning Period for Each Vehicle Weight Class

5.3.3 Starts and Idle Time by Day of Week

Table 21 displays information in a similar structure to Table 20, but with "planning period" replaced by "day of week." The primary distinction here is that, when calculating average number of starts per day and average idle time per day, a separate denominator is used for each day of the week. For example, the number of starts observed on Mondays is divided by the number of truck-days of data recorded on Mondays. This correction adjusts for imbalances that may have resulted from having different size samples for different days of the week.

Table 21. Summary of Number of Starts and Idle Time Per Day, by Day of Week

Weight Class	Day of Week	Total # Trucks	Total Truck-Days	Total # Starts	Average # Starts/ Day	Total Idle Time (Min.)	Average Idle Time/ Day	% of Time Spent Idling
T4	Mon.	3	3	158	52.7	95	31.6	25
	Tue.	4	4	196	49.0	112	27.9	20
	Wed.	10	10	499	49.9	341	34.1	25
	Thu.	10	10	501	50.1	406	40.6	27
	Fri.	10	10	434	43.4	378	37.8	26
	Sat.	4	4	104	26.0	94	23.5	20
T5	Mon.	2	2	41	20.5	93	46.7	34
	Tue.	4	4	163	40.8	134	33.4	23
	Wed.	10	10	415	41.5	399	39.9	28
	Thu.	11	11	445	40.5	441	40.1	32
	Fri.	10	10	323	32.3	491	49.1	36
	Sat.	2	2	4	2.0	8	4.0	85
T6	Mon.	18	19	486	25.6	1,117	58.8	27
	Tue.	16	19	441	23.2	1,602	84.3	36
	Wed.	24	32	1,273	39.8	1,656	51.7	26
	Thu.	21	27	1,035	38.3	1,730	64.1	31
	Fri.	21	22	671	30.5	1,251	56.8	31
	Sat.	3	3	70	23.3	123	41.1	30
T7	Sun.	3	3	12	4.0	99	33.1	15
	Mon.	26	29	282	9.7	2,861	98.7	22
	Tue.	24	26	234	9.0	2,747	105.6	23
	Wed.	23	25	200	8.0	1,975	79.0	21
	Thu.	20	21	218	10.4	2,543	121.1	26
	Fri.	16	17	135	7.9	1,651	97.1	28
	Sat.	5	5	20	4.0	179	35.9	27
T8	Sun	1	1	1	1.0	12	11.9	100
	Mon.	5	5	68	13.6	627	125.5	23
	Tue.	3	3	46	15.3	408	136.1	25
	Wed.	3	3	38	12.7	447	149.2	26
	Thu.	4	4	39	9.8	509	127.2	21
	Fri.	2	2	5	2.5	336	168.0	25

Figure 26 shows the number of starts per day of the week for the five vehicle weight classes. In general, more starts occurred on weekdays than on weekends, and the number of starts tended to peak in the middle of the week. The lighter vehicles (T4, T5, and T6), dominated by postal/parcel business use, experienced substantially more starts per day than the heavier trucks.

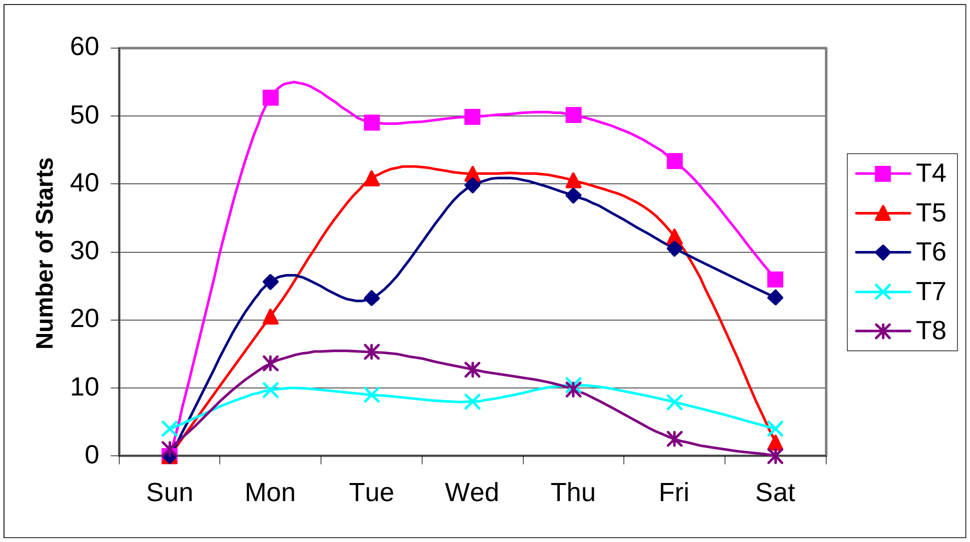


Figure 26. Number of Starts per Day of Week for the Vehicle Weight Classes

Figure 27 illustrates the percent idle time per day of week for the five vehicle weight classes. Idle time percentages are generally steady between 20 percent and 35 percent during Monday through Saturday. Although there are variations day by day, the T5 and T6 trucks appear to spend a slightly larger fraction of their time at idle than the other vehicle weight classes. Again, when the total number of starts observed was less than ten the idle time for that day was not shown in the figure.

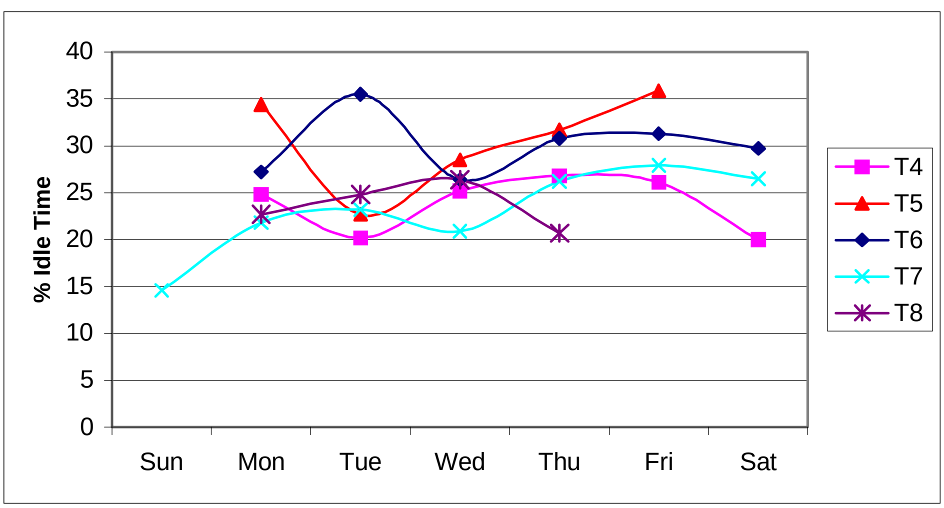


Figure 27. Percent Idle Time per Day of Week for the Vehicle Weight Classes

5.3.4 Starts and Idle Time by Region of Trip Origin

Table 22 summarizes information obtained on numbers of starts and idle time by region of trip origin.

Table 22. Summary of Number of Starts and Idle Time Per Day by Region of Trip Origin

Weight Class	Region	Total # Trucks	Total Truck-Days	Total # Starts	Average # Starts/ Day	Total Idle Time (Min.)	Average Idle Time/ Day	% of Time Spent Idling
T4	2	5	16	649	40.6	389	24.3	23
	3	6	17	721	42.4	745	43.8	27
	4	2	8	506	63.3	278	34.7	24
T5	2	11	31	908	29.3	1,365	44.0	39
	3	3	8	479	59.9	184	243.0	13
T6	1	2	7	14	2.0	146	20.8	14
	2	17	53	1,100	20.8	4,829	91.1	37
	3	3	7	166	23.7	99	14.1	11
	4	12	65	2,681	41.2	2,392	36.8	24
T7	1	13	32	151	4.7	1,223	38.2	20
	2	12	33	228	6.9	2,731	82.8	26
	3	22	90	613	6.8	6,188	68.8	25
	4	14	29	66	2.3	950	32.8	16
T8	1	4	10	97	9.7	859	85.9	28
	2	1	1	1	1	18	18.4	6
	3	5	7	94	93	1,418	83.4	22

Interpretation of these tables is problematic. For example, although a sizeable number of starts were observed on T4 vehicles in Regions 2, 3, and 4, it is not meaningful to compare the average number of starts recorded on T4 vehicles across these regions. The T4 vehicle sample is dominated by postal/parcel trucks and is not representative of the T4 vehicle population in these regions. Thus the aggregate travel of these vehicles is not representative of these regions' travel activity patterns. These numbers are purely descriptive of the sample obtained during the project.

Similar cautions must be considered for the information presented in Tables 23 and 24, which present analogous information regarding starts and idle time occurring in distinct air basins and urban versus rural areas, respectively.

Table 22 indicates that, for T4 vehicles, roughly the same number of starts per day were observed in Regions 2 and 3 but substantially more minutes spent at idle was observed in Region 3. On the other hand, T5 vehicles were observed in Regions 2 and 3, with almost twice the number of starts per day occurring in Region 3, and the vast majority of the engine idle time occurring in Region 2.

Most of the starts occurring on T6 vehicles were recorded in Region 4, and the greatest time spent idling was observed in Region 2. Like the T5 vehicles in Regions 2 and 3, there appears to be an inverse relationship between starts per day and idle time. Possibly some trucks chain consecutive origin and destinations together without shutting off the engine. The parity seen between regions is most likely representative of the sample (because most of these vehicles were of the same fleet) rather than regional characteristics.

5.3.5 Starts and Idle Time by Air Basin of Trip Origin

Table 23 displays information on starts and idle time by air basin for each weight class. Again, these tables are useful for understanding the nature of the sample obtained, but any inferences to general activity patterns would be tenuous.

Table 23. Summary of Number of Starts and Idle Time Per Day by Air Basin of Trip Origin

Weight Class	Air Basin	Total # Trucks	Total Truck-Days	Total # Starts	Average # Starts/ Day	Total Idle Time (Min.)	Average Idle Time/ Day	% of Time Spent Idling
T4	N-Ctrl. Coast	2	8	506	63.3	278	34.7	24
	Sacramento Vly.	6	17	721	42.4	745	43.8	27
	San Diego Cty.	3	9	504	56.0	272	30.2	22
	South Coast	2	7	145	20.7	117	16.7	24
T5	Sacramento Vly.	3	8	479	59.9	184	23.0	13
	San Diego Cty.	6	17	435	25.6	733	43.1	45
	South Coast	5	14	473	33.8	632	45.2	34
T6	N-Ctrl. Coast	11	62	2,639	42.6	2,193	35.4	24
	N-East Plateau	1	3	42	14.0	199	66.3	33
	Sacramento Vly.	3	7	166	23.7	99	14.1	11
	San Diego Cty.	9	17	631	37.1	621	36.6	20
	San Franc. Bay	2	7	14	2.0	146	20.8	14
	S-Ctrl. Coast	2	2	6	3.0	19	9.4	8
	South Coast	11	40	463	11.6	4,189	104.7	43
T7	Grt. Basin Vly.	1	1	4	4.0	34	33.7	11
	Lake Tahoe	4	4	9	2.3	60	15.0	11
	S-East Desert	2	3	8	2.7	49	16.2	8
	Mountain Cnties.	8	13	21	1.6	582	44.8	25
	N-Ctrl. Coast	6	7	23	3.3	227	32.4	13
	North Coast	1	2	2	1.0	17	8.3	4
	N-East Plateau	2	3	7	2.3	31	10.4	5
	Sacramento Vly.	21	85	516	7.1	4,699	55.3	26
	Salton Sea	2	5	22	4.4	462	92.5	25
	San Diego Cty.	2	2	4	2.0	66	33.1	19
	San Franc. Bay	13	32	151	4.7	1,223	38.2	20
	San Joaquin Vly.	15	26	97	3.7	1,489	57.3	22
	S-Ctrl. Coast	2	3	14	4.7	108	36.1	22
	South Coast	11	30	180	6.0	2,046	68.2	29
T8	Sacramento Vly.	4	9	51	5.7	408	45.4	20
	Salton Sea	1	1	1	1.0	18	18.4	6
	San Franc. Bay	4	10	97	9.7	859	85.9	28
	San Joaquin Vly.	5	14	43	3.1	1,009	72.1	24

T4 vehicles were observed in the North Central Coast, Sacramento Valley, San Diego County, and South Coast Air Basins, with the smallest number of starts occurring in the South Coast. Sacramento Valley had almost three times the idle time compared with other air basins.

T5 vehicles had about the same number of starts in the three air basins represented, but had the least duration of idle time observed in the Sacramento Valley.

A large majority of starts observed on T6 vehicles occurred in the North Central Coast. T7 starts were scattered over 14 air basins, averaging between one and seven starts per day in these air basins. T8 vehicle starts were focused in the Sacramento Valley, San Francisco Bay, and San Joaquin Valley.

5.3.6 Starts and Idle Time in Urban Versus Rural Areas

The vast majority of starts recorded in this study were observed in urban areas. Table 24 presents starts and idle time information for urban versus rural starts in a similar format to that of previous tables. Not surprisingly, the ratio of urban to rural starts was greater for the lighter trucks. Similarly, a greater percentage of engine idle time was observed consistently in urban areas rather than in rural areas, and this ratio was also greater for the lighter trucks.

Table 24. Summary of Number of Starts and Idle Time Per Day, by Trips Originating in Urban Versus Rural Area

Weight Class	U/R Area	Total # Trucks	Total Truck-Days	Total # Starts	Average # Starts/ Day	Total Idle Time (Min.)	Average Idle Time/ Day	% of Time Spent Idling
T4	Urban	13	41	1,699	41.4	1,317	32.1	26
	Rural	7	16	193	12.1	108	6.8	15
T5	Urban	14	39	1,333	34.2	1,519	39.0	32
	Rural	4	9	58	6.4	47	5.2	18
T6	Urban	31	122	3,702	30.3	6,918	56.7	31
	Rural	15	50	274	5.5	560	11.2	19
T7	Urban	31	122	837	6.9	8,303	68.1	25
	Rural	26	80	264	3.3	3,752	46.9	20
T8	Urban	6	16	145	9.1	1,534	95.9	26
	Rural	6	16	52	3.3	806	50.4	20

5.4 Soak Times

Emissions incurred at vehicle start-up are a function of the engine and emission control system temperature. Because it is currently impractical to measure the temperature on a vehicle at every start, the time between starts, or "soak time," is used as a surrogate. Burden 7G applies emission factors based on the soak time. This section discusses the pattern of soak times observed and the variables that may be related to soak time characterizations.

The first trip monitored for each truck had an unknown soak time. Rather than leave these values unaccounted for and possibly bias the distribution, each truck's daily pattern was reviewed and a soak time was estimated. Because of the way soak times are used by Burden 7G, the precision requirements of these estimates are not very stringent. In fact, all soak times greater than 588 minutes are pooled into one category. The inferred temperatures for these vehicles would be equivalent for emissions calculations.

