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Environmental Research & Technology

Improving Vehicle Fleet, Activity, and Emissions Data for On-Road Mobile Sources Emissions Inventories

FINAL REPORT

Prepared for:

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1. Introduction

1.1. Background

The U.S. Environmental Protection Agency (EPA)'s Motor Vehicle Emission Simulator (MOVES) has replaced MOBILE6 as a regulatory emissions model for use in State Implementation Plan (SIP) development and transportation conformity analyses in all States, except California. With several methodological improvements, MOVES appears to be more data intensive as compared to MOBILE6. Therefore, preparing local input data for model runs in MOVES can be challenging, if not demanding. Although much of the MOVES data requirements may be converted from existing data used in MOBILE6, some data still need to be newly developed or further refined.

The modeling concepts and methodologies in MOVES are also significantly different from those in MOBILE6. For example, the functional design concepts in MOVES disaggregate emission sources primarily by source use type (e.g. passenger car, passenger truck, single-unit long-haul truck, etc.), each of which are further categorized into several source bins by several characteristics including model year, fuel type, engine technology, loaded weight, engine size, and regulatory class. As another example, the basis of vehicle activity for exhaust running emissions is source-hours operating (SHO) rather than vehicle-miles traveled (VMT) that have been used in the MOBILE model series. These modeling changes can be taken as a good opportunity for the transportation and air quality community to explore new data sources and to develop new methods for utilizing existing data sources to improve the emission inventory and analysis of on-road mobile sources.

1.2.   Current Practices, Trends, and Future Needs

In general, on-road emission modeling requires three types of data: 1) vehicle fleet data, 2) vehicle activity data, and 3) vehicle emission rate data. The current practices, trends, and future needs on how each of these data types is generated and used are briefly discussed below.

1.2.1. Vehicle Fleet Data

In terms of vehicle fleet data, it has been recognized that in the development of an emissions inventory, reliable data of vehicle fleet population such as vehicle class and age distributions are as important as accurate data concerning vehicle emission factors and vehicle activities. However, this is probably the area that has been given the least amount of attention by practitioners and researchers.

The current practice of deriving vehicle fleet data relies heavily on the use of vehicle registration databases. These databases are sufficient for creating base vehicle fleet distributions for an area, but the sole dependency on this type of data is problematic for several reasons. For example, a significant fraction of vehicle miles traveled (VMT), and thus emissions, for an area could be attributable to vehicles registered outside the area [Malcolm et al., 2003; Lutsey, 2009]. This is particularly true for tourist areas and areas with major transportation hubs (e.g., international airports and seaports). The bias in vehicle fleet distributions could have significant impacts on both SIP and transportation conformity analyses. Another example is the inability to provide specific vehicle fleet distributions for short time periods (e.g. hours of day, months of year).

Therefore, there is a need for tools and methods that will enable the collection and development of highly-resolved and area-specific vehicle fleet data.

1.2.2. Vehicle Activity Data

When constructing emission inventories for use in SIP development and transportation conformity analyses, several vehicle activity data inputs are required. For instance, MOVES requires VMT, average speed distribution, number of trip starts, soak time distribution, among other inputs. These data inputs need to be generated for all vehicle types and, depending on a particular data input, may need to be characterized by road type, month, day, and hour. Acquiring all these data inputs are not easy as the availability of existing data is limited, especially for non-passenger vehicles such as heavy-duty trucks (HDTs).

Albeit a very small fraction in the total vehicle population, HDTs contribute disproportionately to the emissions inventory of on-road mobile sources. This is due to their high annual mileage and high emission rates. In addition, HDTs are also a significant source of idling emissions especially at truck stops and terminals as they often engage in long-duration idling activities (e.g., loading/unloading, heating/cooling the cabin during rest stops, etc.) at these locations [Miller et al., 2007; Frey et al., 2008]. Therefore, an accurate characterization of HDT activity is crucial to the construction of emissions inventory of on-road mobile sources.

In the current state of the practice, the Highway Performance Measurement System (HPMS) has been used as a primary source for VMT data for various road and vehicle types, including HDTs

[U.S. Environmental Protection Agency, 2005]. Although HPMS contains roadway speed limit information, it does not provide measured traffic speed data. Therefore, the reported VMT cannot be characterized by speed bins. As vehicle emissions are sensitive to vehicle speed among other things, it is desirable to characterize VMT into multiple speed bins so that appropriate emission factors for each speed bin can be applied.

Alternatively, HDT activity can be estimated using travel demand models, especially those with a dedicated module for HDTs (e.g., [Southern California Association of Governments, 2008]). There has also been increasing interest in developing freight flow models (e.g., [Sarvareddy et al., 2005]), which can be used to derive truck trips and miles traveled. Nevertheless, these models are still in their early stages and have not been adopted widely. Also, the availability of measured truck traffic data, especially with regards to speed, that can be used for model validation is limited so that the accuracy of speed data from the models may be questionable.

Another method that has been used is to instrument a fleet of HDTs with GPS-based data loggers and log their travel activity over a period of time (e.g., [Battelle, 1999]). This method offers the most detailed and probably the most reliable information on HDT miles and speed. Also, it is able to capture the information about non-driving activities such as soak time and idling, which are not available in either the HPMS or travel demand models. However, this type of data collection requires significant resources; and thus, is usually performed for a small number of trucks and for a short period of time.

Thus, there is a need to explore alternative sources of HDT activity data that have not been used in the past, but have potential to be useful. Also, it is desirable to develop new and innovative methods for utilizing existing data sources to their full potential.

1.2.3. Vehicle Emission Data

In terms of vehicle emissions, although the development of MOVES is based on a wide variety of measured energy and emissions datasets, there are still approximately 50% data "holes" [U.S. Environmental Protection Agency, 2005]. For instance, emissions data of HDTs of the recent model years were not available by the time MOVES was developed. These holes have been filled using hole filling methods. It is assumed that as more emissions data from vehicles are collected, the emissions rates in MOVES can be updated and thus the fidelity of the model should improve.

It should be noted that not all data holes are equally important. For instance, data holes for emissions sources that do not contribute much to an emissions inventory (e.g., diesel passenger car) will only make negligible differences to the inventory even though they may be significantly underestimated or overestimated. On the other hand, some data holes will have significant impacts on the resulting emissions inventory as well as the policy implications. One example is the energy/emission rates of HDTs with various loaded weights. It can be argued that not all VMT of HDTs carry the same amount of weight, and it is intuitive that the higher the loaded weight, the higher the amount of engine power required, and thus the higher emission rates.

Hence, there is a need to continue measuring vehicle emissions in order to fill in the emission data holes in MOVES. These emission measurement programs should be prioritized so that critical data holes are addressed first.

1.3. Objectives of the Research

The goal of this research is to improve the estimation or measurement of the three data types necessary for on-road emission modeling, namely vehicle fleet data, vehicle activity data, and vehicle emission data. For each of these data types, this research targets specific areas or data elements that are considered gaps in the current state of the knowledge and practices by evaluating alternative data sources as well as developing new tools and methods for filling such gaps. Specifically, the objectives of this research are to:

- Review the current state of the practice in estimating vehicle class and age distributions, vehicle miles traveled of heavy-duty trucks, and idling hours of heavy-duty trucks;

- Evaluate the use of license plate survey in conjunction with vehicle registration database and vehicle identification number (VIN) decoder to estimate local vehicle fleet data;

- Evaluate the use of alternative sources of heavy-duty truck (HDT) activity data including truck's electronic control unit (ECU) and telematics-based vehicle tracking and monitoring system to generate HDT activity data inputs for MOVES;

- Develop methods for fusing HDT activity datasets from multiple sources to result in more refined and accurate HDT activity data; and

- Measure emissions from recent model year HDTs at different loaded vehicle weight.

1.4. Organization of the Report

This report is organized into five chapters as follows:

1. Chapter 1 is the introduction, which briefly describes the topics being addressed in this research.

2. Chapter 2 reviews the current state of the practice in estimating vehicle class and age distributions, VMT of HDTs, and idling hours of HDTs from selected agencies around the Nation.

3. Chapter 3 presents the method for deriving local vehicle fleet data through the use of license plate survey in conjunction with vehicle registration database and VIN decoder.

4. Chapter 4 consists of three parts. The first part describes the use of truck's ECU data to generate some HDT activity data inputs for MOVEs. The second part describes a large-scale truck telematics dataset and demonstrates methods for generating HDT activity data inputs for MOVES based on this dataset. In the third part, a methodology is presented that combines data from weigh-in-motion stations and vehicle detector stations on freeways to generate highly resolved HDT activity data.

5. Chapter 5 describes an emission testing program that measures emissions from two HDTs meeting the 2007 emission standard at different loaded vehicle weight.

The last chapter is followed by a list of references and a series of appendices that show detailed results from the various analyses in this research.

The report is written in a way that each chapter can be a standalone document. They start with background information on the topic being address, followed by a detailed presentation of data used, methodology, and results, and then end with concluding remarks specific to that chapter.

2. Current State of the Practice

2.1. Background

There are many methods for preparing local data inputs for emission modeling. The decision to select a particular method may depend on the availability and quality of data, costs, resources, and individual preference. The objective of this task is to review the current state of the practice used by state agencies and metropolitan planning organizations (MPOs) to develop local data inputs for transportation conformity analyses and SIP development. The local data inputs of interest in this task are:

- Vehicle class and age distributions,
- Vehicle miles traveled of heavy-duty trucks, and
- Idling hours of heavy-duty trucks.

The list of areas whose SIP submission(s) was under the EPA adequacy review was obtained in December 2009 from the website http://www.epa.gov/otaq/stateresources/transconf/currsips.htm. Five areas were then selected from the list based on their size (in terms of population) and geographic location. The areas with very large (more than 10 million) and large (1-10 million) population were selected as they were likely to have more resources to invest in developing local data inputs for emission modeling. The selection was also made in a way that areas from the different parts of the country were represented. The final five areas selected for the state-of-the-practice review include:

1. South Coast, CA
2. San Joaquin Valley, CA
3. New York Metro, NY
4. Denver Metro, CO
5. Maricopa County, AZ

In the review, the information was mainly gathered from the areas' SIP and transportation conformity documents. In some cases, personal communication with the areas' staff was also made to acquire more detailed information or clarification. The next section presents a summary of findings from the state-of-the-practice review.

2.2. Summary of Findings

2.2.1. South Coast, CA

The South Coast air basin in California consists of Orange County, and part of Los Angeles, Riverside, and San Bernardino Counties. The MPO for the region is the Southern California Association of Governments (SCAG). Since South Coast is in California, it uses the California Air Resource Board (CARB)'s EMFAC as the regulatory model in its transportation conformity analyses. In addition to developing and updating the EMFAC model, CARB also plays a significant role in developing many of the data inputs for running the model.

Vehicle Class and Age Distributions

Vehicle population, age distribution, and fleet mix data for each county in California are developed and included in the EMFAC model by CARB. The primary source of these data is the vehicle registration database maintained by the California Department of Motor Vehicles (DMV). The data in the current version of the model (EMFAC 2007) are based on six years (2000 – 2005) of DMV data [California Air Resources Board, 2007]. CARB has committed to update the vehicle fleet data in EMFAC on a 3-year cycle thereafter.

Vehicle Miles Traveled of Heavy-Duty Trucks

The estimate of VMT of HDTs is one of the outputs of SCAG's regional travel demand model (TDM), which contains a specific HDT module. SCAG's regional TDM follows a standard four-step modeling approach. The modeling methodologies, parameters, and inputs are periodically updated to reflect current travel conditions and demographic changes. The model is also subject to periodic peer reviews to insure that the model is valid and represents the current state of the practice for transportation modeling [Southern California Association of Governments, 2010].

The HDT module in SCAG's regional TDM consists of two major components: internal truck trip models and external truck trip models. The internal truck trips are generated using a cross-classification method by applying truck trip rates for a two-digit code by the North American Industry Classification System (NAICS) to the number of employees in that category and also the number of households within each zone. The daily truck trip ends are distributed using a gravity model to create daily truck trips for each of the three truck types: 1) light HDT, 2) medium HDT, and 3) heavy HDT. The external truck trips are developed using an econometric model to estimate inbound and outbound commodity flows by counties. The county to county commodity data is allocated to the zonal level based on NAICS employee distribution and then converted to truck trips using observed data collected during model development. Seaport and airport-related truck trips are included as special generator truck trips. The daily truck trips by truck types are allocated to four time periods and merged with the auto trips in trip assignment [Southern California Association of Governments, 2010].

Additionally, in order to maintain consistency of model results with VMT estimates from the Highway Performance Measurement System (HPMS), a set of base year HPMS VMT to model VMT ratios (factors) is developed for each subarea of county by air basin. Separate factors are generated for autos and trucks. These same factors are applied to final network assignments of

each model run to yield final network flows and congestion [Southern California Association of Governments, 2010].

SCAG is currently in the process of enhancing the HDT module. The enhancements include an extensive travel survey, an updated external trip estimation methodology, and a more accurate representation of warehouse related trips [Southern California Association of Governments, 2010].

Idling Hours of Heavy-Duty Trucks

The number of idling hours of HDTs is also developed by CARB and included in the EMFAC model. It was developed from three instrumented studies of a total of 147 HDTs. Idle trips were identified from this combined dataset where an idle trip is a key-on to key-off event with a speed of less than 5 mph and a trip length of less than 5 miles. All other trips with speeds greater than or equal to 5 mph and trip length greater than or equal to 5 miles were considered non-idle trips. Then, the idling duration was calculated from these idle trips [California Air Resources Board, 2000].

2.2.2. San Joaquin Valley, CA

The San Joaquin Valley Air Pollution Control District is made up of eight counties in California's Central Valley: San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare and the San Joaquin Valley Air Basin portion of Kern.

Vehicle Class and Age Distributions

Vehicle population, age distribution, and fleet mix data for each county in California are developed and included in the EMFAC model by CARB. The primary source of these data is the vehicle registration database maintained by the California Department of Motor Vehicles (DMV). The data in the current version of the model (EMFAC 2007) are based on six years (2000 – 2005) of DMV data. CARB has committed to update the vehicle fleet data in EMFAC on a 3-year cycle thereafter.

Vehicle Miles Traveled of Heavy-Duty Trucks

All MPOs in the San Joaquin Valley region use network- based travel models. However, none produces specific estimates of heavy-duty truck VMT. VMT estimates for HDTs are based on CARB calculations from DMV updates and HDT trip statistics derived from the instrumented HDT studies [California Air Resources Board, 2000].

Idling Hours of Heavy-Duty Trucks

The number of idling hours of HDTs is also developed by CARB and included in the EMFAC model. It was developed from three instrumented studies of a total of 147 HDTs. Idle trips were identified from this combined dataset where an idle trip is a key-on to key-off event with a speed of less than 5 mph and a trip length of less than 5 miles. All other trips with speeds greater than or equal to 5 mph and trip length greater than or equal to 5 miles were considered non-idle trips. Then, the idling duration was calculated from these idle trips [California Air Resources Board, 2000].

2.2.3. New York Metro, NY

The New York Metro Transportation Council (NYMTC) is the MPO for New York City, Long Island and the lower Hudson Valley.

Vehicle Class and Age Distributions

The vehicle age distributions used in MOBILE6 are obtained from the New York State Department of Motor Vehicles (NYSDMV) registration data for the current year at the beginning of each July. Each record is sorted into the 28 vehicle types by county. The 2002 registration distribution was used for 2002 inventories. Diesel fractions are obtained at the same time as the registration distributions.

Vehicle Miles Traveled of Heavy-Duty Trucks

The NYMTC uses an activity-based travel demand model in conjunction with a post-processing tool called PPSuite. The VMT outputs for all vehicle classes combined from the travel demand model are disaggregate into five vehicle classes based on the vehicle mix fraction data provided by the New York State Department of Transportation.

Idling Hours of Heavy-Duty Trucks

No information is available.

2.2.4. Maricopa County, AZ

The Maricopa Association of Governments (MAG) is a Council of Governments (COG) that serves as the regional agency for the metropolitan Phoenix area.

Vehicle Class and Age Distributions

Vehicle class and age distributions are based on vehicle registration data provided by the Motor Vehicle Division of the Arizona Department of Transportation (ADOT). The distributions are developed from only those vehicles registered in the county. The MAG internally develops a scheme to map the vehicle classes in the vehicle registration database to MOBILE6 vehicle classes. Then, a conversion tool provided by the EPA is used to convert MOBILE6 vehicle class fraction to MOVES source type fraction.

Vehicle Miles Traveled of Heavy-Duty Trucks

The MAG performs regional transportation modeling in TransCAD software. The VMT outputs for five vehicle classes from the transportation model are distributed to different vehicle classes based on local survey data.

Idling Hours of Heavy-Duty Trucks

The MAG develops local HDT population data as an input and uses the default calculation of extended idling hours of HDT supplied by MOVES.

2.2.5. Denver Metro, CO

The Denver Regional Council of Governments (DRCOG) is an MPO for the nine-county Denver region. The DRCOG provides vehicle activity results from travel demand model runs to the Colorado Air Pollution Control Division for air quality analyses.

Vehicle Class and Age Distributions

Vehicle class and age distributions are based on vehicle registration database.

Vehicle Miles Traveled of Heavy-Duty Trucks

The DRCOG uses an activity-based travel demand model called Focus. The Focus travel model was estimated based on detailed data from multiple surveys, including a commercial vehicle survey that gathered complete travel information from more than 800 commercial vehicles on an assigned day. The VMT fraction by vehicle type including heavy-duty trucks is obtained from the permanent traffic counter data recorded by the Colorado Department of Transportation. This VMT fraction is used for both baseline and future year scenarios.

Idling Hours of Heavy-Duty Trucks

The default values in MOVES are used.

2.3. Concluding Remarks

Based on the limited review of the current state of the practice conducted in this study, it is found that the data sources and methodology used to develop local data inputs for emission analyses vary from one area to another.

For vehicle class and age distributions, although all five areas reviewed in this study rely on the use of vehicle registration databases, the vehicle class definition used in the registration database for each state is different. Therefore, the responsible agencies have to develop a tool to map the vehicle classes in the registration database to MOBILE6 vehicle classes or MOVES source types. In addition, it is found that none of the five areas currently accounts for out-of-area vehicles in the development of vehicle class and age distributions.

For vehicle miles traveled of HDTs, although there are differences among the areas such as the choice of and the level of details in the travel demand models used, the general trend is that VMT outputs from travel demand models are distributed to different vehicle classes including HDTs based on some sorts of vehicle class fraction derived from surveys or traffic counters. Only the SCAG's travel demand model has a dedicated HDT modeling capability.

Lastly, for idling hours of HDTs, the two areas in California use the data derived from instrumented studies of a total of 147 HDTs in the state. For Maricopa County, AZ, and Denver metro, CO, the default data in MOVES for extended idling of HDTs are used.

3. Vehicle Fleet Data

3.1. Background

In the development of on-road mobile source emission inventories, reliable data on vehicle fleet characteristics such as age distribution and alternative vehicle fuels and technologies fraction are as important as accurate data concerning vehicle activity and emission rates. For example, fleets with a higher percentage of older vehicles will have higher emissions for two reasons. First, older vehicles have typically been driven more miles and have experienced more deterioration in emission control systems. Second, a higher percentage of older vehicles also means that there are more vehicles in the fleet that do not meet newer, more stringent emissions standards. Studies have shown that the class and age distributions of vehicle fleets can vary significantly from area to area, e.g., [Malcolm et al., 2003]. Therefore, for state implementation plan (SIP) and transportation conformity purposes, the U.S. Environmental Protection Agency (EPA) recommends that agencies develop local vehicle class and age distributions [U.S. Environmental Protection Agency, 2004; U.S. Environmental Protection Agency, 2009].

The current practice in developing vehicle fleet data relies heavily on the use of vehicle registration database. This practice is sufficient for creating base vehicle fleet characteristics for an area, but it also has certain limitations. For instance, a significant fraction of vehicle miles traveled (VMT), and thus emissions, for an area could be attributable to vehicles registered outside the area (e.g., [Lutsey, 2009]). This is usually the case for, for instance, tourist areas and areas with major transportation hubs such as international airports and seaports. Applying inaccurate vehicle fleet characteristics could have significant impacts on the resulting emission inventories.

Furthermore, some vehicle emission and air quality studies may benefit from careful characterization of vehicle fleet at a more refined scale. For example, a project-level analysis of vehicle emissions may be performed using vehicle fleet data localized to the project. In another example, a modeling of regional air quality during ozone episodes may be based on emissions estimated using vehicle fleet data specific to the modeling period. Yet, in another example, a measurement of pollutant concentration near roadways for dispersion model development or validation may be conducted in conjunction with vehicle fleet characterization during the measurement in order to reduce biases in the emission estimates.

Therefore, there is a need for a tool or method that will enable the collection and development of highly-resolved and area-specific vehicle fleet data. An example is the use of license plate survey to capture vehicle license plate numbers and then apply these license plate numbers to a vehicle registration database to extract vehicle information. The remaining of this chapter describes a method for using license plate survey to obtain local vehicle fleet data, and presents a case study on this method.

3.2. Method for Collecting Local Vehicle Fleet Data

The need for better vehicle fleet data mentioned earlier can be met by conducting vehicle license plate survey. The survey is aimed at collecting the license plate numbers of vehicles that are present at the location of interest during the survey period. License plate survey has been used for a variety of purposes including trip origin and destination study, travel time study, automatic vehicle identification, etc. It has also been used for vehicle fleet characterization [Malcolm et al., 2003; Boriboonsomsin et al., 2009]. One advantage of license plate survey is that it does not interrupt traffic flow. Another advantage is that the license plate numbers obtained can be used to identify the vehicles and their information such as vehicle type, model year, and registration address.

There are two types of license plate survey that may be conducted.

1. *On-road survey*: This type of license plate survey is performed on the road of interest. It is appropriate for a vehicle fleet characteristic study of a large area (i.e., conducting the survey at cordon locations), a corridor, or a roadway segment. The survey can be conducted on any type of road as long as a safe and feasible survey spot can be identified. This type of survey is typically performed by using video cameras to capture license plate numbers of moving vehicles on the road. This can be challenging in the case of freeways and highways where vehicles are traveling at relatively high speeds, and during low lighting or visibility such as nighttime. Guidance on conducting on-road license plate survey using video cameras is provided in Appendix B.

   Systems consisting of specialized video cameras and automatic license plate recognition (ALPR) software are available that can be used for conducting the license plate survey. These systems can result in a high capture rate of license plate numbers even at high traveling speeds. They are also claimed to provide high accuracy of license plate number reading. However, the costs of such systems can be very high and may not be justifiable if they will not be used regularly. Alternatively, these systems may be rent or a contractor may be hired to perform the survey on an as-needed basis.

2. *Parking lot survey*: This type of license plate survey is performed in a parking lot where the license plate numbers of the parked vehicles are recorded. It is suitable for a vehicle fleet characteristic study of a small area (i.e., conducting the survey at major trip attractions) or a specific location (e.g., ports, terminals). For parking lot survey, the capture of the license plate number is much easier than the on-road survey. It can be done manually or with the aid of an ALPR system on a vehicle driven around the parking lot, of which the capture rate and the accuracy can be very high.

3.2.1. Vehicle Information Extraction

For the license plate survey with video cameras, the recorded videos are normally processed by human. The processing involves playing back the videos and extracting from each vehicle its license plate number, and if desirable, its vehicle class, as shown in the diagram in Figure 3-1. The extracted license plate numbers can then be matched up with vehicle registration databases in order to extract vehicle information. Vehicle registration databases for different states contain

a different amount of vehicle information, but basic vehicle information such as VIN and model year should be available in most vehicle registration databases. The obtained VINs can be run through a VIN decoder to extract detailed vehicle information such as body type, fuel type, gross vehicle weight, etc.
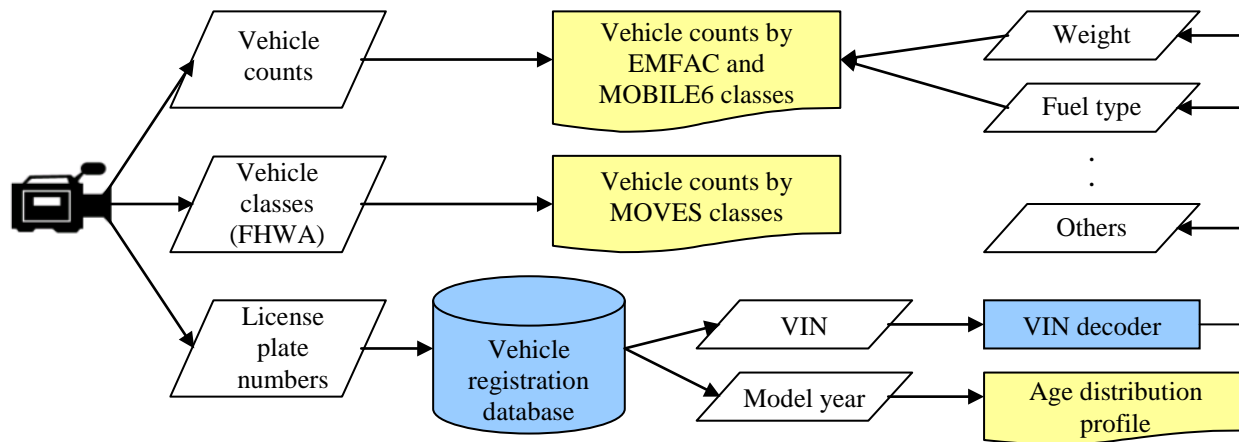
Figure 3-1. Method for collecting local fleet data through license plate survey

The extracted vehicle model year information can be used to derive vehicle age distribution. The fuel type information can be used to develop alternative fuel vehicle fraction. In the past when MOBILE6 was used, the gross vehicle weight information in conjunction with the body type information can be used to determine vehicle class faction. In MOVES, the vehicle classification is no longer based on vehicle weight, but rather tied directly to the HPMS classification system, which are based mainly on the body type and the number of axles. Nevertheless, the MOVES vehicle classes (or "source types") can also be determined visually from the videos.

Note that ALPR systems only return license plate number, but not vehicle class. Another set of camera and vehicle classification software can be added to the system to generate vehicle counts by vehicle class simultaneously. However, this will be at an additional cost.

3.2.2. Validation of VIN Decoder Accuracy

In this research, one subtask was devoted to validating the accuracy of vehicle information obtained from VIN decoder. A sample of 100 light-duty vehicles and 50 heavy-duty vehicles was selected and their attributes including VIN were gathered from local vehicle dealers. The attributes of these sample vehicles are given in Appendix A.

The VINs of these vehicles were run through a commercial VIN decoder to obtain vehicle attributes, and comparisons were made between the two datasets for model year, body type, and fuel type as these are key data attributes for developing vehicle fleet data inputs for MOVES. The comparison results show that the model year and fuel type obtained from the VIN decoder match the actual information for all the vehicles. The comparison of the body type could not be made directly as the two body type datasets use different body type categorization. However, they are in general agreement with each other.

3.3. Case Study: Impact of Out-of-State Vehicles on Local Vehicle Fleet Characteristics

The license plate survey was used to evaluate the impact of out-of-state vehicles on local vehicle fleet characteristics as a case study. In the study, license plate surveys were conducted at multiple locations in two metropolitan areas—(1) Los Angeles and (2) Las Vegas. These two metropolitan areas were chosen because they are in relatively close proximity to each other and are nonattainment areas for multiple criteria pollutants, as shown in Figure 3-2.

Counties Designated "Nonattainment" or "Maintenance"
for Clean Air Act's National Ambient Air Quality Standards (NAAQS) *

6/2010

Legend *
- County Designated Nonattainment or Maintenance for 6 NAAQS Pollutants
- County Designated Nonattainment or Maintenance for 5 NAAQS Pollutants
- County Designated Nonattainment or Maintenance for 4 NAAQS Pollutants
- County Designated Nonattainment or Maintenance for 3 NAAQS Pollutants
- County Designated Nonattainment or Maintenance for 2 NAAQS Pollutants
- County Designated Nonattainment or Maintenance for 1 NAAQS Pollutants

Figure 3-2. Nonattainment and maintenance areas in the U.S. as of June 2010

Figure 3-3 and Figure 3-4 show the survey locations in the Los Angeles and Las Vegas metros, respectively. Three survey locations were selected for each metro to capture the major freeways that lead traffic into the areas. Then, for each freeway a bridge overcrossing the freeway that provided safe working area was selected.

Figure 3-3. Locations of license plate survey in the Los Angeles metro

Figure 3-4. Locations of license plate survey in the Las Vegas metro

3-5

3.3.1. Data Collection

The surveys were conducted in July 2010, which represents the ozone season for the year. It was decided that the survey should be conducted on both weekday and weekend as business trips usually occur on weekdays and recreational trips on weekends. In addition, it was desirable to collect as many video hours as possible in a day in order to get the most return on the costs (i.e., traveling to the sites, setting up equipment, etc.) for the day. Thus, the surveys were conducted for eight hours a day using two video cameras simultaneously at each location. In summary, the license plate survey program was set us as follows:

- Two metropolitan areas (Los Angeles and Las Vegas)
- Three locations per metropolitan area (see Figure 3-3 and Figure 3-4)
- Two video cameras per location (rotated across all lanes of freeway to capture both car and truck traffic as trucks usually travel in the outer lanes)
- Five days per camera (Tuesday, Wednesday, Thursday, Saturday, and Sunday)
- Eight hours per day (6-10 a.m. and 3-7 p.m.)

Figure 3-5 shows the setup of the survey at one location.
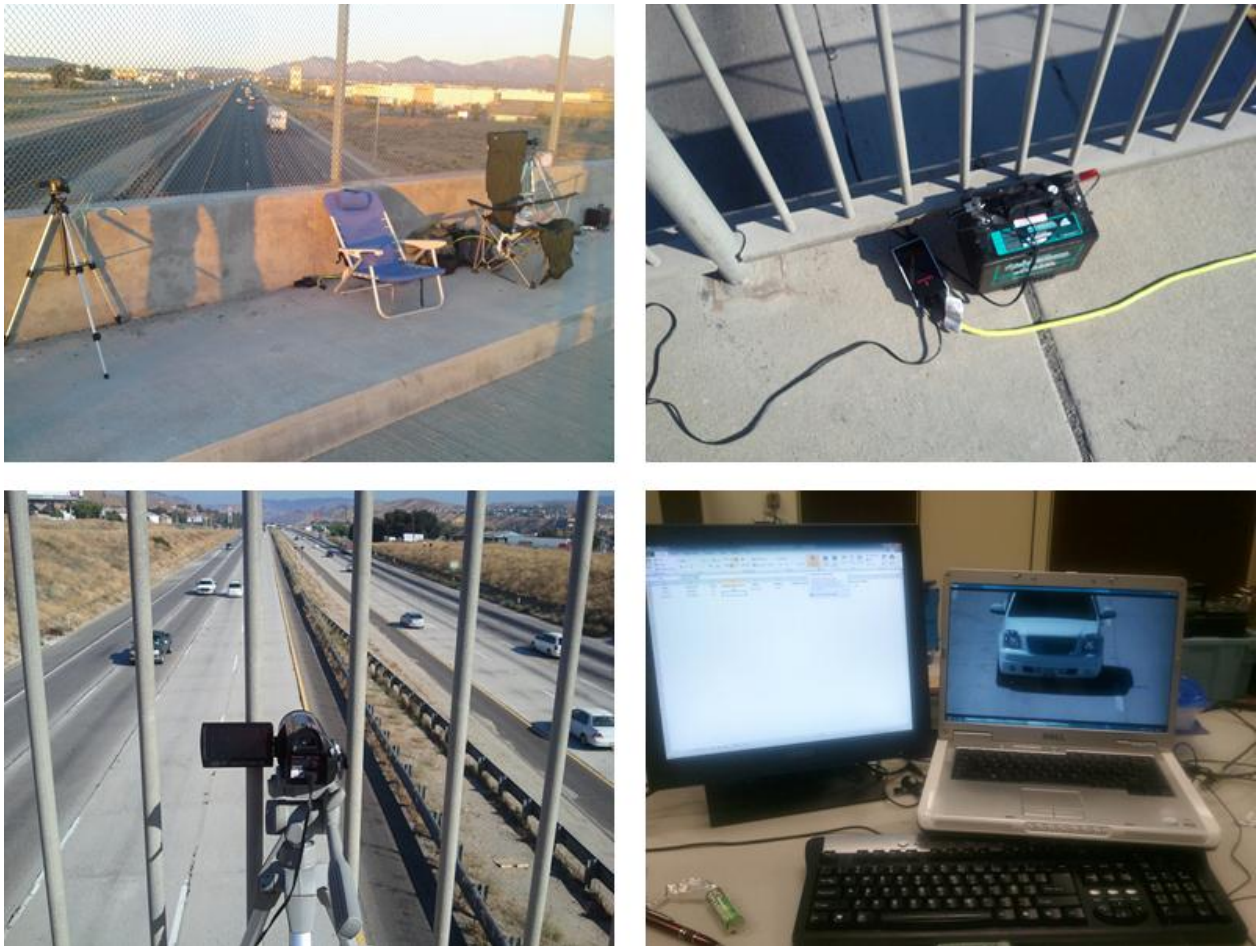
Figure 3-5. License plate survey setup

The equipment consists of two high-definition video cameras, two tripods, two 12-Volt marine batteries, a power converter, and necessary power cables. The video cameras were attached to the tripods, which were set up on a sidewalk on the bridge.