Of the 8,904 trips included in the subsequent summaries, 85 soak time values (0.95 percent) were estimated. This estimation was generally very accurate because most trucks in the study were active during well-defined hours and did not work longer than 12 hours. In many cases, the equipment was installed on the weekend, and the first trip did not occur until the first working day. For these trucks the first soak time was assumed to be greater than 588 minutes. Only four of the 85 estimates were less than 588 minutes because these trucks typically had an operating period greater than 14 hours.

Temporal and spatial variations in soak times are characterized in the following sections. Soak time distributions are first displayed by planning period (time of day), and then by location of trip origin. Trip origin is presented first by region, then by air basin, and then comparing urban versus rural starts. In each case, soak time distributions are characterized separately for each weight class.

5.4.1 Soak Times by Planning Period

Table 25 presents the soak time distribution for each weight class broken out by the six planning periods discussed above, and totals are also provided for each weight class.

The soak time distribution varied substantially, depending on the trip start time. Nonetheless, well over 50 percent of the trips were made after a soak time of less than 30 minutes for each weight class, and almost every planning period. The notable exceptions were T4, T5, and T6 vehicles on trips made before 9:00 am. But these exceptions are not surprising – starts occurring during these planning periods most likely occurred after a night in the garage. Figure 28 displays the distribution of soak times by weight class for each planning period.

5.4.2 Soak Times by Region of Trip Origin

Table 26 provides the soak time distribution as observed across region of trip origin. Caution must be taken when inferring conclusions from these results, as indicated previously for starts and idle times (Section 5.3.4).

The lighter trucks (T4, T5, and T6) exhibit soak times generally less than 30 minutes in all regional samples. The T7 trucks regional soak time distributions are flatter with the Region 2 and 3 samples showing smaller peaks than the Region 1 and 4 samples. The T8 samples are more comparable to the lighter trucks with soak times generally less than 30 minutes, however there are relatively few starts for the T8 vehicles used in this comparison.

Weight Category	Planning Period	# Trucks	# Trips	0-2.5	2.5-7.5	7.5-12.5	12.5-27.5	27.5-47.5	47.5-72.5	72.5-107.5	107.5-137.5	137.5-227.5	227.5-373.5	373.5-587.5	>587.5
T4	Midnight-6 am	5	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.0	0.0	20.0	0.0
	6-9 am	14	66	16.7	13.6	4.5	1.5	1.5	3.0	1.5	1.5	0.0	0.0	4.5	51.5
	9 am-noon	14	988	63.0	26.9	5.2	1.7	1.0	0.5	0.5	0.2	0.2	0.0	0.1	0.7
	Noon-3 pm	14	579	45.6	31.8	9.7	6.2	2.9	2.2	1.0	0.0	0.2	0.3	0.0	0.0
	3-6 pm	14	368	34.8	29.9	13.9	11.7	4.3	2.4	1.6	0.0	0.5	0.8	0.0	0.0
	6 pm-Midnight	11	43	7.0	20.9	9.3	7.0	16.3	9.3	11.6	7.0	2.3	9.3	0.0	0.0
	TOTAL	14	2,049	50.2	28.2	8.1	4.9	2.5	1.6	1.1	0.3	0.5	0.4	0.2	2.0
T5	Midnight-6 am	3	7	14.3	0.0	14.3	0.0	0.0	0.0	0.0	0.0	14.3	0.0	14.3	42.9
	6-9 am	14	83	14.5	18.1	4.8	8.4	3.6	2.4	3.6	0.0	1.2	1.2	2.4	39.8
	9 am-noon	14	693	57.6	29.6	6.2	3.9	1.0	0.7	0.6	0.1	0.1	0.1	0.0	0.0
	Noon-3 pm	13	330	37.9	37.0	8.2	7.0	2.4	3.6	1.8	0.0	0.9	1.2	0.0	0.0
	3-6 pm	14	305	25.9	31.1	17.0	15.7	3.6	2.3	0.7	0.3	1.0	2.0	0.3	0.0
	6 pm-Midnight	10	37	8.1	10.8	5.4	8.1	10.8	18.9	8.1	10.8	16.2	2.7	0.0	0.0
	TOTAL	14	1,455	42.5	30.3	8.9	7.4	2.3	2.3	1.2	0.4	1.0	0.9	0.3	2.5
T6	Midnight-6 am	10	27	0.0	0.0	3.7	3.7	11.1	0.0	0.0	0.0	3.7	0.0	11.1	66.7
	6-9 am	29	202	24.8	18.3	7.4	8.4	1.5	1.0	1.5	0.5	2.0	0.0	1.0	33.7
	9 am-noon	28	2,022	62.4	27.5	4.7	3.3	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.9
	Noon-3 pm	30	1,014	43.2	30.8	8.1	8.7	2.8	2.4	0.8	0.8	1.1	0.4	0.0	1.1
	3-6 pm	28	747	31.2	38.4	12.4	11.0	2.8	1.6	0.8	1.2	0.3	0.1	0.0	0.1
	6 pm-Midnight	21	83	9.6	20.5	6.0	16.9	8.4	6.0	7.2	8.4	13.3	3.6	0.0	0.0
	TOTAL	31	4,095	48.6	29.5	7.1	6.6	1.8	1.2	0.6	0.6	0.7	0.2	0.1	2.9
T7	Midnight-6 am	25	188	9.6	10.1	11.7	18.1	10.6	9.0	2.7	0.0	1.6	2.1	2.1	22.3
	6-9 am	28	172	5.8	11.6	4.1	23.8	18.6	8.1	5.8	0.0	0.6	0.0	2.9	18.6
	9 am-noon	30	261	10.3	16.9	14.9	21.8	14.2	9.2	4.2	0.8	0.4	0.0	1.5	5.7
	Noon-3 pm	27	185	8.1	14.6	16.2	24.9	13.5	8.6	3.8	2.7	3.2	1.6	0.5	2.2
	3-6 pm	26	142	15.5	16.9	9.9	13.4	16.9	13.4	7.0	2.1	2.8	0.0	1.4	0.7
	6 pm-Midnight	20	159	8.2	18.9	15.7	14.5	17.0	13.2	1.9	1.9	1.3	1.9	1.9	3.8
	TOTAL	31	1,107	9.5	14.8	12.4	19.9	14.9	10.0	4.2	1.2	1.5	0.9	1.7	9.0
T8	Midnight-6 am	5	27	18.5	11.1	7.4	7.4	3.7	0.0	0.0	0.0	3.7	0.0	11.1	37.0
	6-9 am	6	62	19.4	29.0	22.6	12.9	6.5	3.2	1.6	0.0	0.0	0.0	0.0	4.8
	9 am-noon	4	47	34.0	27.7	14.9	12.8	4.3	2.1	2.1	0.0	0.0	0.0	0.0	2.1
	Noon-3 pm	5	29	24.1	31.0	20.7	13.8	3.4	3.4	0.0	0.0	3.4	0.0	0.0	0.0
	3-6 pm	4	24	8.3	58.3	8.3	20.8	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0
	6 pm-Midnight	2	9	33.3	0.0	11.1	33.3	11.1	0.0	0.0	0.0	0.0	11.1	0.0	0.0
	TOTAL	6	198	22.7	28.8	16.2	14.1	4.5	2.0	1.0	0.5	1.0	0.5	1.5	7.1

Table 25. Soak Time Distribution (Minutes) by Weight Class and Planning Period

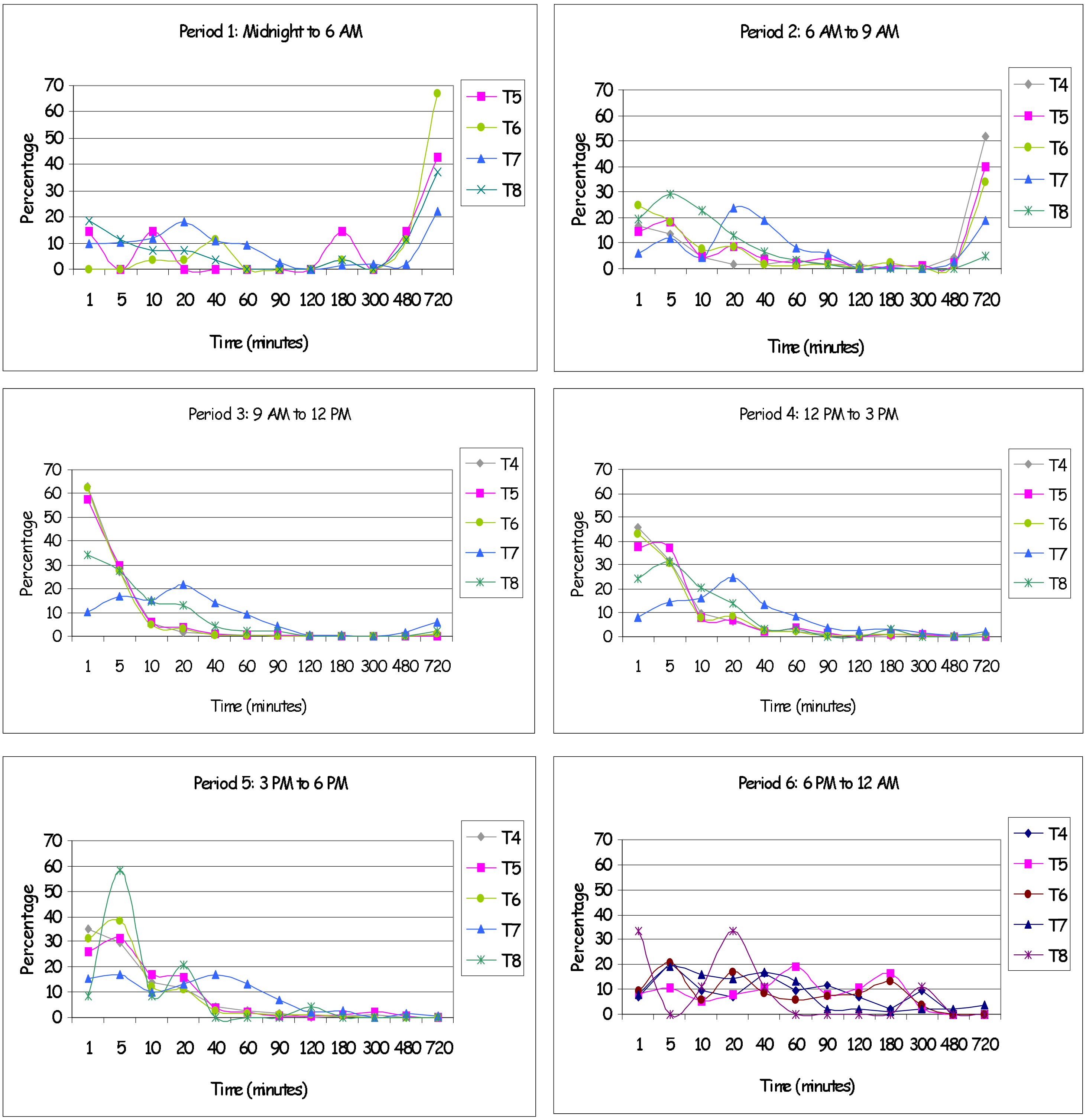


Figure 28. Observed Soak Times by Vehicle Weight Class for Each Planning Period (Time of Day)

Weight Category	Region	# Trucks	# Trips	0-2.5	2.5-7.5	7.5-12.5	12.5-27.5	27.5-47.5	47.5-72.5	72.5-107.5	107.5-137.5	137.5-227.5	227.5-373.5	373.5-587.5	>587.5
T4	2	5	649	37.3	36.4	11.1	7.2	3.4	1.4	0.5	0.3	0.5	0.3	0.0	1.7
	3	6	721	59.5	25.2	7.6	3.6	0.4	0.7	0.7	0.0	0.3	0.0	0.4	1.5
	4	2	506	62.6	23.9	5.9	3.8	0.6	1.0	0.4	0.0	0.2	0.0	0.0	1.6
T5	2	11	908	35.7	32.0	10.2	9.7	2.4	2.6	1.7	0.4	1.0	1.1	0.2	2.9
	3	3	479	59.1	28.2	6.3	1.7	1.9	1.5	0.2	0.0	0.2	0.2	0.0	0.8
T6	1	2	14	0.0	42.9	35.7	21.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	17	1,100	34.5	29.5	9.7	11.0	3.9	2.3	1.2	1.5	1.2	0.5	0.4	4.4
	3	3	166	39.8	31.9	8.4	9.6	3.0	0.6	0.6	1.2	0.6	0.6	0.6	3.0
	4	12	2,681	56.4	29.0	5.6	4.3	0.7	0.8	0.4	0.2	0.4	0.0	0.0	2.0
T7	1	13	151	9.3	8.6	7.3	24.5	25.8	14.6	3.3	1.3	0.7	0.0	0.0	4.6
	2	12	228	7.5	15.8	14.5	17.1	9.6	7.9	6.6	3.1	2.6	1.3	4.4	9.6
	3	22	613	11.4	17.3	13.2	20.1	12.9	7.8	2.6	0.7	1.5	1.1	1.1	10.3
	4	14	66	1.5	9.1	12.1	15.2	27.3	18.2	12.1	0.0	1.5	0.0	0.0	3.0
T8	1	4	97	29.9	35.1	14.4	10.3	6.2	2.1	2.1	0.0	0.0	0.0	0.0	0.0
	2	1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
	3	5	94	16.0	24.5	17.0	18.1	3.2	2.1	0.0	1.1	1.1	1.1	3.2	12.8

Table 26. Soak Time Distribution (Minutes) by Weight Class and Region, Percent of Total Number of Trips Within Category

5.4.3 Soak Times by Urban Versus Rural Areas

Table 27 displays the observed dependence of soak time distribution on whether the trip originated in an urban or rural location. Many more trips were originated in urban areas than in rural areas. The lighter trucks had a greater percentage of trips starting after a long break in urban areas than in rural areas. This is likely due to these vehicles being garaged over night in urban areas. The heavier truck soak time patterns indicate that they are more likely to take longer breaks on long trips.

Weight Category	Region	# Trucks	# Trips	0-2.5	2.5-7.5	7.5-12.5	12.5-27.5	27.5-47.5	47.5-72.5	72.5-107.5	107.5-137.5	137.5-227.5	227.5-373.5	373.5-587.5	>587.5
T4	Urban	13	1,699	52.3	29.2	8.1	4.8	1.6	1.1	0.4	0.1	0.4	0.1	0.2	1.8
	Rural	7	193	55.4	25.4	10.9	6.2	0.5	0.0	1.6	0.0	0.0	0.0	0.0	0.0
T5	Urban	14	1,333	42.9	30.8	9.1	7.1	2.3	2.3	1.2	0.8	0.8	0.8	0.2	2.3
	Rural	4	58	60.3	32.8	5.2	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T6	Urban	31	3,702	49.5	29.3	6.8	6.2	1.7	1.2	0.6	0.7	0.7	0.2	0.1	2.9
	Rural	15	274	47.8	30.7	9.5	9.1	1.5	1.1	0.0	0.0	O.0	0.4	0.0	0.0
T7	Urban	31	837	9.7	16.1	12.5	19.0	14.2	7.9	3.8	1.7	1.7	1.2	1.9	10.5
	Rural	26	264	8.3	11.0	12.1	23.1	16.7	17.0	5.3	1.1	1.1	0.0	1.1	3.8
T8	Urban	6	145	24.8	31.7	15.2	15.2	4.8	2.1	1.4	0.7	0.7	0.7	0.7	2.1
	Rural	6	52	15.4	21.2	19.2	11.5	3.8	1.9	0.0	1.9	1.9	0.0	3.8	21.2

Table 27. Soak Time Distribution (Minutes) by Weight Class and Urban/Rural

6. Summary and Conclusions

This section provides overall conclusions, suggestions, and commentary related to the process and results of the Heavy Duty Truck (HDT) Activity Data Project. Where appropriate, comparative comments reference the recent FHWA Lexington study[8] that employed a similar methodology for data collection.

The objectives of the FHWA HDT Activity Data Project were to collect truck travel activity data to describe truck travel patterns in urban and rural areas to support congestion modeling activities. These data include several truck vehicle classes, trip definition based on engine start and stop, trip time and distance, and highway functional classification. The analyses characterize the collected data by producing speed profiles, trip patterns, and start patterns and other data summaries by vehicle class, urban area types, highway functional class, and California counties and air basins.

Battelle performed data collection activities using automated equipment that included Global Positioning System (GPS) technology to record and subsequently describe truck travel activity within the state of California. The project data collection activity was dependent on a volunteer sample from the California trucking industry, which contributed to a smaller, less representative sample than was planned.

The following paragraphs discuss various components of this activity and suggests some "lessons learned" from the data collection and analysis effort.

Hardware. The hand-held computer employed in the data collection activity was deployed in a service environment that was generally more severe than envisioned by the equipment vendors. While the Sony MagicLinks performed reasonably well[9], they periodically "froze" and thus did not record data as intended. The specific causes of these events are not clear – the devices were discovered to be inoperative upon retrieval by the installation technician. Usually the physical process of resetting the machine returned the device to working condition so hardware issues are suspected to be the prime cause of these stoppages. This problem is difficult to diagnose since the failures were not observed in the field and they are difficult to reproduce under controlled conditions.

The system batteries are aging but held up well during the field activities. The MagicLinks were generally powered by the vehicle electrical system during data collection and the internal batteries were sufficient to manage the shutdown sequence after the vehicle's engine was turned off. One data set was lost due to a failed battery within the PCMCIA memory card. Other failures that were experienced included cabling failures that were replaced with heavier duty material during the course of the field activities.

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[8]Lexington Area Travel Data Collection Test – Global Positioning Systems for Personal Travel Surveys, Office of Highway Information Management, Office of Technology Application, Federal Highway Administration, US Department of Transportation, Final Report, September 15, 1997.

[9]The hand-held computers experienced 292 actual deployments in the Lexington and California data collections, approximately 16 deployments per unit, plus the wear and tear of repeated tests and shipping.

The MagicLinks were one of only two available units that met project requirements when they were first purchased in 1995. Although the original MagicLinks are no longer manufactured, a number of newer personal digital assistant (PDA) and palm-computer products are currently available that could perform in this type of application. The growth in the market for these devices makes parts compatibility less of a problem.

The GPS receivers were the best performing piece of equipment, as expected, because they were essentially designed for the service environment. The GPS receivers also contain an internal battery, which has a rated 10-year life and is not scheduled for replacement for several years.

Durability of the equipment for repeated use is the principal hardware issue, particularly with respect to the hand-held computer/data storage unit.

Sampling Process. The response rate for the sampling process was low. Two areas can be discussed related to the sampling process – (1) recruiting the trucking company and (2) addressing the driver's cooperation with the data collection activity.

Additional effort is required to achieve an improved response rate. There was no pre-deployment publicity and no effective pre-test to identify problems or issues related to recruiting. Effectively, the recruiting process relied on "cold-calling" to trucking companies.

A more directed sampling process would be necessary to achieve a sample that would be more descriptive of statewide HDT activity. For example, the recruiting could focus on a smaller geographic region, specific truck weight category and business use, and then move on to the next region after the quota was filled. This approach could allow focused pre-collection publicity to help build the recruitment rate in a particular geographic area.

Given the nature of the trucking industry, mandated participation might be required to ensure an adequate sample for a more realistic characterization on a statewide basis. However, this option is considered unlikely.

Future applications, especially if a large, representative sample is desired, should include a pre-test to refine the recruitment strategy and to fine-tune the data collection equipment prior to large-scale deployment. While a pre-test may consume resources without promising fully useful data, lessons learned in the pre-test should result in resource savings during the later data collection period, allowing more data to be obtained. At a minimum, the pre-test activity will help focus the planning process and recruiting strategy for improved results.

Incentives. Incentives also need to be included as a part of the recruitment and compliance strategy. Overall, incentive offers to fleet owners, operators, and especially HDT drivers would be expected to help assure a more broad-based data sample and increase the recruiting success rate.

The trucking company received summaries of the data collected on their trucks as incentive for participating. The trucking companies expressed interest in this feedback from the process;

however, the feedback process was slow and, in the early stages (Phase I), incomplete due to equipment problems. The feedback must be prompt to achieve its maximum benefit.

Incentives to encourage driver compliance should also be considered in the placement strategy. Driver incentives were not initiated until Phase II of this data collection and were well received by the drivers. Driver compliance was suspect in Phase I of the data collection but the degree of this problem is uncertain due to other issues associated with the Phase I data. Driver compliance improved when additional efforts were taken to include them in the information stream (Phase II) and also included a non-cash incentive upon request.

Overall, both drivers and, to a lesser extent, owners seemed somewhat mistrustful of the project objectives. These concerns were generally voiced as uncertainties over enforcement issues (such as hours of service, compliance to route, and unscheduled stops) and the ultimate use of the data (e.g., additional regulations that may impact their business). However, the limited incentives offered did contribute to recruitment of trucking firms and driver compliance.

Equipment Installation. The approach to equipment installation required an installation technician to visit the site and calibrate the data collection equipment for each truck. The individual calibration was necessary based on data collection equipment design and the wide variation in voltage response of different trucks as seen through the accessory power port. This approach is not optimal. Technicians cost money and drive time to sites was significant, especially if an appointment was missed or cancelled.

The calibration process is another issue. A poor calibration leads to poor results. In this application, even when the calibration was good the data collection equipment sometimes failed; thus the data collection period was shortened and there are few “complete” sampling periods associated with a truck.

Even with these issues, power collection through the accessory power port is still the best option for a “plug and play” data collection device. Redesigning the power management circuit to eliminate the calibration process should improve the success of the data collection and reduce the costs associated with placing the equipment by eliminating the need for a technician to install the equipment.

User interface. Another issue relates to including an interactive user interface that relies on the vehicle driver for some data input or device activation, or an autonomous device that is transparent to the vehicle driver, as was used in the HDT data collection. The use of an interactive user interface can allow the collection of important data that may not be available through an autonomous device, and may also assist in establishing “buy in” of the vehicle driver through their active participation in the process.

The downside of an interactive user interface is user inattention (data not entered), driver distraction (a safety hazard if the vehicle is moving), or deliberate omission of data entry (omissions or deliberate incorrect entry) if “buy in” is not achieved. An autonomous device can avoid some of these issues however this approach places some limits on the data collection process. Overall, participant "buy in" is probably better approached via incentives or other alternatives rather than an interactive user interface.

GPS Data Analysis Incorporating GIS. The GPS/GIS data integration contains two issues: (1) tagging the GPS data points to specific geographic areas, such as counties or urban areas, and (2) map-matching the GPS data points to the roadway network represented in the GIS map.

Tagging the GPS data points to geographic areas is a straightforward process supported by the GIS software once geographic areas are defined. Some geographic area definitions are not perfect as gaps may exist near odd-shaped boundaries (difficulties were encountered around San Francisco Bay), bridges, and islands. Some care is required to ensure that the geographic area definitions encompass all the features that are desired in the analysis.

Map-matching the GPS data points to the roadway networks and subsequently representing the travel by the GIS based roadway network requires additional software tools. The map-matching process has improved since its application in the Lexington study. However, the sheer size of the HDT database challenged the software capacity. Several modifications to the software were made during the map-matching process to address issues observed during the matching process.

Another issue related to the map-matching process is the accuracy of the roadway network, both its positional accuracy and its completeness. Positional accuracy is important if the GPS point is to be matched to the correct roadway. Errors exist in both measurements and it is generally believed that the collected GPS data points have better positional accuracy than some readily available roadway networks (such as TIGER files). Roadway network completeness is also important to achieving a high percentage of map-matched points. GPS data points that are judged to be off-network (as compared to the GIS file) do not contribute to the analysis results. Some travel will always be off-network, such as large parking lots or trucking terminals. However, if the GIS roadway network lacks detail (such as some lower functional class or rural roads) then the results may be biased toward the roadway features included in the GIS network. Roadway network positional accuracy is needed to aid the success of the map-matching process and roadway network completeness contributes to balanced results.

GPS data point accuracy can be improved by differential correction, which may be done by directly employing differential GPS (DGPS) in the data collection process or in post-processing if the appropriate reference data are available. Up until the time of this study, DGPS required a larger investment in equipment and was not universally available as a commercial service. Like other parts of the equipment market, the expense and difficulty of using DGPS continue to decrease and in the future, may be as readily available as the uncorrected GPS data.

Data Collection Costs. Cost comparison to traditional survey methods such as telephone surveys is inappropriate because the method and results of the data collection are vastly different. However, FHWA's Lexington study offers a basis of comparison since the methods, equipment, and resultant data are similar. Also, both the Lexington study and this HDT study were conducted essentially as a research process rather than a "production" mode of data collection. The following remarks compare the Lexington and HDT data collection costs for selected activities on a “per installation” basis as the most appropriate measure of the activity required to collect an individual sample.

The recruiting processes for these two studies were quite different and experienced substantially different success rates – Lexington was considered very successful and HDT was more difficult. Costs associated with the Lexington recruiting effort, which included substantial pre-collection publicity and planning, were approximately 45 percent higher per installation than the HDT study.

Field activities, defined as preparing, transporting, installing, and retrieving the data collection devices, were approximately 29 percent higher per installation for the HDT study. This is directly attributable to the drive time required to reach the HDT installation sites (Lexington equipment was delivered by private courier and installed by the respondent without a technician). The costs associated with preparation and installation of the data collection equipment are essentially equivalent for the two studies once the transportation costs are removed.

Data analysis and reporting costs for the HDT study were approximately 35 percent to 40 percent higher per installation than for the Lexington study. Substantially more data were collected per installation[10] and additional analyses were required for the HDT study because of the substantially higher VMT and the travel was not limited to a single, local area as was the Lexington study.

Study management and planning costs were substantially less for the HDT study on a per installation basis. This result was expected since the Lexington study was the first application of the automated data collection technology and thus contained a “learning” element that was not as pronounced in the HDT study. However, as discussed above, additional planning expenditures in the HDT study likely could have enhanced the success of the HDT data collection.

Overall, HDT study cost per installation was approximately 80 percent of the Lexington cost per installation, ignoring equipment purchase and software development costs. This reduction is progress in the right direction. However, based on the discussions above, study planning and pre-collection activities likely should have been emphasized more in the HDT study to enhance the recruiting and data collection success.

The HDT Sample and Analyses. The resultant sample and accompanying database are best described as an opportunity sample. Explicit coverage of vehicle classes, geographic coverage, business use, or other data characteristics is problematic when voluntary contributors drive the sample composition. The resulting database described in this report therefore is descriptive only of the sample itself, and may or may not be descriptive of HDT travel activity in the state of California.

The descriptive analyses of the sample data prepared in this project demonstrate that this data collection and analysis process is useful for describing HDT activity data. Analyses based on vehicle classes, geographic areas (e.g., air basins), highway functional classes, and other factors

[10]The HDT study recorded approximately 87,000 VMT as one-second data; the Lexington study recorded approximately 11,600 VMT as, on average, three-second data.

are possible and were performed. The analyses presented in Chapters 4 and 5 offer insights into the HDT activity included in the sample and a level of detail never captured before in an HDT activity data base.

Overall, the resultant database from the HDT Activity Data Project addresses the objectives defined for the project. Although the sample does not sufficiently represent HDT activity throughout the state of California, a substantial amount of HDT activity data were collected and described to support the project objectives. These data therefore represent a new knowledge base for FHWA, CARB, and other researchers engaged in the task of describing HDT activity.

APPENDIX A

DATA PROCESSING DESCRIPTION

Appendix A

Data Processing Description

An Interbase® data base with a Delphi™ front end was developed to store and process the truck activity data collected during the field portion of the study. As the data were imported into the data base, a series of screening procedures identified any bad data points. These procedures included automated data checks, graphical representations of the data for review by the data base manager, and interactive data edit modules. This appendix describes the various raw data screening procedures, the methods for tagging the individual data points with GIS attributes, and the detailed data base organization.

A.1 Raw Data Screening Procedures

The raw data screening procedures were implemented at multiple stages of the data processing. The first stage occurred as the raw data were imported into the data base from the ASCII files that were uploaded from the hand-held computer. There was one ASCII file per truck, and these text files contained four levels of data: truck descriptions, trip headers, trip ignition-on/off time stamps, and trip GPS readings. Figure A-1 shows an example of a partial ASCII file from one of the study trucks.

The truck description data are comprised of data entered by the installer through the hand-held computer user interface; the data occur once at the beginning of the file. The truck description data included truck configuration, fuel type, and business use. Although pull-down menus were built into the hand-held computer user interface to accept only valid choices for these questions, additional checks were made at the time of import into the data base to ensure the integrity of the data base. Data were compared against data base lookup tables, and any values that did not match would have been set to an "Invalid Response" code and would have been noted on the Trip Summary Reports (described later in this appendix.) There were no data problems identified by these checks.

The trip header data were generated by the hand-held computer software, and occurred at the beginning of every trip in the file. Starting and ending times of the trips were the key components of this data. Data screening of this data consisted of verifying that the starting and ending dates and times were valid dates and times. Once again, no data problems were identified by these checks.