3.3.2. Data Processing and Analysis

At the end of the survey program, a total of 480 video hours were collected. These videos were checked for quality in terms of the clarity of the images and the readability of the license plate numbers. The bottom right picture in Figure 3-5 shows an example video image of a vehicle. Based on this image, the license plate number of the vehicle was read and the vehicle class was identified according to the HPMS and MOVES vehicle classes as shown in Figure 3-6 and Table 3-1, respectively. Typically, the manual processing of the videos to extract the license plate number and identify the vehicle classes took approximately four hours per one hour of video. The videos with poor quality will cause the processing time to be much longer, and thus, not cost-effective. Therefore, only selected video hours were fully processed.
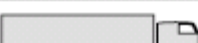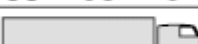
CLASS GROUP		DESCRIPTION	NO. OF AXLES
1		MOTORCYCLES	2
2		ALL CARS CARS	2
		CARS W/ 1-AXLE TRAILER	3
		CARS W/ 2-AXLE TRAILER	4
3		PICK-UPS & VANS 1 & 2 AXLE TRAILERS	2, 3, & 4
4		BUSES	2 & 3
5		2-AXLE, SINGLE UNIT	2
6		3-AXLE, SINGLE UNIT	3
7		4-AXLE, SINGLE UNIT	4
8		2-AXLE, TRACTOR, 1-AXLE TRAILER (2&1)	3
		2-AXLE, TRACTOR, 2-AXLE TRAILER (2&2)	4
		3-AXLE, TRACTOR, 1-AXLE TRAILER (3&1)	4
9		3-AXLE, TRACTOR, 2-AXLE TRAILER (3&2)	5
		3-AXLE, TRUCK W/ 2-AXLE TRAILER	5
10		TRACTOR W/ SINGLE TRAILER	6 & 7
11		5-AXLE MULTI-TRAILER	5
12		6-AXLE MULTI-TRAILER	6
13	ANY 7 OR MORE AXLE		7 or more

(HEAVY TRUCKS bracket spans groups 8–13)

Figure 3-6. HPMS vehicle classes

3-7

SourceType ID	SourceType	HPMS Vehicle Class
11	Motorcycles	Motorcycles
21	Passenger Cars	Passenger Cars
31	Passenger Trucks (primarily personal use)	Other Two-Axle/Four Tire, Single Unit
32	Light Commercial Trucks (other use)	Other Two-Axle/Four Tire, Single Unit
41	Intercity Buses (non-school, non-transit)	Buses
42	Transit Buses	Buses
43	School Buses	Buses
51	Refuse Trucks	Single Unit
52	Single Unit Short-haul Trucks	Single Unit
53	Single Unit Long-haul Trucks	Single Unit
54	Motor Homes	Single Unit
61	Combination Short-haul Trucks	Combination
62	Combination Long-haul Trucks	Combination

3.3.3. Results and Discussion

The state of registration and MOVES source type of the vehicles captured in the Los Angeles license plate surveys are presented in Figure 3-7 and Figure 3-9, respectively. In each figure, the results are given separately for weekday and weekend. Similarly, the state of registration and MOVES source type of the vehicles captured in the Las Vegas license plate surveys are presented in Figure 3-9 and Figure 3-10. The same types of plots for each of the six survey locations are provided in Appendix C.

According to these figures, the majority of vehicles entering the Los Angeles metropolitan area on weekdays are registered in California (82.1%). The same is true for weekends (also 82.1%). On the other hand, only 58.2% of vehicles entering the Las Vegas metropolitan area on weekdays are registered in Nevada. This is even less so on weekends (46.6%). As expected, the majority of the vehicles are passenger cars and trucks (more than 90% in the case of Los Angeles and more than 85% in the case of Las Vegas).
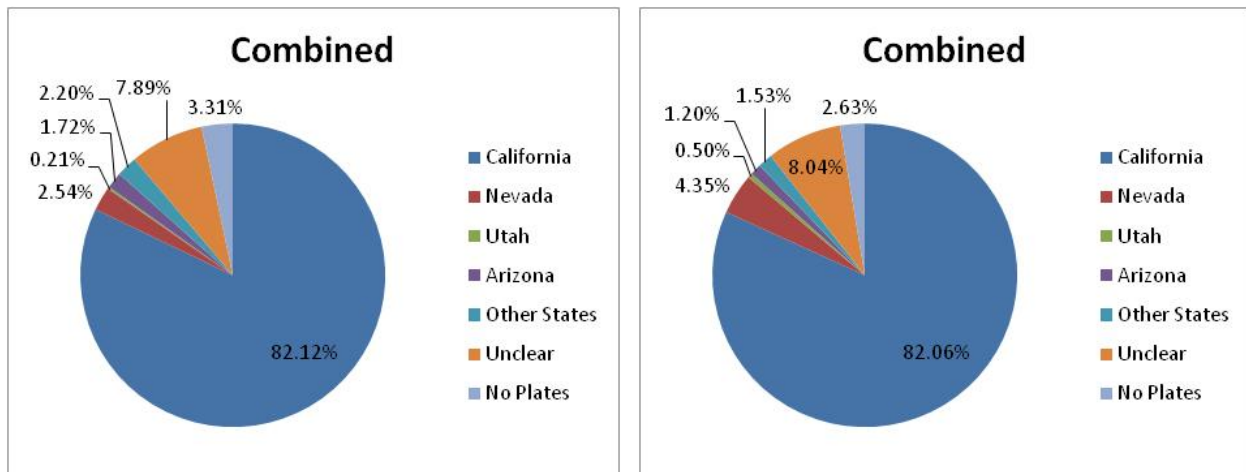
Figure 3-7. State of registration – Los Angeles locations combined, (left) weekday and (right) weekend
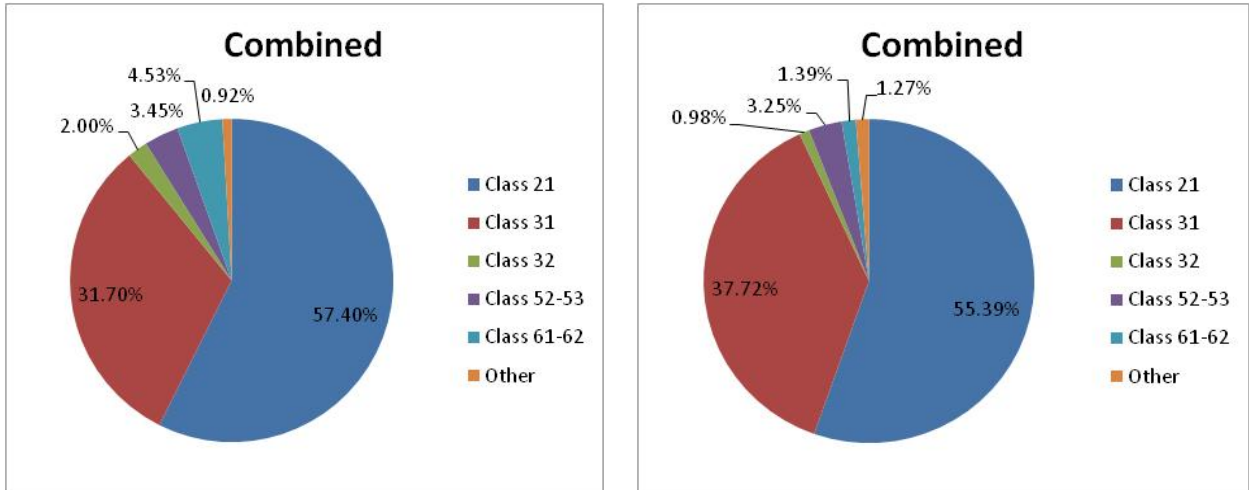
Figure 3-8. MOVES SourceType – Los Angeles locations combined, (left) weekday and (right) weekend
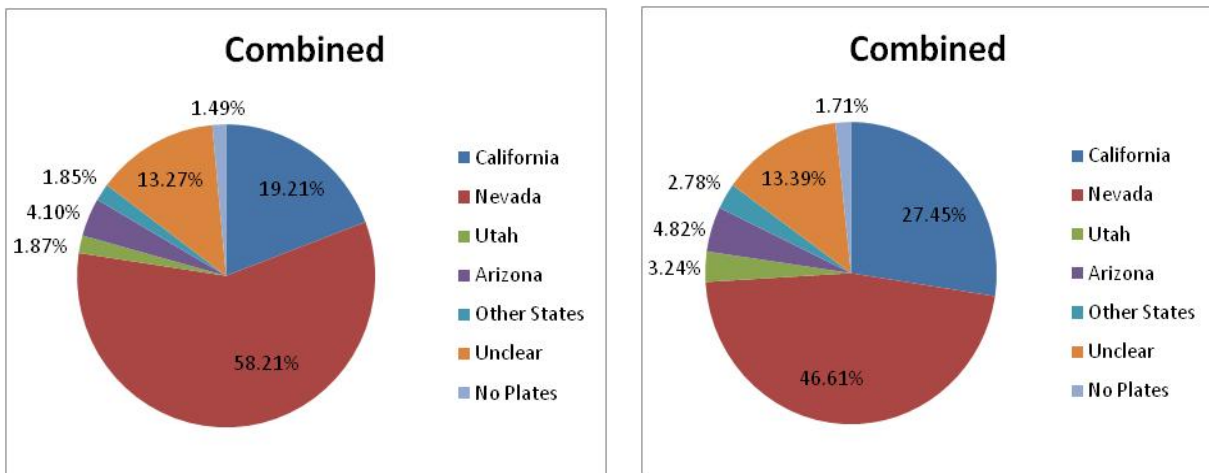
Figure 3-9. State of registration – Las Vegas locations combined, (left) weekday and (right) weekend
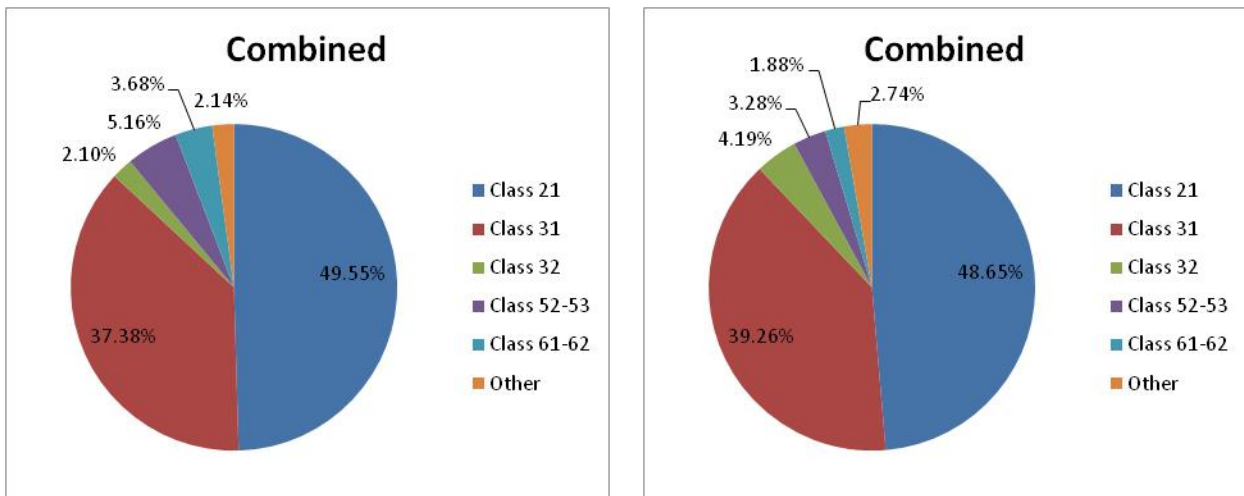
Figure 3-10. MOVES SourceType – Las Vegas locations combined, (left) weekday and (right) weekend

It is interesting to find that approximately 40% of the vehicles entering the Las Vegas metropolitan area on weekdays and 55% on weekends are not registered in Nevada. About a half of these vehicles are from California (19.2% on weekdays and 27.5% on weekends). This finding implies that many Californians travel to Las Vegas throughout the week, especially so on weekend. In the current practice that uses vehicle registration database to develop vehicle fleet characteristic data, these non-Nevada vehicles would not be accounted for.

To examine the possible biases, Figure 3-11 through Figure 3-15 plots the vehicle model year distributions of California and Nevada-registered vehicles that were captured in the Las Vegas license plate surveys during weekdays. According to these figures, there are several differences. For passenger cars and trucks, the California vehicles are relatively newer with the majority being less than one year old (note that the surveys were conducted in July 2010). For light commercial trucks, the shape of the two distributions looks similar, but the peak of the California distribution is three years newer. For single-unit trucks, the overall shape and position of the two distributions are comparable. Lastly, for combination trucks, the Nevada vehicles are newer.
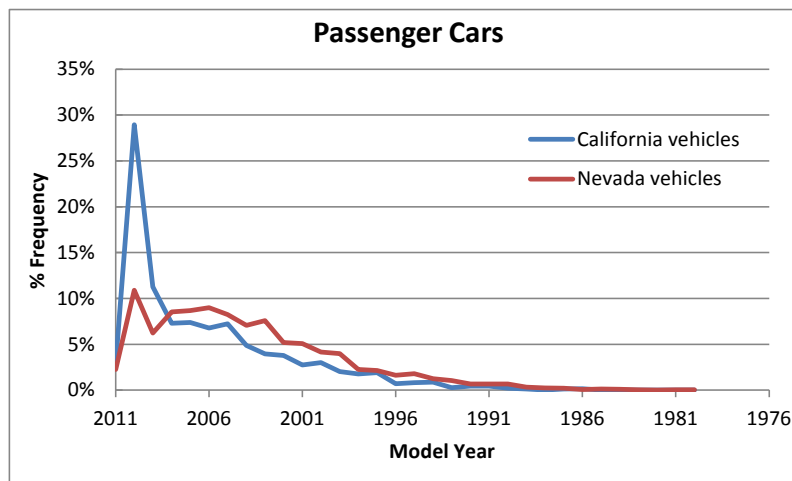
Figure 3-11. Model year distributions of passenger cars
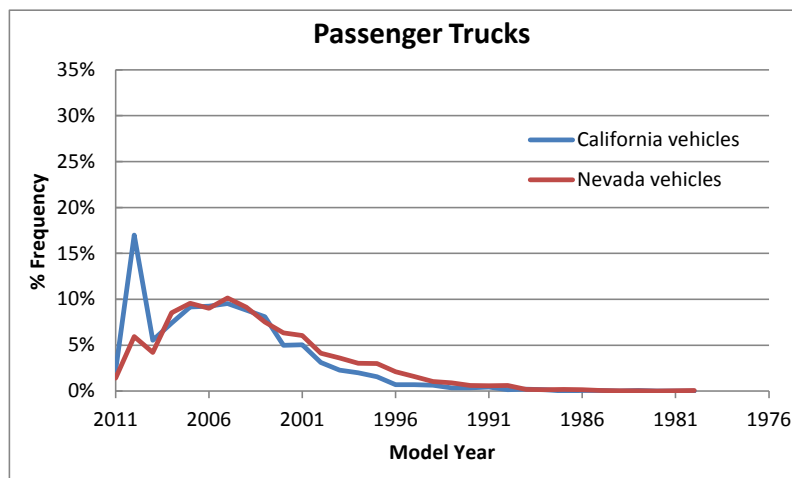
Figure 3-12. Model year distributions of passenger trucks
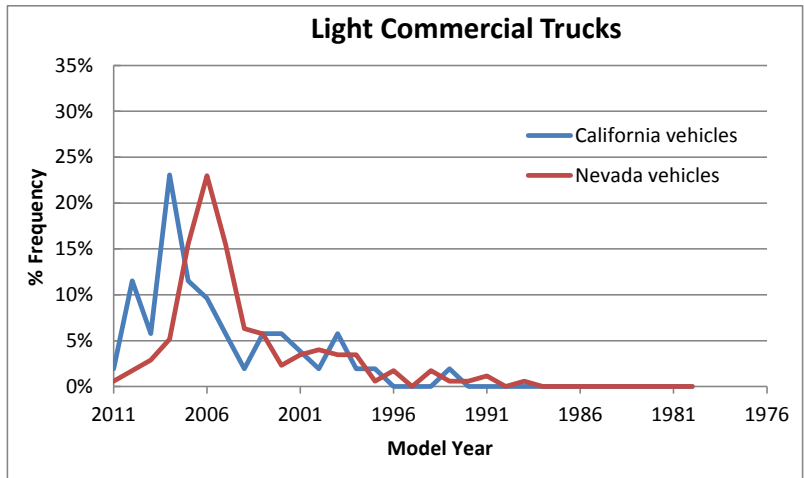
Figure 3-13. Model year distributions of light commercial trucks
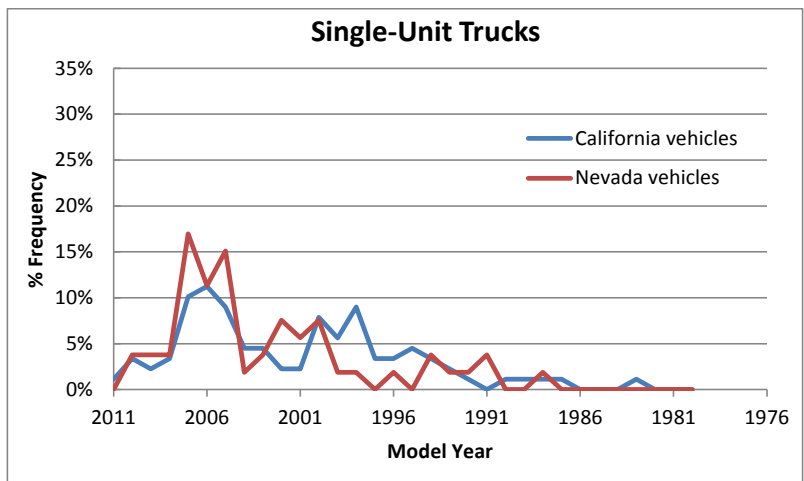
Figure 3-14. Model year distributions of single-unit trucks
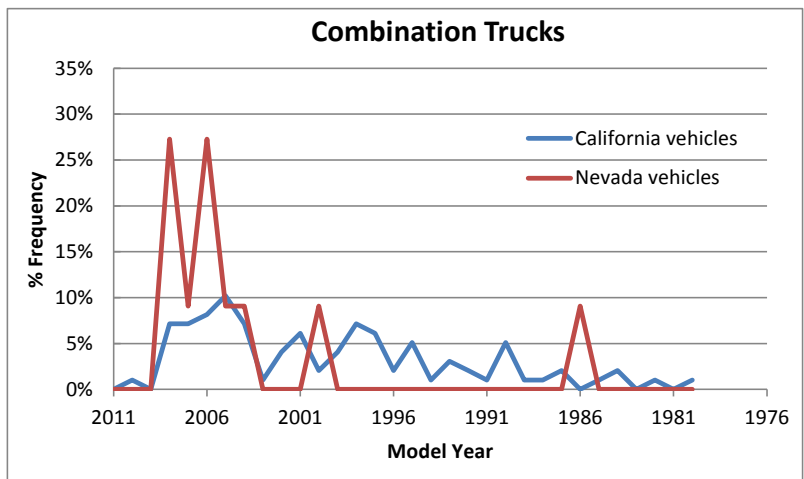
Figure 3-15. Model year distributions of combination trucks

3.4. Concluding remarks

In the development of on-road mobile source emission inventories, reliable data on vehicle fleet characteristics such as age distribution and alternative vehicle fuels and technologies fraction are as important as accurate data concerning vehicle activity and emission rates. In many emission and air quality analyses, there is a need for of highly-resolved and area-specific vehicle fleet data. This need can be met by using the vehicle license plate survey technique in conjunction with vehicle registration database and VIN decoder. The commercial VIN decoder evaluated in this study is found to provide accurate vehicle information. Depending on the vehicle attributes available in the individual states' vehicle registration database, a VIN decoder may or may not be necessary in the development of vehicle fleet data inputs for MOVES.

The license plate survey can be conducted in different ways. It may be done on-road or in parking lots, depending on the area type (e.g., area-wide, corridor, or terminal). It may also be done manually or with an ALPR system, depending on the need and the availability of resources.

The case study of using license plate survey to evaluate the impact of out-of-state vehicles reveals a striking finding that approximately 40% of the vehicles entering the Las Vegas metro on weekdays and 55% on weekends are not registered in Nevada. In addition, about a half of these vehicles are from California (19.2% on weekdays and 27.5% on weekends), which have significantly different model year distributions from the Nevada vehicles. In the current practice that relies heavily on vehicle registration database alone, these non-Nevada vehicles would not be accounted for.

These findings imply that care should be exercised when estimating emissions from vehicles in tourist areas and areas with major transportation hubs. License plate surveys may be conducted to determine the fraction of out-of-state, or even out-of-region, vehicles. Based on the finding, the vehicle fleet characteristic profiles may be adjusted accordingly. For example, in the case of the Las Vegas metropolitan area, the emission calculation could take into account the significant fraction of vehicles from California.

4. Heavy-Duty Truck Activity Data

4.1. Background

Albeit a very small fraction in the total vehicle population, HDTs contribute disproportionately to the emissions inventory of on-road mobile sources. This is due to their high annual mileage and high emission rates. In addition, HDTs are also a significant source of idling emissions especially at truck stops and terminals as they often engage in long-duration idling activities (e.g., loading/unloading, heating/cooling the cabin during rest stops, etc.) at these locations [Miller et al., 2007; Frey et al., 2008]. Therefore, an accurate characterization of HDT activity is crucial to the construction of emissions inventory of on-road mobile sources.

In the current state of the practice, the HPMS has been used as a primary source for VMT data for various road and vehicle types, including HDTs [U.S. Environmental Protection Agency, 2005]. However, it does not include the information about traffic speed; and thus, the reported VMT cannot be characterized by speed bins. As vehicle emissions are sensitive to vehicle speed among other things, it is desirable to characterize VMT into multiple speed bins so that appropriate emission factors for each speed bin can be applied.

Alternatively, HDT activity can be estimated using travel demand models, especially those with a dedicated module for HDTs (e.g., [Southern California Association of Governments, 2008]). There has also been increasing interest in developing freight flow models (e.g., [Sarvareddy et al., 2005]), which can be used to derive truck trips and miles traveled. Nevertheless, these models are still in their early stages and have not been adopted widely. Also, the availability of measured truck traffic data, especially with regards to speed, that can be used for model validation is limited so that the accuracy of speed data from the models may be questionable.

Another method that has been used is to instrument a fleet of HDTs with GPS-based data loggers and log their travel activity over a period of time (e.g., [Battelle, 1999]). This method offers the most detailed and probably the most reliable information on HDT miles and speed. Also, it is able to capture the information about non-driving activities such as soak time and idling, which are not available in either the HPMS or travel demand models. However, this type of data collection requires significant resources; and thus, is usually performed for a small number of trucks and for a short period of time.

In this research, two alternative sources of HDT activity data including truck's electronic control unit (ECU) and telematics-based vehicle tracking and monitoring system were investigated to determine their potential for generating HDT activity data inputs for MOVES. In addition, a method was developed to fuse HDT activity datasets from multiple existing data sources to result in more refined and accurate HDT activity data.

4.2. Truck Electronic Control Unit Data

Modern diesel engines have rather sophisticated computers that control engine operation and allow manufacturers to program changes in efficiency and also allow for archiving of operating parameter information such as vehicle speed and engine speed. The original equipment manufacturers (OEMs) use this information to learn about typical vehicle operation as well as to monitor vehicle usage to determine if warranty repair service will be approved. A large number of variables are available on the engine downloads from electronically controlled engines a standard for the data links (SAE J1939) used in the heavy-duty vehicle industry was widely adopted by diesel engine manufacturers. The specific data available from the ECU varies by manufacturer, but generally includes engine identification and vehicle operational summaries as well as information on the current engine control program and the date when it was installed.

Heavy-duty diesel engines have been electronically controlled since the late 1980's. Part of the electronic control systems manages engine operation and another part collects and stores data on vehicle use. As the electronics have become more sophisticated they have enabled greater levels of control of engine operation (optimization of fuel use on extended cruises for example) as well as greater levels of data collection and storage. Modern electronic control systems collect and can provide operating information (temperatures, pressures, fuel consumption), customer programmable information (idle speed, cruise control mode), as well as diagnostic information. Engine manufacturers provide various specialized software systems for retrieving the data from these on-board computer systems using laptops or handheld computers. The specialized software and interface hardware are unique for each manufacturer.

While the different manufacturers record many of the same engine variables, the functions and the specific variables are not uniform across manufacturers. Even for the same manufacturers, different software versions also provide different amounts of data in different formats. Because of this lack of uniformity in variables, names, and data format, the task of compiling the data into a format useful for analysis is quite labor intensive.

A large number of variables are available on the engine downloads. The specific variables available vary from manufacturer to manufacturer, and across model years within manufacturers. For example, the Caterpillar Electronic Technician (CatET) software was used exclusively for the CAT vehicles. The ET program permits access to a range of diagnostic and archived engine and vehicle activity data. The engine variables available on a Caterpillar engine download are presented in Table 4-1. Similarly, Table 4-2 through Table 4-4 list the engine variables available on Cummins and Detroit Diesel downloads. Note that the fields in bold text are main headers.

Table 4-1. Variables available on downloads from Caterpillar engine

Cat Electronic Technician Cat ET2002A		
Parameter	Parameter	Parameter
Vehicle ID	Idle Vehicle Speed Limit	Maintenance Indicator Mode
Engine Serial Number	Idle RPM Limit	PM1 Interval
ECM Serial Number	Idle/PTO RPM Ramp Rate	Engine Oil Capacity
Personality Module Part Number	Idle/PTO Bump RPM	Trip Parameters
Personality Module Release Date	Dedicated PTO Parameters	Fuel Correction Factor
Personality Module Code	PTO Configuration	Dash - Change Fuel Correction Factor
ECM Date/Time	PTO Top Engine Limit	Dash - PM1 Reset
Description	PTO Engine RPM Set Speed (0 = Off)	Dash - Fleet Trip Reset
Selected Engine Rating	PTO Engine RPM Set Speed A	Dash - State Selection
Rating Number	PTO Engine RPM Set Speed B	Theft Deterrent System Control
Rating Type	PTO to Set Speed	Theft Deterrent Password
Multi-Torque Ratio	PTO Cab Controls RPM Limit	Quick Stop Rate
Advertised Power	PTO Kickout Vehicle Speed Limit	Vehicle Activity Report Parameters
Governed Speed	Torque Limit	Minimum Idle Time (0 = Off)
Rated Peak Torque	PTO Shutdown Time (0 = Off)	Driver Reward
Top Engine Speed Range	PTO Shutdown Timer Maximum RPM	Driver Reward Enable
Test Spec	PTO Activates Cooling Fan	Input Selections
Test Spec with BrakeSaver	Engine/Gear Parameters	Fan Override Switch
ECM Identification Parameters	Lower Gears Engine RPM Limit	Ignore Brake/Clutch Switch
Vehicle ID	Lower Gears Turn Off Speed	Torque Limit Switch
Engine Serial Number	Intermediate Gears Engine RPM Limit	Diagnostic Enable
ECM Serial Number	Intermediate Gears Turn Off Speed	Remote PTO Set Switch
Personality Module Part Number	Gear Down Protection RPM Limit	Remote PTO Resume Switch
Personality Module Release Date	Gear Down Protection Turn On Speed	PTO Engine RPM Set Speed Input A
Security Access Parameters	Top Engine Limit	PTO Engine RPM Set Speed Input B
Total Tattletale	Top Engine Limit with Droop	Starting Aid On/Off Switch
Last Tool to change Customer Parameters	Low Idle Engine RPM	Two Speed Axle Switch
Last Tool to change System Parameters	Transmission Style	Cruise Control On/Off Switch
ECM Wireless Communications Enable	Eaton Top 2 Override with Cruise Switch	Cruise Control Set/Resume/Accel/Decel Switch
Vehicle Speed Parameters	Top Gear Ratio	Clutch Pedal Position Switch
Vehicle Speed Calibration	Top Gear Minus One Ratio	Retarder Off/Low/Med/High Switch
Vehicle Speed Limit	Top Gear Minus Two Ratio	Service Brake Pedal Position Switch #1
VSL Protection	Timer Parameters	Accelerator Pedal Position
Tachometer Calibration	Idle Shutdown Time (0 = Off)	Output Selections
Soft Vehicle Speed Limit	Idle Shutdown Timer Maximum RPM	Engine Running Output
Low Speed Range Axle Ratio	Allow Idle Shutdown Override	Engine Shutdown Output
High Speed Range Axle Ratio	Minimum Idle Shutdown Outside Temp	Auxiliary Brake
Cruise Control Parameters	Maximum Idle Shutdown Outside Temp	Starting Aid Output
Low Cruise Control Speed Set Limit	A/C Switch Fan On-Time (0 = Off)	Fan Control Type
High Cruise Control Speed Set Limit	Fan with Engine Retarder in High Mode	Passwords
Engine Retarder Mode	Engine Retarder Delay	Customer Password #1
Engine Retarder Minimum VSL Type	Smart Idle Parameters	Customer Password #2
Engine Retarder Minimum Vehicle Speed	Battery Monitor and Engine Control Voltage	Data Link Parameters
Auto Retarder in Cruise (0 = Off)	Engine Monitoring Parameters	Powertrain Data Link
Auto Retarder in Cruise Increment	Engine Monitoring Mode	System Parameters
Cruise/Idle/PTO Switch Configuration	Engine Monitoring Lamps	Personality Module Code
SoftCruise Control	Coolant Level Sensor	FLS
Idle Parameters (Old PTO)	Maintenance Parameters	FTS

Table 4-2. Variables available on downloads from Cummins engine

Engine serial number	**trip since last reset**	**other**
ECM Image Name	**distance**	engine brake activations
signature/ISX-CM870	active service brake distance	engine protection shutdown overrides
CM870	cruise control distance	idle shutdowns
All trips (cumulative)	driver reward 1 distance	maximum accelerator vehicle speed fuel used
Distance	driver reward 2 distance	number of sudden decelerations
Total ECM distance	driver reward 3 distance	service brake actuations
total engine brake distance	driver reward 4 distance	trip average engine speed
total engine distance	engine brake distance	trip average one gear down speed
total service brake distance	maximum accelerator vehicle speed distance	trip average top gear speed
fuel used	PTO drive distance	trip average vehicle speed
smart torque high torque fuel used	smart torque high torque distance	trip maximum engine speed
total cruise control fuel used	trip distance	trip maximum engine speed
total fuel used	trip gear down distance	trip maximum vehicle speed
total gea down fuel used	trip percent distance vehicle overspeed 1	**time**
total idle fuel used	trip percent distance vehicle overspeed 2	cruise control time
total loaded PTO drive fuel used	trip top gear distance	driver reward 1 time
total maximum accelerator vehicle speed fuel used	vehicle overspeed 1 distance	driver reward 2 time
total PTO drive fuel used	vehicle overspeed 2 distance	driver reward 3 time
total PTO fuel used	**fuel used**	driver reward 4 time
total top gear fuel used	cruise control fuel used	engine brake time
multiple PTO	driver reward 1 fuel used	engine brakes
PTO device 1	driver reward 2 fuel used	fan on time
PTO device 2	driver reward 3 fuel used	fan time air conditioning pressure switch
PTO device 3	driver reward 4 fuel used	fan time due to engine conditions
PTO device 4	maximum accelerator vehicle speed fuel used	fan time fan control switch
PTO device 5	PTO drive fuel used	fan time with vehicle speed
PTO device 6	PTO fuel used	fan time without vehicle speed
PTO device 7	smart torque high torque fuel used	maximum accelerator vehicle speed time
PTO device 8	trip average fuel economy	percent time at idle
fuel	trip average fuel rate	percent time in cruise control
PTO device 1 total fuel used	trip drive average fuel economy	percent time in PTO
PTO device 2 total fuel used	trip drive fuel used	percent time in top gear
PTO device 3 total fuel used	trip fuel used	percent time one gear down
PTO device 4 total fuel used	trip gear down fuel used	PTO drive time
PTO device 5 total fuel used	trip idle fuel used	PTO time
PTO device 6 total fuel used	trip top gear fuel used	smart torque high torque time
PTO device 7 total fuel used	vehicle overspeed 1 fuel used	trip gear down time
PTO device 8 total fuel used	vehicle overspeed 2 fuel used	trip idle time
time	**multiple PTO**	trip percent distance in cruise control
PTO device 1 total time	PTO device 1	trip percent distance in top gear
PTO device 2 total time	PTO device 2	trip percent distance one gear down
PTO device 3 total time	PTO device 3	trip percent fan on time
PTO device 4 total time	PTO device 4	trip percent fan on time due to air conditioning
PTO device 5 total time	PTO device 5	pressure switch
PTO device 6 total time	PTO device 6	trip percent fan on time due to engine conditions
PTO device 7 total time	PTO device 7	trip percent fan on time due tofan control switch
PTO device 8 total time	PTO device 8	trip percent fan on time with vehicle speed
other	**fuel**	trip percent fann on time without vehicl speed
total average engine speed	PTO device 1 trip fuel used	trip service brake time
total average fuel economy	PTO device 2 trip fuel used	trip time
total engine brake activations	PTO device 3 trip fuel used	trip top gear time
total engine protection shutdown manual overrides	PTO device 4 trip fuel used	vehicle overspeed 1 time
time	PTO device 5 trip fuel used	vehicle overspeed 2 time
smart torque high torque time	PTO device 6 trip fuel used	
total cruise control time	PTO device 7 trip fuel used	
total ECM time (key on time)	PTO device 8 trip fuel used	
total engine brake time	**time**	
total engine run time	PTO device 1 trip time	
total gear down time	PTO device 2 trip time	
total idle time	PTO device 3 trip time	
total maximum accelerator vehicle speed time	PTO device 4 trip time	
total PTO drive time	PTO device 5 trip time	
total PTO time	PTO device 6 trip time	
total service brake time	PTO device 7 trip time	
total top gear time	PTO device 8 trip time	

Table 4-3. Variables available on downloads from Detroit Diesel engine (summary version)

Vehicle Unit Number	engine brake totals	VSG totals
Engine serial Number	time	fuel
ECU version	**percentages**	time
Engine totals	on idle	**optimized idle totals**
Accumulated totals	on cruise	optimized idle not enabled
fuel	**last de-green reset**	**cruise totals**
time	distance	time
distance	**trip totals**	**engine brake totals**
idle totals	accumulated totals	time
fuel	fuel	**fuel economy**
time	time	**percentages**
VSG totals	distance	on idle
fuel	**idle totals**	on cruise
time	fuel	
optimized idle totals	time	
cruise totals		
time		

Table 4-4. Variables available on downloads from Detroit Diesel engine (detailed version)

print date	**speeding A(>=66 mph and <71 mph)**	**optimized idle batter charging run time**
trip	count	normal stats
vehicle id	time	continuous run starts
driver id	percent	alternate battery time starts
odometer	**speeding B (>=71 mph)**	**fan on time**
trip distance	count	total time
trip fuel	time	engine system
fuel economy	percent	manual
avg drive load	**highest speed occurred**	A/C
avg vehicle speed	**coasting time**	**pump on time**
driving time	**coasting percent**	time
driving percent	trip time	distance
driving fuel	fuel consumption	fuel
driving economy	idle time	engine utilization
vehicle speed limiting	idle percent	vehicle utilization
time	idle fuel	hard brake limit
percent	VSG (PTO) time	stop idle limit
distance	VSG (PTO) percent	top gear limit
fuel	VSG (PTO) fuel	top gear-1 limit
top gear	stop idle time	ECM S/W
time	stop idle percent	ECM type
percent	stop idle fuel	config. Change
distance	**over rev limit**	idle method
fuel	count	idle-load method
top gear -1	time	idle-RPM limit
time	percent	reset lockout
percent	highest rpm occurred	fleet time zone
distance	diag. records	**maintenance visual reminder**
fuel	hard brake count	enabled
cruise	brake count	percentage
time	eng. Brake time	vehicle speed bands (mph)
percent	**optimized idle time**	engine speed bands (rpm)
distance	active	percent load bands (%)
fuel	run	trip status
top gear cruise	battery	
time	engine temp.	
percent	thermostat	
distance	extended idle	
fuel	continuous	

4.2.1. Example Dataset

Summary data from an ECU can be downloaded using engine manufacturer specific diagnostic software such as Cat ET for Caterpillar, Detroit Diagnostic Link for Detroit Diesel, and INSITE for Cummins. The cost for the software and the hardware required to connect to the on-board ECM is in the range of $1,000-$3,000 depending on manufacturer. Data available on ECU downloads also vary by manufacturer and software version. With the proper knowledge and skill on how to use the software and hardware, each ECU download takes approximately 10 to 15 minutes. It can be seen that the task of downloading ECM data from trucks is simple and does not require a significant amount of resources. What is more difficult is a time and resource burden in acquiring trucks for the download.