The ignition-on/off time stamp data were recorded by the hand-held computer software based on signals from the power management/ignition detection circuit. The ignition-on/off data followed their respective trip headers in the ASCII file. Screening of this data consisted of verifying that the time stamps assigned to each ignition-on/off were valid dates and times. No data problems were identified by these checks, although there were cases when a poor power connection or poor calibration of the ignition detection circuit caused spurious ignition-on/offs to be recorded.

```
-- HDT Trip Data base -- 6/6/98 at 20:03:14
vehicle config: SU2
body type: van
fuel type: gasoline
state of registration: CA, California
case number: 321502
starting odometer: 63019
starting engine hours: unknown
business use: postal/parcel
catalytic: yes
VIN: 1GDJP32K5S3XXXXXX
ending odometer: 63270
ending engine hours: unknown
GVWR: 12000
device number: Unit12
notepad:
----begin trip record
start: 09:10:12 06/03/1998
end: 09:12:15 06/03/1998
ignition off time: 09:11:59 06/03/1998
Collected 83 samples
------begin position samples
00:00:00 01/01/1904    0000.0000    0000.0000     0.0
00:00:00 01/01/1904    0000.0000    0000.0000     0.0
00:00:00 01/01/1904    0000.0000    0000.0000     0.0
00:00:00 01/01/1904    0000.0000    0000.0000     0.0
00:00:00 01/01/1904    0000.0000    0000.0000     0.0
00:00:00 01/01/1904    0000.0000    0000.0000     0.0
16:11:45 06/03/1998    4037.6066    12222.3734    0.0
16:11:46 06/03/1998    4037.6064    12222.3731    2.1
16:11:47 06/03/1998    4037.6059    12222.3716    3.3
16:11:48 06/03/1998    4037.6052    12222.3702    4.4
16:11:49 06/03/1998    4037.6033    12222.3685    7.6
16:11:50 06/03/1998    4037.6011    12222.3671    10.3
16:11:51 06/03/1998    4037.5980    12222.3668    10.7
16:11:52 06/03/1998    4037.5943    12222.3668    12.3
16:11:53 06/03/1998    4037.5901    12222.3666    13.8
16:11:54 06/03/1998    4037.5858    12222.3667    14.5
16:11:55 06/03/1998    4037.5817    12222.3668    13.8
16:11:56 06/03/1998    4037.5761    12222.3699    13.3
16:11:57 06/03/1998    4037.5715    12222.3733    11.8
```

Figure A-1. Example Data File from a Sample Truck

The GPS readings for each trip followed the ignition-on/off time stamps in the ASCII file. These data were a selective set of the GPS receiver output and consisted of a time and date, latitude, longitude, and a speed value. The GPS records required the bulk of the data screening procedures. As a first-level screening, each GPS record was checked to see if all of the expected fields (date, time, latitude, longitude, and speed) existed on the record and were in a valid format (e.g., mm/dd/yy, hh:mm:ss, one decimal point in numeric fields), and that no extra fields existed on the record. Records which failed this check were transferred into an “Error” table for possible correction at a later time. These types of data errors were caused by problems occurring when the data were uploaded from the hand-held computer to a PC via the serial port. Only 668 GPS records (out of over 8,000,000) were identified by this screening step, and because of the extremely small percentage of problem records, no effort was made to correct these records.

GPS records that were determined to be valid at a record level were then subjected to a series of data quality checks to identify any individual data points which were invalid. Table A-1 lists the data quality checks that were performed on the GPS records. Records passing all of the checks had a data screening variable *(ReadFlag*) set to "blank". Records failing at least one of the checks had *ReadFlag* set to the error code indicated in Table A-1. For a record that failed more than one check, *ReadFlag* was set to the error code of the first check that was not met.

Table A-1. Data Quality Checks Performed on GPS Reading Data

Error Condition	Error Code	Error Description
Date = 01/01/1904	0	GPS receiver failed to establish position
· Date < 08/01/97 · Date > "date of import" · Date < "date of previous record" · Date > "date of previous record + 14 days"	1	· Date is prior to start of study · Date is after completion of travel · Date is prior to previous record's date · Date is more than 2 weeks in the future of previous record's date
Latitude < 32 or Latitude > 43	2	Latitude is outside approximate area of California
Longitude < -125 or Longitude > -114	3	Longitude is outside approximate area of California
Speed > 100	4	Speed exceeds 100 mph
Time < "time of previous record"	5	Time is prior to previous record's time
Distance/Duration > 0.065	6	Distance traveled exceeds 0.065 miles/sec
$(Speed_i - Speed_{i-1}) / 3600 / Duration > 0.003$	7	Acceleration exceeds 15 $feet/sec^2$
Time > "last ignition off time"	8	GPS record collected after trip ended
NA	9	Receiver malfunctioned (set by data base manager post-import for one truck only)

All of these error conditions were met at least once during the duration of the field study. However, with the exception of Error Codes 0, 8, and 9, all types of errors occurred less than one tenth percent of the time. Error Codes 0, 8, and 9 occurred 1.8 percent, 1.4 percent, and 0.2 percent of the time, respectively. The Error Code 8 records were a product of the data collection method and were the records collected after a trip ended and before another trip began. Appendix B provides further description of the data collection process and explanation of how trips were stored by the software.

The second stage of raw data screening was performed by the data base manager after the data were imported into the data base. A Trip Summary Report (Figure A-2) and a graphical representation of the speed data (Figure A-3) were reviewed by the data manager in an attempt to identify problems in the data that could not be caught by the automated data checks discussed above. For each trip, the Trip Summary Report listed the starting and ending times, the number of good and bad records based on the automated data checks, the time of the first good GPS reading, the time of the last ignition-off, and an estimate of the time offset between the hand-held computer clock and the satellite clock. The time offset occurred because the clock in the hand-held computer could not be synchronized to the time as reported by the GPS satellites. The graphical representation of the speed data showed truck speed plotted against time for each trip.

Import Summary

Case Number: 32[illegible]	Configuration: SUC	Starting Odometer: 53010	Starting Engine Hours: -0	Device Number: 12
Truck Number: 502	Body Type: van	Ending Odometer: 53270	Ending Engine Hours: -0	GVWR: 12000

Trip Number	Start of Trip	End of Trip	Number GPS Records Bad	Good	Speed > 5	Number of Ignitions On	Off	Last Ignition Off	First Good GPS
002	06/03/98 08:47:36	06/03/98 09:06:56	33	800	804	0	0		06/03/98 08:40:38
003	06/03/98 09:10:12	06/03/98 09:12:15	3	77	74	0	0		06/03/98 09:11:45
004	06/03/98 09:12:49	06/03/98 09:14:45	3	47	45	0	0		06/03/98 09:14:22
005	06/03/98 09:10:27	06/03/98 09:17:20	0	0	0	0	0		06/03/98 09:17:56 (09)
006	06/03/98 09:20:09	06/03/98 09:22:17	3	53	52	0	0		06/03/98 09:2[illegible]
007*	06/03/98 09:29:13	06/03/98 09:33:[illegible]	19	92	88	1	2	06/03/98 09:32:02	12/08/25 09:30:48
008	06/03/98 09:33:58	06/03/98 09:36:24	0	53	40	0	1	06/03/98 09:34:52	06/03/98 09:35:20 (09)
009	06/03/98 09:37:36	06/03/98 09:38:56	5	36	34	0	1	06/03/98 09:38:13	06/03/98 09:39:10
010	06/03/98 09:40:21	06/03/98 09:42:26	0	86	75	0	1	06/03/98 09:41:47	06/03/98 09:41:50 (89)
011	06/03/98 09:48:29	06/03/98 09:56:25	16	356	344	0	2	06/03/98 09:54:22	06/03/98 09:49:58
012	06/03/98 09:56:59	06/03/98 10:06:14	13	439	418	0	0		06/03/98 09:58:10
013	06/03/98 10:06:06	06/03/98 10:17:2[illegible]	5	631	625	0	0		06/03/98 10:07:40
014	06/03/98 10:20:43	06/03/98 10:22:[illegible]	4	32	31	0	0		06/03/98 10:22:16
015	06/03/98 10:23:09	06/03/98 10:30:27	9	370	371	0	0		06/03/98 10:24:40
016	06/03/98 10:31:35	06/03/98 10:34:19	19	93	74	0	1	06/03/98 10:33:23	06/03/98 10:33:22
017	06/03/98 10:35:45	06/03/98 10:42:16	3	340	313	0	0		06/03/98 10:37:16
018*	06/03/98 10:47:20	06/03/98 10:50:40	10	321	270	0	0		06/03/98 10:40:50
019	06/03/98 10:57:45	06/03/98 11:02:43	0	238	230	0	0		06/03/98 10:59:10 (88)
020	06/03/98 11:08:06	06/03/98 11:13:36	0	248	241	0	0		06/03/98 11:09:35 (89)
021	06/03/98 11:13:57	06/03/98 11:18:10	2	197	180	0	0		06/03/98 11:15:27
022	06/03/98 11:18:28	06/03/98 11:19:47	15	29	29	0	0		06/03/98 11:20:10
023	06/03/98 11:21:10	06/03/98 11:23:50	3	94	68	0	0		06/03/98 11:22:40
024	06/03/98 11:25:16	06/03/98 11:29:32	3	197	166	0	1	06/03/98 11:25:44	06/03/98 11:26:52
025	06/03/98 11:31:40	06/03/98 11:37:29	0	270	254	0	1	06/03/98 11:36:23	06/03/98 11:33:16 (00)
026	06/03/98 11:37:46	06/03/98 11:41:23	7	162	149	0	0		06/03/98 11:39:22
027	06/03/98 11:41:39	06/03/98 11:44:24	2	112	83	0	0		06/03/98 11:43:09
028	06/03/98 11:45:10	06/03/98 11:50:10	25	371	334	0	1	06/03/98 11:52:00	06/03/98 11:47:10
029	06/03/98 11:53:44	06/03/98 11:57:22	0	181	161	0	1	06/03/98 11:56:43	06/03/98 11:55:10 (89)

* Starting location not the same as ending location of previous trip. + Two trips concatenated.

Date Report Printed: 11/12/98 10:25:32 AM Page No: 1

Figure A-2. Example Trip Summary Report

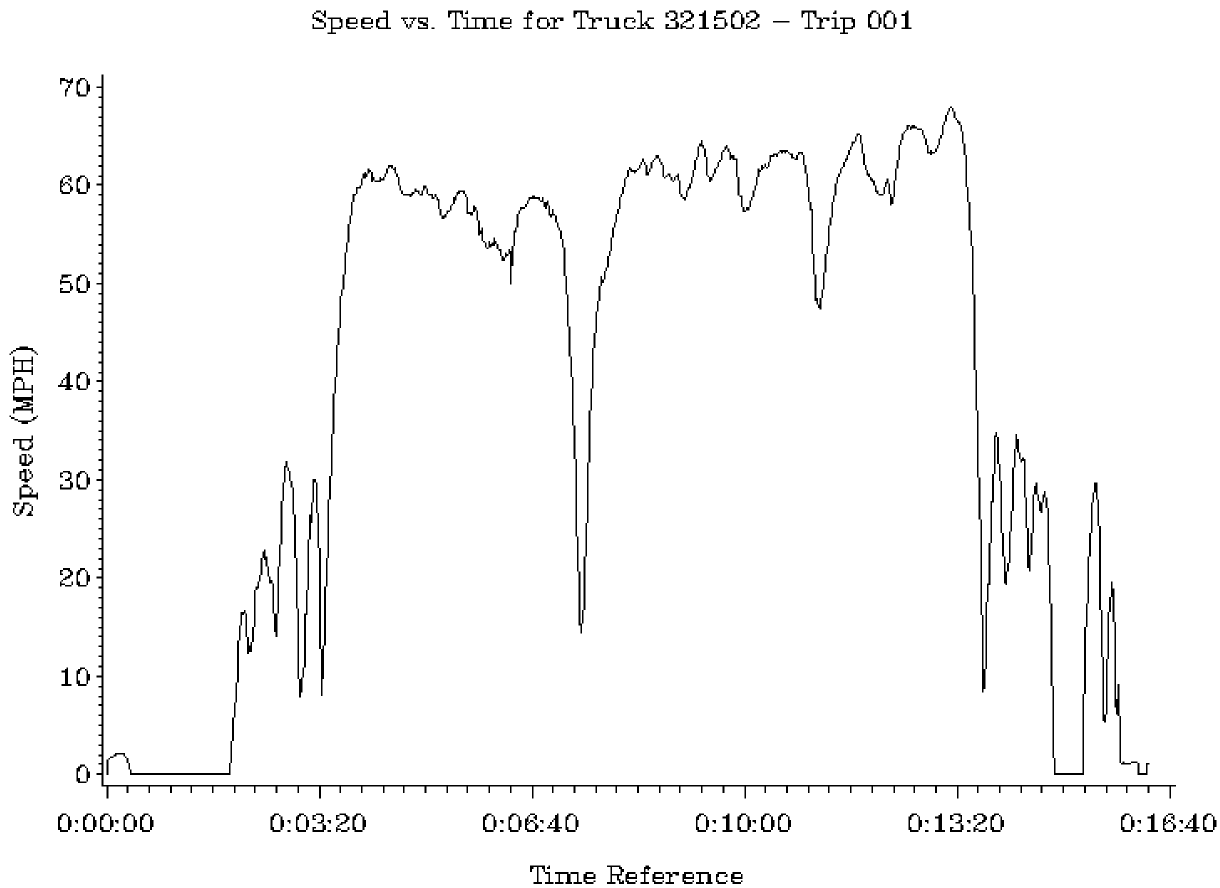

Figure A-3. Example of Truck Speed Versus Time Chart

These trip reports allowed the data base manager to find instances in which:

- One trip should be separated into two or more trips as indicated by ignition-on/off time stamps
- The end-of-trip time did not correspond with the time of the ignition-off signal
- Multiple trips should be defined as one because a software error in the hand-held computer caused the data collection to temporarily stop; the ignition detection system was not functioning properly due to either poor circuit calibration or hardware failure
- The field technician simulated a trip as part of the installation protocol.

An edit module was designed as part of the data base system to enable the data base manager to correct some of the problems that were identified by reviewing the trip reports. In order to accurately perform the corrections, the time offset described previously had to be taken into account when correcting the data. The problems that could be corrected are as follows:

- Redefining one trip into multiple trips based on ignition-on/off times

- Redefining the end of trip to correspond with the last ignition off time. GPS readings that were collected past the end of a trip were assigned a *Readflag* of 8 (see Table A-1)

- Redefining multiple trips as a single trip when error exceptions forced the software to start a new trip definition midway through an actual trip

- Deletion of trips simulated by the field technician as part of the installation and retrieval protocol.

The final data base contains a total of 8,300,797 GPS records collected during the field portion of the study. After performing all of the raw data screening procedures described above, 8,011,343 (96.5 percent) of the records, comprising 11,499 trips, were found to be valid and eligible for analysis.

A.2 Tagging Records with GIS Information

As the raw data screening procedures were completed for each truck, the GPS records were exported into dBASE tables that could be imported into TransCAD, the GIS software used for this study. Prior to the start of the data collection, separate geographical layers had been created in TransCAD for California counties, air basins, and urban areas. By matching the latitude and longitude of each GPS record against these layers, each GPS record could be identified or tagged with the appropriate county, air basin, and urban area identification number. This procedure was executed for all GPS records collected.

After the tagging was completed for each truck, dBASE tables were exported from TransCAD. An import module in the data base system was used to electronically merge the tagged records with their corresponding GPS readings already stored in the data base. By performing this merging, the GPS records in the data base were updated with their tagged values for county, air basin, and urban area.

A.3 Data Base Organization

The Interbase® data base designed for this study is comprised of eight data tables. All of these tables are keyed by at least two fields (*CaseNo* and *TruckNo*) to ensure the uniqueness of records stored in the data base. *CaseNo* is the unique ID assigned to each company providing trucks for the study, and *TruckNo* is the unique ID assigned to each truck that each company provided.