Alternatively, there are many truck repair shops that perform ECU diagnostic as part of their everyday job. These shops vary in size (in terms of the average number of trucks they work on each day) and capability (some shops only use basic code readers, which do not have access to the ECU summary data). Although many shops have the proper diagnostic software, it is not common practice to download the ECU summary data and store it. Downloading the ECU summary data is often done only upon customers' request, and the downloaded data is not typically stored by the shops except for some authorized dealer shops that handle warranty repairs. In these instances, the ECU summary data is sent to a corporate database.

Still, it is possible to contract with truck repair shops or truck fleets that have proper software and deal with a large volume of trucks to collect a sizable amount of ECU summary downloads in a timely manner. In this study, a small sample of 150 ECU downloads were obtained through working with truck fleets in the state of New York. This area was chosen because it is under nonattainment and has major seaports that process a significant portion of U.S. freight flow (see Figure 4-1).

The acquired ECU downloads are from four engine manufactures:
- Caterpillar – 2 downloads
- Cummins – 55 downloads
- Detroit Diesel – 16 downloads
- Hino – 77 downloads

Figure 4-2 presents the model year distribution of HDTs in the ECU download sample by engine manufacturer. It is shown that most of the HDTs with known model year are less than five years old (note that the ECU downloads were acquired in 2010).

Sources: http://www.epa.gov/air/oaqps/greenbk/map8hrnm.html
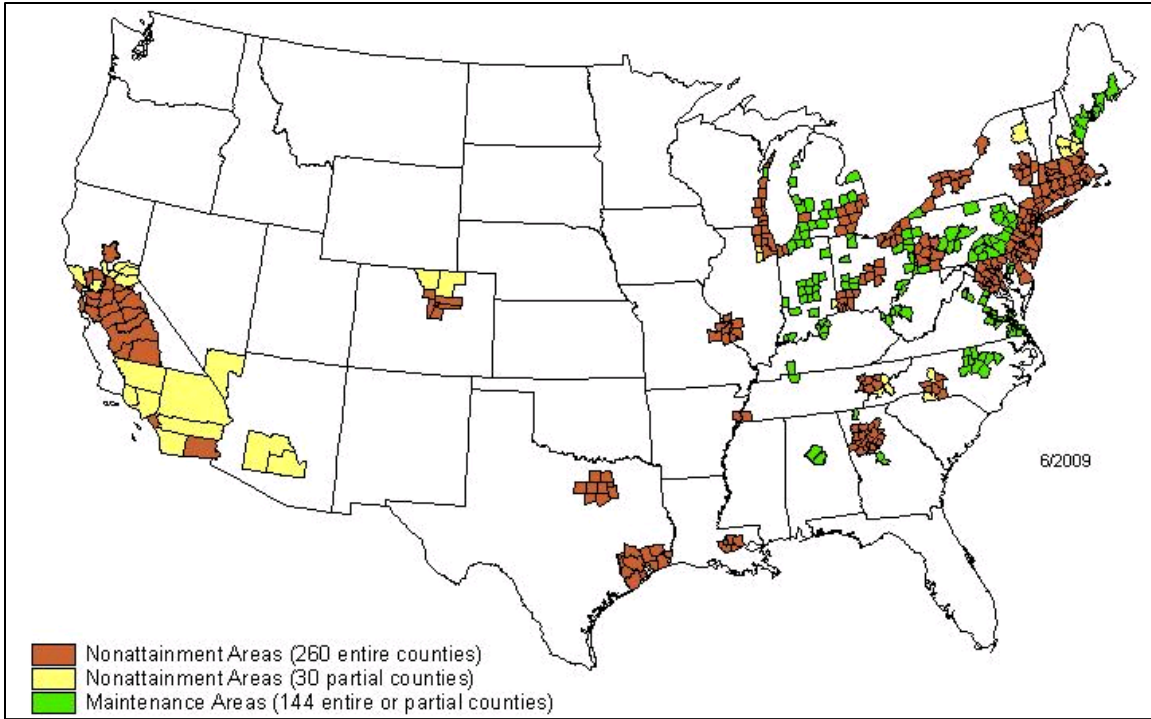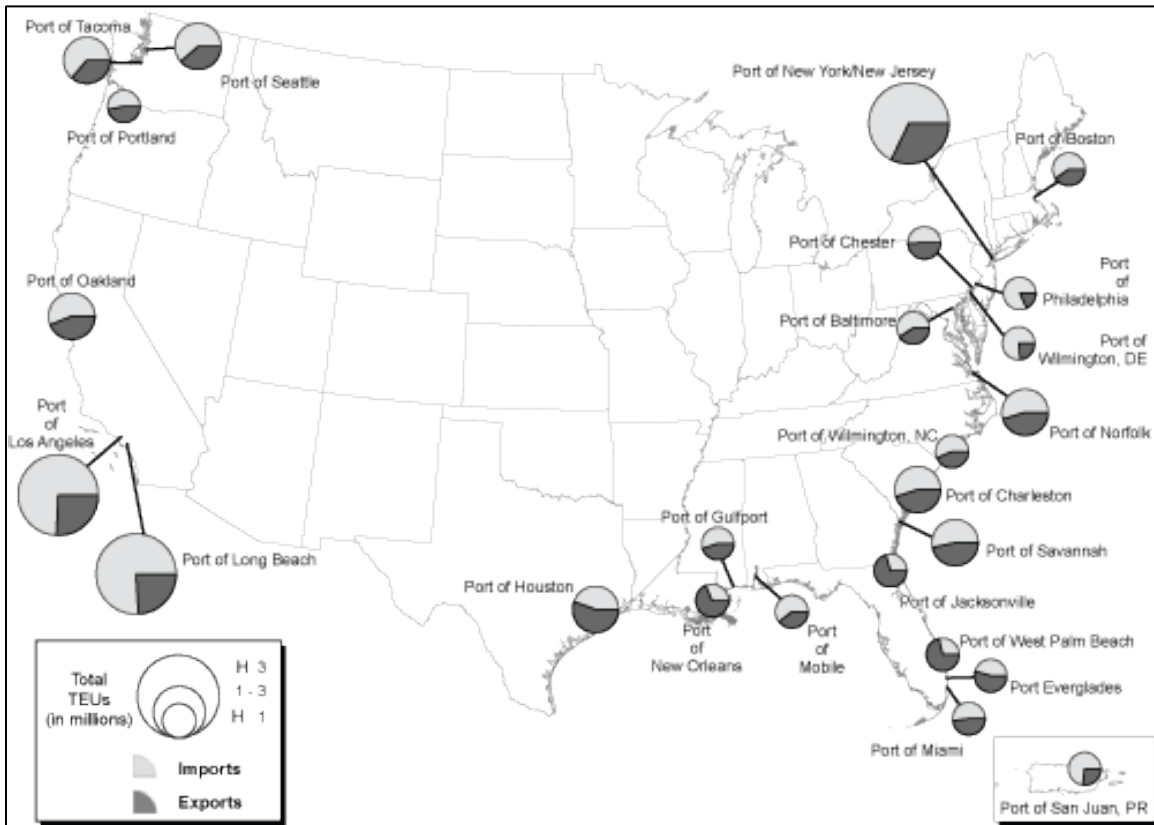
Source: http://www.bts.gov/publications/americas_container_ports/2009/html/figure_08.html

Figure 4-1. (top) 8-hr ozone nonattainment and maintenance areas in the U.S., and (bottom) 2008 freight flow at U.S. ports
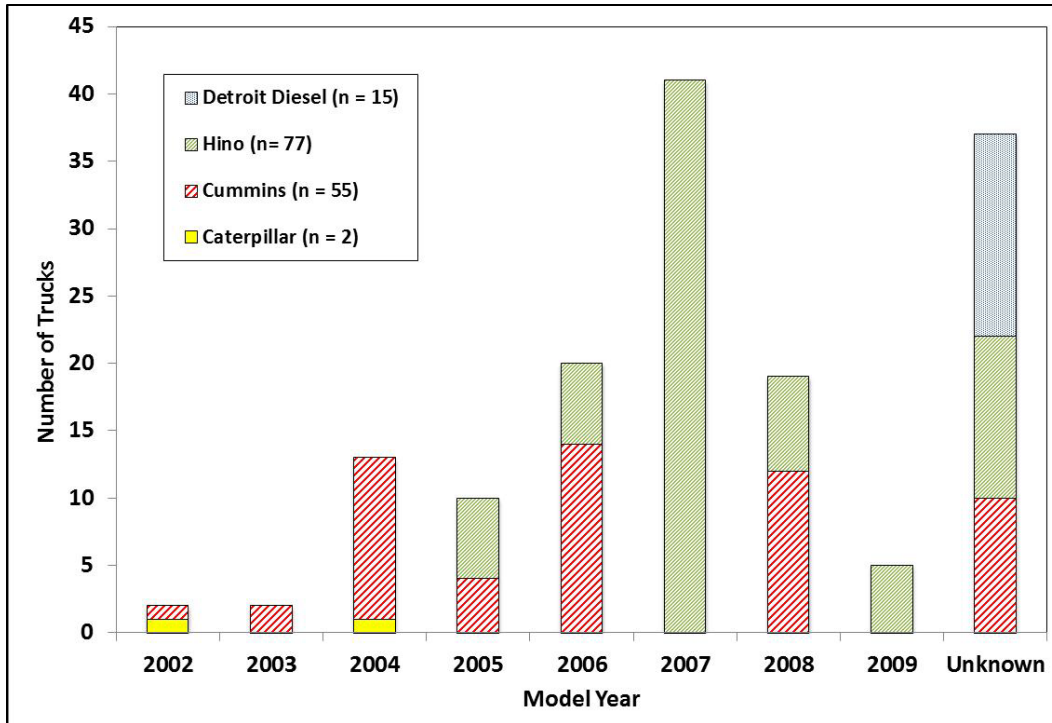
Figure 4-2. Model year of HDTs in the ECU download sample.

4.2.2. Data Processing and Analysis

ECU downloads are usually generated as a customized report and not in a file format that can be readily transferred to a database. The ECU downloads obtained in this study were provided in a PDF format. For each engine manufacture format, the data items of interest were identified and manually entered into an Excel spreadsheet. For creating HDT activity data inputs for MOVES, the key data items of interest include:

- Total distance
- Total hours
- Time at idle
- Time at power take-off (PTO)

Based on these data items, additional information were calculated as follows:

$$Average\ speed\ with\ idling = \frac{total\ distance}{total\ hours}$$

$$Average\ speed\ without\ idling = \frac{total\ distance}{(total\ hours - time\ at\ idle)}$$

Note that is PTO is a splined driveshaft, usually on a tractor or truck, that can be used to provide power to an attachment or separate machine. The PTO allows implements to draw energy from the tractor's engine, which increases emissions.

4-8

4.2.3. Results and Discussion

Figure 4-3 shows the distributions of the average speed of all HDTs in the sample. When idling is included, the mid speed range of 35-40 mph dominate the distribution. When idling is not included in the calculation, the typical "driving" speed of these HDTs is around 45-55 mph. These trends are similar to those found in a similar study using ECU downloads from HDTs in California [Boriboonsomsin et al., 2010].
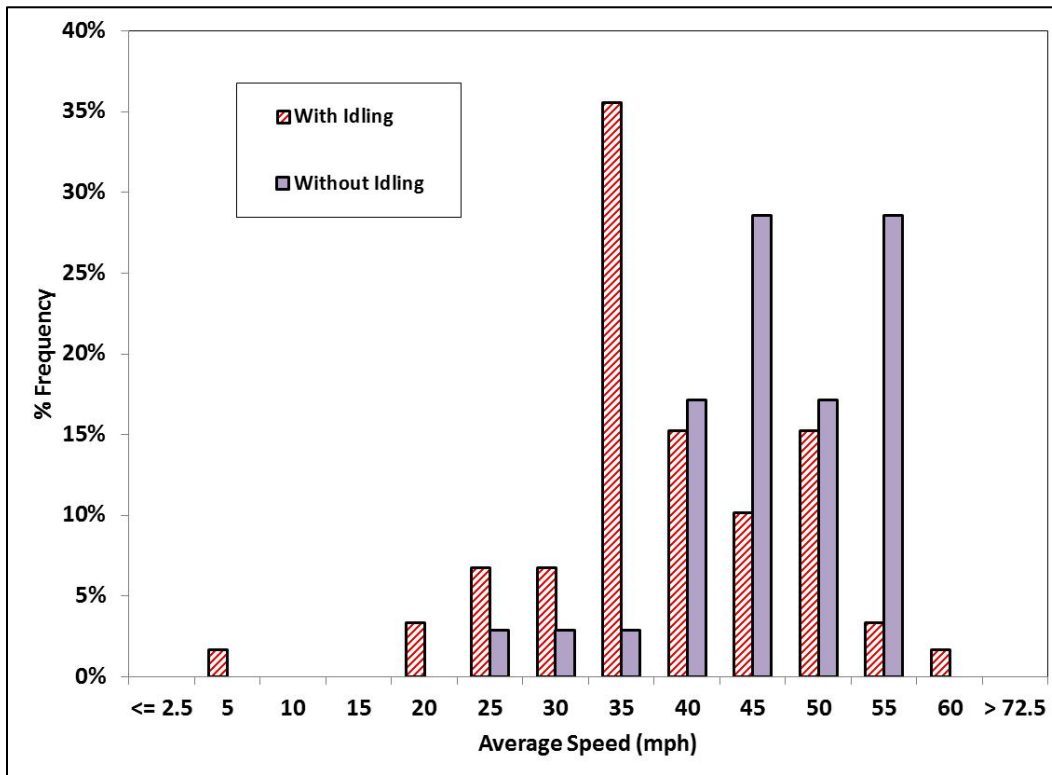
Figure 4-3. Distributions of average speed with and without idling.

Figure 4-4 presents the distributions of idling and PTO activity. According to the figure, the percentage that the HDTs are in idle mode is distributed across a wide range of 2.5-45% with some outliers at 55% and more. In general, these HDTs idle for about a quarter of the total operating hours, which is considered significant. On the other hand, over 60% of the HDTs in this sample rarely use PTO by more than 10%. When compared with the trends from the California study [Boriboonsomsin et al., 2010], it is found that the HDTs in this study spend a smaller fraction of their operating time in idle and PTO modes.

It should be noted that the idling time in ECU downloads cannot be differentiated between regular idling and extended idling, which is a new data inputs in MOVES. It is characterized by a higher engine speed, and thus higher emissions. However, the information regarding the total idling time can be combined with the information of extended idling from specialized studies (e.g., [Frey et al., 2008]) to estimate the total extended idling hours.
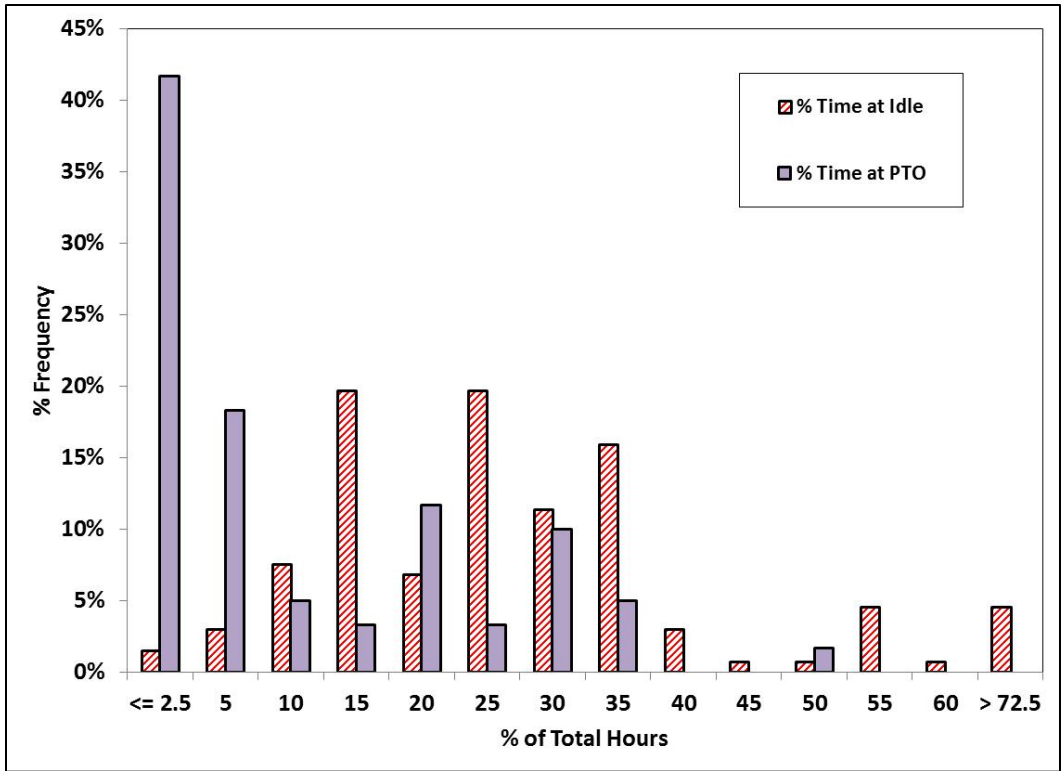
Figure 4-4. Distributions of percent time at idle and at PTO.

4.3. Truck Telematics Data

For the last couple of years, the use of wireless communication or telematics technology has been increasingly adopted by the fleet management industry. There is now a large number of fleet vehicles that are equipped with telematics-based vehicle tracking and monitoring systems which can wirelessly transmit the position information of the vehicles that is obtained from an on-board GPS device to a system server on a periodic basis. Furthermore, some systems are also connected to the vehicle's on-board diagnostic bus (OBD-II for light-duty vehicles and SAE J1939 bus for heavy-duty trucks), allowing not only the vehicle's position but also vehicle and engine operating conditions (e.g., engine speed, fuel use, etc.) to be monitored and reported in real-time (e.g., [NetworkFleet, 2011]).

These vehicle tracking and monitoring systems have potential to be a very rich source of HDT activity data. However, they have not been fully evaluated, especially in the context of supporting emissions inventory development. The objectives of this subtask in this research are: 1) to examine how telematics data from HDT tracking and monitoring systems can be used to generate HDT activity data inputs for the MOVES model; and 2) to assess the advantages and limitations of this data source.

4.3.1. Example Dataset

The HDT telematics data used in this study are from the Highway Visibility System (HIVIS) [Calmar Telematics, 2011]. HIVIS is a private database containing several hundred million records of commercial vehicle activity data from the telematics-based tracking and monitoring systems in the vehicles of participating fleets. Each of the participating fleets has arranged for the telematics data from their fleet operations to be automatically transmitted to HIVIS in exchange of both monetary compensation and access to the database for their own use. The HIVIS database has been used in a number of ways such as measuring truck travel time, developing truck trip tables, and studying truck VMT fees. At the time of reporting, it has never been used in air quality-related studies.

The HIVIS dataset used in this study comes from a collective fleet of more than 2,000 Class 8 HDTs traveling across the U.S. for the entire year of 2010. These HDTs comprise a broad cross-section of the commercial vehicle industry. Within the database there are single- and multi-trailers, dry bulk trailers, petroleum tankers, and milk trucks. In general, there is approximately a 90/10 split between combination trucks and straight trucks.

Figure 4-5 shows the plot of 1,791,816 GPS points from the HIVIS dataset across the U.S. in January 2010. A majority of the data points is clustered around the Northeast and Southern California regions where the home bases of most of the trucks in the dataset are located. It should be noted that these two regions are home of the three major ports that carry a significant portion of U.S. freight flow. Specifically, the ports of Los Angeles, Long Beach, and New York/New Jersey together carried about 50% of the total U.S. import and export containers in 2009 [Port Import Export Reporting Service, 2011].

It can be seen from the pattern of the GPS points in Figure 4-5 that many of the trucks are operated in large regional or long-haul fleets while some are operated locally within metro areas.

Table 4-5 lists the top 20 metropolitan planning organization (MPO) areas that have the highest number of data points in this dataset. As expected, most of them are in the northeastern states, especially New York, as well as in California.
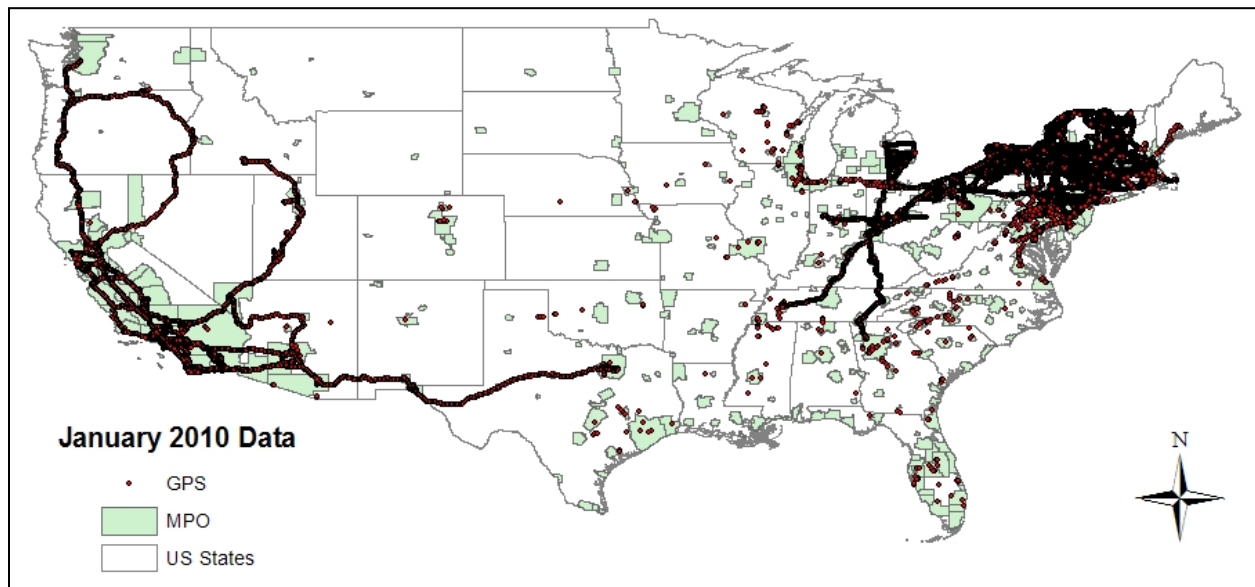
Figure 4-5. U.S. nationwide truck telematics data for January 2010.

Table 4-5. Top 20 MPOs with the most number of data points in January 2010 dataset

No.	Metropolitan Planning Organization	State	Population in Year 2000	No. of Data Points
1	Capital District Transportation Committee	NY	780,467	513,270
2	Greater Buffalo-Niagara Regional Transportation Council	NY	1,170,111	228,240
3	San Diego Association of Governments	CA	2,813,833	214,097
4	Southern California Association of Governments	CA	16,516,006	100,543
5	Herkimer-Oneida Counties Transportation Study	NY	299,896	99,712
6	Adirondack/Glens Falls Transportation Council	NY	138,171	75,041
7	Syracuse Metropolitan Transportation Council	NY	468,018	67,285
8	Binghamton Metropolitan Transportation Study	NY	215,457	58,637
9	Berkshire MPO	MA	134,953	54,469
10	Central Massachusetts MPO	MA	518,480	42,569
11	Pioneer Valley MPO	MA	608,479	40,675
12	Lackawanna-Luzerne Transportation Study	PA	532,545	32,325
13	Orange County Transportation Council	NY	341,367	31,873
14	Genesee Transportation Council	NY	823,147	29,119
15	North Jersey Transportation Planning Authority	NJ	6,310,989	25,194
16	Ulster County Transportation Council	NY	177,749	23,758
17	Chittenden County MPO	VT	146,571	22,359
18	Capital Region COG	CT	721,320	16,742
19	Southeast Michigan COG	MI	4,833,493	11,840
20	New York Metropolitan Transportation Council	NY	12,068,148	11,158

The particular data items that are collected from the trucks vary with the particular telematics solution that each fleet uses. Some fleets use simple tracking systems which merely return the vehicle's location at regular periods of time. Other fleets opt for highly sophisticated systems which also access the vehicle's data bus and can potentially return hundreds of vehicle and engine operating variables such as fuel consumption, engine speed, coolant temperature, and braking events.

The HIVIS dataset obtained in this study consist of two data files – a Trip Summary file and a Trip Points file. The Trip Summary file contains aggregated trip information while the Trip Points file contains the information regarding individual telematics data points. Table 4-6 lists the data items in each file and their description. Note that some data items such as tractorYear, engineMake, Distance, FuelConsumed, and ptRPM are only available for a limited number of trucks depending on the particular telematics solution used by the fleet as discussed above.

Note that the data in the Trip Points file are similar to what can be obtained from instrumented vehicle studies. The main difference is that instrumented vehicle studies usually record data at a one-second interval while the data in the Trip Points file are much coarser (e.g, 30-second or 5-minute reporting interval depending on the fleet). This is because fleets have to balance the resolution of the data they obtain against the cost of the wireless transmission of the data. Generally, that level of data resolution is sufficient for the purpose of tracking and monitoring their vehicles.

Table 4-6. Data items and their description

Data Items	Description
Trip Summary File	
tripNum	Unique identifier for this trip within this set of dated files
Veh_ID	Unique identifier for the vehicle, which is randomized weekly
tractorYear	Year of the tractor
tractorMake	Make of the tractor
tractorModel	Model of the tractor
engineMake	Make of the engine
engineModel	Model of the engine
odometerRange	The engines odometer range, truncated to 10,000 miles
HIVIScommodityCode	Commodity Code Abbreviation for the vehicle's fleet within HIVIS
DataMonth	Month that this trip occurred (GMT)
DataDOW	Day of week that this trip occurred (GMT)
firstLocTime5min	Time of day that this trip started (GMT), truncated to a 5-minute interval
lastLocTime5min	Time of day that this trip ended (GMT), truncated to a 5-minute interval
elapsedMinutes	Number of minutes elapsed during this trip
numPts	Number of data point locations recorded during this trip
pctSpeedBin0	Percent of data points with speed of 0mph
pctSpeedBin1	Percent of data points with speed < 2.5mph
pctSpeedBin2	Percent of data points with speed >= 2.5mph and < 7.5mph
pctSpeedBin3	Percent of data points with speed >= 7.5mph and < 12.5mph
pctSpeedBin4	Percent of data points with speed >= 12.5mph and < 17.5mph
pctSpeedBin5	Percent of data points with speed >= 17.5mph and < 22.5mph
pctSpeedBin6	Percent of data points with speed >= 22.5mph and < 27.5mph
pctSpeedBin7	Percent of data points with speed >= 27.5mph and < 32.5mph
pctSpeedBin8	Percent of data points with speed >= 32.5mph and < 37.5mph
pctSpeedBin9	Percent of data points with speed >= 37.5mph and < 42.5mph
pctSpeedBin10	Percent of data points with speed >= 42.5mph and < 47.5mph
pctSpeedBin11	Percent of data points with speed >= 47.5mph and < 52.5mph
pctSpeedBin12	Percent of data points with speed >= 52.5mph and < 57.5mph
pctSpeedBin13	Percent of data points with speed >= 57.5mph and < 62.5mph
pctSpeedBin14	Percent of data points with speed >= 62.5mph and < 67.5mph
pctSpeedBin15	Percent of data points with speed >= 67.5mph and < 72.5mph
pctSpeedBin16	Percent of data points with speed >= 72.5mph
Distance	Approximate distance traveled, in miles, during this trip
FuelConsumed	Approximate amount of fuel consumed, in gallons, during this trip
CalculatedFuelEfficiency	Approximate fuel economy, in miles per gallon, during this trip
Trip Points File	
tripNum	Unique identifier for this trip within this set of dated files
ptOrder	This point's order within the trip
Latitude	This point's locational latitude
Longitude	This point's locational longitude
Speed	This point's speed (from engine data bus if available, otherwise from GPS)
Direction	This point's GPS direction
elapsedSeconds	Number of seconds elapsed since beginning of trip
ptDistance	Travel distance since last point
ptFuel	Fuel level, in percentage
ptRPM	Engine speed, in revolutions per minute

4.3.2. Data Processing and Analysis

The data analysis methodology generally involves multiple steps, which are different for different MOVES data inputs. Described below are selected data analysis steps that are nontrivial as compared to other steps.

Map Matching

Map matching is the assignment of each data point to a geographic entity based on its position in relative to surrounding geographic entities, for example, assigning a data point to one road link or one MPO area. This is a critical analysis step for characterizing HDT activity into one of the five road types in MOVES, which are off-network, urban restricted, urban unrestricted, rural restricted, and rural unrestricted. It was performed using geographic information system (GIS) software.

To perform map matching of data points for road type characterization in GIS, a digital road network with road type information in shapefile format is required. In this study, three publicly available digital road network shapefiles including HPMS, TIGER/Line 2000, and ESRI StreetMap USA were examined. The ESRI StreetMap USA was selected because it has better quality than the HPMS and is more up-to-date than the TIGER/Line 2000. The road type attribute called "CLASS_RTE" ranges from 0 to 9. According to their definition (not shown here for brevity), the types 0-2 and 7 are considered restricted access and the rest unrestricted access. The point-to-line matching algorithm was used where a data point is assigned to a road link that has the shortest orthogonal distance to the data point. To differentiate between urban and rural areas, an urban boundary shapefile was used where a data point is considered to be on an urban road if it is within the boundary of an urban area. Since the data points are across the entire U.S., another round of map matching was also performed to differentiate the data points by time zone before calculating local time from the reported Greenwich Mean Time (GMT).

Off-Network Activity

The MOVES model allows users to input off-network activity, which is the portion of activity that is not reflected in the other four road types. Examples are driving on an unspecified road or idling in a parking lot. In this study, off-network activity is represented by data points that are not on one of the road links in the ESRI StreetMap USA network. Since the road network shapefile is a polyline feature (i.e., a road is represented by only its centerline and not its width), a criterion must be established to determine whether a data point is on road or off road. Figure 4-6 shows the percentage frequency distribution of the orthogonal distance from GPS point to road centerline. By considering this figure, along with the typical GPS horizontal positioning accuracy (30 ft) and lane width of roadways (10-12 ft), the criterion was set that the GPS points having the orthogonal distance from road centerline greater than 60 feet are considered to be off network. Based on this criterion, approximately 15% of the GPS points are off network.
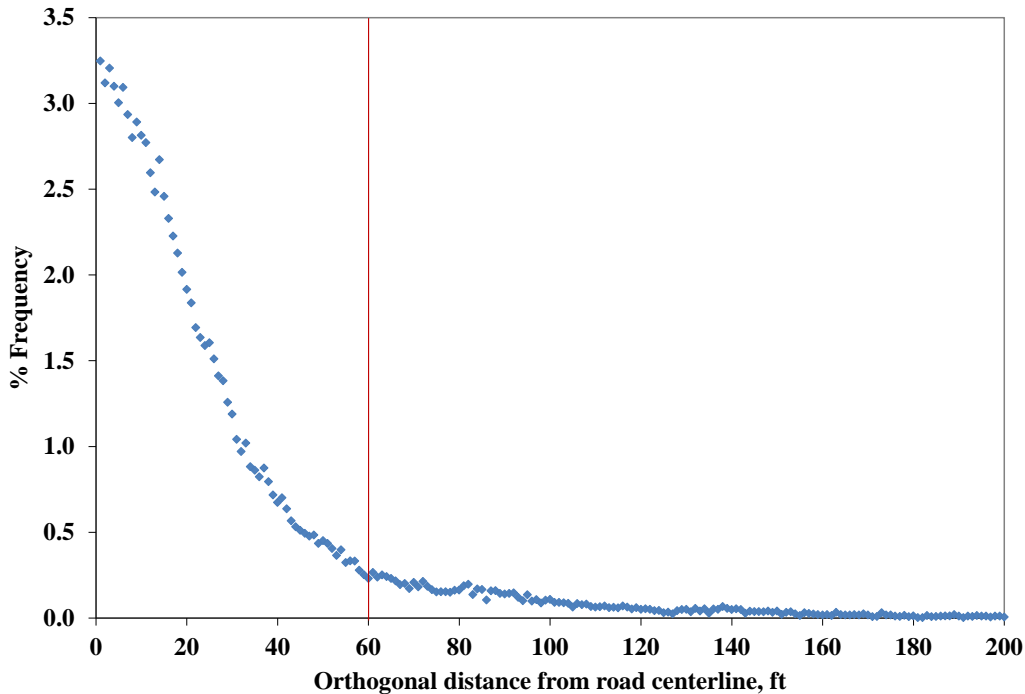
Figure 4-6. Orthogonal distance of GPS points from road centerline.

Road Centerline Distance Calculation

As mentioned earlier, some fleets in the HIVIS do not report distance values as their telematics systems are not connected to the vehicle's odometer. For these fleets, the distance between two consecutive GPS points needs to be calculated based on their GPS coordinates (i.e., latitude and longitude). However, this cannot be calculated as a Euclidean distance because its value may be lower than the actual travel distance along the roads, especially at curves or intersections. In addition, the data interval is large enough to cause two consecutive GPS points to be in different areas. In this study, the road centerline distance between two consecutive GPS points was calculated by first projecting each point onto the road centerlines and then calculating the distance using a shortest-path algorithm.

4.3.3. Results and Discussion

Several HDT activity data inputs for MOVES were derived from the HIVIS dataset. This section presents some of the resulting data inputs for January 2010 (representing winter). Where applicable, the data inputs for July 2010 (representing summer) as well as the default values in MOVES2010 are also given. A complete set of MOVES data inputs that were derived is provided in Appendix D.

VMT Fraction by Road Type

RoadTypeVMTFraction is the fraction of total VMT for each vehicle type (i.e., source type in MOVES) on each of the five road types. For MOVES2010, this fraction is derived from the 1999 Federal Highway Administration (FHWA) Highway Statistics, Tables VM-1 and VM-2 [U.S. Environmental Protection Agency, 2010]. Table 4-7 presents such fractions as well as the ones

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derived in this study. The off-network VMT for the base year 1999 in MOVES2010 is zero because the reported VMT in the FHWA Highway Statistics are assumed to include all VMT. In this study, off-network VMT were also not calculated as road centerline distance cannot be calculated for the GPS points that are considered to be off network. The total VMT on the other four road types are 2,966,869 miles for January 2010 and 5,662,240 miles for July 2010.

According to Table 4-7, it is observed that the fraction for January 2010 derived in this study is similar to that in MOVES2010. However, the one for July 2010 is very different where the greatest fraction of VMT occurred on urban unrestricted roads. This difference may be due to the difference in fleet composition in the HIVIS dataset for the two months. As HIVIS collects telematics data from multiple fleets, HDTs from any fleets may be removed from HIVIS (for service or other reasons) anytime. In addition, new fleets may be added to HIVIS anytime as well. Thus, the distinct RoadTypeVMTFraction for July 2010 seems to be caused by urban delivery fleets being added to HIVIS prior to that month.

Table 4-7. RoadTypeVMTFraction.

RoadType ID	Description	This Study		MOVES2010
		January 2010	July 2010	1999
1	Off-Network	-	-	-
2	Rural Restricted	0.3350	0.2373	0.3247
3	Rural Unrestricted	0.3047	0.2898	0.2941
4	Urban Restricted	0.1869	0.1555	0.2075
5	Urban Unrestricted	0.1734	0.3174	0.1737
	Total	*1.0000*	*1.0000*	*1.0000*

VMT Fraction by Weekday/Weekend and by Hour

MOVES uses VMT fraction by month, day, and hour to estimate emissions for every hour of every day of the year. In MOVES2010, these temporal distributions of VMT are derived from a 1995 data sample of 5,000 continuous traffic counters distributed throughout the U.S., which was used in a report by the Office of Highway Information Management [Festin, 1996]. The data sample is not differentiated by month or vehicle type. Thus, the same temporal VMT distributions are used for every month and source type in MOVES2010 [U.S. Environmental Protection Agency, 2010]. However, it is very likely that these distributions are biased towards passenger cars as they account for the majority of the vehicles in the data sample.

Table 4-8 provides the default DayVMTFraction in MOVES2010 and the ones derived in this study. It is observed that the VMT in this study are generally 10% higher on weekdays (and thus, 10% lower on weekends) than what MOVES2010 indicates. For instance, it is found that 86% of the VMT on urban roads in January 2010 occurred on weekdays while only 76% did so according to the default DayVMTFraction fraction in MOVES2010. This is true for both rural and urban roads, and for both January and July 2010. This trend is likely because HDTs do not accumulate miles from social and recreational travel on weekends as passenger vehicles do.

Table 4-8. DayVMTFraction.

| Day | This Study | | | | MOVES2010 | |
| | January 2010 | | July 2010 | | 1995 | |
	Rural	Urban	Rural	Urban	Rural	Urban
Weekday	0.8207	0.8594	0.7967	0.8621	0.7212	0.7624
Weekend	0.1793	0.1406	0.2033	0.1379	0.2788	0.2376
Total	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*	*1.0000*

Figure 4-7 shows the diurnal profiles of the daily VMT (i.e., HourVMTFraction) by road type for January 2010. They have a totally different shape from the typical two-peak profile of commute traffic. For the HDTs in this study, they drove quite a large portion of their miles during nighttime (8 p.m. – 6 a.m.) and their VMT was highest around midday (11 a.m. – 12 p.m.). This pattern is consistent with the one found in another study based on ECM data [Boriboonsomsin et al., 2010]. By comparing between the two road types, it is observed that there was a higher portion of VMT on rural roads in the evening and late night than in the early morning. This is opposite for urban roads.
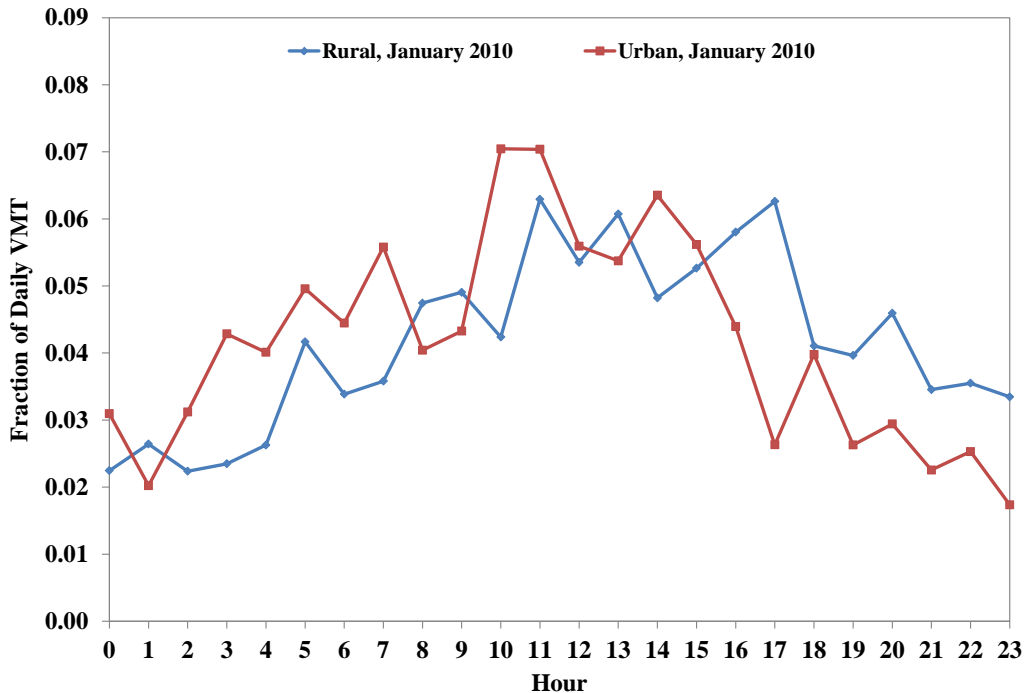
Figure 4-7. HourVMTFraction.

Average Speed Distribution

AvgSpeedDistribution is the fraction of driving time for each source type, road type, day, and hour in each average speed bin. There are 16 speed bins in MOVES, with the average speed value of 2.5 (speed < 2.5 mph), 5 (2.5 mph <= speed < 7.5 mph), 10 (7.5 mph <= speed < 12.5 mph), …, 70, (67.5 mph <= speed < 72.5 mph), and 75 (72.5 mph <= speed) [U.S. Environmental Protection Agency, 2010]. In MOVES2010, the average speed distributions for urban roads are derived from the default VMT-speed distributions in MOBILE6 [Systems

Applications International, Inc., 2001], which do not vary by vehicle type. The average speed distributions for rural roads are derived from instrumented vehicle studies of light-duty vehicles (LDVs) collected in California [Sierra Research, Inc., 2004]. It has been shown that the speed distribution of HDTs is likely to be different from that of LDVs, especially in states or areas where the two vehicle types are imposed by different speed limits [Boriboonsomsin et al., 2011].

Hr\Speed	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
0	0.046	0.002	0.003	0.001	0.004	0.009	0.025	0.039	0.058	0.059	0.050	0.162	0.186	0.331	0.013	0.013
1	0.017	0.002	0.002	0.004	0.005	0.011	0.026	0.056	0.072	0.067	0.044	0.151	0.184	0.313	0.027	0.020
2	0.016	0.002	0.006	0.004	0.004	0.013	0.028	0.045	0.063	0.062	0.042	0.144	0.199	0.330	0.025	0.019
3	0.019	0.002	0.003	0.004	0.004	0.014	0.029	0.042	0.057	0.061	0.042	0.137	0.207	0.324	0.039	0.017
4	0.018	0.003	0.001	0.002	0.004	0.007	0.025	0.041	0.052	0.049	0.039	0.149	0.249	0.297	0.040	0.022
5	0.018	0.003	0.005	0.002	0.003	0.008	0.026	0.038	0.057	0.049	0.047	0.170	0.246	0.257	0.042	0.031
6	0.021	0.002	0.003	0.003	0.006	0.019	0.027	0.046	0.056	0.056	0.056	0.165	0.237	0.233	0.040	0.030
7	0.058	0.009	0.012	0.013	0.016	0.026	0.041	0.050	0.066	0.068	0.058	0.124	0.189	0.192	0.034	0.047
8	0.050	0.011	0.014	0.018	0.021	0.029	0.049	0.062	0.071	0.068	0.053	0.109	0.159	0.183	0.038	0.065
9	0.051	0.006	0.008	0.010	0.013	0.019	0.037	0.055	0.064	0.055	0.052	0.124	0.193	0.215	0.043	0.057
10	0.057	0.004	0.004	0.006	0.008	0.017	0.033	0.053	0.059	0.052	0.040	0.133	0.221	0.218	0.040	0.053
11	0.041	0.005	0.005	0.005	0.009	0.017	0.031	0.046	0.054	0.056	0.052	0.124	0.233	0.226	0.042	0.054
12	0.042	0.002	0.003	0.005	0.009	0.016	0.029	0.047	0.056	0.057	0.052	0.131	0.216	0.232	0.041	0.062
13	0.048	0.005	0.005	0.006	0.007	0.016	0.029	0.044	0.052	0.053	0.044	0.118	0.229	0.245	0.037	0.064
14	0.044	0.007	0.006	0.008	0.009	0.018	0.037	0.051	0.056	0.053	0.047	0.122	0.220	0.229	0.039	0.055
15	0.042	0.008	0.009	0.012	0.013	0.034	0.047	0.056	0.063	0.066	0.050	0.115	0.186	0.205	0.030	0.064
16	0.046	0.011	0.015	0.019	0.025	0.036	0.046	0.059	0.068	0.062	0.056	0.108	0.158	0.198	0.028	0.065
17	0.042	0.017	0.023	0.026	0.029	0.036	0.053	0.061	0.076	0.074	0.064	0.118	0.127	0.189	0.015	0.049
18	0.038	0.009	0.017	0.018	0.019	0.029	0.048	0.056	0.069	0.062	0.067	0.137	0.157	0.224	0.012	0.038
19	0.020	0.004	0.004	0.005	0.009	0.017	0.034	0.045	0.060	0.059	0.067	0.165	0.202	0.261	0.012	0.035
20	0.018	0.004	0.015	0.005	0.005	0.011	0.032	0.044	0.054	0.057	0.056	0.185	0.232	0.251	0.010	0.021
21	0.027	0.002	0.002	0.002	0.005	0.010	0.027	0.042	0.049	0.048	0.062	0.186	0.241	0.276	0.009	0.011
22	0.021	0.001	0.002	0.001	0.003	0.010	0.025	0.045	0.054	0.060	0.054	0.165	0.218	0.323	0.005	0.011
23	0.025	0.003	0.003	0.004	0.009	0.009	0.025	0.037	0.061	0.066	0.059	0.142	0.182	0.346	0.009	0.022

Figure 4-8. AvgSpeedDistribution, urban restricted roads, weekday, January 2010

Hr\Speed	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
0	0.175	0.015	0.030	0.020	0.037	0.049	0.116	0.124	0.120	0.084	0.032	0.070	0.058	0.064	0.001	0.005
1	0.160	0.005	0.016	0.023	0.027	0.049	0.114	0.128	0.132	0.086	0.041	0.075	0.066	0.067	0.004	0.006
2	0.182	0.024	0.011	0.033	0.027	0.042	0.109	0.155	0.118	0.067	0.041	0.058	0.063	0.061	0.005	0.004
3	0.141	0.007	0.005	0.018	0.023	0.058	0.135	0.140	0.124	0.088	0.034	0.057	0.090	0.067	0.010	0.004
4	0.150	0.007	0.010	0.019	0.021	0.046	0.128	0.136	0.115	0.069	0.043	0.073	0.098	0.068	0.009	0.007
5	0.175	0.011	0.009	0.013	0.028	0.048	0.120	0.130	0.104	0.061	0.037	0.083	0.097	0.063	0.009	0.011
6	0.161	0.012	0.013	0.017	0.026	0.059	0.128	0.119	0.100	0.067	0.045	0.076	0.100	0.058	0.010	0.009
7	0.290	0.021	0.016	0.018	0.031	0.053	0.095	0.105	0.102	0.063	0.033	0.055	0.054	0.038	0.006	0.018
8	0.214	0.027	0.024	0.035	0.041	0.070	0.114	0.118	0.111	0.070	0.032	0.044	0.045	0.032	0.007	0.016
9	0.213	0.028	0.025	0.026	0.037	0.062	0.096	0.124	0.119	0.072	0.037	0.047	0.058	0.036	0.006	0.013
10	0.223	0.030	0.021	0.026	0.035	0.058	0.092	0.108	0.120	0.074	0.040	0.055	0.061	0.037	0.006	0.013
11	0.241	0.024	0.020	0.026	0.036	0.059	0.093	0.104	0.114	0.076	0.036	0.048	0.064	0.036	0.008	0.014
12	0.230	0.026	0.017	0.024	0.033	0.055	0.095	0.109	0.118	0.078	0.037	0.052	0.062	0.041	0.007	0.016
13	0.234	0.029	0.022	0.028	0.035	0.054	0.086	0.107	0.113	0.078	0.035	0.052	0.061	0.041	0.008	0.017
14	0.212	0.026	0.023	0.028	0.043	0.061	0.097	0.115	0.119	0.073	0.035	0.050	0.057	0.038	0.007	0.015
15	0.234	0.030	0.024	0.037	0.043	0.065	0.094	0.106	0.102	0.069	0.035	0.046	0.056	0.038	0.005	0.014
16	0.256	0.032	0.032	0.034	0.040	0.063	0.100	0.101	0.098	0.062	0.032	0.046	0.049	0.036	0.005	0.014
17	0.227	0.030	0.032	0.033	0.055	0.068	0.118	0.110	0.094	0.060	0.036	0.050	0.038	0.034	0.004	0.010
18	0.203	0.028	0.035	0.024	0.032	0.063	0.122	0.106	0.094	0.063	0.042	0.067	0.057	0.047	0.003	0.012
19	0.192	0.019	0.019	0.020	0.032	0.049	0.107	0.115	0.099	0.072	0.045	0.085	0.080	0.053	0.003	0.010
20	0.166	0.017	0.013	0.029	0.024	0.043	0.096	0.111	0.121	0.075	0.042	0.105	0.092	0.055	0.004	0.007
21	0.130	0.019	0.016	0.032	0.031	0.048	0.110	0.114	0.122	0.071	0.040	0.097	0.104	0.061	0.002	0.005
22	0.155	0.013	0.013	0.021	0.028	0.042	0.102	0.124	0.121	0.087	0.044	0.095	0.083	0.067	0.001	0.004
23	0.124	0.025	0.026	0.026	0.022	0.049	0.101	0.133	0.136	0.085	0.040	0.074	0.080	0.071	0.001	0.007

Figure 4-9. AvgSpeedDistribution, urban unrestricted roads, weekday, January 2010

Figure 4-8 and Figure 4-9 show the AvgSpeedDistribution for urban restricted roads and urban unrestricted roads on weekdays derived from the January 2010 dataset. The fraction is color coded from red (low value) to green (high value). Based on the patterns of the color code, the following observations are made:

- For urban restricted roads, the HDTs spent most of their time at free-flow speeds around 60-65 mph. This is consistent with the finding in [Boriboonsomsin et al., 2011]. Also, there was a fair amount of time spent in the 2.5-mph speed bin, which is probably not due to congestion but rather a result of idling on roadsides or rest stops.

- For urban unrestricted roads, the HDTs spent the largest fraction of their time each hour in the 2.5-mph speed bin, probably idling at traffic lights or loading/unloading zones. The most dominant non-idle speed range is 30-40 mph, which is consistent with the typical speed limits found on that type of road. Note that the small fraction of time at very high speeds (70-75 mph) shown in the figure is very unlikely in the real world, and probably is caused by errors from the map matching.

Trip Start Locations and Distributions

Data regarding the number of trip starts (or vehicle starts) by area and by time of day are necessary for estimating start emissions. In MOVES2010, StartAllocFactor is the fraction that distributes the nationwide estimates of the number of trip starts to individual counties. There is no available data on the number of trip starts by county at a national level, so VMT by county obtained from the National Mobile Inventory Model database is used as a surrogate to determine this fraction [U.S. Environmental Protection Agency, 2010].

Figure 4-10 shows the number of trip starts by county derived from the January 2010 dataset in this study. The data pattern is similar to the one in Figure 4-5, and reflects the fact that many of the trucks in this dataset are operated out of the Northeast and Southern California regions. Although the truck samples in the dataset are biased towards these two regions, a weighting function such as one based on VMT by county as used in MOVES2010 could allow the number of trip starts in these two regions to be projected to counties in the other regions. However, this is out of the scope of the current study.

In addition to the spatial allocation factor, MOVES also uses trip starts distributions by time of day to allocate the number of trip starts temporally. Figure 4-11 shows trip starts distributions by time of day for both weekday and weekend derived from the January 2010 dataset in this study. According to the figure, the trip starts distributions of both day types have a similar shape with the peak occurring in the morning (9-10 a.m.). For both weekdays and weekends, a majority of the trip starts occurred during daytime, but there were more trip starts during nighttime on weekends as compared to weekdays.
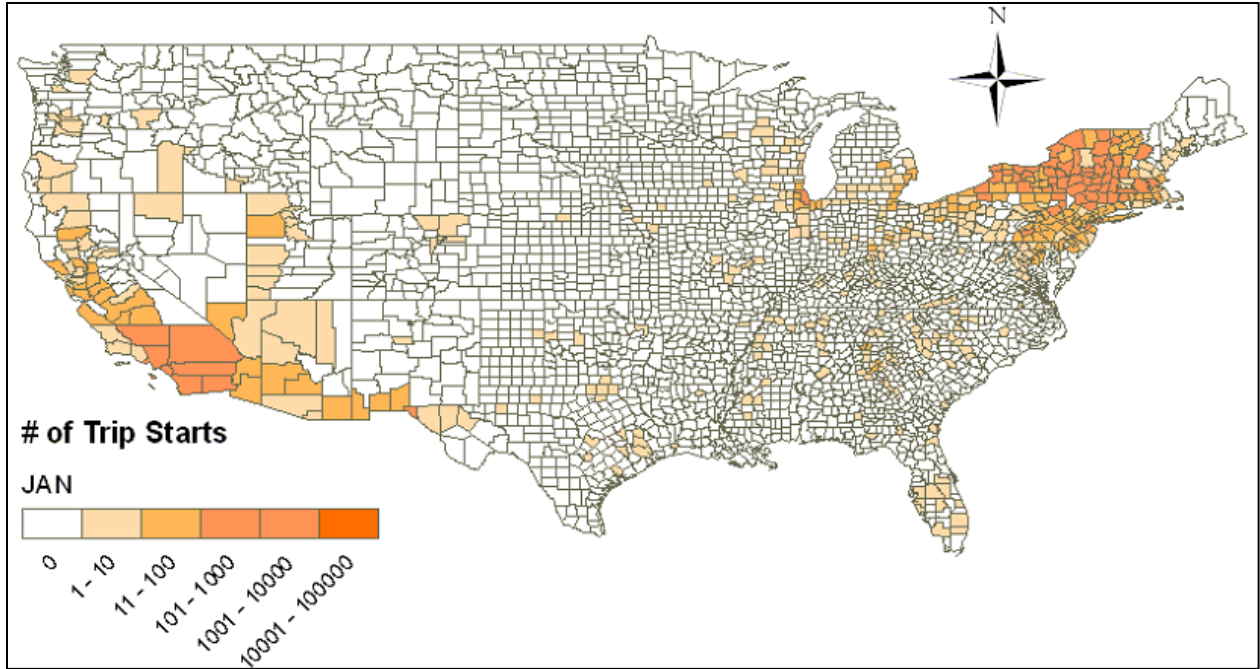
Figure 4-10. StartAllocFactor, January 2010.
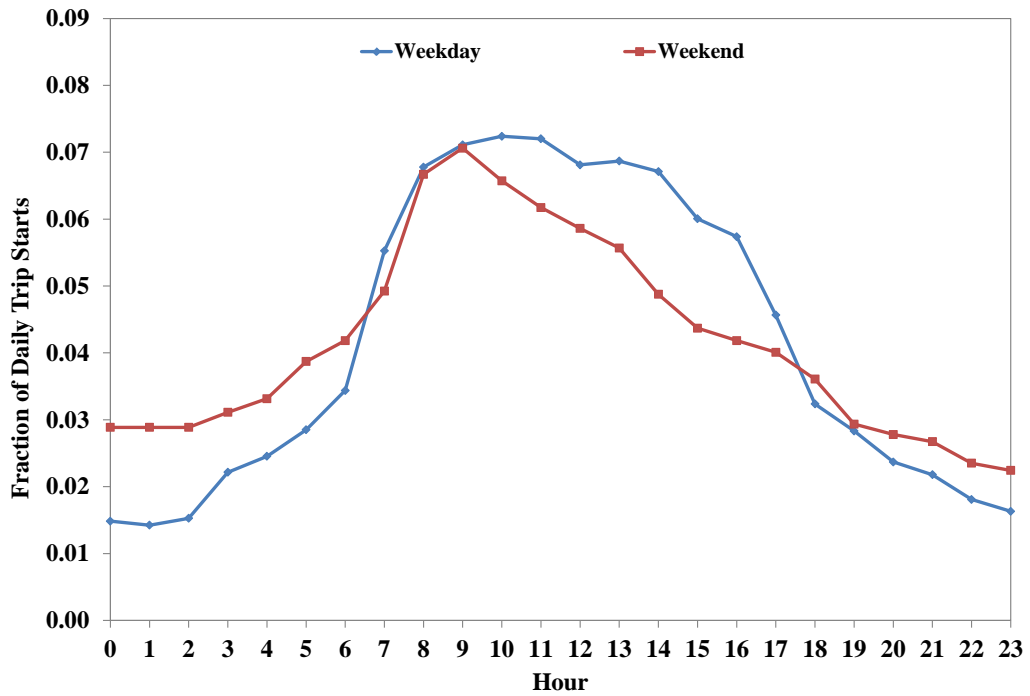
Figure 4-11. Trip starts distribution by time of day, January 2010.

4.4.   Truck Activity Data Fusion

In the previous sections, new sources of HDT activity data are presented and methods for using them to generate HDT activity data inputs for MOVES are described. In this section, the focus is turned to the fusion of data from existing sources to improve HDT activity data inputs for MOVES.

Each of the existing HDT activity data sources provides different unique data elements but also lacks one or more other data elements. For instance, the Highway Performance Monitoring System (HPMS) can provide estimates of truck miles traveled by roadway functional class but it provides no information on the speed at which those truck miles are traveled or how much weight is carried by the trucks on those miles. On the other hand, weigh-in-motion (WIM) stations can provide the information regarding truck speed and loaded truck weight but only at a limited number of locations. For example, California has only 106 WIM stations throughout the entire state. In contrast, it has more than 8,100 vehicle detector stations (VDS), each comprised of multiple single-loop detectors, across its freeway systems. Figure 4-12 shows the comparison between the coverage of WIM stations and VDS in the Los Angeles area.

Efforts have been made in fusing data from different sources to create better HDT activity data inputs. For example, statistical models were developed based on truck traffic speed from a WIM station and overall traffic speed from a nearby VDS so that truck traffic speed at other VDS can be estimated based on the knowledge of the overall traffic speed alone [Boriboonsomsin et al., 2011]. According to that research, it was found that the regional truck activity in terms of VMT by speed distribution on Southern California freeways was significantly different from the activity of the overall traffic. The resulting emission inventories showed that using the HDT-specific speed distribution rather the overall speed distribution reduced the estimates of NO_x emissions by 4% and $PM_{2.5}$ emissions by 26%.

In MOVES, the basis of vehicle activity for exhaust running emissions is source hours operating (SHO) rather than VMT. SHO is characterized by vehicle operating mode (OpMode) bins, which is a function of vehicle specific power (VSP) and speed, rather than speed bins. To add to that complexity, VSP is a function of speed, acceleration, mass, road grade (if any), and vehicle-specific coefficients (i.e., rolling, rotating, and drag coefficients). Therefore, it can be seen that developing vehicle activity data inputs for MOVES is not a trivial task. Recognizing this challenge, the U.S. EPA has developed tools and methodologies that simplify the processes of developing vehicle activity data inputs for MOVES. These methodologies are based on a number of assumptions that represent best practices given the type and quality of data available for use in vehicle activity data input development.

This subtask of the research is aimed at investigating existing data sources that have not been used by the U.S. EPA and practitioners to generate HDT activity data inputs for MOVES. Specifically, efforts were made to extend the previous research in combining data from WIM stations and VDS to make use of truck weight information from WIM stations to generate HDT activity data inputs for MOVES on the basis of vehicle OpMode distribution.
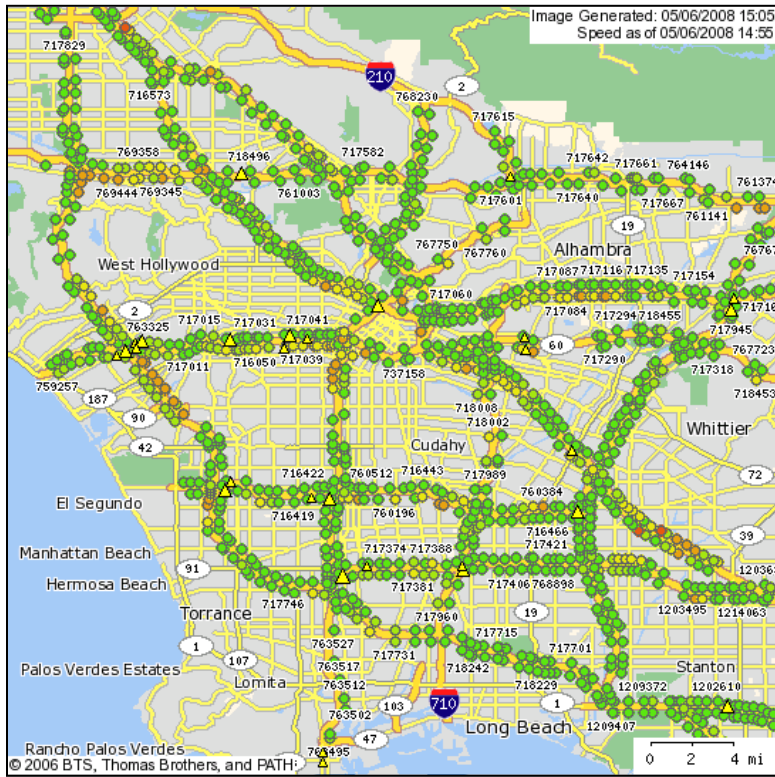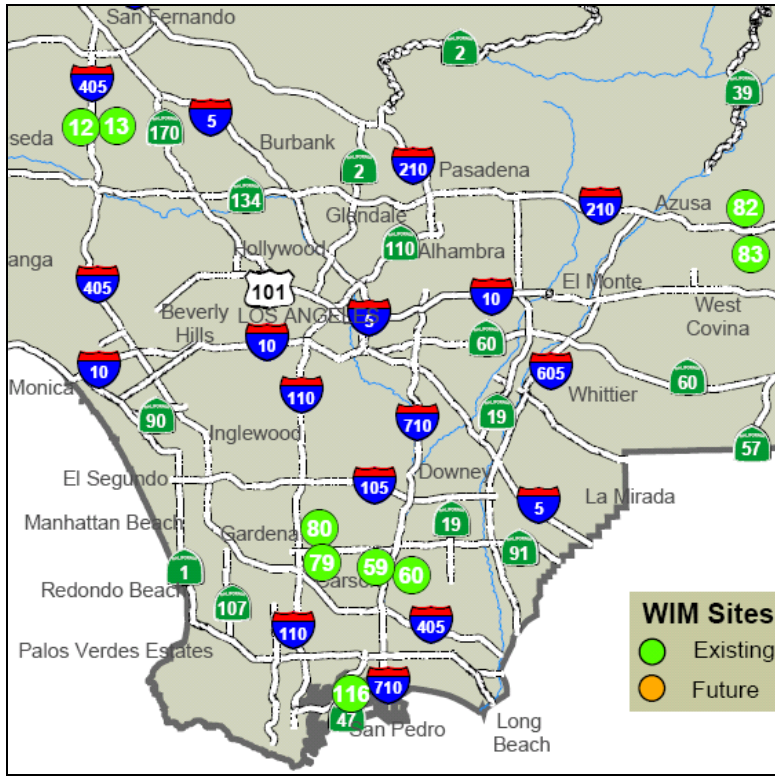
Figure 4-12. Coverage of (top) WIM stations and (bottom) vehicle detector stations in Los Angeles

4.4.1. Data Sources and Characteristics

Three traffic data sources in California were used. Each of them has different characteristics and provides a different type of data. They are described briefly below.

Freeway Performance Measurement System (PeMS)

PeMS is an interactive system that allows users to query various performance measures of the major freeways in California historically and in real-time [Choe et al., 2002]. The system consists of numerous embedded loop detectors, each reporting flow and lane occupancy and thus allowing average traffic speed to be estimated [Kwon, 2004]. These data are gathered through local Traffic Management Centers (TMCs), and then filtered, processed, and made accessible at 30-second intervals via the PeMS server, or at 5-minute intervals on the PeMS website (https://pems.eecs.berkeley.edu/).

The main advantage of PeMS is its large coverage, both spatially and temporally. The system covers more than 30,000 directional freeway miles throughout the state and the historical data for some freeways are available back to the late 90's. Although the data from PeMS includes a certain amount of uncertainty (e.g. when loop detectors are malfunctioning), it is still considered one of the most comprehensive and reliable data sources currently available in California.

In this study, PeMS is used to provide data of average traffic speed, total flow, and truck flow. The total flow reported by PeMS is from direct measurement, but the truck flow is based on estimation [Kwon et al., 2003]. It should be noted that the average traffic speed reported by PeMS is for *overall* traffic (i.e. all vehicles in the traffic stream). PeMS does not report separate speed values for different vehicle types.

Weigh-In-Motion (WIM) Stations

In California, WIM sensors consist of either bending plates on frames embedded in concrete or piezo sensors epoxied into the pavement. Inductive loops are placed before and after the WIM sensor array. These double-loops measure vehicle speed and overall length. Smooth pavement and proper calibration ensures quality and consistency in weight data. The calibration must be performed to +/- 5% accuracy with a test vehicle of known static weight driven at various highway speeds over the WIM instrumentation. For more information about WIM stations in California, see http://www.dot.ca.gov/hq/traffops/trucks/datawim/index.html.

WIM stations provide various data on vehicle and traffic characteristics, including vehicle class, gross vehicle weight, axle weight, axle spacing, vehicle speed, etc. It should be noted that the WIM stations in California use a similar vehicle classification system to the HPMS' classification system. However, they do not record data for passenger vehicles (classes 1-3) and have one additional HDT class (class 14) as depicted in Figure 4-13. In this research, raw data for individual vehicles were obtained. Classes 8-10 are considered single-unit trucks (source types 52 & 53 in MOVES) and classes 11-13 are considered combination trucks (source types 61 & 62 in MOVES).
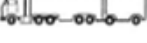
Figure 4-13. Vehicle classification system used by WIM stations in California

4.4.2. Data Fusion Method

Data fusion is the combining of data from multiple sources such that the resulting information is better than would be possible when these sources were used individually. The resulting information can be better in several ways such as being more accurate, less ambiguous, more complete, and more robust. Many data fusion techniques have been used in traffic engineering applications, for example, Kalman filter [Kim et al., 2007], Bayesian theory [Choi and Chung, 2002], neural network [Cheu et al., 2001], and fuzzy logic [Choi and Chung, 2002]. These techniques were reviewed but were considered to be unsuitable for the purpose of this subtask of the research, which is to combine data from WIM stations and VDS by making use of truck weight information from WIM stations in generating HDT activity data inputs for MOVES on the basis of vehicle OpMode distribution.