Brief descriptions of each of the tables are provided in Table A-2 below. A complete data dictionary is provided on the study CD that contains the complete data base. The first four tables contain the raw data collected by the hand-held computer and GPS receiver. The last four tables contain summaries and calculations based on the raw data.

Table A-2. Description of Data Tables

Table	Description
GPS_TRUCK	Contains descriptive information (e.g., fuel type, VIN) for each truck; keyed by *CaseNo* and *TruckNo*, resulting in one record per truck.
GPS_TRIP	Contains trip header information (e.g., start time, end time) for each trip; keyed by *CaseNo*, *TruckNo*, and *TripNo*, resulting in one record per trip per truck.
GPS_IGNI	Contains timestamp for each ignition on/off; keyed by *CaseNo*, *TruckNo*, *TripNo*, and *IgniNo*, resulting in one record per ignition on/off per trip. (Used only for QC and editing purposes—not included on the study CD.)
GPS_READ	Contains GPS information (e.g., latitude, county) for each GPS reading; keyed by *CaseNo*, *TruckNo*, *TripNo*, and *ReadNo*, resulting in one record per GPS reading per trip.
TRIP_ALL	Contains summary information (e.g., distance, duration) of entire trips; keyed by *CaseNo*, *TruckNo*, and *TripNo*, resulting in one record per trip.
TRIP_REG	Contains summary information (e.g., distance, duration) of travel within distinct counties, air basins, and urban areas for each trip; keyed by *CaseNo*, *TruckNo*, *TripNo*, *County*, *AirBasin*, and *UrbArea*, resulting in one record per distinct combination of county, air basin, and urban area per trip.
TRIP_HR	Contains speed profile information (e.g., distance, duration) for 5 mph speed bins for each hour of travel within distinct counties, air basins, and urban areas for each trip; keyed by *CaseNo*, *TruckNo*, *TripNo*, *County*, *AirBasin*, *UrbArea*, *TripDate*, and *TripHour*, resulting in one record per distinct combination of county, air basin, and urban area per hour per trip.
TRIP_MAT	Contains map-matched information (e.g., link ID, distance) for each trip; keyed by *CaseNo*, *TruckNo*, and *TripNo*, resulting in one record per trip.

APPENDIX B

DATA COLLECTION EQUIPMENT

APPENDIX B

DATA COLLECTION EQUIPMENT

This section provides an overview description of the data collection equipment configured by Battelle for the CARB/FHWA Heavy-Duty Truck activity survey.

B.1 General Description

Figure B-1 illustrates the data collection device, which is configured as a portable, “plug-and-play” concept that requires minimal effort to install in the vehicle. The completed unit consists of the following individual items.

Figure B-1. Data Collection Equipment

- Hand-held computer - The hand-held computer is a Sony® MagicLink PIC-2000 personal digital assistant, with a backlit touch screen user interface.

- GPS receiver - The GPS receiver is a Garmin® TracPak-35 that is equipped with a magnetic roof mount, a mounting bracket suitable for attachment to a HDT mirror support, or a suction cup device for mounting inside the windshield.

- Software interface - Software that configures the unit and controls data collection. The HDT user interface software (described in Section B.3) identifies truck characteristics, business uses, and controls the recording of GPS data. The HDT software was designed for use by an installation technician (i.e., installation requires moderate knowledge about the equipment and its operation).

- SRAM PCMCIA card (not shown) - A memory card containing the application software and memory for data storage.

- Voltage Detection/Power Management Circuit (not shown) - A control circuit that detects changes in electrical noise or voltage in the vehicle power source that indicate the engine has started or stopped. On engine start, the data collection device activates, records the event, begins data collection, and recharges the hand-held computer battery. On engine stop, the data collection device records the event, stops data collection after a preset time period, and shuts down to preserve the hand-held computer battery.

- Connecting cables - Power cable that plugs into the vehicle's accessory power port (cigarette lighter) to provide power for the GPS receiver and hand-held computer, fuse protection for these components, and a serial cable that enables communications between the GPS receiver and user interface software via the hand-held computer. These connecting cables also contain the voltage detection/power management circuit.

Table B-1 provides a complete equipment list for the data collection equipment.

Table B-1. GPS Data Collection Equipment Parts List

Travel Data Collection Equipment

- Garmin GPS 35 TracPak PC GPS Receiver
    - Magnetic, Clamp, and Suction Cup Mounts
- Sony MagicLink PIC-2000 PDA
    - General Magic MagicCap version 1.5 operating system
    - Stylus
    - Lithium ion rechargeable main battery
    - Lithium backup battery
    - Protective Case
- 2.0MB PCMCIA Type II SRAM memory card
- Wrapped Connecting Cable
    - Power Cable - services PDA and GPS receiver via vehicle cigarette lighter/accessory port
    - Serial Communications Cable - enables PDA and GPS to communicate
    - Noise/Voltage Detection Circuit
- Burlap field pouch

Operating Instructions

- Field Manuals describing data collection procedures
- HDT Activity Survey On-screen Installation and Calibration Instructions

Interface Software

- Developed by Battelle.

B.2 Hardware Description

The hardware used in assembling the data collection equipment consists almost entirely of off-the-shelf components. This approach permitted a relatively low cost configuration to be fielded for data collection. The principal components are the hand-held computer and the GPS receiver. Tables B-2 and B-3 provide more detailed specifications for the Sony® hand-held computer and the Garmin® GPS receiver.

Table B-2. Sony MagicLink PIC-2000 Specifications

Features

- Touch (pressure-sensitive) screen interface
- Backlighting on interface
- Employs sophisticated power-management scheme
- Supports serial communications
- Based on an intuitive operating system

Performance

- Processor - MC68349, 16 MHZ clock (3.3V operation)
- ROM Memory - 4MB (runs system and application software)
- RAM Memory - 2MB, battery backed-up
- Operating System - MagicCap v1.5 (General Magic)

Physical Features

- Weight - 1.3 lbs.
- Size - 1.0 in. (h) x 5.2 in. (l) x 7.5 in. (w)
- Operating Temperature - 0 to +50 deg C

LCD and Touch Screen

- Screen Size - 3.2 in. (h) x 4.7 in. (w)
- Resolution - 480 x 320
- Dot Pitch - 100 dpi
- Backlighting - ON/OFF switch
- Contrast - manual

Power Requirements

- Power Consumption - 2.4 Watts (max)
- Power Requirement - 7.2 Vdc via lithium ion rechargeable main battery (or accessory port)
- Rechargeable Main Battery Life
  - 6 hrs with back-lighting on and in normal operations (1350mAh capacity)
  - 10 hrs with back-lighting off and in normal operations
  - 15 hrs when idle
- Backup Battery - On-board 3 volt lithium battery – 7 months without main battery

Interfaces

- Communications - 14-pin slide-type Magic Port multi-purpose serial bus connector
- Baud Rate - 14,400 baud
- Memory Card Slot - 2 PCMCIA Type II slots

Table B-3. Garmin GPS35 TracPak PC Specifications

Features

- Relatively low cost (<$250) and high output
- Plug and play
- Tracks and uses up to 12 satellites for accurate, reliable GPS data collection
- Relatively low power requirement
- Combines a GPS engine and antenna in an all-weather, low profile housing that can be mounted in a variety of ways for in-vehicle applications
- Terminated for in-vehicle field use
- Does not require input to initialize or navigate
- Differentially correctable

Performance

- Satellite Tracking - 12 channel (MultiTrac 12 engine)
- Horizontal Position Accuracy - 15m (49ft) no SA, <10m (33ft) dgps, 100m (328ft) SA
- Time-to-First-Fix -
  - <2 sec reacquisition
  - 15 sec warm
  - 45 sec cold
  - 5 min automated locating
  - 5 min sky search

Physical Features

- Type - Integrated Engine/Antenna
- Description - Waterproof Enclosure
- Weight - 7.2 oz. (TracPak), 1.1 oz. (OEM)
- Size - 1.04 in. (h) x 3.80 in. (l) x 2.23 in. (w) (TracPak), .45 in. (h) x 2.75 in. (l) x 1.83 in. (w) (OEM)
- Operating Temperature – -30 to +85 deg C

Power Requirements

- Power - 10-30 Vdc via terminated cigarette lighter/accessory port adapter (1.8 Watts OEM)
- Backup - On-board 3 volt lithium battery – 10 year life

Interfaces

- Communications - 9-pin Serial Port (part of terminated cable)
- Baud Rate - 1200 to 9600 baud, user-adjustable
- Update Rate - 1 PPS (Hz) +/- 1 microsecond continuous
- Output - NMEA 0183 v2.0, ASCII
- Input - Not required, but accepts position, date, time, and datum
- Memory - Non-volatile
- DGPS - RTCM SC-104

B.3 Software Interface Description

The Heavy-Duty Truck (HDT) Activity software developed for the California data collection has two principal functions: (1) allow the installation technicians to easily enter information about the vehicle and its business uses, and (2) capture positional data from the GPS receiver associated with each trip. The installation technician is required to enter basic data about the vehicle and its business use at the time the equipment is installed in the vehicle. Most of this information is required in order for the data collection to proceed. If the data entries are incomplete, the software will prohibit the start of the GPS data collection routine and remind the technician to enter the appropriate data. When all required data are entered, the software signals the technician that data collection is in progress.

The three operating portions of the software are (1) vehicle information, consisting of two input screens, (2) administrative information, which also contains the GPS interface, and (3) data collection.

B.3.1 Vehicle Information

Vehicle data are entered through two interface screens, the "vehicle information screen" and the "more information screen." The vehicle information screen allows the installation technician to enter basic data about the vehicle for which data are being collected. The vehicle information screen is shown in Figure B-2.

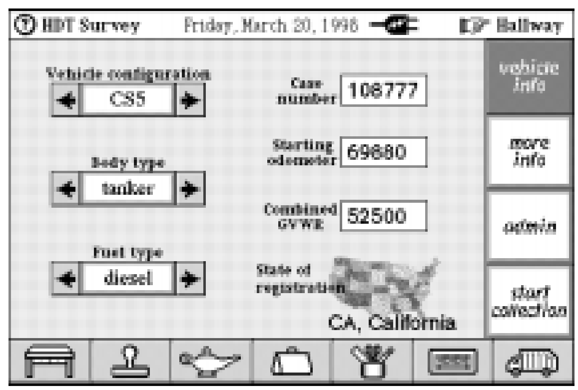

Figure B-2. Vehicle Information Screen

The vehicle information screen is accessed by touching the "vehicle info" button on the right-hand side of the screen. Basic information includes vehicle configuration, body type, and fuel type, listed on the left-hand portion of the screen. Values for these data are entered via pre-defined choice lists that are accessed by touching the window containing the data value or scrolling through the choices using the arrows at the edge of the windows.

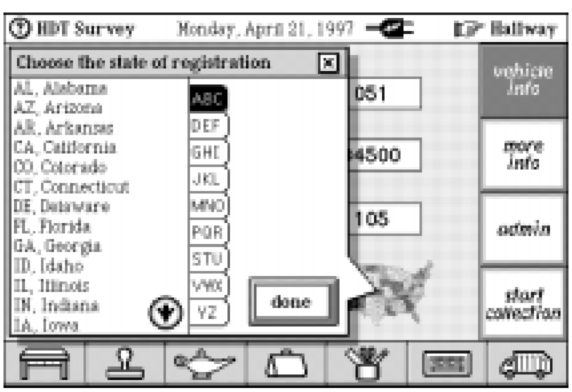

Figure B-3. Index File for Choosing the Vehicle's State of Registration

Other data values requested are the case number (assigned during the vehicle recruiting process), starting odometer, and gross vehicle weight rating (GVWR). These data values are entered via a numeric keyboard that is part of the basic operating system of the MagicLink. The vehicle information screen also requests the vehicle's state of registration, indicated by the small U.S. map in the lower right-hand portion of the screen. Touching the map accesses an index file of state names (Figure B-3) allowing the installation technician to easily choose the vehicle's state of registration. Once the proper state is highlighted in the list, the technician touches "done" to complete the selection.

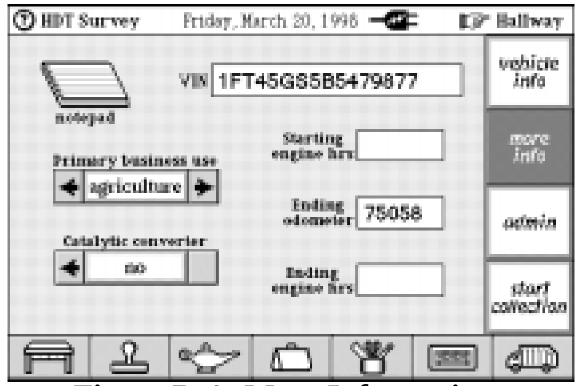

Figure B-4. More Information Screen

The more information screen consists of a single screen that allows the installation technician to enter additional data about the vehicle. The more information screen is shown in Figure B-4.

The more information screen is accessed by touching the "more info" button on the right-hand side of the screen. These additional data consist of the vehicle's primary business use, whether or not the vehicle has a catalytic converter, vehicle identification number (VIN), starting engine hours, if available, and the ending odometer and engine hours if available. The vehicle's primary business use and catalytic converter status are entered using predefined choice lists, similar to the vehicle information screen. The VIN, engine hours, and ending odometer are entered using a numeric keypad that is accessed by touching the keyboard icon at the bottom of the screen. This feature, shown in Figure B-5, is a standard feature of the MagicLink operating system.

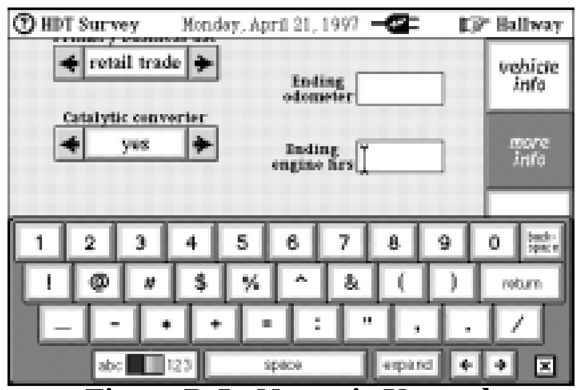

Figure B-5. Numeric Keypad Used for Data Entry

The more information screen also contains a notepad feature that permits additional information to be recorded by the installation technician. The notepad is a standard feature of the MagicLink operating system. This notepad is accessed by touching the notepad icon in the upper left-hand corner of the screen. Figure B-6 illustrates this notepad with the accompanying keypad used for data entry. Information recorded in the notepad becomes a reference text field in the resulting data file.

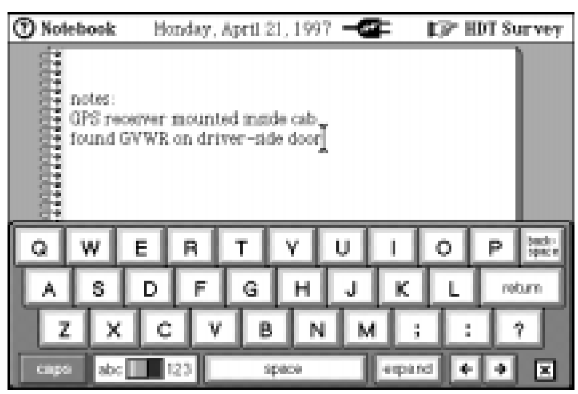

Figure B-6. Notepad Feature Used for Additional Data Entry

B.3.2. Administrative Information

The administrative information screen consists of a single screen that allows the installation technician to set basic parameters for the data collection. The administrative information screen is shown in Figure B-7.