Therefore, a data fusion method based on data association concept, which correlates one set of observations with another set of observations, was developed. In this subsection, the developed data fusion method is presented using the freeway system in Los Angeles County, California, as an example. Figure 4-14 shows the flow chart of the developed data fusion method.
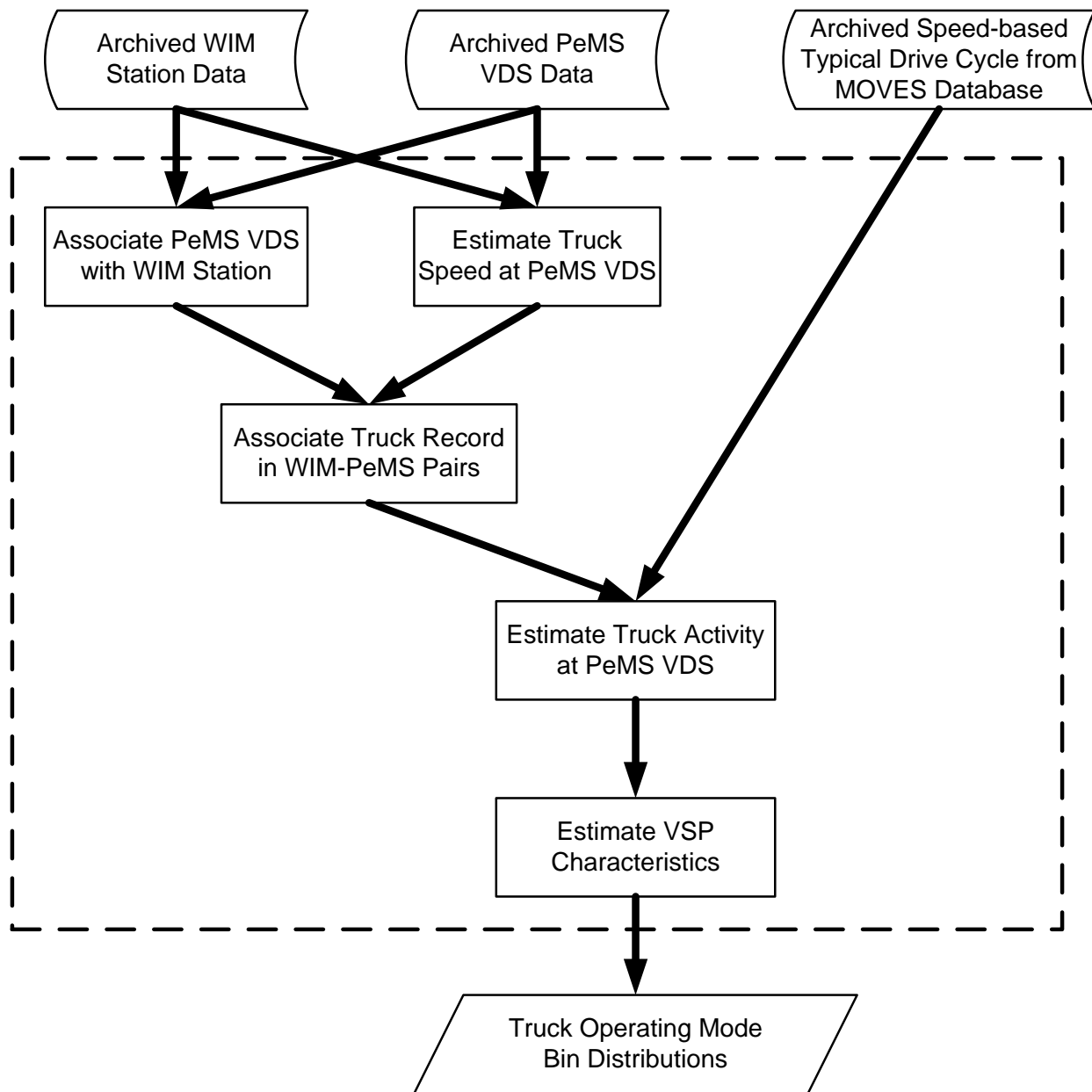
Figure 4-14. Flow chart of the proposed data fusion method

Data Screening

There are 20 WIM stations in both directions of the freeways in Los Angeles County. Based on the health report of these WIM stations, only 11 of them are functional. These stations include VAN NUYS (SB/NB) along I-405, CASTAIC (SB/NB) along I-5, LA 710 (SB/NB) along I-710, ARTESIA (EB/WB) along SR-91, GLENDORA (EB/WB) along I-210, and LONG BEACH PORT along SR-47. Figure 4-15 shows the locations of the PeMS VDS (mainline only) and the selected 11 WIM stations in the Los Angeles County. Note that there are five WIM stations that are located at the same location as another station, but in the opposite direction of the freeway, which may not be easily identified in Figure 4-15.
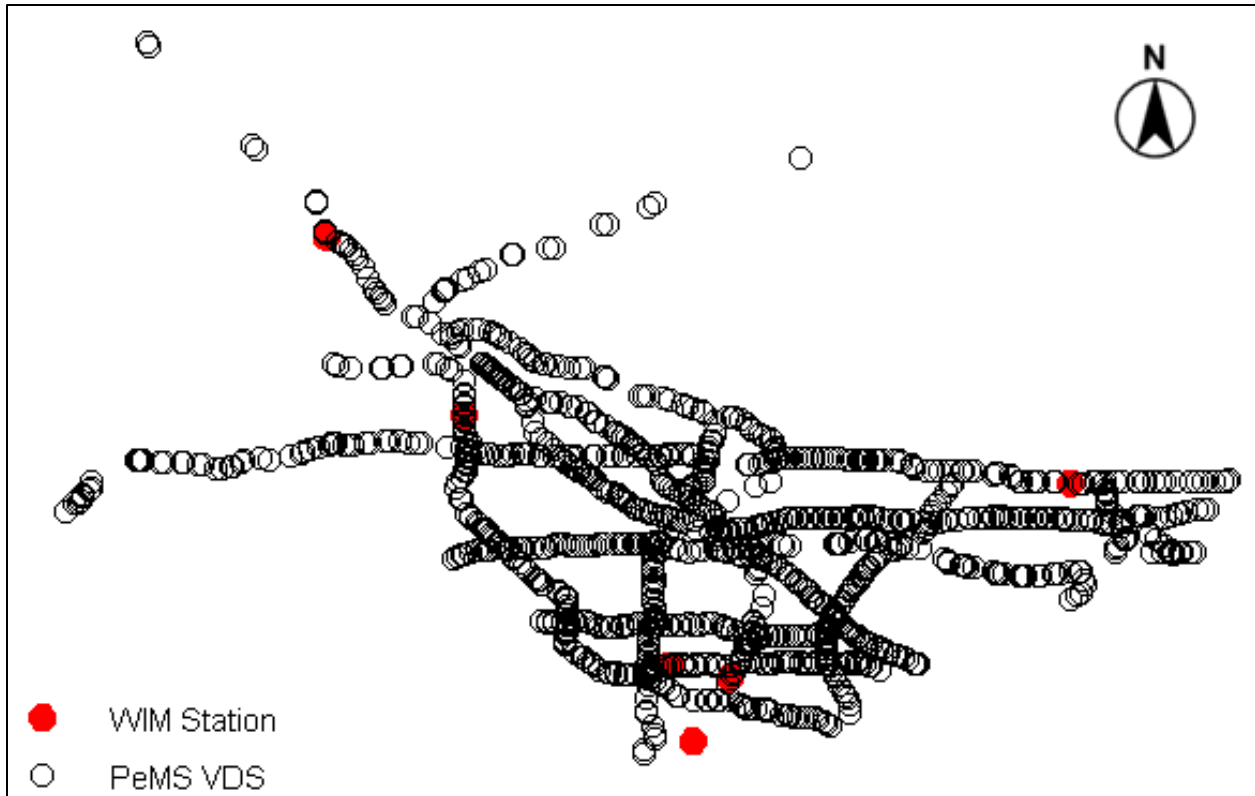
Figure 4-15. Locations of 1466 PeMS VDS and the selected 11 WIM stations in the Los Angeles County.

As to the one-year WIM data from July 2008 to June 2009, the following can be observed on the healthy condition:

- WIM data at CASTAIC (SB/NB) are not good for use across the year due to "restriped lanes";

- LA 710 NB always reports higher values in both class and weight than ground truth;

- Since November 2008, measurement with positive systematic bias has been reported at LA 710 SB;

- WIM data at ARTESIA (EB/WB) were not available until the completion of construction in March 2009;

- At some stations, classification data could be erroneous in a certain month while weight data may not be correct during another month;

- There is not any month with all 11 WIM stations being healthy for both classification and weight measurement. April 2009 or May 2009 has been considered the best candidate in terms of the number of healthy study sites (totally 6 sites), including VAN NUYS (SB)

along I-405, ARTESIA (EB/WB) along SR-91, GLENDORA (EB/WB) along I-210, and
LONG BEACH PORT along SR-47.

The examination of the PeMS VDS health condition reveals that good data accounts for a
slightly higher percentage in April 2009 than in May 2009 (66.2% vs. 64.3%). Figure 4-16
shows a plot on the day-to-day health condition for all mainline VDS in District 7 (including the
Los Angeles county and the Ventura county). Table 4-9 provides more detailed information on
detector health for both April and May 2009. Therefore, WIM data and PeMS VDS data in April
2009 are used in the following analyses.
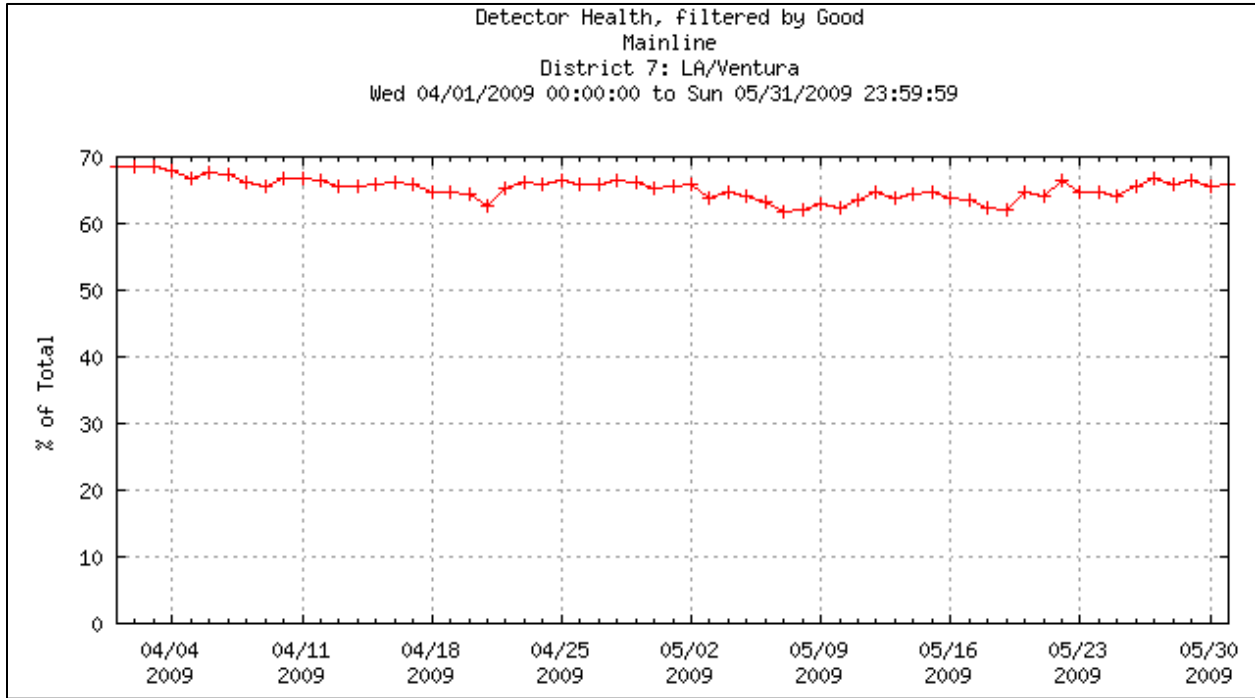
Figure 4-16. Day-to-day health condition for all mainline VDS in District 7 from April 1st, 2009 to May 31st, 2009.

Table 4-9. Summary of mainline VDS health in District 7 for April and May 2009

Month	Good	Line Down	Controller Down	No Data	Insufficient Data	Card Off	High Value	Intermittent	Constant	Feed Unstable
April	66.2	7.3	11.0	2.9	1.7	6.6	3.2	1.1	0.0	0.0
May	64.3	7.3	11.9	3.4	1.9	6.5	3.7	1.0	0.0	0.0

WIM Station and PeMS VDS Association

The next step is to determine the association between PeMS VDS with each candidate WIM
station. Figure 4-17 illustrates a flow chart for a set of heuristic association rules. For each VDS,
the closest WIM station (in terms of route distance) along the same freeway in the same direction
is associated. If not available, then the closest WIM station (in terms of route distance) along the

4-28

same freeway in the opposite direction is associated. If still not available, then the closest station (in terms of Euclidean distance) within the study region is associated.
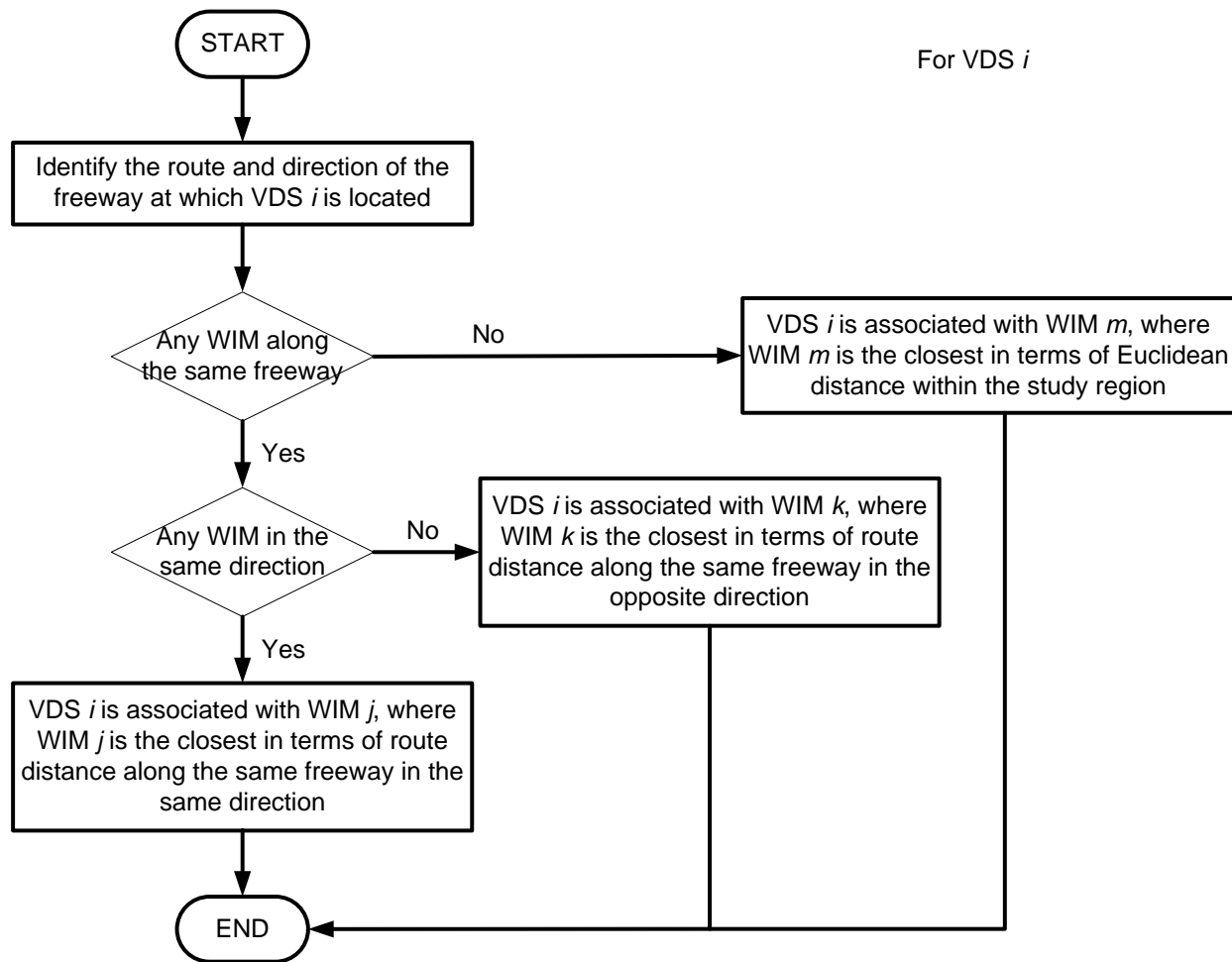
Figure 4-17. WIM station and PeMS VDS association rules.

Truck Record Association

At each WIM station, any truck passing by is logged with several information including time stamp, class, weight, speed, number of axles, etc. On the other hand, truck volume (without any detailed estimated arrival time) within a certain time interval (e.g. 5 minutes) at each VDS is estimated and archived in PeMS. However, it should be noted that even though each VDS can be associated with one WIM station using the set of rules above, it does not mean that every recorded truck in one WIM station will have a footprint on the associated VDS at some time point and vice versa. That is, not all truck passing by a VDS can be traced back to a specific record from the associated WIM station. This is because:

1. There are a very limited number of WIM stations within the study scope and some trucks may not be recorded by any WIM stations;

2. The truck volume recorded at each PeMS VDS is an estimated value instead of ground truth using the well-known g-factor method; and

3. There is no prior knowledge on the route of each truck or truck signature information among different WIM stations.

Due to the limitation mentioned above, a heuristic truck record association strategy is developed based on the following assumptions:

- There is no measurement error in the record from each WIM station;

- There is no estimation error in the record from each PeMS VDS;

- The "first-in-first-out (FIFO)" rule applies to the association strategy, i.e. no over-take is allowed;

- At each time interval, the truck weight and classification distribution at every PeMS VDS is the same as a certain consecutive set of truck record from the associated WIM station.

The basic idea of the proposed truck record association strategy is that based on the truck volume recorded at each PeMS VDS during each time interval and the estimated travel time distribution of each recorded truck from the associated WIM station under prevailing traffic condition, the same number of recorded trucks of the WIM station with the maximum likelihood are associated with the record at the PeMS VDS during the specified time interval. This is only to say the number of trucks matches with each other between a PeMS VDS and the associated WIM station, which can be called "weak" association. It is not meant to say each truck record matches with each other between a PeMS VDS and the associated WIM station, which is called "strong" association. According to the discussion above, it is self-evident that conducting "strong" association in this study is meaningless due to the lack of detailed information and too computationally demanding as well. So, "weak" association is conducted in the current study.

Numerous studies have focused on the estimation of travel time based on loop detector data [Chen et al., 2003; Coifman, 2002; Ni and Wang, 2008]. Some of them use vehicle re-identification technique, while others recursively estimate vehicle trajectories given hypothetic trip starting time and then calculate the travel time. However, these strategies may not be applicable to this study due to the computational load. For simplicity, during time interval k, the estimated (mode) travel time $\overline{\overline{tt}}(k)$ between the i-th PeMS VDS and its associated WIM station is calculated as

$$\overline{\overline{tt}}(k) = d_i^{route}/\bar{v}_i(k)$$

where d_i^{route} represents the route distance between VDS i and its associated WIM station; and $\bar{v}_i(k)$ denotes the average truck speed between the i-th PeMS VDS and the VDS closest to the associated WIM station at time interval k. It needs to be pointed out that the calculation of route distance between a VDS and the associated WIM station is far from being trivial if the associated WIM station is not located at the same freeway as that VDS. A geographic information system (GIS) has to be used and a large database needs to be explored to determine d_i^{route}. In addition, a

PeMS VDS only provides speed estimate for overall traffic flow without differentiating the truck flow. [Boriboonsomsin et al., 2011] analyzed the truck data from 15 WIM stations and traffic data from the corresponding closest PeMS VDS in Southern California, and pointed out that there is a strong linear relationship between truck speed and overall traffic speed although the linear coefficient may vary from site to site. In this study, therefore, truck speed is estimated based on the results from [Boriboonsomsin et al., 2011].

Due to uncertainties, actual travel time should be a random variable. Generally speaking, estimation of travel time distribution is very challenging [Wan, 2011]. [Rakha et al., 2006] argued that although the travel time data collected from a section of I-35 South failed the goodness-of-fit tests for the Normal and lognormal distributions due to outlier observation at the tail, these distributions should be considered reasonable from a practical standpoint. In this study, a one-sided truncated symmetric distribution (say, Normal distribution) is used as the estimate of travel time distribution, where the truncated values are governed by the shortest possible truck travel time tt_i^{min}

$$tt_i^{min} = d_i^{route}/v^{max}$$

where $v^{max} = 70$ mph is set for all VDS as the maximum limit of truck speed.

Considering all ingredients discussed above, a heuristic truck record association method is proposed as follows. Without loss of generality, given the truck volume, n, at the i-th downstream PeMS VDS during the time interval k, n consecutive recorded trucks from the associated WIM station will be selected for association whose recorded arrival times are the closest (from both sides) to the time point, $T_i'(k)$, by taking into account the truncation effect. And

$$T_i'(k) = \hat{t}(k) - \overline{tt}(k)$$

where $\hat{t}(k)$ represents the mid-point of time interval k, e.g. $\hat{t}(k)$ is 08:02:30 for the time interval between 08:00:00 and 08:05:00. Figure 5 presents an example of truck record association for a case where the truck volume $n = 3$ at the i-th downstream PeMS VDS. The "circles" depict the recorded arrival time of trucks at the WIM station and those "circles" in red denotes the associated recorded trucks. The curve f represents a hypothetical travel time distribution with one tail being truncated by $t_i'(k) = \hat{t}(k) - tt_i^{min}$.

Truck Activity Estimation

After the truck record has been associated for each PeMS VDS during every time interval, second-by-second truck activities can be estimated from the drive schedule defined in MOVES [U.S. Environmental Protection Agency, 2010] based on source type, roadway type and average speed. Table 4-10 and Table 4-11 list default driving cycles in MOVES for single-unit trucks and combination trucks, respectively [U.S. Environmental Protection Agency, 2010]. These driving cycles have approximate average speed from 5 mph to 70 mph. Note that driving cycle IDs 206 and 306 were not used in this study as driving cycle IDs 251 and 351 were already used to represent 30-mph freeway driving.

The speed profile and joint speed-acceleration frequency distribution of driving cycle ID 354 are illustrated in Figure 4-19. The speed profiles and joint speed-acceleration frequency distributions of other driving cycles are given in Appendix E.

Table 4-10. MOVES driving cycles for single-unit trucks

ID	Cycle Name	Average Speed (mph)	Non-Freeway		Freeway	
			Rural	Urban	Rural	Urban
201	MD 5mph Non-Freeway	4.6	X	X	X	X
202	MD 10mph Non-Freeway	10.7	X	X	X	X
203	MD 15mph Non-Freeway	15.6	X	X	X	X
204	MD 20mph Non-Freeway	20.8	X	X	X	X
205	MD 25mph Non-Freeway	24.5	X	X	X	X
206	MD 30mph Non-Freeway	31.5	X	X	X	X
251	MD 30mph Freeway	34.4	X	X	X	X
252	MD 40mph Freeway	44.5	X	X	X	X
253	MD 50mph Freeway	55.4	X	X	X	X
254	MD 60mph Freeway	60.4	X	X	X	X
255	MD High Speed Freeway	72.8	X	X	X	X

Table 4-11. MOVES driving cycles for combination trucks

ID	Cycle Name	Average Speed (mph)	Non-Freeway		Freeway	
			Rural	Urban	Rural	Urban
301	HD 5mph Non-Freeway	5.8	X	X	X	X
302	HD 10mph Non-Freeway	11.2	X	X	X	X
303	HD 15mph Non-Freeway	15.6	X	X	X	X
304	HD 20mph Non-Freeway	19.4	X	X	X	X
305	HD 25mph Non-Freeway	25.6	X	X	X	X
306	HD 30mph Non-Freeway	32.5	X	X	X	X
351	HD 30mph Freeway	34.4	X	X	X	X
352	HD 40mph Freeway	47.1	X	X	X	X
353	HD 50mph Freeway	54.2	X	X	X	X
354	HD 60mph Freeway	59.4	X	X	X	X
355	HD High Speed Freeway	71.7	X	X	X	X

Speed Profile for Driving Cycle ID 354
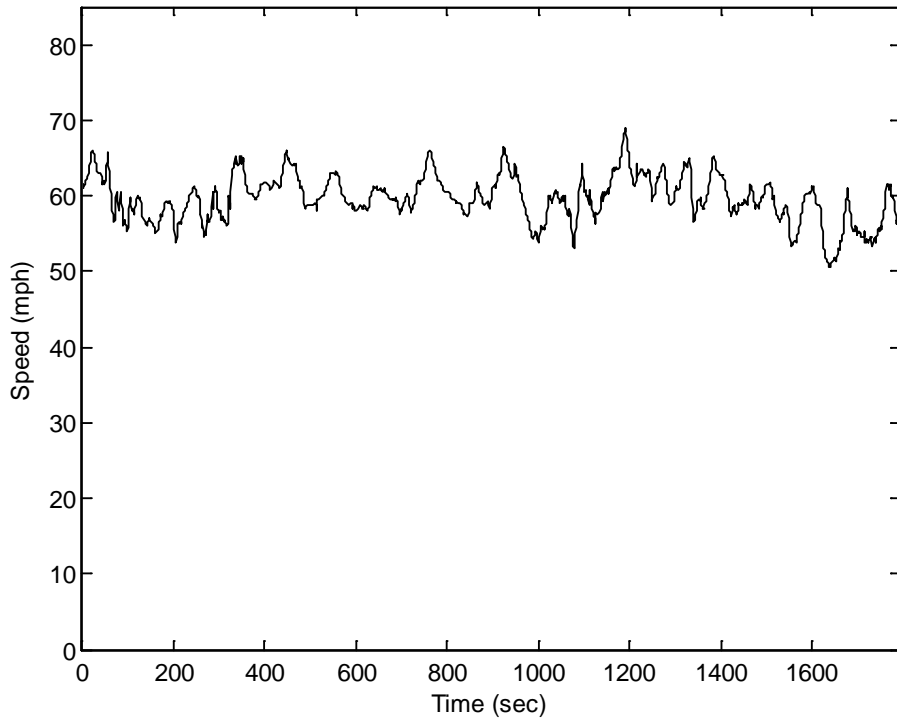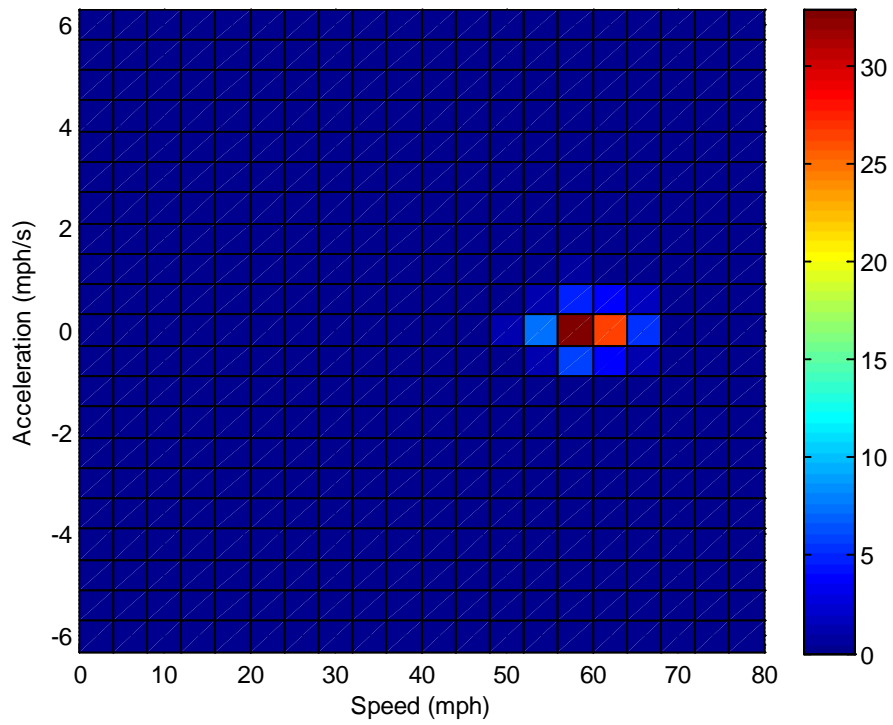
N = 1792

The truck activity estimation method is described as follows:

1. Based on the estimated truck speed, two MOVES driving cycles whose average speeds are the closet to the estimated speed and bracket it will be selected for later acceleration generation. For example, if the estimated truck speed is 55 mph, then Driving Cycle #353 (average speed of 54.2 mph) and #354 (average speed of 59.4 mph) are selected.

2. Obtain the typical second-by-second acceleration distribution vs. different bin of speed for the selected driving cycles. This can be done by applying the Central Difference Method to those second-by-second speed data.

3. Determine the second-by-second acceleration by randomly picking a value from those two selected driving cycles. The probability for selecting whichever cycle is governed by the difference between the estimated speed and the average speed of each driving cycle. For the same example mentioned above, the probability of choosing an acceleration value from Driving Cycle #353 is 0.846 while 0.154 for the other. So Driving Cycle #353 is more likely to be selected as a target acceleration pool.

4. Uniformly randomly sample an acceleration value from the target sample pool to get the estimate of acceleration for each second and calculate the speed for the next second. Care needs to be taken to select the acceleration sample from the associated speed bin which is comparable to the speed estimation of the current step. Otherwise, the speed value could drift out of the range of those bracketed Driving Cycles. In this study, the size of speed bin is chosen as 2 mph.

5. Set the initial speed as the estimated truck speed from the PeMS VDS and keep looping on step 3) and 4) until the end of temporal span of the truck's foot-print at the VDS during the time interval. Such temporal span can be estimated by

$$s_i(k) = min(l_i/v_i(k), \Delta t)$$

where l_i refers to the effective length of VDS i (see Figure 4-20); $v_i(k)$ is the estimated truck speed at VDS i in the k-th time interval; and Δt is the length of each time interval (e.g. 5 minutes).
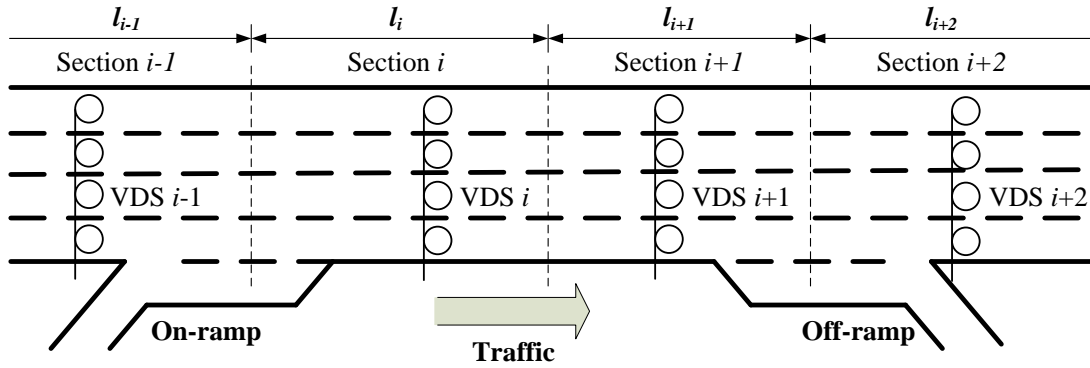
Figure 4-20. Layout of detectors and illustration of effective lengths along a freeway section.

VSP Calculation and Binning

With the estimate of second-by-second activity (including both speed and acceleration) for each truck as well as the information on vehicle class and weight, the vehicle specific power (VSP) or Scaled Tractive Power (STP) characteristics for trucks in kWatt/tonne can be calculated using the following formula [Gururaja, 2011].

$$STP = \frac{A \cdot v + B \cdot v^2 + C \cdot v^3 + m \cdot v \cdot a}{f_{scale}}$$

where A, B and C are the road-load related coefficients for rolling resistance ($kW \cdot sec/m$), rotating resistance ($kW \cdot sec^2/m^2$) and aerodynamic drag ($kW \cdot sec^3/m^3$), respectively; v is the vehicle speed (m/sec); m is the mass of truck (metric ton); a is the vehicle acceleration (meter/sec^2); and f_{scale} is the fixed mass factor for the source type (kg); [U.S. Environmental Protection Agency, 2010] provides recommendation on the values of these parameters. In addition, the road grade is assumed to be zero in this study.

After the STP values were calculated, they were binned according to the U.S. EPA's vehicle operating model bin definition, shown in Figure 4-21.

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Operating Modes for Running Exhaust Emissions

VSP Class (kW/tonne)	Speed Class (mph)		
	1-25	25-50	50 +
30 +	16	30	40
27-30			
24-27		29	39
21-24		28	38
18-21			
15-18			37
12-15		27	
9-12	15	25	
6-9	14	24	35
3-6	13	23	
0-3	12	22	33
< 0	11	21	

21 modes representing "cruise & acceleration" (VSP>0)

PLUS
2 modes representing "coasting" (VSP<=0)

PLUS
One mode each for
   idle, and
   decel/braking

Gives a total of
23 opModes

7

Figure 4-21. Vehicle operating mode bin definitions for heavy-duty trucks

4.4.3. Numerical Example

Truck Record Association

On Wednesday April 15th, 2009, there were 12 trucks estimated to pass by VDS #718479 during the 5-minute period from 00:40:00 to 00:45:00. The estimated overall traffic speed at this VDS is 66.2 mph and the estimated truck speed is

$$66.2*0.863 = 57.1 \text{ mph.}$$

where 0.863 is the coefficient for the linear relationship between the truck speed and overall traffic speed derived from a previous study [Boriboonsomsin et al., 2011]. Since the effective length of this VDS is 0.33 mile, the temporal foot-prints of these trucks at this VDS during this 5-minute period is

$$\min(\text{round}(0.33/57.1*3{,}600), 300) = 21 \text{ seconds.}$$

The VDS #718479 is associated with the Van Nuys WIM station on the same freeway (I-405) in the same direction (southbound). Figure 4-22 depicts the locations of the Van Nuys WIM station (Point A) and the VDS #718479 (Point B).
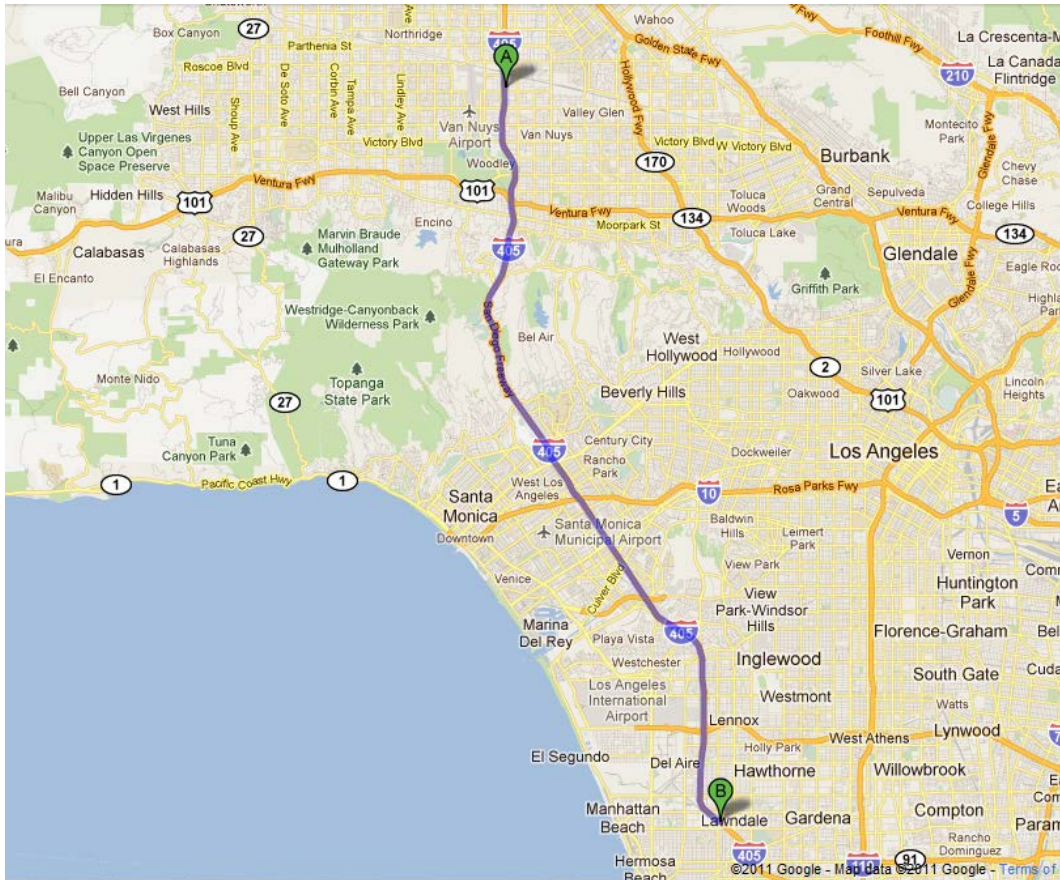
Figure 4-22. Locations of the WIM station (Point A) and the VDS (Point B)

The VDS is located 24.7 miles *downstream* of the WIM station. The closest VDS to the WIM station is VDS #767366. At this VDS, the recorded overall traffic speed from 00:40:00 to 00:45:00 is 71.7 mph and the estimated truck speed is

$$71.7*0.863 = 61.9 \text{ mph}.$$

Therefore, the average speed used for the association is

$$(57.1+61.9)/2 = 59.5 \text{ mph}.$$

And the estimated travel time is

$$24.7/59.5*3,600 = 1,495 \text{ seconds or 24 min 55 seconds}.$$

Note that the maximum truck speed is set as 70 mph, so the minimum travel time is

$$24.7/70*3,600 = 1,270 \text{ seconds or 21 min 10 seconds}$$

Therefore, starting from the mid-point (00:42:30) of the time period between 00:40:00 and 00:45:00, we checked the vehicle records from the WIM station before 00:21:20 and selected 12

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vehicles whose arrival times are closest to 00:17:35. Table 4-12 shows the sample vehicle records from the Van Nuys WIM station on Wednesday April 15th, 2009. The 12 vehicle records that were selected are in boldface:

Table 4-12. Sample truck records from the WIM station on Wednesday April 15th, 2009

Date	Time	Class	Weight (kg)
4/15/2009	00:11:07	9	2.99E+04
4/15/2009	00:11:37	5	3.76E+03
4/15/2009	00:12:08	14	9.71E+03
4/15/2009	00:12:53	9	1.57E+04
4/15/2009	**0:13:25**	**9**	**2.37E+04**
4/15/2009	**0:14:07**	**11**	**2.35E+04**
4/15/2009	**00:15:02**	**3**	**2.90E+03**
4/15/2009	**00:15:37**	**9**	**1.32E+04**
4/15/2009	**00:16:01**	**9**	**1.28E+04**
4/15/2009	**00:17:35**	**Best Estimated Arrival Time at WIM**	
4/15/2009	**00:18:45**	**9**	**1.29E+04**
4/15/2009	**00:18:48**	**9**	**1.26E+04**
4/15/2009	**00:19:33**	**9**	**1.36E+04**
4/15/2009	**00:19:46**	**9**	**9.71E+03**
4/15/2009	**00:19:47**	**9**	**1.13E+04**
4/15/2009	**00:20:23**	**9**	**1.06E+04**
4/15/2009	**00:20:29**	**5**	**5.67E+03**
4/15/2009	00:22:20	6	1.18E+04
4/15/2009	00:23:32	9	1.43E+04
4/15/2009	00:25:59	9	2.26E+04
4/15/2009	00:26:28	9	1.04E+04

Effect of Truck Information on Operating Mode Estimation

Using the data described above, we investigated the effect of detailed truck information on the operating mode estimation. For those 12 recorded vehicles, there were two vehicles not belonging to the vehicle classes of interest (i.e., Classes 8 to 13). Of the remaining 10 vehicles (trucks), only 1 truck was a combination truck while the rest were single-unit trucks. Note that if detailed vehicle records such as shown above are not available, other data sources may be used or an assumption may be made regarding the fraction between single-unit and combination trucks. For example, based on the analysis of the WIM data from all WIM stations in the Los Angeles area in April 2009, it was found that among all the trucks belonging to Classes 8 through 13, single-unit trucks (Classes 8-10) accounted for 92% while combination trucks (Classes 11-13) accounted for 8%.

As stated earlier, the estimated average truck speed at VDS #718479 is 57.1 mph. In a procedure used by MOVES, this average truck speed information is first used to identify two default driving cycles whose average speeds bound the average truck speed. In this example, these are driving cycle IDs 253 (average speed of 55.4 mph) and 254 (average speed of 60.4 mph) for single-unit trucks, and driving cycle IDs 353 (average speed of 54.2 mph) and 354 (average speed of 59.4 mph) for combination trucks. Then, a vehicle OpMode distribution is determined by calculating a weighted average between the distributions of the two bracketing driving cycles. No truck weight information is used.

For instance, the vehicle OpMode distributions of driving cycle IDs 253 and 254for single-unit trucks are shown in Figure 4-23. Then, the top plot in Figure 4-24 shows the vehicle OpMode distribution of the single-unit trucks of interest that is calculated by the weighted average method. It is clearly shown that the pattern of the distribution assimilates that of the two distributions it is created from. On the other hand, the vehicle OpMode distribution created by the method proposed in this study (shown in the bottom plot of Figure 4-24) has a distinctively different pattern. Although the dominant bin is Bin 33 for both methods, the proposed method has a significantly higher fraction of truck activity in Bin 35 while there is no truck activity in Bins 11, 12, 21, 22, and 23 as in the weighted average method. The differences are contributed mainly by the use of actual truck weight information in the proposed method.

Similarly, the vehicle OpMode distributions of driving cycle IDs 353 and 354for combination trucks are shown in Figure 4-25. Then, the top plot in Figure 4-26 shows the vehicle OpMode distribution of the combination truck of interest that is calculated by the weighted average method, which assimilates the two distributions it is created from. Again, the vehicle OpMode distribution created by the method proposed in this study (shown in the bottom plot of Figure 4-26) has a distinctively different pattern where all the truck activity is in only three bins, which are Bins 33, 35, and 37.

Single-Unit Truck Operating Mode Distribution (Driving Cycle ID = 353, N = 5333)

Single-Unit Truck Operating Mode Distribution (Driving Cycle ID = 354, N = 1792)
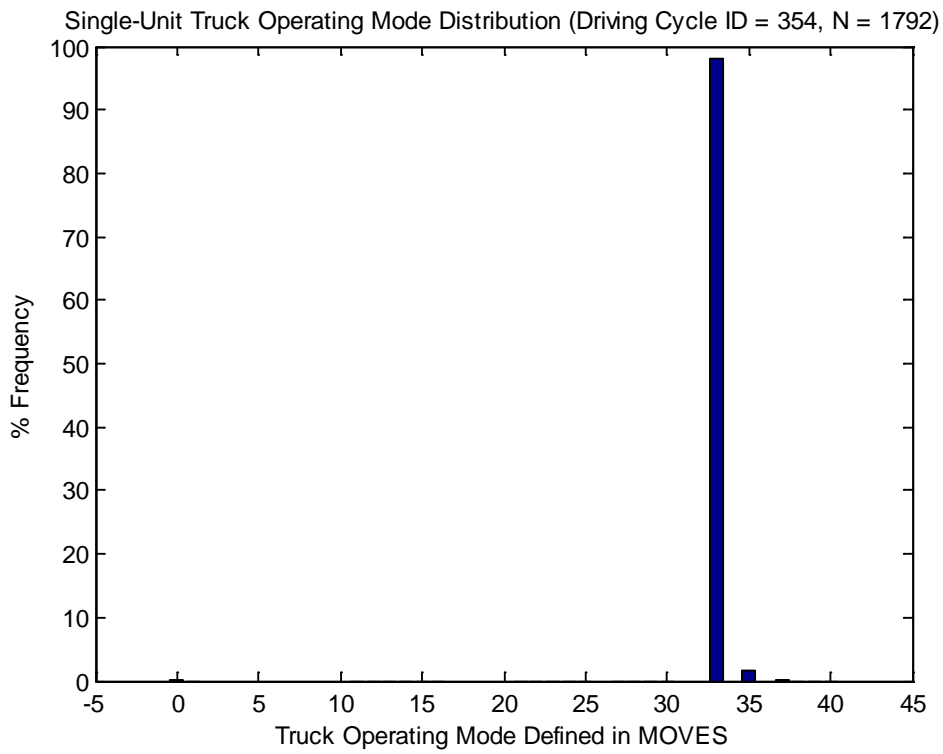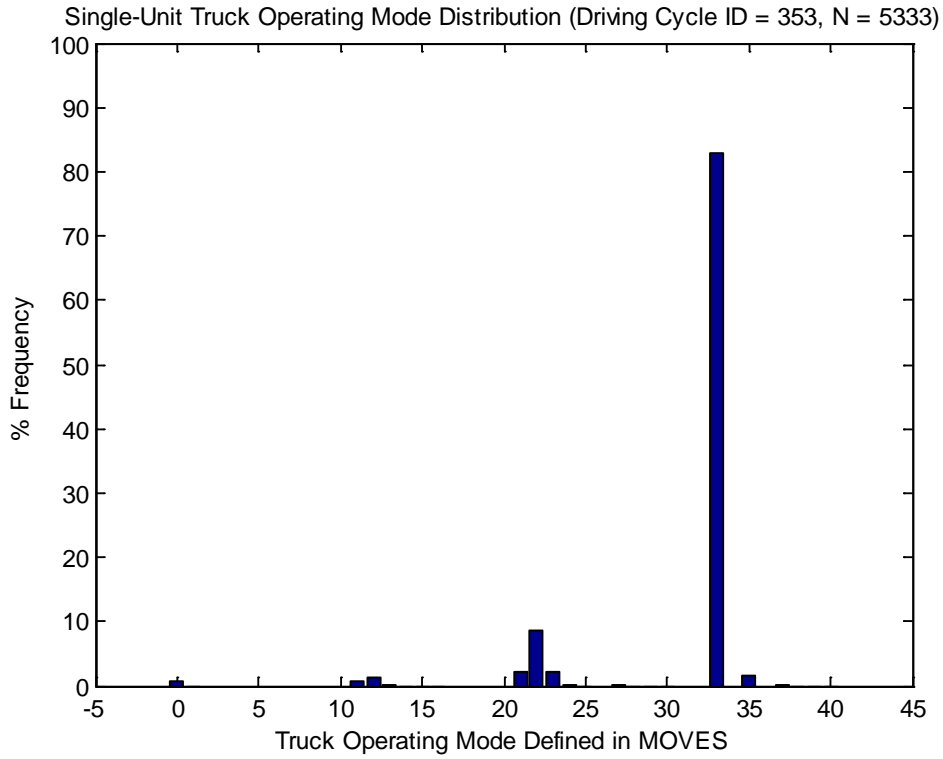
Figure 4-23. Vehicle OpMode distributions for single-unit trucks for driving cycle ID 253 (top) and driving cycle ID 254 (bottom)
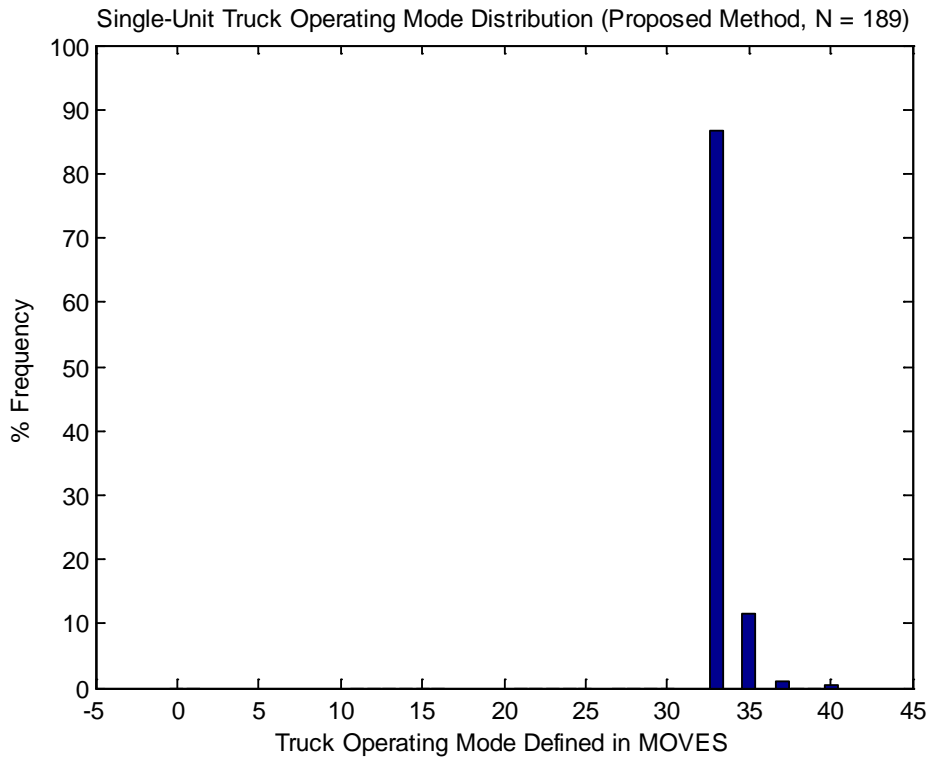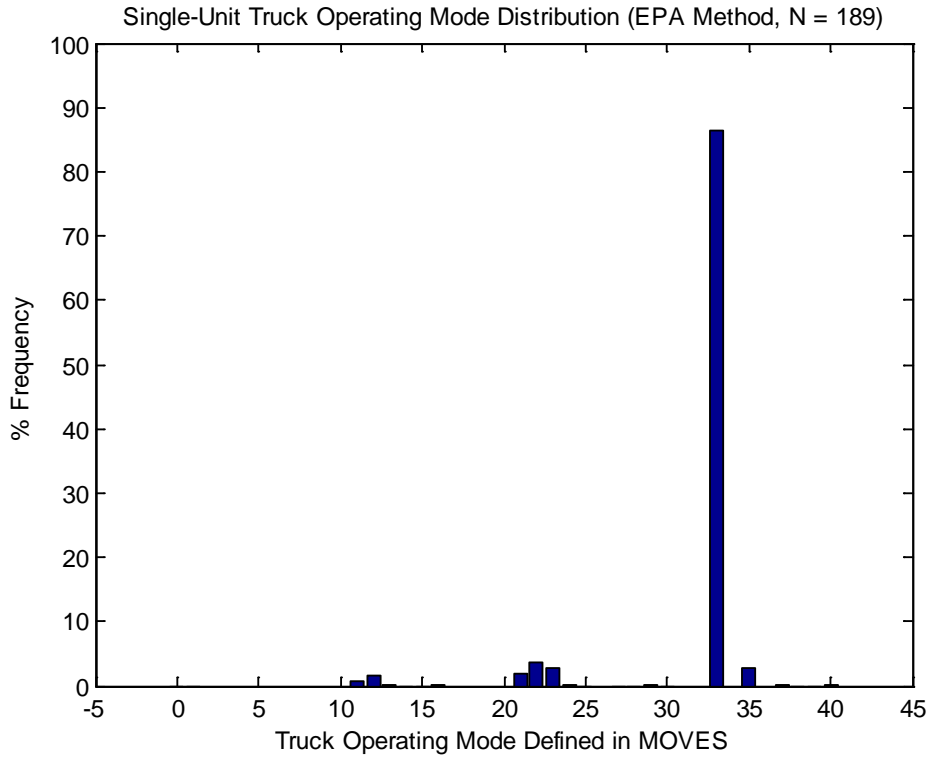
Figure 4-24. Vehicle OpMode distributions for single-unit trucks for the weighted average method (top) and the proposed method (bottom)
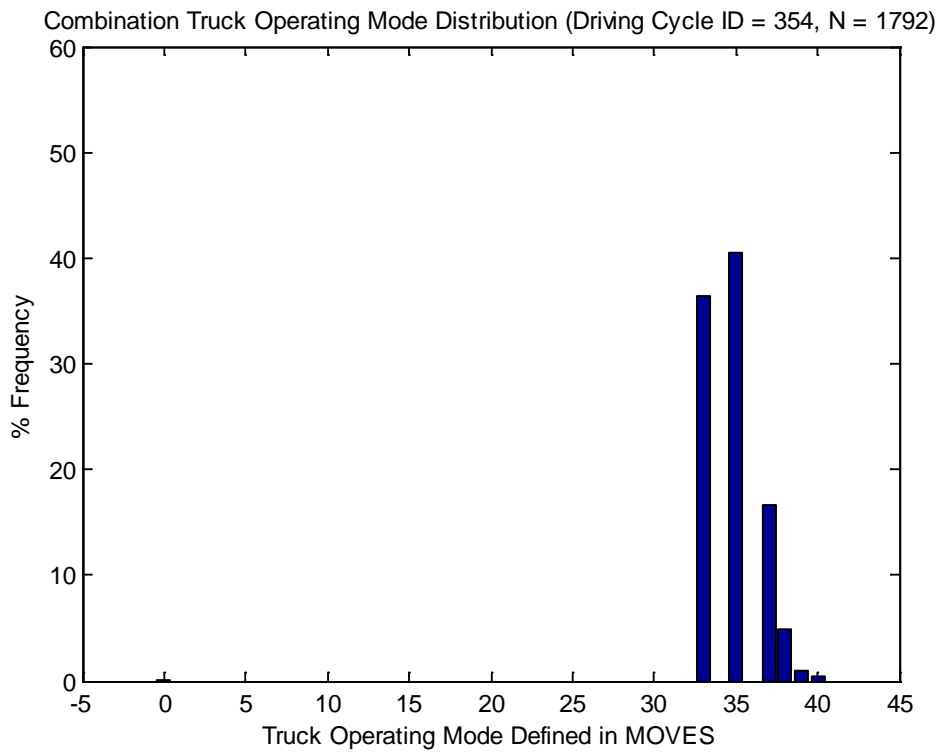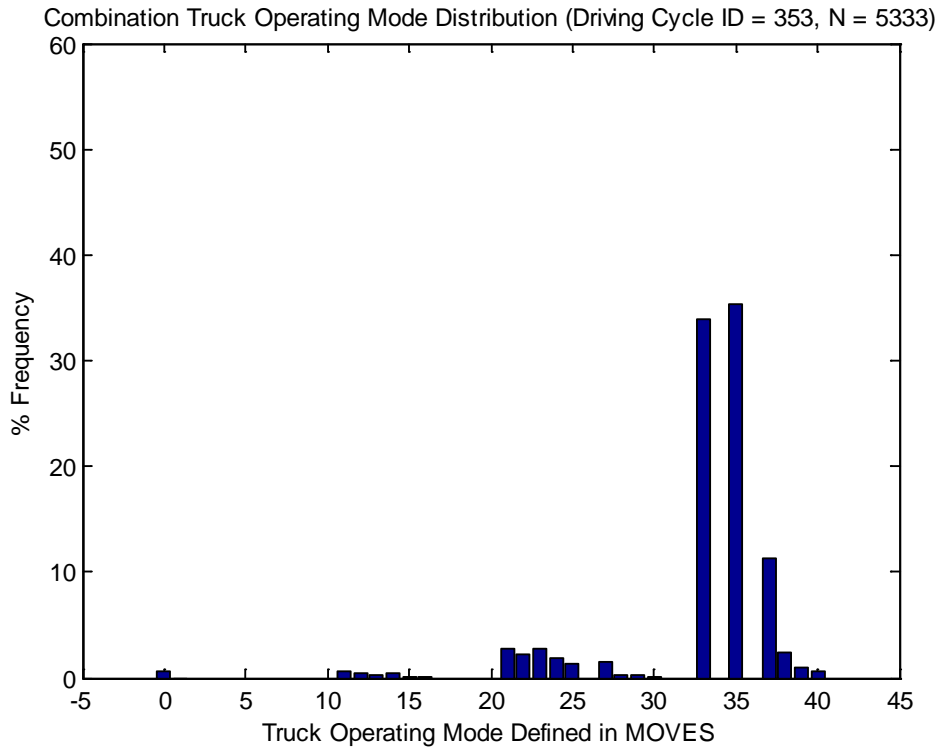
Figure 4-25. Vehicle OpMode distributions for combination trucks for driving cycle ID 353 (top) and driving cycle ID 354 (bottom)
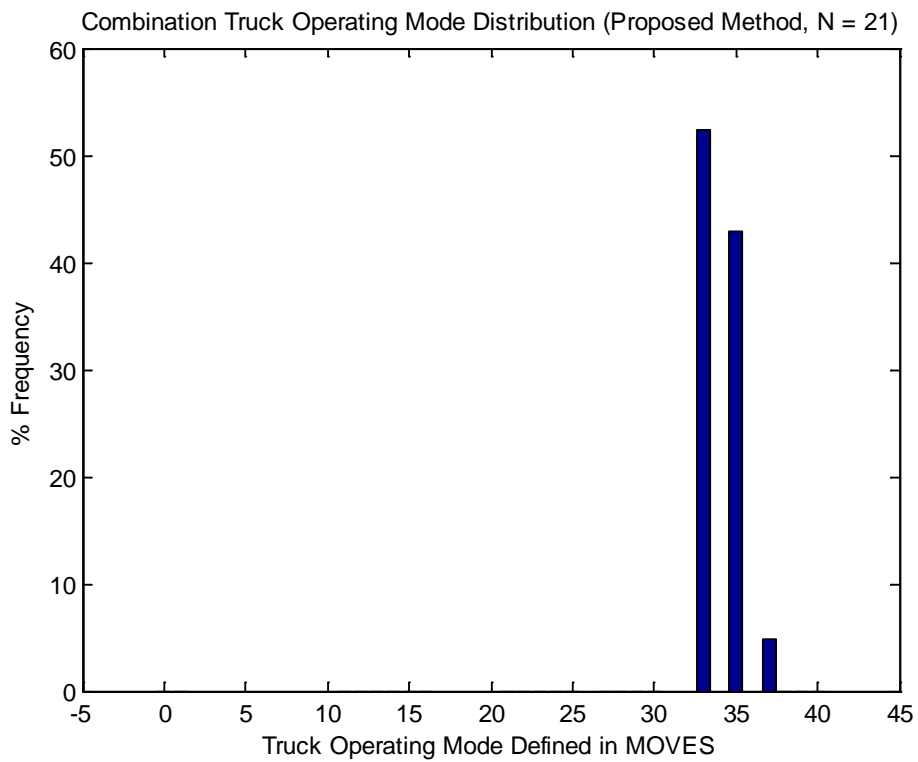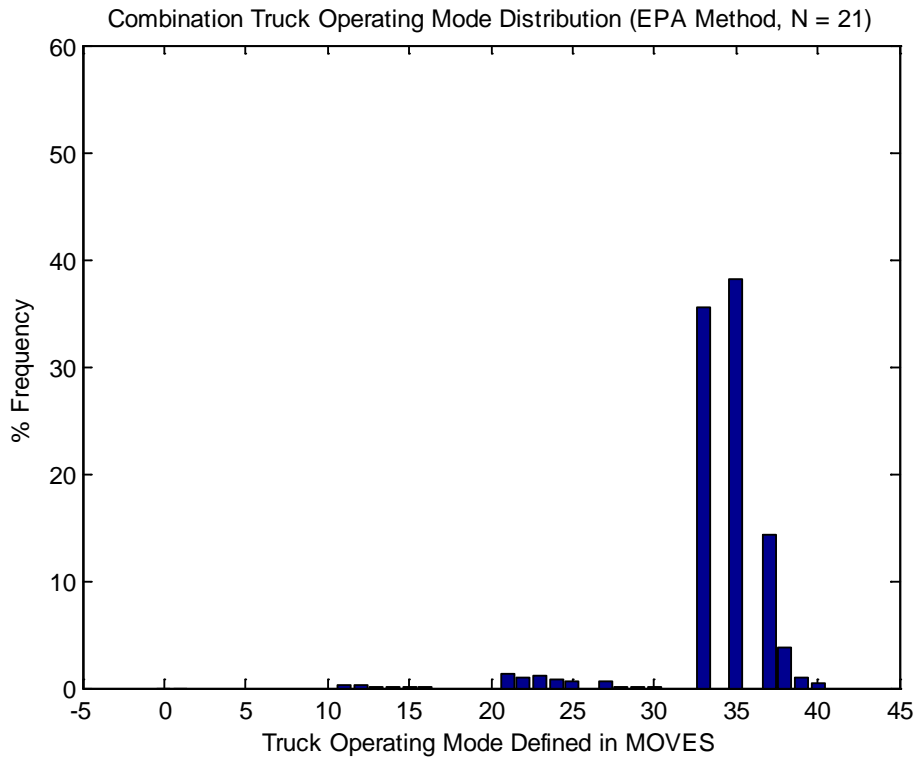
Figure 4-26. Vehicle OpMode distributions for combination trucks for the weighted average method (top) and the proposed method (bottom)

4.4.4. Results and Discussion

VSP distributions and vehicle OpMode distributions were created for single-unit trucks and combination trucks on freeways in the Los Angeles County using the entire month of data in April 2009. These distributions were created using both the proposed method and the weighted average method used by MOVES that were discussed in the numerical example. The distributions were also created separately for weekdays and weekends.

Figure 4-27 and Figure 4-28 show the VSP distributions for single-unit trucks for weekdays and weekends, respectively. Similarly, Figure 4-29 and Figure 4-30 show the VSP distributions for combination trucks for weekdays and weekends, respectively. In all the figures, the distributions created by both methods are shown. It is observed that in every case, the VSP distributions created by both methods follow the Gaussian distribution. However, the ones created by the proposed method have higher variation, which is due to the variation of truck weight used in the calculation of VSP.