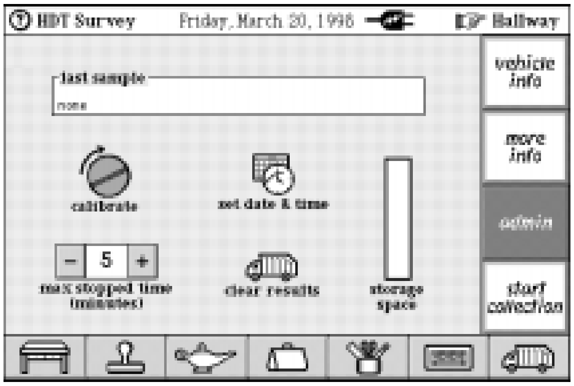

Figure B-7. Administrative Screen

The administrative information screen is accessed by touching the "admin" button on the right-hand side of the screen. The administrative settings are described in the following paragraphs.

Calibrate – The "calibrate" icon allows the installation technician to calibrate the circuit that detects vehicle engine start and stop. This detection is based on variations in the vehicle's electrical system measured as voltage flow through the vehicle's power port. Touching the calibrate icon produces on-screen instructions for performing the calibration procedure during the installation process.

Max Stopped Time – The "max stopped time" icon allows the installation technician to set the time duration before the equipment automatically shuts off after the conclusion of a trip. This feature is intended to conserve the equipment's internal batteries when an engine stop has been detected by the equipment or no change in position/velocity is observed over the max stopped time interval, as measured by the GPS receiver output. This setting is displayed in the window above the label "max stopped time", and the value is changed by touching the plus (+) or minus (-) indicators on each side of the window, and the value can be set between one and 30 minutes.

Set Date & Time – The "Set Date & Time" icon allows the installation technician to set the proper date and time in the equipment memory. An option is also available to automatically adjust the time for the change from standard time to daylight savings time. This setting has no influence on the time recorded with GPS records, which include the time as generated by the GPS satellites. This time setting is important, however, to synchronize other events that are recorded (such as engine on/off) with the GPS records.

Clear Results – The "clear results" icon allows the user to erase, or clear, the data memory in the equipment before field use. This feature does not erase the software from the memory card.

Storage Space – The "storage space" icon on the right-hand side of the screen is a simple bar chart that indicates the relative amount of storage available for collected data. An empty bar, as shown in Figure B-7, indicates that maximum memory is available.

Last Sample - The GPS receiver output data stream in the HDT software is almost invisible to the installation technician. The long rectangular window located at the top of the screen is the only visible evidence of GPS receiver operation. During data collection, this window displays raw GPS output as it is being written to memory. Following data collection, this window displays the last output record received from the GPS receiver. This window does not allow any additional control or interface with the GPS receiver, but simply displays the last record.

B.3.3. Data Collection

After all required preliminary data fields are completed and the equipment is properly installed on the vehicle, the installation technician initiates data collection by touching the “start collection” button on the right-hand side of the screen. If the equipment is working properly, the data collection message (Figure B-8) will appear in the window. The equipment is then stored until its removal at the end of the data collection period. The data collection process requires no interaction from the vehicle driver.

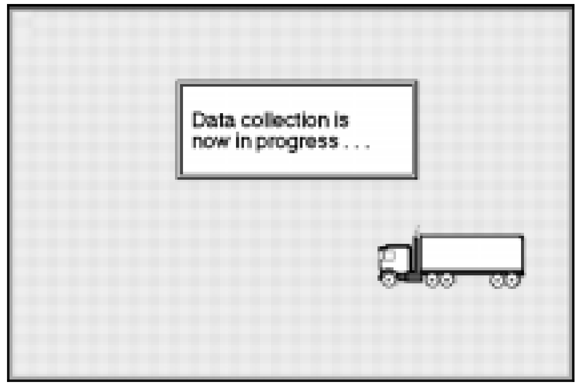

Figure B-8. Data Collection In Progress Screen

These four interface screens constitute the complete interface in the HDT software.

APPENDIX C

MAP-MATCHING GPS DATA

APPENDIX C

MAP-MATCHING GPS DATA

One of the principal objectives of this project was to capture Global Positioning System (GPS) position data for individual trips made by the participating heavy-duty trucks described in this report. These data in combination with a California area base map permitted analysis of the individual trips based on attribute information that is part of the map network data base. Base map or network attribute information includes such characteristics as road name, street address, closest intersecting street name, and highway functional class. The primary reason for map-matching GPS position data on this project was to enable the analysis of travel details by the functional class of road being traveled.

A key part of the map-matching effort involved positioning the collected GPS data points onto individual links in the base map to facilitate this analysis. It is also significant to note that an intermediate "smoothing" step was employed by the map-matching software to increase the likelihood for a successful network match, and that certain data results were extracted at this point as described below. The map-matching process is described in Section C.4 of this appendix.

Throughout this report, truck activity results are reported based upon either the raw GPS truck activity data or the GPS truck activity data once it has undergone the map-matching process. The reader should be aware that tables and charts that include highway functional classifications of truck activity use map-match data as their source. The source for all other tables and charts in this report is the raw GPS truck activity data.

For truck activity based on highway functional class (i.e., the map-match data), the source for table or chart parameters is as follows:

- **Speed**. The source for reported speeds by functional class of road traveled is the raw GPS data. Speed refers to the instantaneous velocity of the vehicle at each GPS position point.

- **Duration**. Duration, or time, is the elapsed time between the collection of two adjacent GPS position points. The source of the position point time values used to calculate duration is the raw GPS data.

- **Distance**. Distance is reported as vehicle miles of travel (VMT) throughout this report. This distance is calculated from the difference in position between two adjacent GPS collection points after the map-matching "smoothing" step is completed, but before the network match is achieved (see below for rationale). The GPS position data are collected as latitude and longitude values and are then translated into miles when distance is calculated.

- **Functional Classification**. Functional classes refer to the Census Bureau's Census Feature Class Codes (CFCC) for roads. Once raw GPS data points have been matched onto individual links in the base map, the functional class of each link to which GPS point data is matched is made available to that point. The Preparation Activities explanation in Section C.4.1 describes the highway functional classifications used in the base map network.

Thus, when the map-matching process is complete, GPS data that have been successfully matched to the base map network have associated with them a functional class, speed, duration, and distance from the sources described above. These are the values that constitute the map-match data in this report.

Generally, GPS data that cannot be matched to a base map network link are disregarded and are not represented in the map-match data set. However, there are circumstances in which some GPS data not matched to a network link are kept as a part of the map-match data set. It has been observed that both in-state off-network and out-of-network (i.e., out-of-state) GPS data contribute to the map-matched data set. Because no functional class can be obtained from the base map in these instances, such data are assigned functional class "6" – other and undefined (see Section C.4.1). Some circumstances that contribute to keeping these data may include the following:

- Data points serve as route gap filler, where otherwise a discontinuity would truncate a trip that obviously continues beyond the network interruption
- Data points that are not thrown out until a discard condition is met by the map-matching algorithm
- The large amount of data throughput managed by the map-matching algorithm may have caused it to not operate properly and not properly apply the discarding criteria
- The base map network being less accurate than the GPS data may restrict the map-matching algorithm from more successful link matches.

The rationale for using "smoothed" raw GPS position values instead of map-matched network link values to calculate distance stems from the belief that the GPS positions are more accurate than the map-matched positions. There are two primary reasons why this belief is held. The first reason involves a comparison between the absolute position accuracy that can be achieved using the base map links versus using the raw GPS position data. Because the original source for the streets that constitute the base map network used in map-matching were TIGER/Line files, the position accuracy of the GPS point data from the receivers used in this project exceeds the base map position accuracy. This is particularly true when positions are being compared in the vicinity of local streets. If this belief is true, it is reasonable to expect that calculated distances would be more accurate as a result of using raw GPS positions.

The second reason involves the characteristics of the map-matching algorithm. There is a greater potential for the map-matching algorithm to make position fix errors when attempting to match:

- Off-network travel (e.g., travel that beings or ends a significant distance from a road in the network, such as in a large parking lot)
- Travel that includes many starts and stops
- Travel that involves traversing numerous corners
- Travel that has large periods of low speed movement (e.g., less than 10 mile per hour).

Each of these characteristics was observed in the travel of the fleets sampled. Therefore, the GPS position data after smoothing were used in the calculation of distance because they were more reflective of the raw GPS position, and were conveniently extracted from the map-matching software data base export in point data format.

Before the GPS position point data were map-matched, each point was tagged with associated boundary layer information based on its non-matched position in the California area base map (i.e., within a specific county, urban zone area, and air basin). This information was then treated as characteristics of the GPS point data throughout the matching process, consequently being available with map-match details for later analysis. Also, before the tagging exercise, data quality screening checks were performed on the raw GPS position point data. These checks are described in Appendix A.1. The tagging process is described in Appendix A.2. Details about the boundary layers used in the tagging effort are described in Section C.3 of this appendix. Finally, once the map-matching process was completed for all trips, the results were compiled and analyzed. See Section C.5 of this appendix for a summary of the results.

The accuracy and continuity of the GPS point data influence the success of the map-matching process. Details about GPS data accuracy and continuity are described in Sections C.1 and C.2 of this appendix. The results of the GPS data that have been map-matched, however, are subject to the accuracy and detail of the California area base map. Details about the California area base map are described in Section C.3 of this appendix.

C.1 GPS Data Accuracy

The accuracy of the GPS data obtained during field collection is dependent upon several factors, including the GPS receiver design, the status and position of the Navstar GPS satellites, and the location of truck travel.

The GPS receivers deployed to collect position data were not configured to collect and apply real time differential corrections. Further, no attempt to apply differential corrections was undertaken in post-processing. Because the collected GPS data were not differentially corrected, the positional accuracy associated with this data is dependent upon the implementation status of selective availability. Selective availability, controlled by the Department of Defense, is a purposeful degradation of the signals transmitted by the GPS satellites so that unauthorized users cannot achieve the full military accuracy of the system. With selective availability on, receiver accuracy is within ±100 meters (328 feet) with 95 percent probability and a most probable error of approximately 50 meters (165 feet). With selective availability off, receiver accuracy improves to within ±15 meters (49 feet) with 95 percent probability.

Differential GPS (DGPS) can reduce these errors substantially in many applications. The Garmin receivers used in this project are differentially correctable to less than 10 meters (33 feet). However, DGPS was not employed in this program because of prohibitive field equipment, service, and processing costs, and because the use of map-matching software precluded the need for the level of accuracy offered by differential corrections. For more details about the GPS receivers used in this effort, refer to Appendix B.2 and C.1.

In this data collection effort, the status and position of the Navstar GPS satellites and the location of truck travel could not be controlled. Thus, to the degree it was possible, the challenges to positional accuracy posed by these factors was managed by the data quality screening checks and the map-matching process.

C.2 GPS Data Continuity

The continuity of the GPS data collected during field collection was influenced by gaps in the data stream due to receiver operation. These gaps represent the time segments required for the receiver to establish a positional solution. Gaps can be experienced when the GPS receiver is first turned on following the loss of power for a considerable length of time (known as time to first fix), or after there has been a loss of a position fix while the receiver is being powered. A position fix is lost when the requisite minimum number of GPS satellite signals cannot be obtained. Loss of a fix can occur because the line of sight between the GPS receiver and a minimum number of satellites is obstructed, such as when the vehicle moves into a parking garage, into a tunnel, or for some other reason the signal is blocked from reaching the receiver.

The data collection software permitted the collection of one-second GPS data. Collecting one-second GPS data was, of course, still dependent upon the status of the Navstar satellites, readiness of the GPS receiver, and the location of vehicle travel. The more continuous the GPS data stream, the more successful the map-matching attempt. Conversely, the amount of risk regarding the correctness of the match is directly related to the length of the gaps in the GPS data stream, even though intermediate points are fabricated by the map-matching software to increase the potential for a successful match.

C.3 California Base Map

C.3.1 California Base Map Creation

The California area base map used in this study, parts of which are shown in Figures C-1, C-2, and C-3, was composed of layers from several sources, as described below. Further details about the geographic source data can be obtained from the vendors listed in Section C.3.2 of this appendix. These three geographic data files were each constructed from a variety of data sources, all of which had associated base scales of 1:100,000 or better.

California Streets. Using the "select by shape" utility in TransCAD 3.0c (GIS software designed for transportation-related applications by Caliper Corporation), a layer of streets for the state of California was prepared from a geographic file of over 30 million streets located throughout the United States and some of its territories. This geographic source file (ccstreet.cdf) was obtained from Caliper Corporation via a CD titled Caliper Data CD: US Streets '95 (Copyright 1994-1996, Caliper Corporation). Caliper adapted this file from the U.S. Census TIGER/Line files. The result is a layer of all Census Feature Class Code (CFCC) roads for the state of California, with the exception of vehicular trails passable only by 4WD vehicles

(CFCC A51) which were manually removed. The California Streets layer contains nearly 2 million links that total over 370,000 km (231,250 mi.) of road length.

U.S. States Layer. The U.S. states geographic boundary layer source file (ccstateh.cdf), that includes the state of California, was obtained from Caliper Corporation via a CD titled Caliper Data CD: US Streets '95 (Copyright 1994-1996, Caliper Corporation). Caliper obtained the high-resolution boundary information for this layer from Geographic Data Technology (GDT), a private third-party provider of geographic data. The California state layer bounds over 158,000 square miles of area. Detailed tabular data contained in this layer, although not utilized in this project, were obtained from the U.S. Census Bureau.

California County Layer. Using the "select by shape" utility in TransCAD 3.0c, a high-resolution layer of counties for the state of California was prepared from a geographic file of U.S. Counties. The geographic boundary layer source file (cccntyh.cdf) was obtained from Caliper Corporation via a CD titled Caliper Data CD: US Streets '95 (Copyright 1994-1996, Caliper Corporation). Caliper obtained the high-resolution boundary information for this layer from GDT. The boundaries for the county layer file are designed to match the state boundaries in the states layer file. The California county layer contains 58 counties that cover an area of over 157,000 square miles. Detailed tabular data contained in this layer, although not utilized in this project, was obtained from the U.S. Census Bureau. Figure C-1 and Table C-1 provide details.