Figure 4-31 and Figure 4-32 show the vehicle OpMode distributions for single-unit trucks for weekdays and weekends, respectively. Similarly, Figure 4-33 and Figure 4-34 show the vehicle OpMode distributions for combination trucks for weekdays and weekends, respectively. In all the figures, the distributions created by both methods are shown. It is observed that for single-unit trucks, the shape of the distributions created by both methods is similar to each other although the scale is different. This is true for both weekdays and weekends. However, for combination trucks, both the shape and the scale of the distributions created by the two methods are very different. The weighted average method has a single dominant bin, which is Bin 33. On the other hand, the proposed method has two dominant bins, which are Bins 33 and 35 where Bin 35 also accounts for a higher fraction.
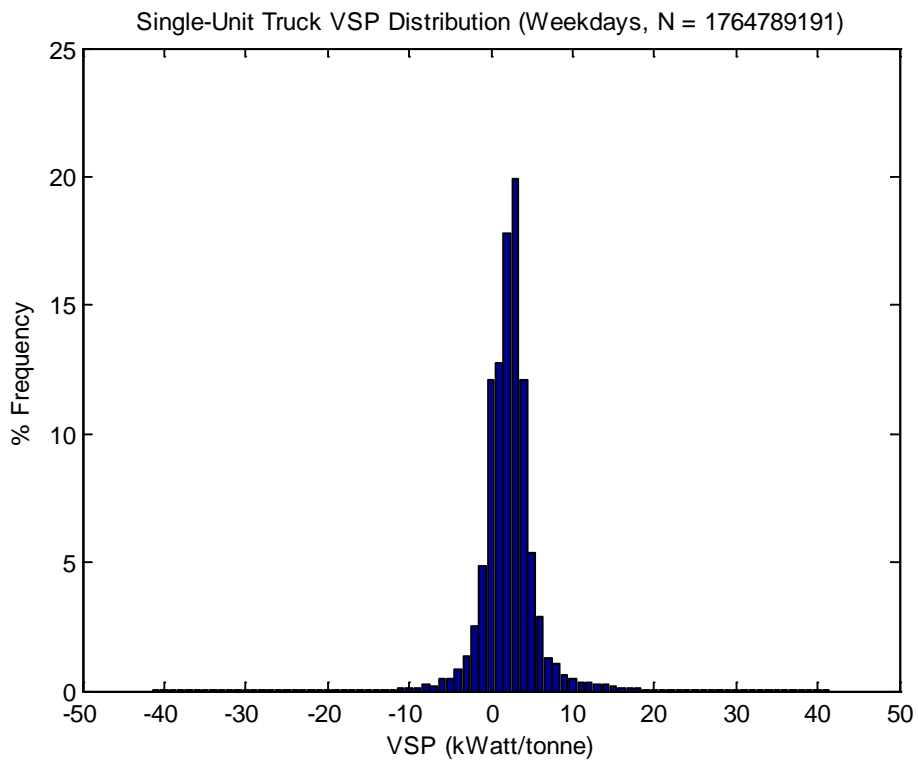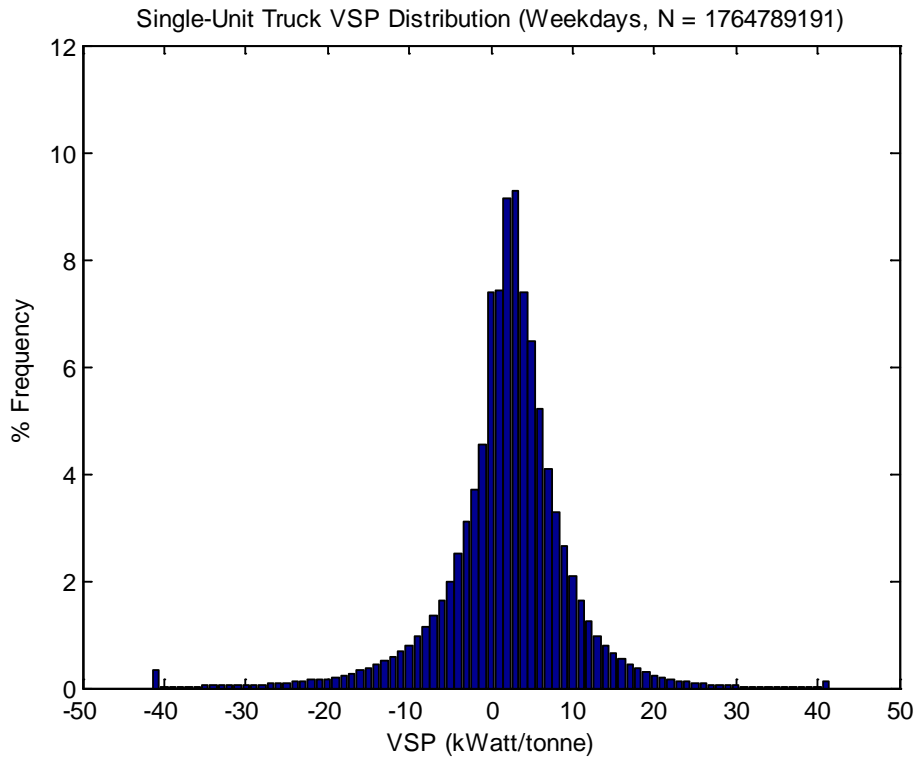
Figure 4-27. VSP distributions for single-unit trucks on weekdays in April 2009 (SHO = 29,413,153 hours) based on the proposed method (top) and the weighted average method (bottom).
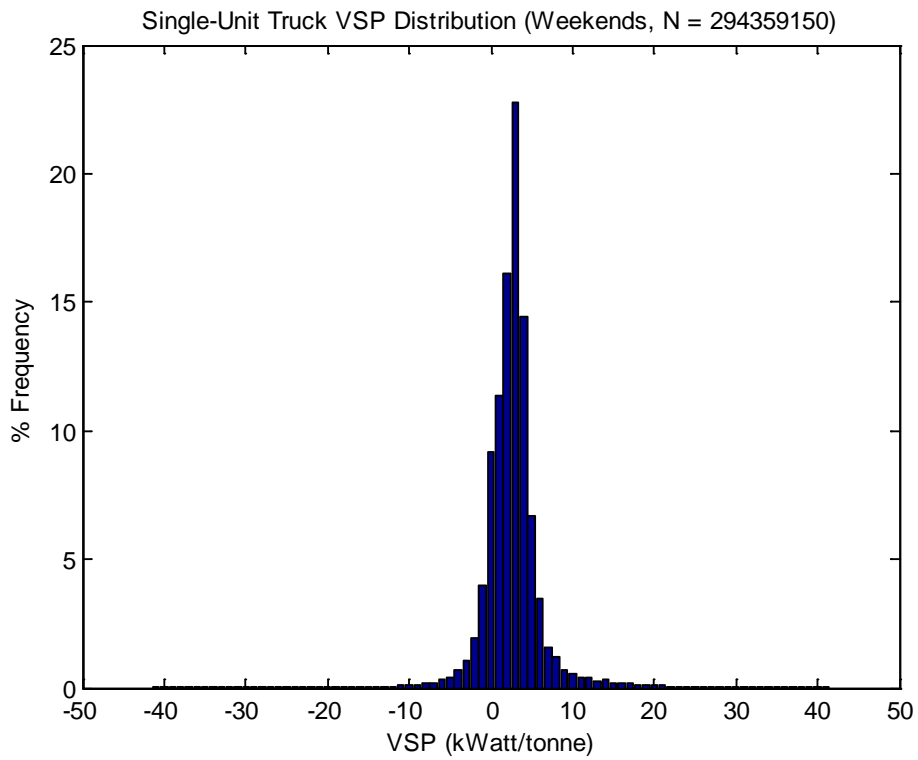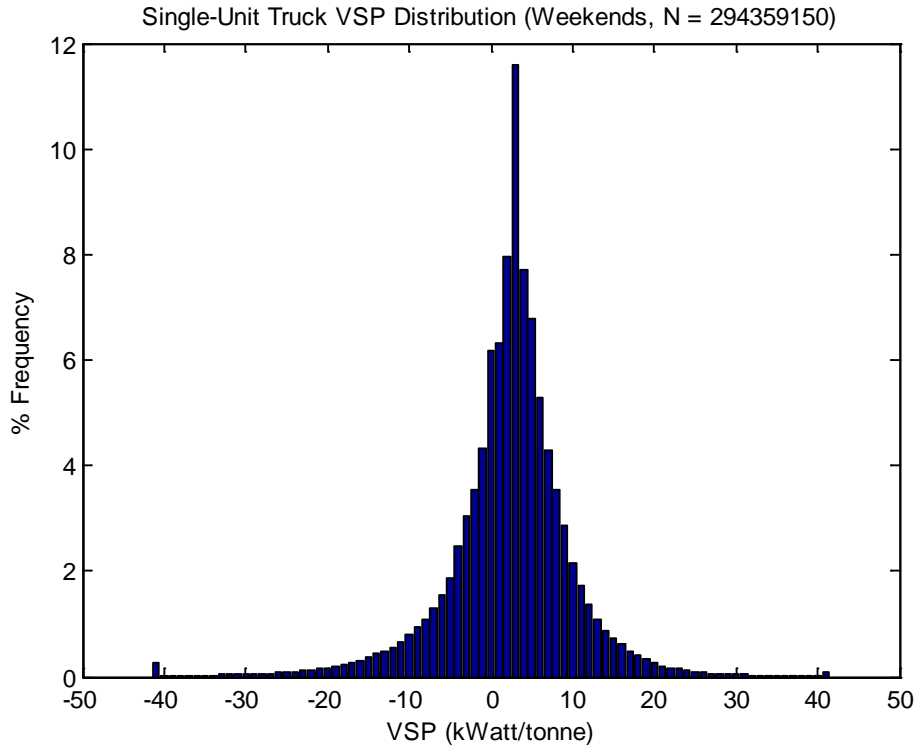
Figure 4-28. VSP distributions for single-unit trucks on weekends in April 2009 (SHO = 4,905,986 hours) based on the proposed method (top) and the weighted average method (bottom).
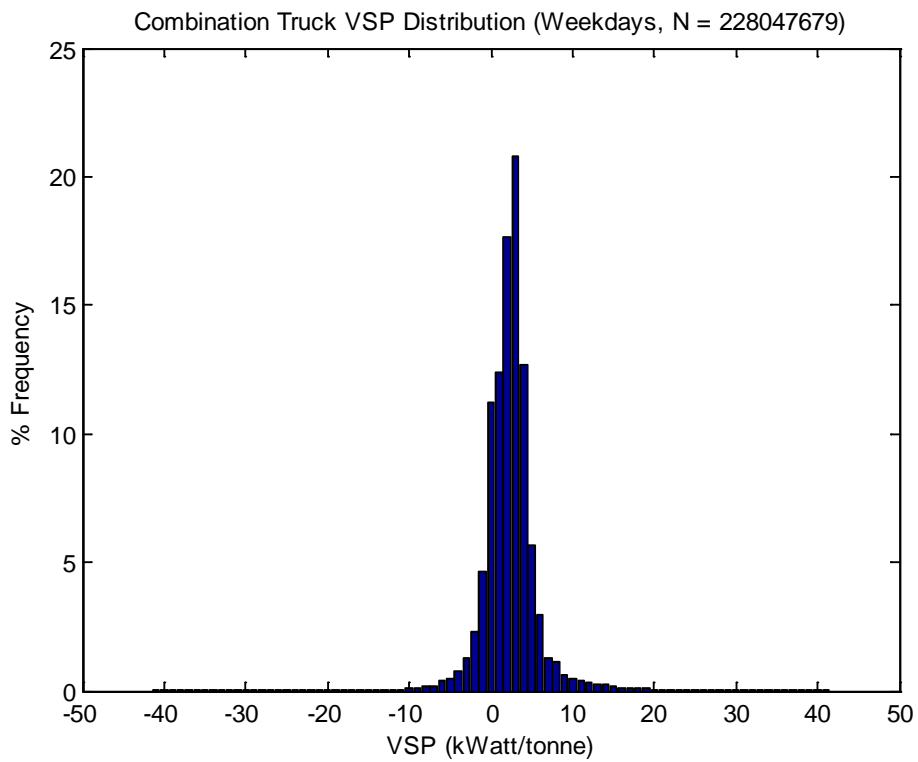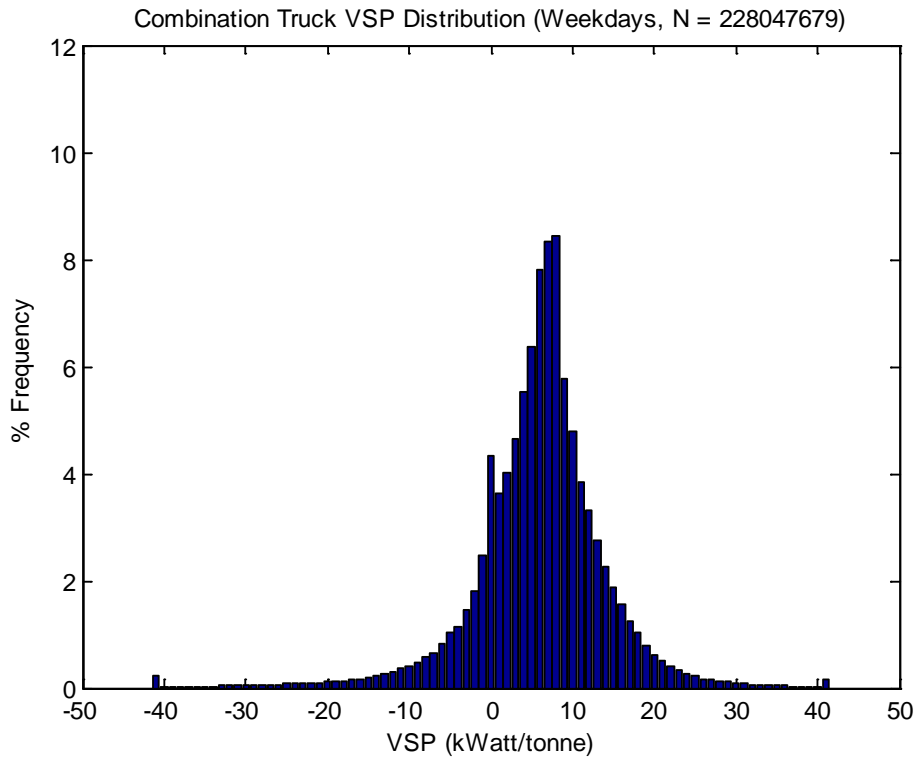
Figure 4-29. VSP distributions for combination trucks on weekdays in April 2009 (SHO = 3,800,795 hours) based on the proposed method (top) and the weighted average method (bottom).
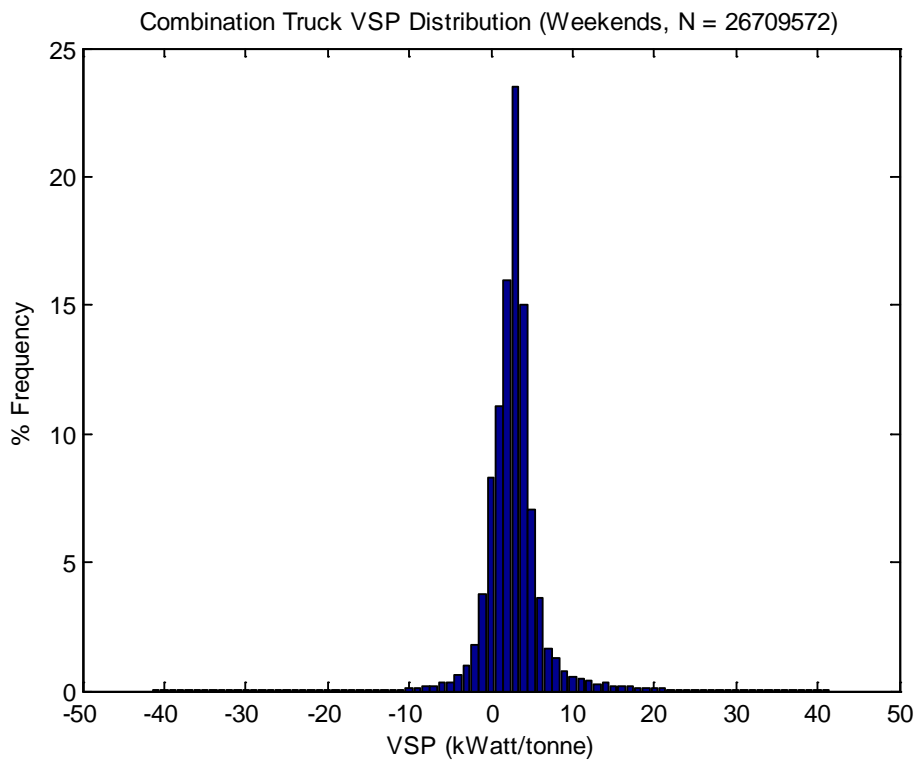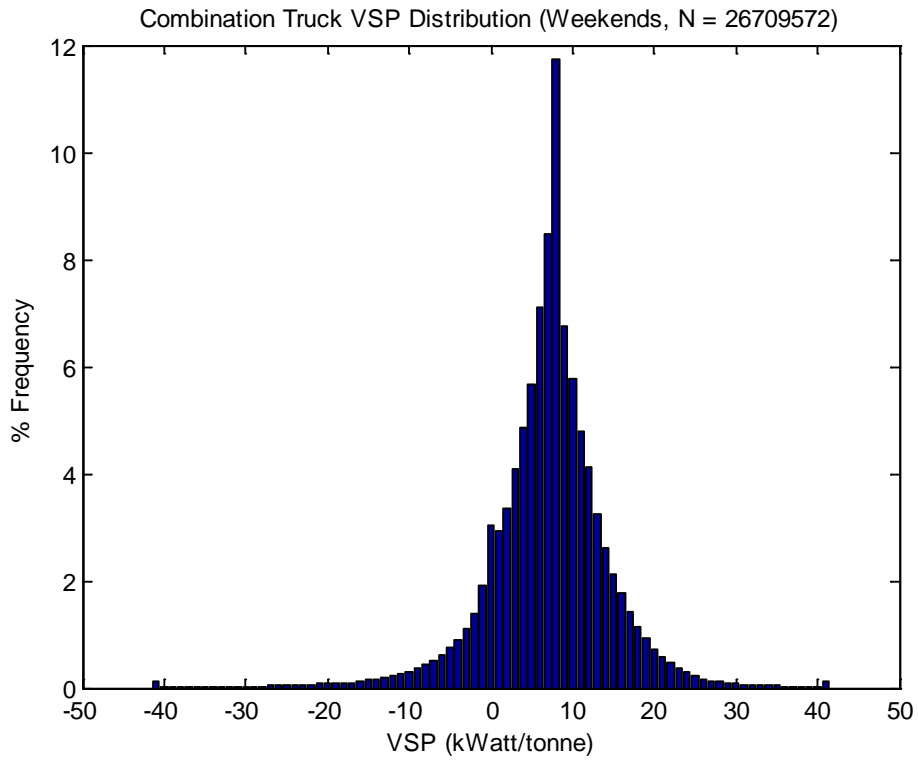
Figure 4-30. VSP distributions for combination trucks on weekends in April 2009 (SHO = 445,160 hours) based on the proposed method (top) and the weighted average method (bottom).
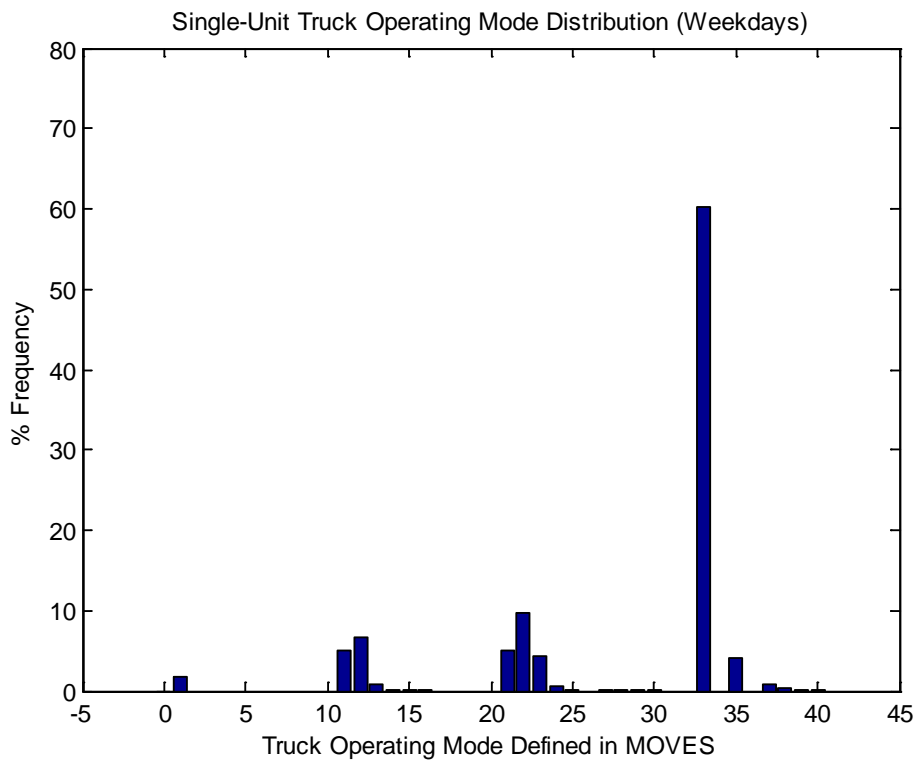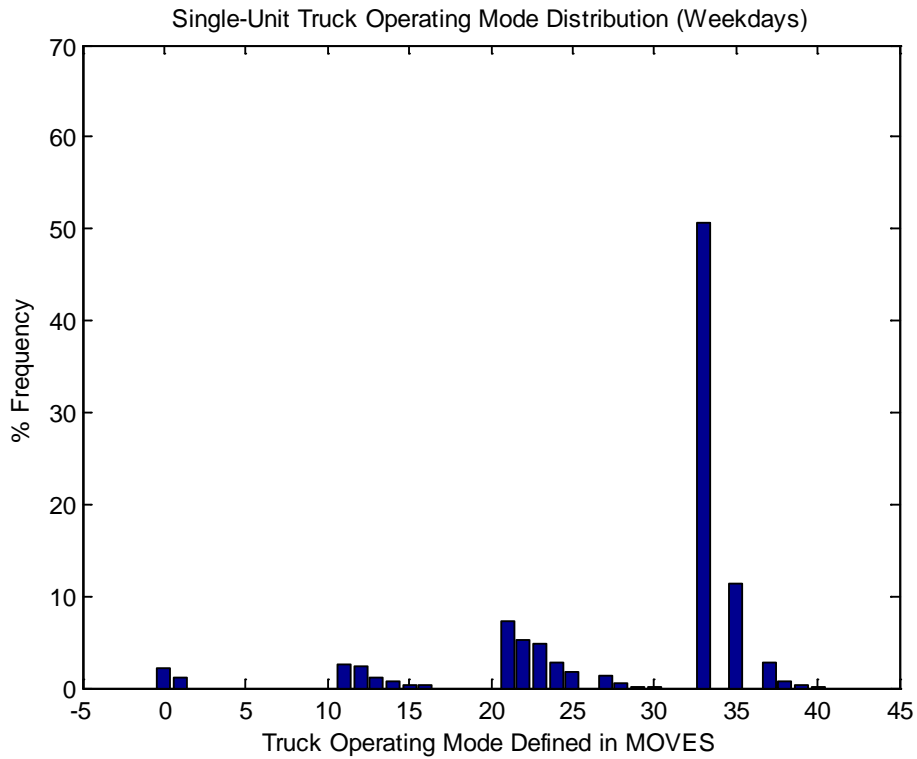
Figure 4-31. Vehicle OpMode distributions for single-unit trucks on weekdays in April 2009 (SHO = 29,413,153 hours) based on the proposed method (top) and the weighted average method (bottom).
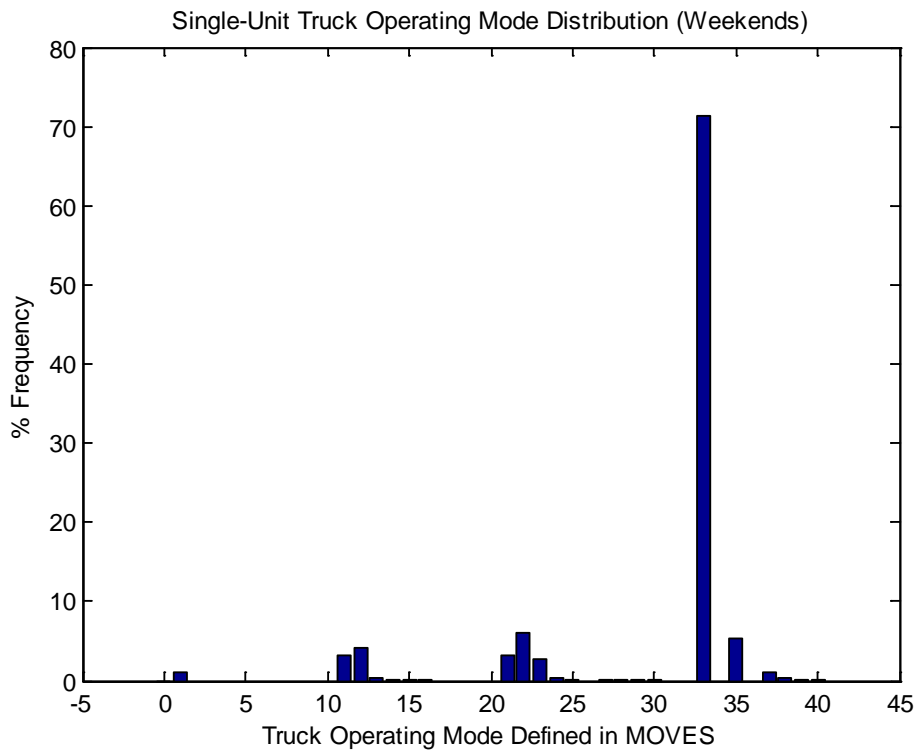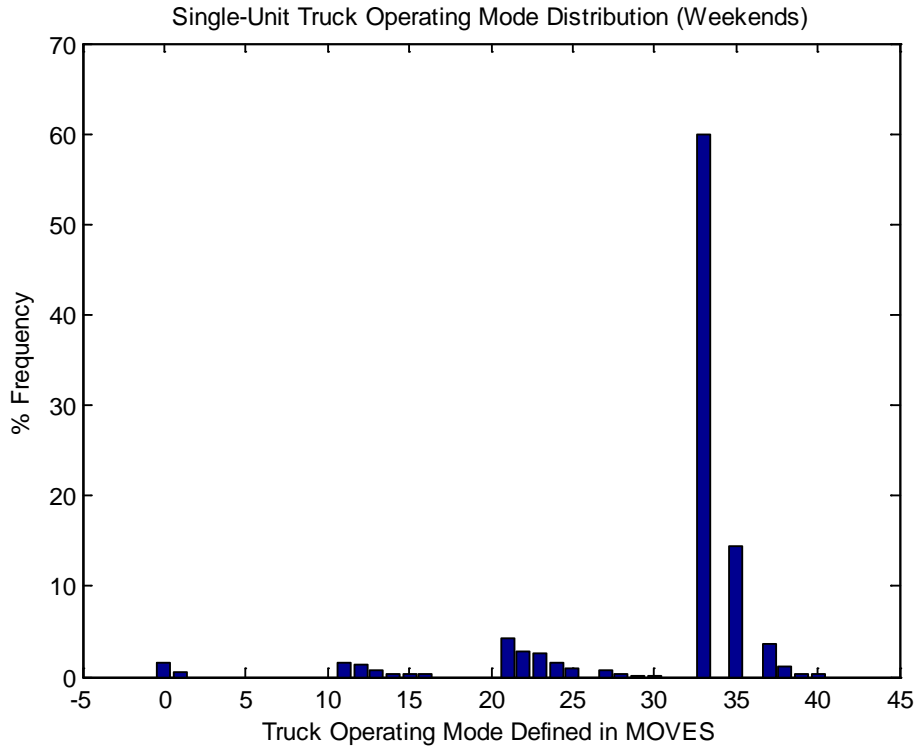
Figure 4-32. Vehicle OpMode distributions for single-unit trucks on weekends in April 2009 (SHO = 4,905,986 hours) based on the proposed method (top) and the weighted average method (bottom).
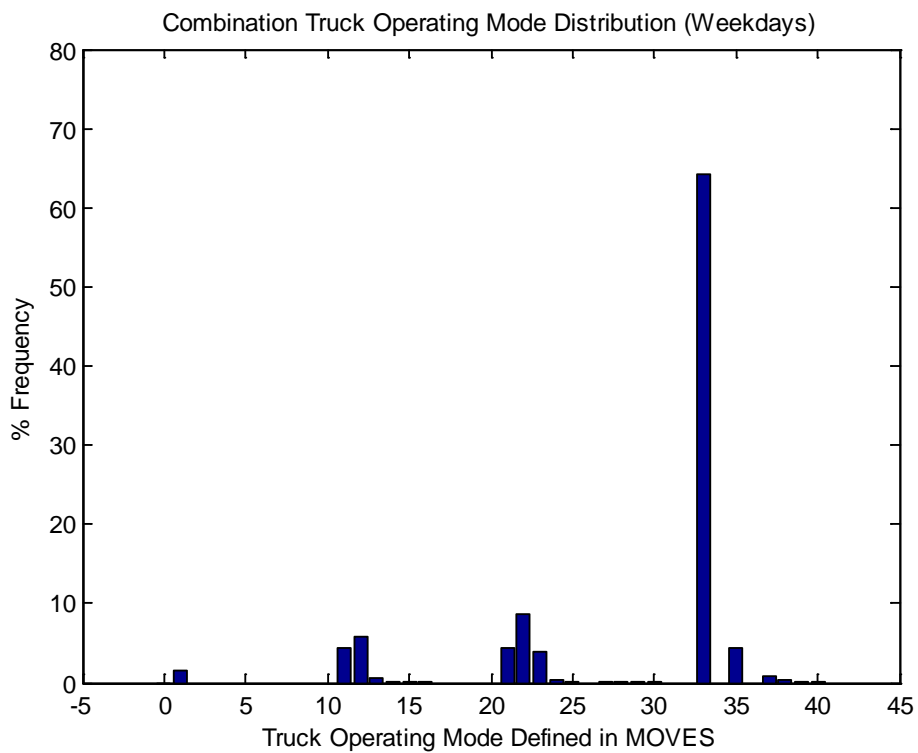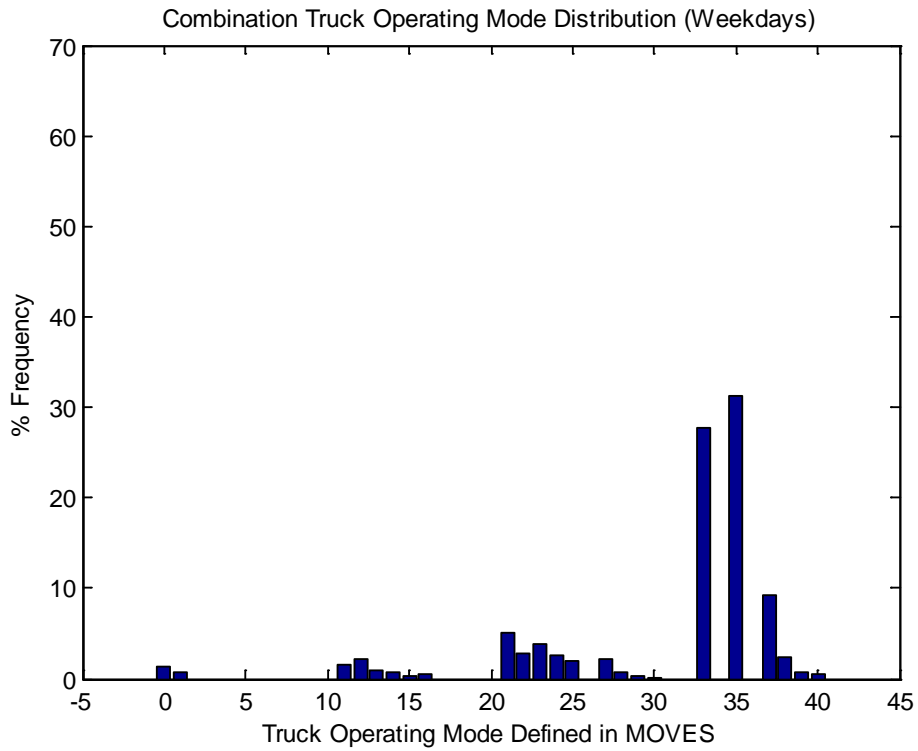
Figure 4-33. Vehicle OpMode distributions for combination trucks on weekdays in April 2009 (SHO = 3,800,795 hours) based on the proposed method (top) and the weighted average method (bottom).
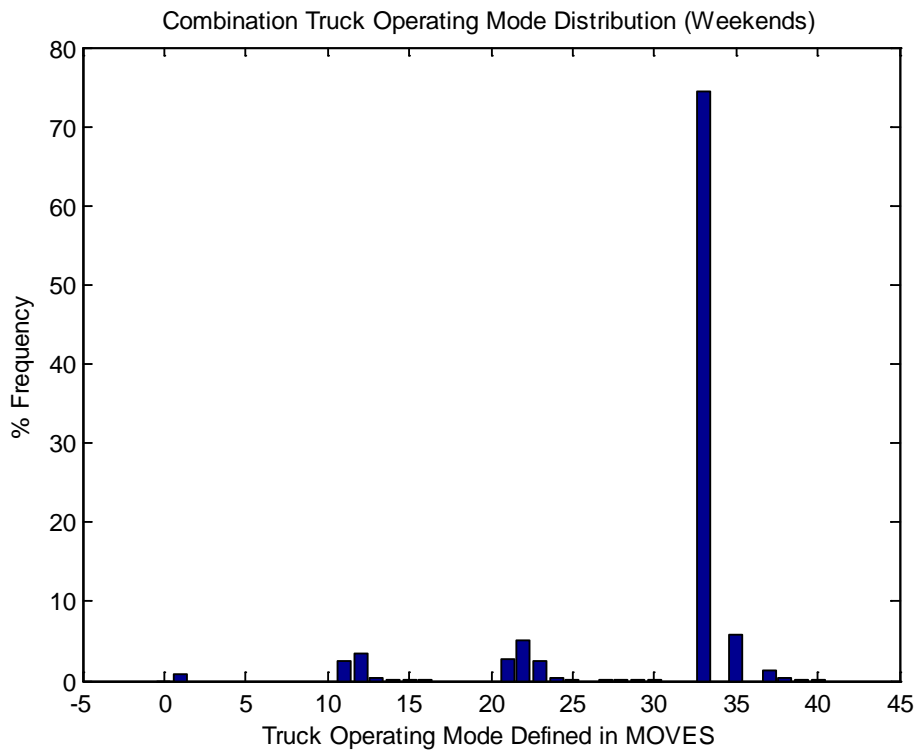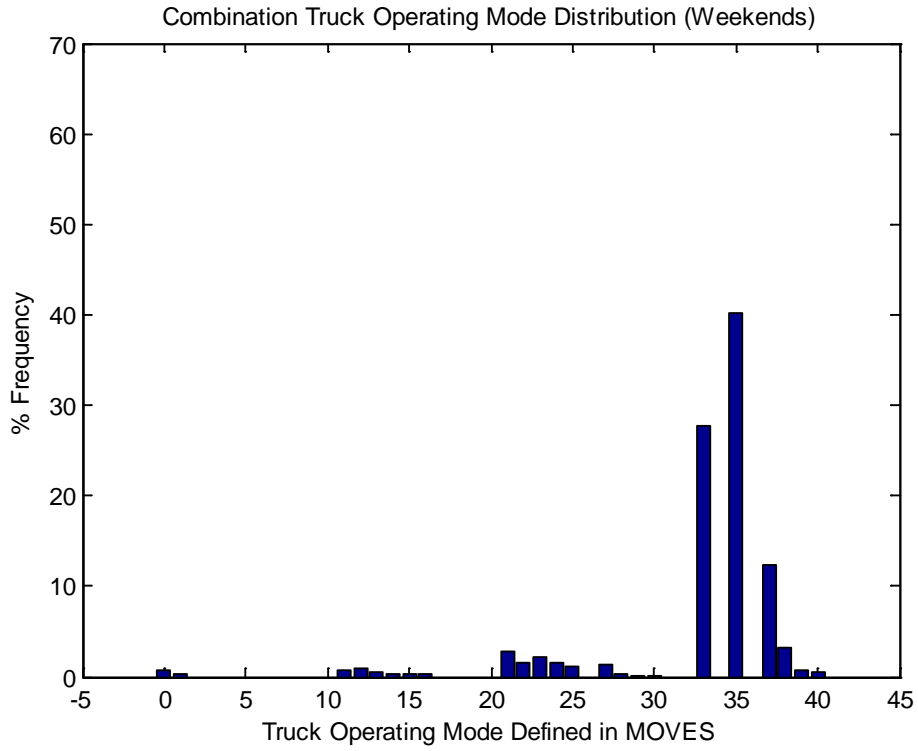
Figure 4-34. Vehicle OpMode distributions for combination trucks on weekends in April 2009 (SHO = 445,160 hours) based on the proposed method (top) and the weighted average method (bottom).

4.5. Concluding remarks

An accurate characterization of vehicle activity is crucial to the construction of regional emissions inventory of on-road mobile sources for use in SIPs and transportation conformity analyses. However, it is a challenging task given the limited availability of vehicle activity data at a large, regional scale. Compared to light-duty vehicles, the availability of vehicle activity data of HDTs are even more limited. This research examines the use of alternative sources of HDT activity data including truck's ECU and telematics-based vehicle tracking and monitoring system to generate HDT activity data inputs for MOVES.

4.5.1. Truck ECU Data

The advantages of truck's ECU data are that they can be acquired in a large amount with relatively low costs, and that they contain a number of vehicle and engine parameters that may also be useful for other purposes. However, their limitations include the fact that the data are aggregated over the lifetime of the truck or from the last time its ECU was reset, and have no detailed spatial or temporal information associated with them. For instance, ECU downloads can provide data regarding VMT, vehicle hours traveled (VHT), number of idling hours, and number of trips starts for an aggregate time period. However, these data cannot be differentiated by road type or area. Nevertheless, ECU downloads can be used to develop base data (e.g., total idling hours) from a large number of HDTs. Then, these base data can be disaggregated using spatial or temporal distribution factors derived from other small-scaled studies (e.g., GPS-based instrumented vehicle studies).

4.5.2. Truck Telematics Data

For the truck telematics data, they have several advantages. First, they include GPS information of the HDTs, which can be used to derive various forms of HDT activity data such as miles traveled, speed, trip starts, and idle time in detail. The use of GPS information also allows detailed activity data on unrestricted access roads, where the availability of traditional traffic sensors is limited, to be collected. Second, they are continuously collected, thus allowing temporal distributions of HDT activity to be developed by hour, day, and even month. Third, they can be obtained from a sizable number of HDT samples at a time, improving the confidence in the derived HDT activity data. As an example, the dataset used in this study includes data from more than 2,000 HDTs while the largest instrumented vehicle study of HDTs ever conducted in the U.S. has only 120 HDTs [Battelle, 1999]. Lastly, by coupling them with proper vehicle and fleet characterization, the truck telematics data can be used to develop vehicle activity data for specific truck groups (e.g., combination long-haul trucks of engine model year 2007 or later) based on their emission characteristics.

On the other hand, it is important to understand the limitations of the truck telematics data used in this study as well. First, they are collected at a much coarser interval (e.g., 30-second or 5-minute depending on the fleet) as compared to the data from instrumented vehicle studies, which are usually collected at a one-second interval. This may slightly affect the accuracy of the derived HDT activity data. Second, they are collected from a subset of HDTs in the total population. Thus, they cannot be used to derive the absolute statistics of the HDT population such as total VMT.

As shown in this report, the truck telematics data can be used to develop several of the HDT activity data inputs required by the EPA's MOVES model. Depending on the availability and quality of the existing data sources, the truck telematics data can be used to provide, supplement, or replace some of the required HDT activity data inputs developed from those existing data sources. For instance, if an area already has continuous traffic counters that differentiate traffic counts by vehicle type, then they can be used to develop VMT fraction by road type as well as by weekday/weekend and by hour, and the truck telematics data can be used to provide average speed distribution as well as trip starts location and distribution.

In addition to the several HDT activity data inputs required by the EPA's MOVES model, the truck telematics data can also be used generate other information for energy and emission analysis of HDTs. For example, link-based and area-based historical maps of truck fuel economy for a region can be generated based on this data set, which can be used to identify links or areas for capital improvement or traffic flow improvement projects.

4.5.3. Truck Data Fusion

This chapter also presents a method to fuse HDT datasets from WIM stations and vehicle detector stations (VDS) to result in more refined and accurate HDT activity data. The main idea is to identify trucks recorded by a WIM station that are likely to travel over a VDS during a time period. Then, the actual weight information of these trucks can be combined with the second-by-second speed and acceleration values from synthetic trajectories created from strategically selected MOVES default driving cycles to calculate the associated truck scale tractive power (STP) values. The STP values can then be binned by operating mode according to the U.S. EPA's definition.

This method should be more accurate than the current default method that assumes an average weight value for all the HDTs in the same class. This would result in more accurate emission inventories of HDTs, especially in areas that have freight terminals or freight corridors. The method relies on HDT weight information from WIM stations, which are available across the nation as depicted in Figure 4-35. Table 4-13 lists the top 20 MPOs that have the most number of WIM stations in their respective jurisdiction.
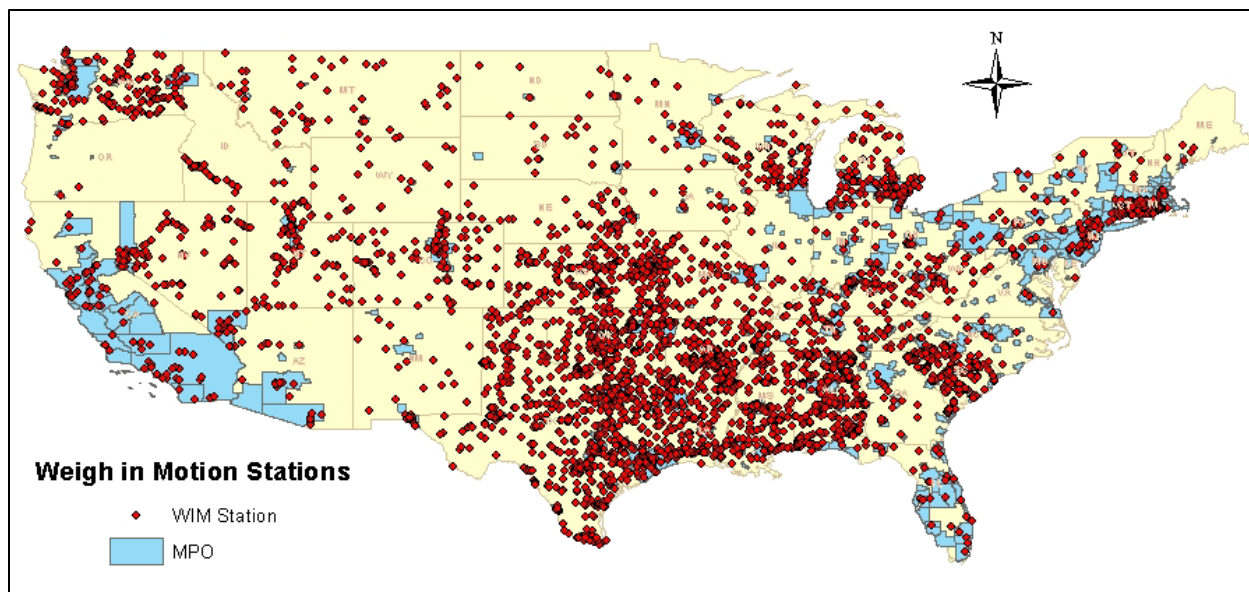
Figure 4-35. WIM stations across the U.S.