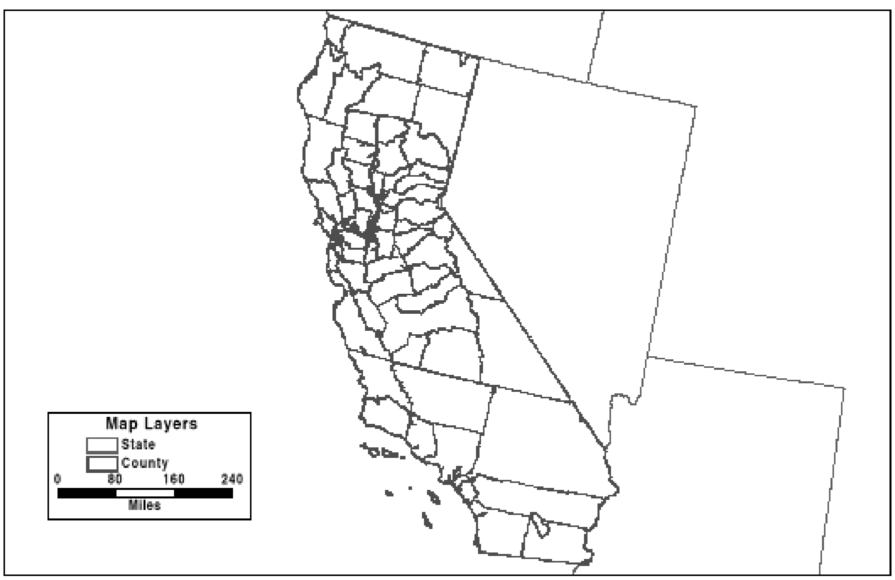

Figure C-1. California County Layer

Table C-1. California Counties

California County Name	Population	County Code	Area (mi^2)
Alameda	1,279,182	23	741.97
Alpine	1,113	1052	741.79
Amador	30,039	1085	597.21
Butte	182,120	1068	1,673.42
Calaveras	31,998	1086	1,029.12
Colusa	16,275	1083	1,152.27
Contra Costa	803,732	24	723.65
Del Norte	23,460	1076	1,011.19
El Dorado	125,995	1087	1,729.19
Fresno	667,490	1090	6,010.03
Glenn	24,798	15	1,317.60
Humboldt	119,118	11	3,567.46
Imperial	109,303	570	4,187.66
Inyo	18,281	572	10,232.10
Kern	543,477	859	8,158.87
Kings	101,469	858	1,393.99
Lake	50,631	16	1,329.09
Lassen	27,598	1055	4,715.37
Los Angeles	8,863,164	862	4,083.66
Madera	88,090	1092	2,148.66
Marin	230,096	1080	527.12
Mariposa	14,302	1091	1,461.88
Mendocino	80,345	12	3,506.12
Merced	178,403	1078	1,970.76
Modoc	9,678	1054	4,085.17
Mono	9,956	1050	3,131.22
Monterey	355,660	1089	3,302.64
Napa	110,765	1079	785.42
Nevada	78,510	1073	971.38

California County Name	Population	County Code	Area (mi^2)
Orange	2,410,556	575	792.92
Placer	172,796	1074	1,410.39
Plumas	19,739	1069	2,612.31
Riverside	1,170,413	574	7,225.73
Sacramento	1,041,219	1084	968.34
San Benito	36,697	22	1,389.18
San Bernardino	1,418,380	571	20,068.68
San Diego	2,498,016	864	4,236.99
San Francisco	723,959	1000	46.10
San Joaquin	480,628	25	1,400.39
San Luis Obispo	217,162	857	3,315.31
San Mateo	649,623	20	453.24
Santa Barbara	369,608	860	2,744.70
Santa Clara	1,497,577	21	1,294.59
Santa Cruz	229,734	19	447.44
Shasta	147,036	1065	3,841.02
Sierra	3,318	1072	959.39
Siskiyou	43,531	1064	6,337.89
Solano	340,421	1082	833.18
Sonoma	388,222	17	1,584.42
Stanislaus	370,522	26	1,509.32
Sutter	64,415	1075	603.18
Tehama	49,625	14	2,948.58
Trinity	13,063	13	3,206.53
Tulare	311,921	863	4,835.91
Tuolumne	48,456	1088	2,267.43
Ventura	669,016	861	1,852.32
Yolo	141,092	1081	1,013.93
Yuba	58,228	1071	640.03

California Large Urban Zone Area (UZA) Layer. The California Large UZA boundary layer source file was obtained from the U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning, Intermodal and Statewide Programs Division. No modifications were made to this file. The California Large UZA layer contains 51 zones that cover over 7,700 square miles of area and represent 38 urban areas. This layer was constructed from source data that had an associated base scale of 1:100,000 or better, and, thus, a positional accuracy of +/-80 meters. Figure C-2 and Table C-2 provide details.

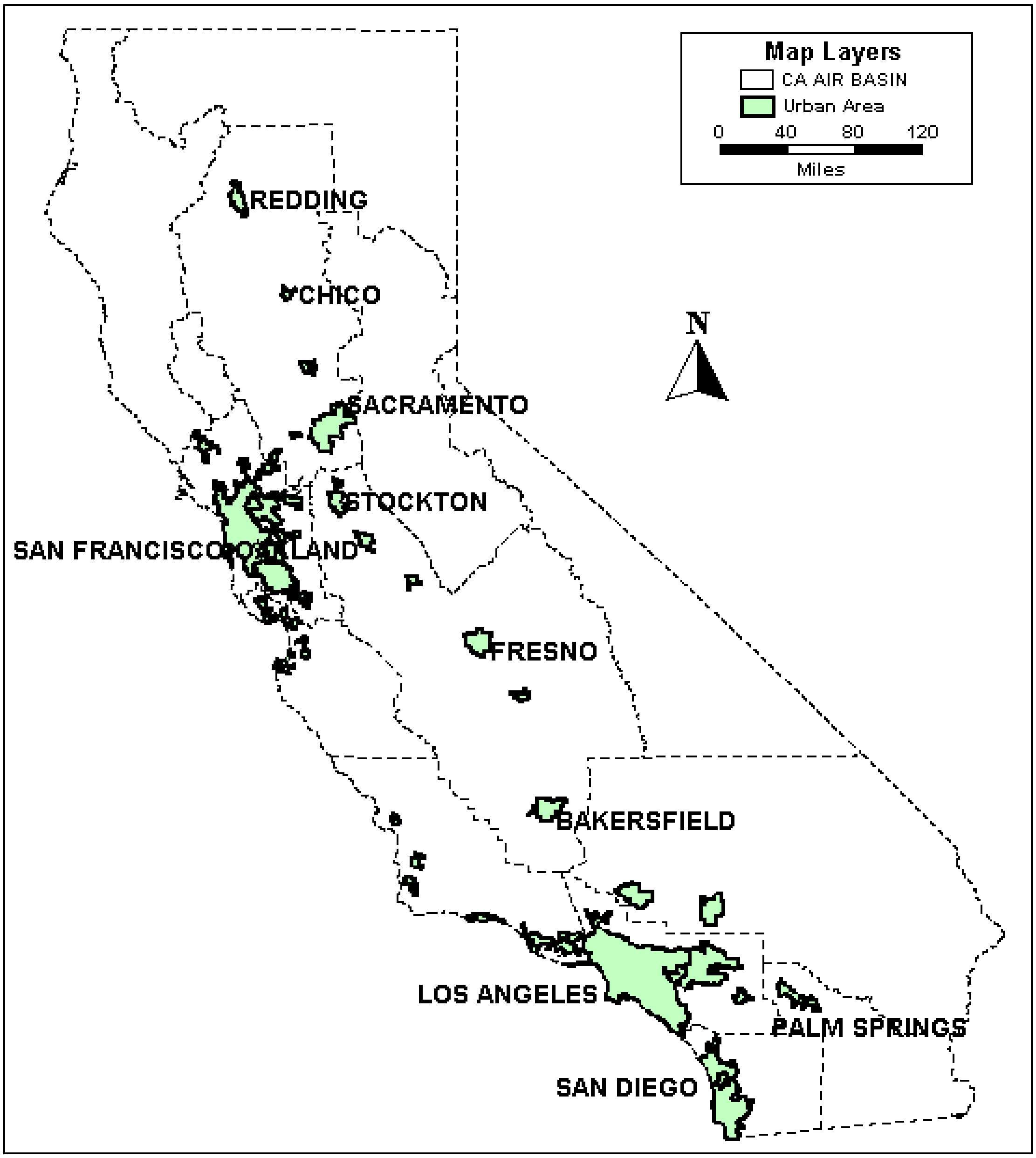

Figure C-2. California Large Urban Zone Areas (UZA) Layer

Table C-2. Urban Areas Defined in California

Area Type	Urban Area	Estimated Population
Large Urban Areas 200,000 < population	Los Angeles	11,299,899
	San Francisco-Oakland	3,710,676
	San Diego	2,327,189
	San Jose	1,440,176
	Riverside-San Bernardino	1,147,688
	Sacramento	1,075,562
	Fresno	459,415
	Oxnard-Ventura	401,173
	Bakersfield	301,621
	Stockton	263,103
	Modesto	220,969
Urbanized Areas 50,000 < population < 199,999	Lancaster-Palmdale	179,372
	Antioch-Pittsbug	149,833
	Santa Rosa	143,762
	Santa Cruz	136,331
	Hesperia-Apple Valley	131,132
	Seaside-Monterey	129,265
	Salinas	124,729
	Simi Valley	113,110
	Palm Springs	107,060
	Santa Barbara	106,342
	Fairfield	86,997
	Visalia	83,555
	Santa Maria	82,391
	Hemet-San Jacinto	80,652
	Redding	80,132
	Chico	74,069
	Yuba City	65,068
	Merced	65,009
	Vacaville	64,440
	Napa	62,886
	Indio-Coachella	51,513
	Lodi	50,549
Small Urban Areas 5,000 < population < 49,999	Watsonville	49,069
	Davis	45,010
	Lompoc	41,079
	San Luis Obispo	39,533
	Yuma	5,670

California Air Basins Layer. The California Air Basins boundary layer source file was obtained from the California Air Resources Board (CARB). No modifications were made to this file. The California Air Basins layer contains 15 air basins that cover the entire state (over 158,000 square miles of area). This layer is based on Teale's county, Public Land Survey System, and hydrography linework. It was digitized from 1:100,000 scale source material or constructed from digital line graph (DLG) sources. Figure C-3 and Table C-3 provide details.

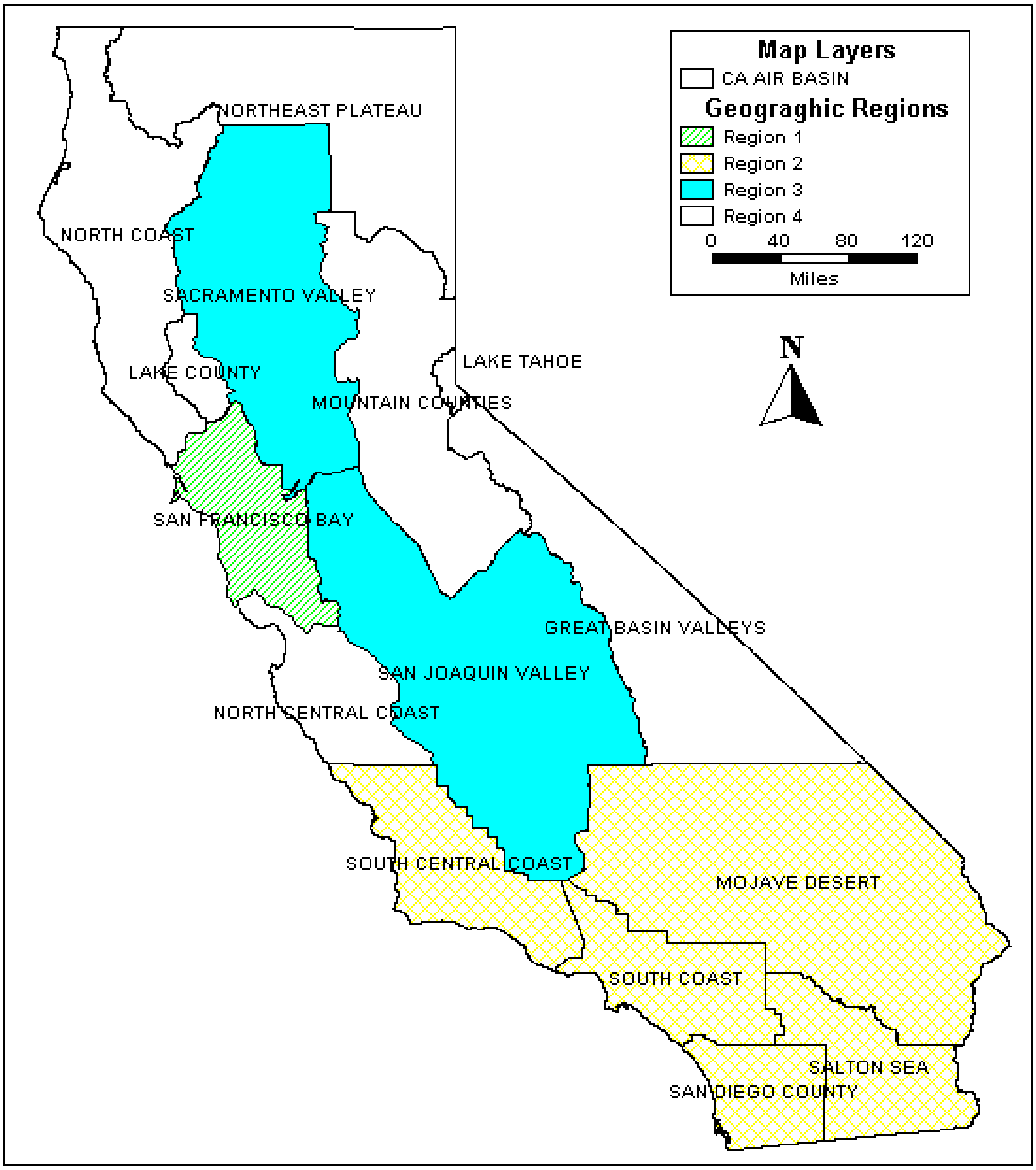

Figure C-3. California Air Basins Layer

Table C-3. California Air Basins

California Air Basin Name	Air Basin Code	Area (mi^2)
Great Basin Valleys	1	14,098.56
Lake County	2	1,329.58
Lake Tahoe	3	369.73
Mojave Desert	4	27,206.53
Mountain Counties	5	12,407.60
North Central Coast	6	5,147.58
North Coast	7	12,279.20
Northeast Plateau	8	15,252.24
Sacramento Valley	9	15,124.05
Salton Sea	10	6,619.59
San Diego County	11	4,239.88
San Francisco Bay	13	6,038.06
San Joaquin Valley	20	23,667.70
South Coast	22	6,611.64
South Central Coast	21	7,716.12

C.3.2 California Base Map Geographic Source Data Vendors

Caliper Corporation
1172 Beacon Street
Newton, MS 02162
Ph: (617) 527-4700
e-mail: info@caliper.com
http://www.caliper.com

Geographic Data Technology, Inc. (GDT)
11 Lafayette Street
Lebanon, NH 03766
Ph: (800) 331-7881
http://www.geographic.com

Office of Environment and Planning
Intermodal and Statewide Programs Division
Federal Highway Administration
U.S. Department of Transportation
Mark Bradford, Information Management & Analysis Team
Ph: 202-366-6810
http://www.fhwa.dot.gov/hep10/gis/gis.html

California Air Resources Board (CARB)
Office of Communications
2020 L Street
Sacramento, CA 95814
Ph: (916) 263-1499 (Steve Flatt)
e-mail: helpline@arb.ca.gov
http://www.arb.ca.gov/homepage.htm

C.4 Map-Matching Analysis

C.4.1 Map-Matching Process Summary

The map-matching process identifies specific roadway nodes and links in the California area base map network that were traveled based on the collected GPS points. The results of the map-matching process allow identification of travel by highway functional class based on base map information contained in the California area base map network. Identifying trip origins and destinations are also made possible by cross-street address matching that are assigned during the map-matching process.

The map-matching procedure was performed using software developed by SAIC (see Section C.4.3 of this appendix for details). This software features an autonomous GPS matching algorithm that uses a network data base (Link, Node, Shape, and Street Name files) to convert raw GPS data files to:

- A GPS Match data base with coordinate adjusted and link referenced time points
- A GPS Trip data base with trip summary and origin-destination information
- A GPS User data base with general user identification information.

These resulting data bases completely describe the collected GPS data in terms of the network defined by the California area base map. Because there were other means for collecting user identification information (see Appendix B.3) and because detailed origin-destination information was not of high interest, only the GPS Match data base was constructed.

Preparation Activities

Several tasks were required to prepare for effective execution of the map-match analysis and to manage the resulting output. First, a California area base map had to be constructed (see Section C.3.1 of this appendix). The base map was constructed using TransCAD GIS software. Next, this network had to be transferred to a format that could be recognized by the SAIC software. To accomplish this step, the TransCAD base map was first exported to an ArcView format map data base (constituted of .shp, .shx, and .dbf files). ArcView format was selected because TransCAD supports exports in this format and the SAIC software is capable of importing them. The ArcView format map data base was then imported into the SAIC software format (link, node, code, and shape files).

To help the California area base network to import and operate as efficiently as possible, several tasks were undertaken. First, to satisfy a requirement of the SAIC software, the format of the California street functional classifications were converted from a three-character Census Feature Class Codes (CFCC) Census Bureau format to a single-digit numerical digit. This conversion was executed using a simple query in external data base software. Although the SAIC software supports such conversions as part of its import utility, it was decided that the conversion should be completed previous to the network import to increase the potential for a successful import. The conversion from U.S. Census Bureau CFCCs to numeric digits is as follows:

- Primary Highway with Limited Access "A1X" series roads (i.e., A11-A18 roads) were converted to "1"s
- Primary Roads without Limited Access "A2X" series roads (i.e., A21-A23 and A25-A27 roads) were converted to "2"s
- Secondary and Connecting Roads "A3X" series roads (i.e., A30-A31 roads) were converted to "3"s
- Local/Neighborhood/Rural Roads "A4X" series roads (i.e., A41-A48 roads) were converted to "4"s
- Access Ramps "A63" roads were converted to "5"s
- Roads without a specified CFCC functional class were converted to "6"s. In addition to map-matched data associated with functional class "6" roads, map-matched data not assigned to a GIS base map link are also assigned a functional class "6" – see p. C-2 for more details.

Second, a network shape file was purposely not constructed during the import of the California area map network. One popular advantage of using the network shape files feature is that graphical depictions of curvilinear matched travel in the SAIC software appear smoother when displayed or reported. However, since no graphical depictions of matched travel were required to be generated by the SAIC software, and because the shape features do not affect the matching algorithm, there was no need for a shape file to be generated, especially when considering the already large size of the California area base map. Finally, before the network import, an external data base query was used to rename the street names for local, neighborhood, and rural roads (roads of functional class "4"). These street names were grouped into sets of less than 65,500, and renamed with a "local streets" name prefix and a unique group name suffix, to remain within the constraints of the SAIC software.

Next, the trip data that were quality screened (see Appendix A.1) were grouped into adequate-sized batches that were determined to be of a size that would not over-tax the computer memory. These groups of ASCII-type files (with .dat extensions) were then converted into binary files (with .gps extensions) using a utility in the SAIC software. The map-matching algorithm is designed to accept this format of binary file. The map-matching algorithm was then executed on each batch of binary files. Following a successful map-match effort (i.e., no memory-related or other difficulties caused the map-matching algorithm to stall or crash unexpectedly), the GPS Match data base was exported to an ASCII file (with an .asc extension). Before the next batch of binary batch files were map-matched, the GPS Match data base was cleared. This was done to avoid the memory-related problems of negotiating very large ASCII text files and maintaining a very large GPS Match data base.

Details and Difficulties Experienced During the Map-Matching Process

The two biggest difficulties associated with preparing and executing the map-matching analysis were with 1) transferring the California area base map to the SAIC software, and 2) the map-matching itself. The strategies described in the "Preparation Activities" section above allowed for the successful completion of the base map transfer. The following paragraphs characterize the map-matching process and the difficulties experienced.

The SAIC software was used to match roughly 10,000 truck files. Eventually, all batches of truck travel were successfully matched. In terms of size, a relatively large batch of trip files ranged in size from 1KB to 6.2MB, with most files occupying less than 1MB. The road network for the state of California was almost 2 million links totaling 370,215 km.

As previously mentioned, several trips were matched together in batches. To minimize the potential of stalling due to memory constraints, 23 trip batches totaling no more than 25-30MB each were run separately (size provided for .dat format batches; the batch size was reduced when converted to .gps). These match efforts were executed using the SAIC map-matching software Modify feature, enabling us to salvage data in cases of stalling. However, after persistently re-running stalled match efforts (some batches were run 2 to 3 times), only one partially matched batch had to be salvaged, and the unmatched trips re-run. A new GPS Match data base was created before each match using the SAIC map-matching software Create feature to limit the size of the ASCII data base dumps that were generated later. The 23 exported data bases total over 1.5GB of ASCII information.

On average, between 75 percent and 80 percent of binary-converted GPS points were matched to the California area base network, and some of the unmatched points can be attributed to out-of-network travel (i.e., out of state travel or within state travel that was not close to the network). It appeared that the sizes of the file batches we used required at least 95MB of RAM, but did not appear to benefit greatly from having more than 128MB of RAM. For example, a machine with 256MB of RAM did not appear to perform significantly better than one with 128MB of RAM. Match efforts ranged between 3 hours and 16 hours to complete, with all but one requiring between 12 to 15 hours.

Interestingly, when about half of the stalled batches were re-matched (in some cases on the same machine, and in some cases on different machines), a successful match effort resulted on the first try. All but one of the batches re-matched within three attempts. About half the time, the batches that did not re-match on the first try stalled on exactly the same network link. But in other cases this was not so. Thus, all of the factors that can affect the successfulness of using the SAIC software to match GPS data to a very large network are not entirely clear. However, because of the large size of the network, it seems likely that computer memory was a big factor.

C.4.2 Map-Matching Software

The SAIC software used to perform the map-matching analysis portion of this project was originally developed as a cost-effective approach to travel time data collection based on Global Positioning System (GPS) technology. The system was designed to collect travel time and trip information for use in congestion management and operational analysis, both for auto/truck travel and bus route analysis. This project did not utilize the full capabilities of that program. The title of the software and vendor information is provided below:

GPS Travel Time Data Collection System – Version 5.5.

SAIC: Science Applications International Corporation
Transportation Consulting Group
7927 Jones Branch Drive, Suite 200
McLean, VA 22102-3305
David Roden
Ph: 703-442-0030
Email: droden@kpmg.com

C.4.3 Map-Matching Algorithm

The algorithm employed by the map-matching portion of the SAIC software used the California area base network to convert screened GPS data files to:

- A GPS Match data base with coordinate adjusted and link referenced time points
- A GPS Trip data base with trip summary and origin-destination information
- A GPS User data base with general user identification information.

As mentioned previously, only the GPS Match data base was used in this project.

The SAIC software uses both header and data information from the GPS data being matched. Information from the GPS file headers identifies such details as:

- User ID
- Trip number
- Trip purpose
- Vehicle occupancy
- User-defined flag (e.g., the weather)
- GPS protocol
- Computer clock time at the beginning of the trip.

Information from the data rows identifies such details as:

- GPS time
- Latitude
- Longitude

- Travel speed
- Direction of travel
- GPS signal quality rating.

The only required fields are GPS time, latitude, and longitude. If the travel speed and/or the direction of travel are zero for all time points, the information will be calculated from the time and position data. If there is more than two seconds between time points, the program will insert time points with interpolated data. These points are identified with a zero in the GPS signal quality rating field.

A high-level description of the map-matching algorithm is as follows:

Step 1: Read the GPS Points and check for Speeds or Angles not equal to zero.
Step 2: Perform general logic checks between points. Delete points with illogical behavior.
Step 3: Adjust calculated speeds through a moving average.
Step 4: Expand the GPS points to include one second time points.
Step 5: Determine the general Angle change for each time point.
Step 6: Identify Corner points and smooth the entering and exiting Positions.
Step 7: Identify Stop locations.
Step 8: Identify Curve points.
Step 9: Identify Shape points.
Step 10: Calculate the Segment Slopes.
Step 11: Match the Corner points to the Network Intersections.
Step 12: Adjust the Line Segments between Corner points.
Step 13: Build network Paths between Corner points.
Step 13.1: If the current Corner has not been assigned to a network Link,
find the network location that best represent the Line Segments entering and exiting the Corner.
For each network Link, compare the Position and Line Segments.
Step 13.2: Build a Path between the current Corner and the next Corner in the sequence.
Step 13.3: If a Path was not found, build a path from the Best Link associated with the next Corner back to the current Corner.
If the Corner does not have a Best Link, do a Best Link search similar to the process described in Step 13.1
Build a path from the Best Link toward the center or starting Corner similar to the process described in Step 13.2.
If the new link entering the destination Corner is equal to the original link leaving that Corner, continue the path building from the Corner that started the rematch process.
If the new link is different from the original link, continue building paths back toward the center or starting Corner until the links are equal.
Step 14: Readjust the Line Segments between Corners based on the Path Links
Step 15: Assign each Point to a network Link using the Path between Corners.
Step 16: Save the Matched Points to the GPS Data base

For more details about the map-matching algorithm or the SAIC software, contact the vendor listed in Section C.4.2 of this appendix.

C.5 Summary of Map-Matching Results

Tables C-4 through C-7 illustrate summary results by highway functional classes that are possible as a result of map-matching the GPS data in post-processing:

- Table C-4 – HDT activity (VMT) for each vehicle class and the total for all vehicles contained in the sample, by highway functional class
- Table C-5 – Total (all trucks in the sample) HDT activity (VMT) by time of day for each highway functional class
- Table C-6 – Total (all trucks in the sample) HDT activity (VMT) within the California air basins for each highway functional class
- Table C-7 – Urban and rural HDT activity (VMT) by highway functional class for each vehicle class and the total for all vehicles contained in the sample.

The highway functional class designations included in these tables are the result of the naming scheme in the GIS base map that is used in map-matching analysis. These highway functional class designators are derived directly from the base files used in the analysis and are not necessarily equivalent to the official FHWA highway functional class designators. Also, described on p. C-2 and in Section C.4.1, travel summarized into the other/undefined functional class includes map-matched GPS data that was not matched to a GIS base map link.

Table C-4. VMT by Functional Class and Within Vehicle Classes

Vehicle Class	Total VMT	VMT by Functional Class					
		Primary Highway	Primary Road	Secondary Road	Local Roads	Access Ramps	Other/ Undefined
T4	2,731	321	3	412	1,815	70	112
T5	1,691	79	0	134	1,346	31	101
T6	10,643	3,278	332	1,243	4,358	357	1,075
T7	44,790	21,674	1,135	4,404	7,292	1,188	9,097
T8	27,361	13,384	206	4,255	4,528	931	4,057
All	87,216	38,736	1,675	10,448	19,338	2,577	14,443

Table C-5. VMT by Functional Class Within Time of Day Bins

Time of Day	Total VMT	VMT by Functional Class					
		Primary Highway	Primary Road	Secondary Road	Local Roads	Access Ramps	Other/ Undefined
Midnight-6 am	15,733	8,093	179	1,468	2,539	425	3,035
6-9 am	17,818	7,675	411	2,232	4,133	547	2,821
9 am-Noon	19,866	8,376	177	2,522	5,139	595	3,052
Noon-3 pm	15,573	6,507	412	1,901	3,812	453	2,498
3 pm-6 pm	9,500	3,640	338	1,284	2,521	283	1,439
6 pm-Midnight	8,725	4,446	162	1,050	1,197	272	1,597

Table C-6. VMT by Functional Class Within Air Basins

Air Basin	Total VMT	VMT by Functional Class					
		Primary Highway	Primary Road	Secondary Road	Local Roads	Access Ramps	Other/ Undefined
Great Basin Valley	241	0	226	0	15	0	0
Lake Tahoe	117	0	90	14	12	0	0
Mountain Counties	3,324	2,039	149	554	367	110	107
North Central Coast	5,859	479	634	1,633	2,680	80	353
North Coast	296	26	77	66	30	1	96
Northeast Plateau	758	562	0	52	72	8	63
Sacramento Valley	20,222	9,851	0	1,702	5,103	485	3,088
Salton Sea	1,540	480	0	541	310	12	197
San Diego County	2,773	898	1	102	1,279	122	373
San Francisco Bay	14,918	8,539	190	1,131	2,579	479	1,987
San Joaquin Valley	20,766	8,442	0	4,077	3,490	552	4,210
South Central Coast	785	419	0	103	97	21	145
South Coast	11,955	6,438	0	288	3,155	697	1,381
Southeast Desert	1,122	417	267	181	115	7	136
Mixed/Unknown	2,539	138	38	2	40	8	2,314

Table C-7. Urban Versus Rural VMT by Functional Class

Travel Within Large Urban Zone Areas (Urban Travel)						
Weight Class	**Primary Highway**	**Primary Road**	**Secondary Road**	**Local Roads**	**Access Ramps**	**Other/ Undefined**
T4	188.4	2.0	239.4	1,416.6	58.9	56.9
T5	77.0	0.0	130.5	1,249.7	31.4	84.9
T6	2,556.4	112.5	771.7	3,537.2	321.6	747.6
T7	11,818.7	108.2	1,060.7	5,130.1	930.8	2,597.5
T8	6,067.1	11.2	806.0	2,250.0	615.7	1,455.2
All Vehicles	20,707.6	233.9	3,008.2	13,583.6	1,958.3	4,942.2
Travel Outside Large Urban Zone Areas (Rural Travel)						
Weight Class	**Primary Highway**	**Primary Road**	**Secondary Road**	**Local Roads**	**Access Ramps**	**Other/ Undefined**
T4	131.5	0.8	173.0	398.3	10.8	54.6
T5	2.3	0.0	4.3	95.9	0.0	16.5
T6	723.9	223.9	471.3	817.7	36.5	330.7
T7	9,859.3	1,018.3	3,355.9	2,175.5	254.6	6,503.5
T8	7,307.5	194.0	3,443.6	2,279.5	323.3	2,602.9
All Vehicles	18,024.5	1,437.1	7,448.1	5,767.0	625.1	9,508.2