Table 4-13. Top 20 MPOs with the most number of WIM stations

No.	Metropolitan Planning Organization	State	Population in Year 2000	No. of WIM Stations*
1	State Planning Council	RI	1,048,319	107
2	North Central Texas COG	TX	4,879,535	104
3	Mid-America Regional Council	MO	1,582,372	84
4	Houston-Galveston Area Council	TX	4,669,571	82
5	Regional Transportation Commission of Southern Nevada	NV	1,375,765	73
6	Southeast Michigan COG	MI	4,833,493	56
7	Denver Regional COG	CO	2,394,504	40
8	Association of Central Oklahoma Governments	OK	990,564	40
9	Puget Sound Regional Council	WA	3,275,847	37
10	Southern California Association of Governments	CA	16,516,006	36
11	Louisville Area MPO	KY	968,313	31
12	Capital Area MPO	TX	1,159,836	30
13	San Antonio-Bexar County MPO	TX	1,415,906	26
14	Metropolitan Transportation Commission	CA	6,783,760	24
15	North Jersey Transportation Planning Authority	NJ	6,310,989	24
16	Cincinnati-Northern Kentucky MPO	OH	1,868,835	20
17	Southeastern Wisconsin Regional Planning Commission	WI	1,932,908	19
18	Birmingham MPO	AL	805,340	18
19	Delaware Valley Regional Planning Commission	PA	5,387,407	16
20	Wasatch Front Regional Council	UT	1,328,198	13

*Source: http://www.bts.gov/publications/national_transportation_atlas_database/2011/

5. Heavy-Duty Truck Emissions Data

5.1. Background

Heavy-Duty Diesel Truck (HDDT) emission rates in MOVES were developed using several data sources. For NO_x emission rates, the data sources consist of the Rover Portable Emission Measurement System (PEMS) dataset collected by the U.S. Army and the Consent Decree testing dataset collected by West Virginia University. Together these two datasets cover HDDT model years 1994-2006. Data for the development of $PM_{2.5}$ emission rates are from the Coordinated Research Council (CRC) E-55/59 program and cover model years 1974-2004. Emission data for the development of CO and HC emission rates are from several data sources including the CRC E-55/59 program, and cover vehicle model years 1969-2005.

Nevertheless, there are still approximately 50% data "holes", which are filled using several hole filling methods [U.S. EPA, 2005]. For instance, at the time that MOVES was developed, emission data was not available for HDDT model years 2007 and newer. Thus, the U.S. EPA estimated the HDDT emission rates of newer model years based on the 2003-2006 emission rates and the ratio between the emission standards for 2003-2006 and those for newer diesel engines. For example, the basic emission standards for NO_x decrease from 2.4 g/bhp-hr for 2003-2006 to 1.2 g/bhp-hr for 2007-2009 to 0.2 g/bhp-hr for 2010 and onward. Therefore, the NO_x emission rate in MOVES for the 2007-2009 model years decreases 50% from the one for the 2003-2006 model years. Similarly, the NO_x emission rate in MOVES for the 2010 and newer model years decreases 90% from the one for the 2003-2006 model years.

The HDDT emission standard for PM2.5 is 0.10 g/bhp-hr for 1994-2006 and 0.01 g/bhp-hr for 2007 and onward. Therefore, the PM2.5 emission rates in MOVES for 2007 and newer model years are estimated based on the age corrected 1998-2006 emission rates and a 90% emission reduction due to the decrease in the PM2.5 emission standard. For HDDTs with engine model years 2007 and newer, meeting the lower PM2.5 standard requires the use of a diesel particulate filter (DPF).

It is assumed that as more emissions data from vehicles are collected, the emissions rates in MOVES can be updated and thus the fidelity of the model should improve. Hence, there is a need to continue measuring vehicle emissions in order to fill in the emission data holes in MOVES. These emission measurement programs should be prioritized so that critical data holes are addressed first. One of the gaps in understanding HDDT emissions is the effect of loaded vehicle weight. HDDT emission rates in emission models are typically developed from emission data measured at a specific truck weight. Although emission measurement programs are usually designed to measure emissions at various driving patterns, they are rarely designed to measure emissions at different loaded vehicle weights. The effect of loaded vehicle weight on emissions is particularly important for HDTs that carry goods in their trailers. The truck operating weight could vary highly depending on the type of goods being carried and whether the container is empty or full.

5.2. Truck Emission Testing

5.2.1. Test Equipment and Facilities

In this research, the Mobile Emissions Laboratory (MEL) at the Center for Environmental Research and Technology (CERT) at the University of California, Riverside, was used in conjunction with CERT's heavy-duty chassis dynamometer to measure truck emissions at various weights and driving patterns. MEL is a unique laboratory containing all of the instrumentation normally found in a conventional vehicle emissions laboratory, but the equipment is mounted inside a 53-foot over-the-road truck trailer. With the chassis dynamometer, truck driving patterns can be simulated for various road grades, container weights, and other conditions while the truck is driven on the computer-controlled testing platform.

Mobile Emission Laboratory

MEL, pictured in Figure 5-1, is a complete emission laboratory enclosed in a 53 foot class-8 trailer, with the ability to measure HDT emissions in-tow. MEL measures on-road and real-world emissions from engines at the quality level specified by the U.S. Congress Code of Federal Regulations. The laboratory contains a full dilution tunnel, analyzers for gaseous emissions, and ports for particulate measurements.

Figure 5-1. CERT's Mobile Emissions Laboratory (MEL)

Vehicle exhaust gases are diluted with conditioned and purified ambient air. Significant mixing occurs as the dilution air and diesel exhaust pass through an orifice plate. The primary dilution system is configured as a full-flow constant volume sampling (CVS) system with a smooth approach orifice (SAO) venturi and dynamic flow controller. The SAO venturi has the advantage of no moving parts and repeatable accuracy at high throughput with low pressure drop. As opposed to traditional dilution tunnels with a positive displacement pump or a critical flow orifice, the SAO system with dynamic flow control eliminates the need for a heat exchanger. The system is capable of total exhaust capture for engines up to 550 kW.

MEL includes an extensive analytical sampling system. Heated probes, heated filters, and sample conditioning are used to prevent condensation and remove moisture in the system. Sample probes can be attached to any of 10 access ports to the primary tunnel, which are located 10 tunnel diameters from the mixing orifice. The mobile laboratory contains a suite of gas-phase

analyzers on shock-mounted benches. The gas-phase analytical devices measure NO, methane (CH_4), total hydrocarbons (THC), CO, and CO_2 at a frequency of 10 Hz and were selected based on optimum response time and on-road stability. Each modal analyzer is time-corrected for tunnel, sample line, and analyzer delay time. MEL is also equipped with a wide range of measurement techniques for full characterization of the diesel exhaust PM composition, real-time PM, and semi-volatile and PM PAHs, C_1-C_{12} gaseous hydrocarbon species and carbonyls.

Figure 5-2 shows a basic schematic of the MEL trailer. The various instruments are powered by an on-board generator making the entire lab mobile. The laboratory can measure emissions in a stationary position, such as is required when sampling from a Back-Up Generator (BUG) or engine dynamometer, or it can be towed by a class 8 tractor, measuring the tractor's emissions in traffic under real-world operating conditions. In the latter setup, the truck's exhaust system is connected to the dilution system and the entire exhaust stream is captured. A driver's aid was developed, which allows the truck operator to follow prescribed driving cycle if the road conditions permit.

Data collected by MEL also includes information from the vehicle's Engine Control Unit (ECU) as well as additional sensors. The ECU provides, among other things, engine speed, percent engine load, and fuel. Emission concentrations and mass flow rates are recorded second-by-second during the testing and are stored in a database. The raw emission gas concentrations are then converted from concentrations in parts-per-million (ppm) to mass emission rates in grams per second, using algorithms for the gas analyzers which account for parameters such as emission densities, exhaust flow rates, and differences in dry and wet gas measurements. This is carried out for CO_2, CO, HC, NOx and PM.
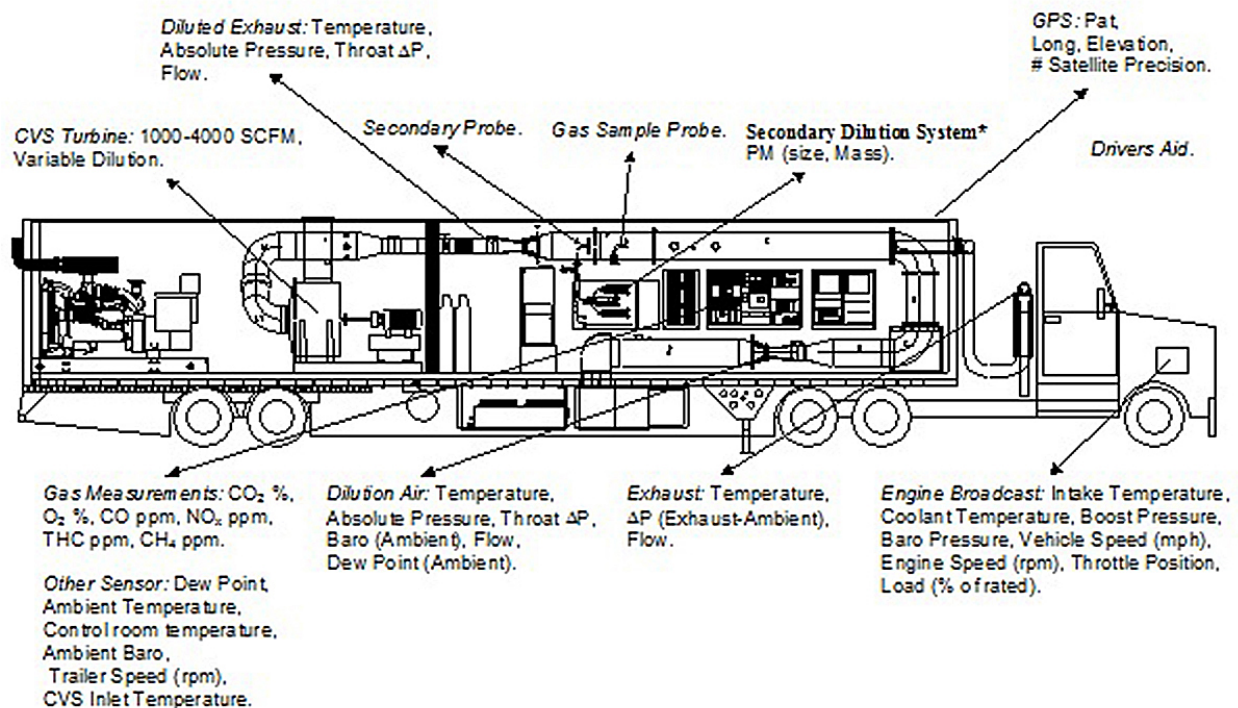
Figure 5-2. Schematic of CE-CERT's Mobile Emission Research Lab

An important part of post-processing is to time align all of the necessary second-by-second emission data. This step is necessary since there is a time delay inherent in each of the gas analyzer response times and between data from the analyzer, the vehicle's ECU and GPS data. Time alignment of the data is crucial in order to establish correlations among various parameters. The proper time shift for the emission data is determined through several steps. An initial time shift for each pollutant emission is provided by MEL as part of the validation and calibration of the emission benches. The second step is to analyze the time shifts for each pollutant emission relative to the ECU data. Since the ECU fuel data shows a strong relationship with the emission data and is the basis for much of the later work, it is used to determine alignment between the ECU and emission data sets. Alignment of these two data sets is done via a cross correlation analysis to calculate lag times between vehicle emissions, vehicle ECU and GPS data.

Heavy-Duty Chassis Dynamometer Laboratory

CERT has installed a heavy-duty tandem axle truck chassis dynamometer in conjunction with Mustang Dynamometer. The development of the chassis dynamometer design was based on target vehicles in the medium to heavy-duty diesel vehicle range. This high performance 48" Electric Chassis Dynamometer has Dual Direct Connected, 300 Hp AC Motors individually attached to each roll set (model MD-AC/AC-300.48/300.48-45,000lb-HD-TANDEM). The dynamometer is capable of simulating exacting road load & inertia forces to a vehicle operating over a range of different driving conditions including highway cruise, urban driving, and other typical on road driving conditions, with the designed based on 17 different drive cycles. The robust dynamometer can continuously absorb/motor loads in excess of 600 HP from 45 to 80 mph and intermittently absorb/motor loads in the range of 1,200Hp. The dynamometer is able perform vehicle inertia simulation across a vehicle weight range of 10,000 to 80,000 lb. MEL is used directly in conjunction with this facility for certification type emissions measurements.

Figure 5-3. Heavy-duty chassis dynamometer laboratory

5.2.2. Truck Selection and Recruitment

Given the increasing proportion of the 2007 and newer model year HDDTs in the current and future HDDT populations, it is of interest to evaluate and possibly update emission rates associated with these model years. Therefore, it was initially designed that one of the two trucks to be tested would have engine model year between 2007 and 2009 (i.e., meeting 2007 emission standards), and the other truck would have engine model year of 2010 or newer (i.e., meeting 2010 emission standards). However, at the time of truck recruitment (in August 2010), it was not possible to find a 2010 model year truck locally. Therefore, two 2007-2009 model year trucks were tested. Their characteristics are given in Table 5-1 and their pictures are shown in Figure 5-4. Although Truck 1 is heavier, it has a more aerodynamic design than Truck 2.

Table 5-1. Two targeted HDDTs for emission testing

Truck	Make	Engine Make/Model	Model Year	Tractor Weight (lbs)
1	International	Cummins/ISX-400	2009	17,480
2	Kenworth	Cummins/ISM-400	2008	15,260

Figure 5-4. (Left) Truck 1 and (right) Truck 2

5.2.3. Test Procedures

Coast Down Testing

The chassis dynamometer, with proper road-load coefficient settings, can realistically simulate load on the truck due to vehicle and cargo weight. The road-load coefficients for any given truck and weight can be determined by performing road-load coast down testing. In the coast down testing, the trucks were run by themselves. In addition, they were equipped with a flatbed trailer, which was loaded with K-rail barriers at two test weights as listed in Table 5-2. In summary, these weight scenarios represented a bobtail, a half loaded, and a fully loaded truck. The maximum allowable combined vehicle weight in California without exemption is 80,000 lbs.

Table 5-2. Three weight scenarios for road-load coast down testing

Weight Scenario	No. of 20' K-Rail Barriers	K-Rail Weight (lbs)	Flat Bed Weight (lbs)	Truck 1 Total Weight (lbs)	Truck 2 Total Weight (lbs)
Bobtail	0	0	0	17,480	15,260
Half	3	23,400	17,000	52,760	50,540
Full	6	46,800	17,000	74,300	72,080

Each coast down testing included six coast down runs, three in one direction of the freeway and the other three on the opposite direction. Each coast down run measured the time in seconds it took for the truck to reduce speed from 65 to 15 mph in 5 mph intervals. The data from the six runs were averaged to obtain the road-load coast down coefficients for a truck at a given weight.

Driving Cycles

The driving cycles for emission testing on the chassis dynamometer include the Urban Dynamometer Driving Schedule (UDDS; see Figure 5-5) and the California Air Resources Board (CARB)'s Heavy-Heavy-Duty Diesel Truck (HHDDT) schedule, which includes four modes (i.e., idle, creep, transient, and cruise; see Figure 5-6). Together, both driving cycles are considered to provide a wide range of operating conditions that represent typical truck driving activity on roads.

Before the test, the truck was set on the dynamometer and its exhaust pipe was connected to the exhaust flow inlet of the MEL as shown in Figure 5-7. Then, the road-load coast down coefficients were programmed into the dynamometer controller. After all the preparation steps were complete, the driver would start to drive the truck following the prescribed driving cycles. The measured emission data were cleaned up and time aligned before being used in the analyses.
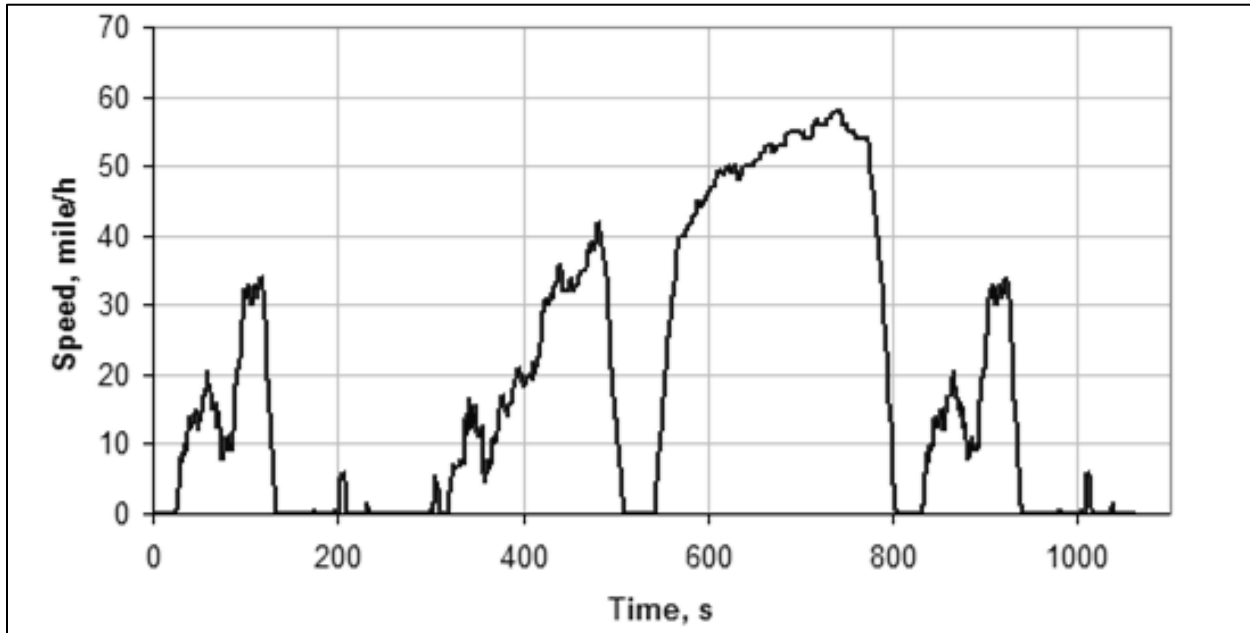
Figure 5-5. Urban Dynamometer Driving Schedule

5-6
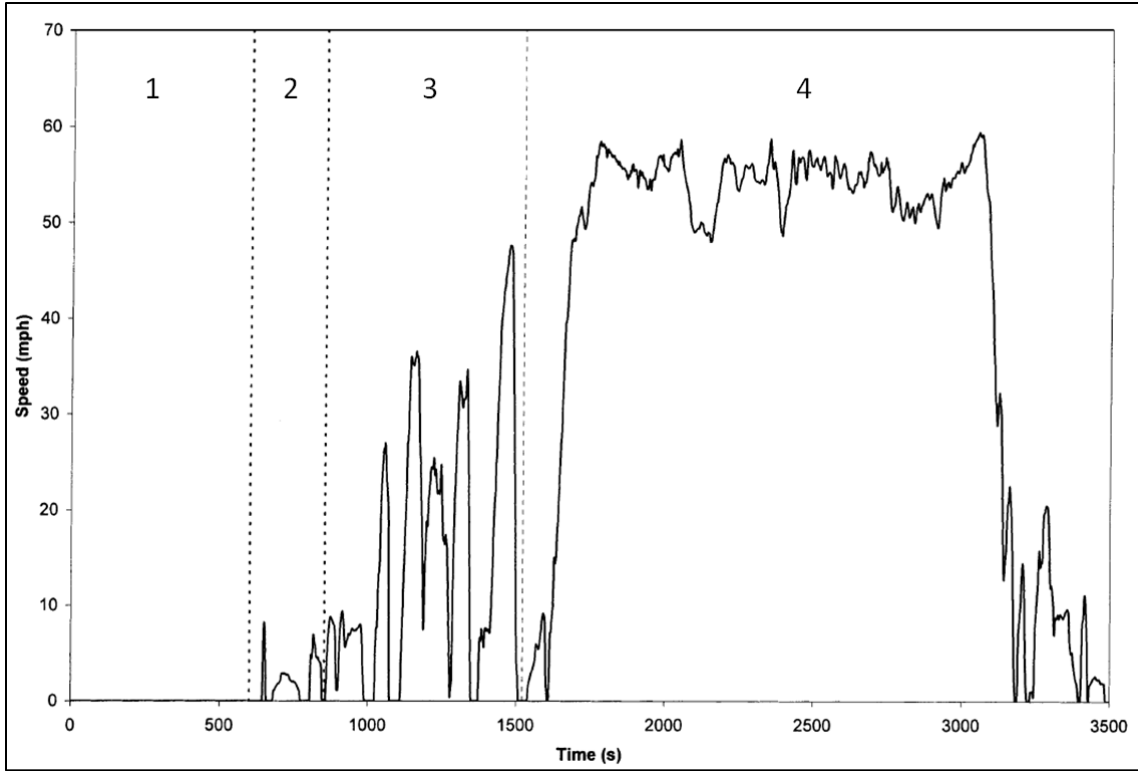
Figure 5-6. CARB's HHDDT schedule

Figure 5-7. Truck being tested on the chassis dynamometer

5.3. Results and Discussion

5.3.1. Effect of Weight on Emission Rates

The major pollutant emissions from HDDTs are NO_x and PM. However, upon initial review of the emission data, it was found that the PM emissions were very low. In fact, most of them were lower than the detection limit of the measurement instrument. Therefore, PM emissions were not further investigated. Figure 5-8 and Figure 5-9 show the NO_x emission results (in grams per mile) for Truck 1 and Truck 2, respectively.
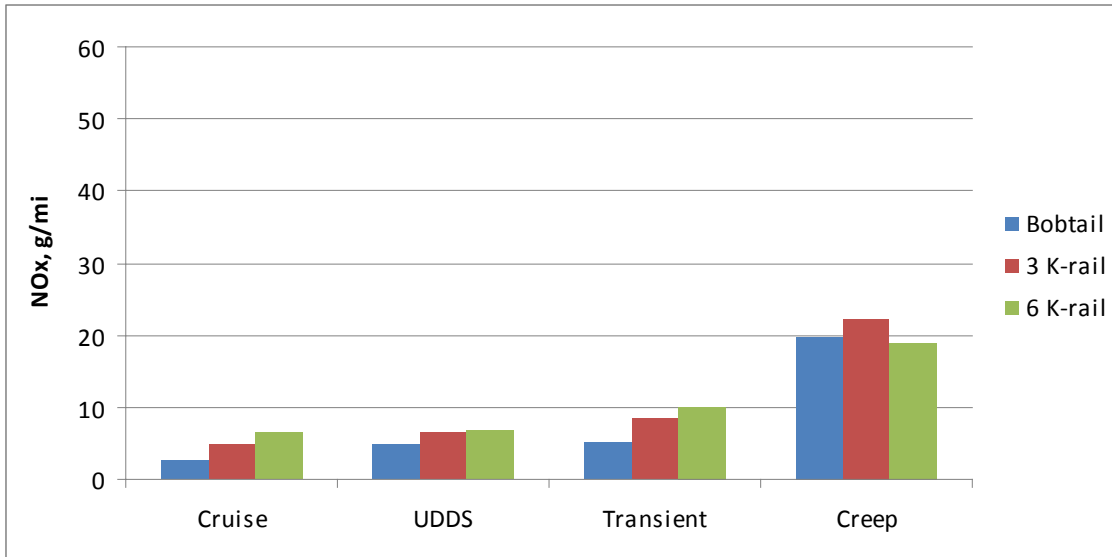
Figure 5-8. NOx emission rates for Truck 1
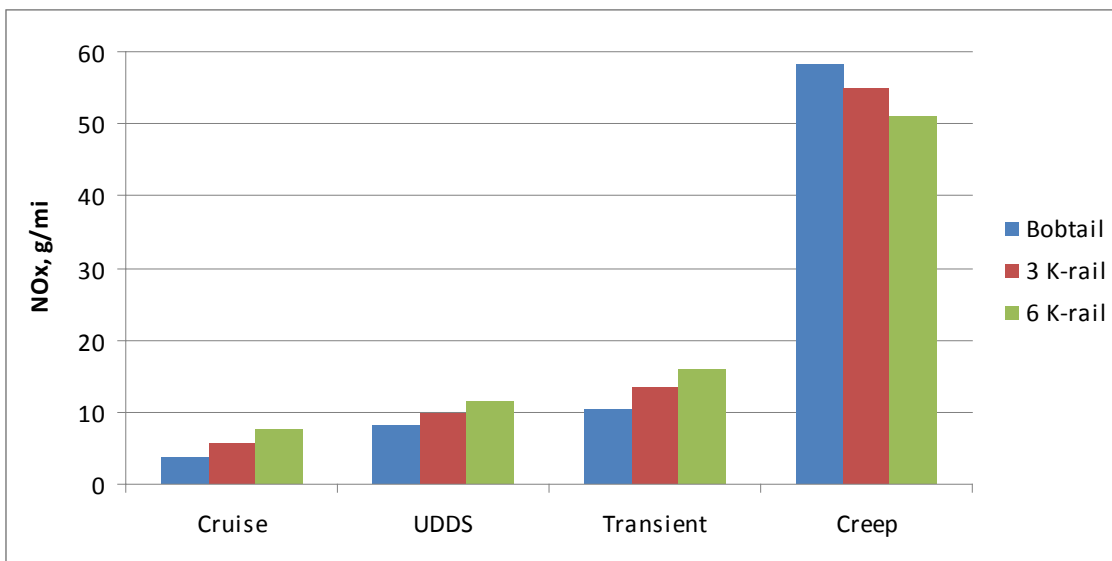
Figure 5-9. NOx emission rates for Truck 2

According to these figures, it is observed that the increasing weight also increases NOx emissions proportionally as expected. This is true for all the driving cycles, except the creep cycle. The creep cycle is very short and is at very low speed. Thus, the presence of a few emission outliers could easily change the trend of the total emissions. By comparing between the two trucks, Truck 2 has higher NOx emissions than Truck 1 in all the cases. By comparing across the driving cycles, the emission rates of the transient cycle are higher than those for the UDDS cycle, which are higher than those for the cruise cycle, respectively. This is expected as the more transient the driving pattern, the higher emissions due to the more frequent acceleration.

Figure 5-10 and Figure 5-11 show the CO_2 emission results (in grams per mile) for Truck 1 and Truck 2, respectively.
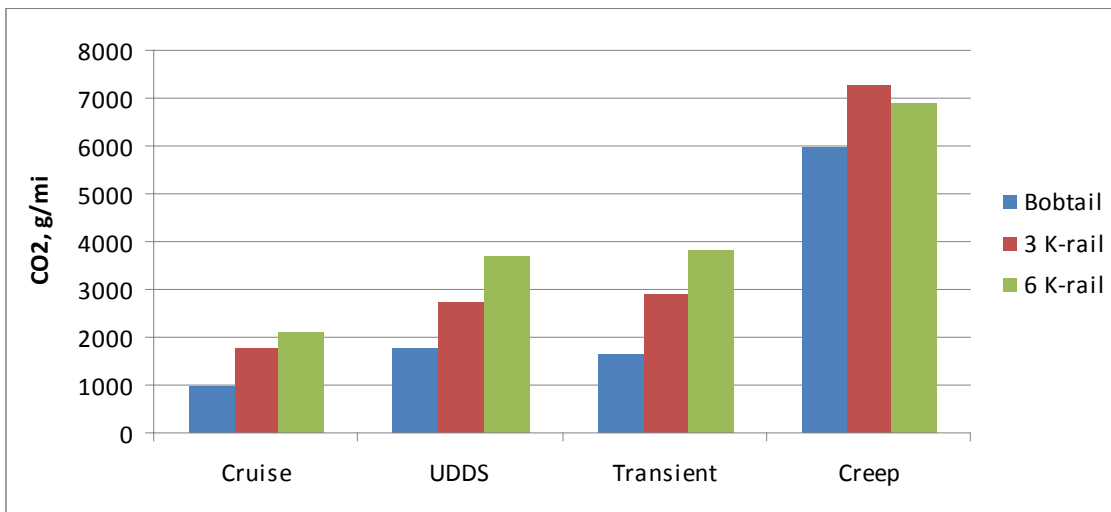
Figure 5-10. CO2 emission rates for Truck 1
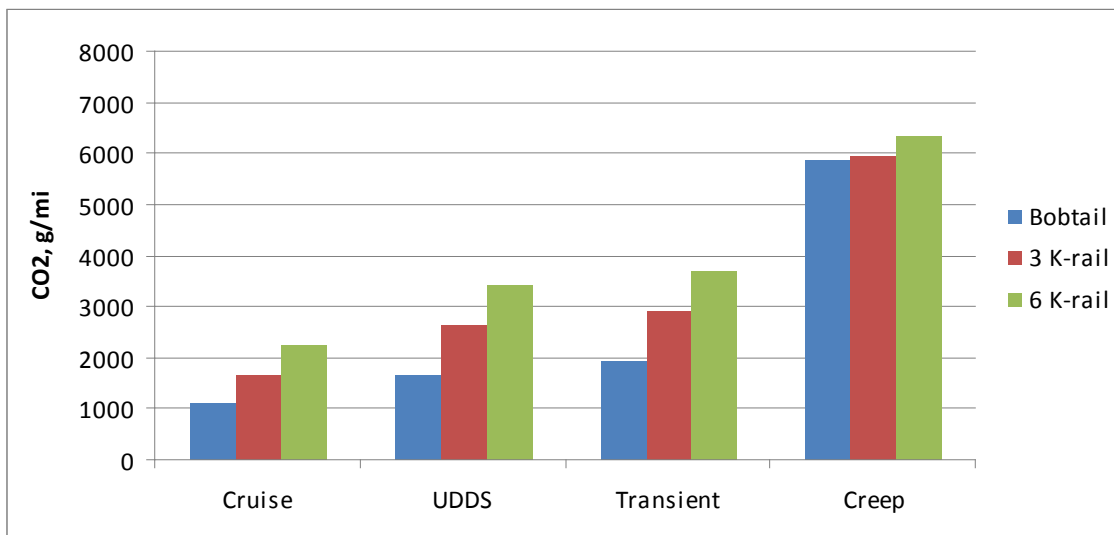
Figure 5-11. CO2 emission rates for Truck 2

Similar to the trend of NOx emissions, it is observed that the increasing weight also increases CO2 emissions proportionally for all the driving cycles, except the creep cycle. By comparing between the two trucks, Truck 1 has slightly higher CO2 emissions than Truck 2 in most cases. This is partly due to the tradeoff between CO2 and NOx emissions. By comparing across the driving cycles, the CO2 emission rates increase from the cruise cycle to the UDDS cycle to the transient cycle as expected.

Since HDDTs produce very little CO and HC emissions compared to NOx, these emission data are quite noisy and no trend can be observed.

5.3.2. Comparison with MOVES Emission Rates

Using the measured emission data, the mean emission rate (in grams per second) and its standard deviation for each MOVES vehicle operating mode (OpMode) bin were calculated. Then, they were compared against the base emission rates in MOVES that were developed based on the hole filling method described earlier. Specifically, the MOVES base emission rates were obtained for the following two SourceBinIDs:

1020147290000000000
1020147280000000000

The description for the first SourceBinID is as follows:

Digit 1	1	leading digit
Digits 2-3	02	fuel type (2 = diesel)
Digits 4-5	01	engine techcology (1 = conventional)
Digits 6-7	47	regulatory class (47 = Heavy Heavy Duty (GVWR > 33K lbs))
Digits 8-9	29	model year group (29 = 2009)

For the second SourceBinID, digits 8-9 are 28, which is for the model year group of 2008.

Figure 5-12 and Figure 5-13 show the comparison results of NOx emission rates for Truck 1 and Truck 2, respectively. For both trucks, there are no measured data for the OpMode bins 28, 29, 30, 38, 39, and 40. In general, the measured mean NOx emission rates are higher than those in MOVES for almost every OpMode bins. The differences are significantly greater in OpMode bins 13, 14, 15, 24, and 25 for Truck 1, and in OpMode bins 13, 14, 15, 24, 25, 27, and 37 for Truck 2.

Figure 5-14 and Figure 5-15 show the comparison results of CO2 emission rates for Truck 1 and Truck 2, respectively. Again, there are no measured data for the OpMode bins 28, 29, 30, 38, 39, and 40 for both trucks. In general, the measured mean CO2 emission rates are higher than those in MOVES for every OpMode bins. The differences are significantly greater in OpMode bins 13, 14, 15, 24, 25, 26, and 37 for Truck 1, and in OpMode bins 13, 14, 15, 24, and 25 for Truck 2. Compared to the measured NOx emission rates, the measured CO2 emission rates have less variation as indicated by smaller standard deviations.
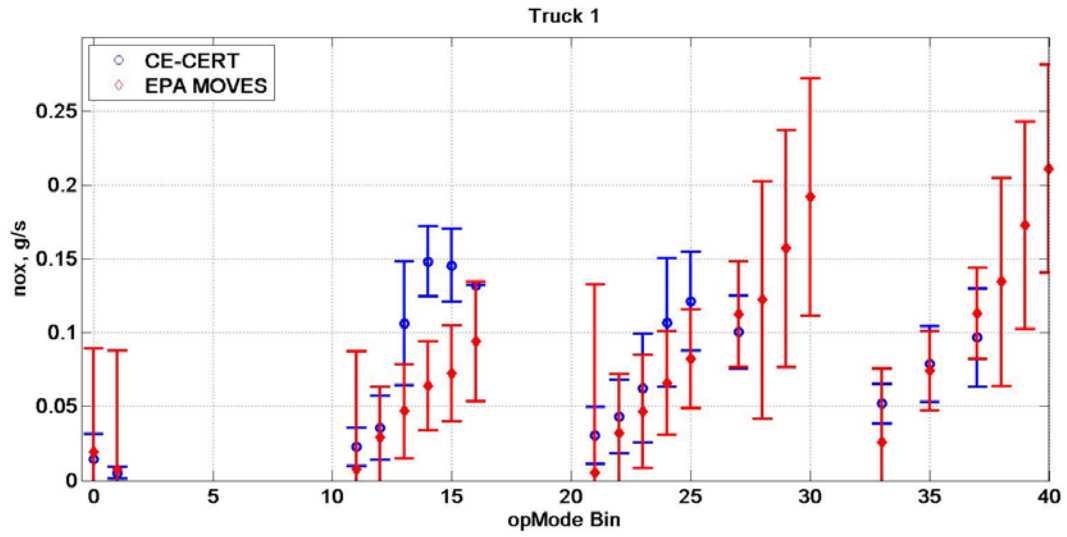
Figure 5-12. NOx emission rates for Truck 1 versus MOVES' rates
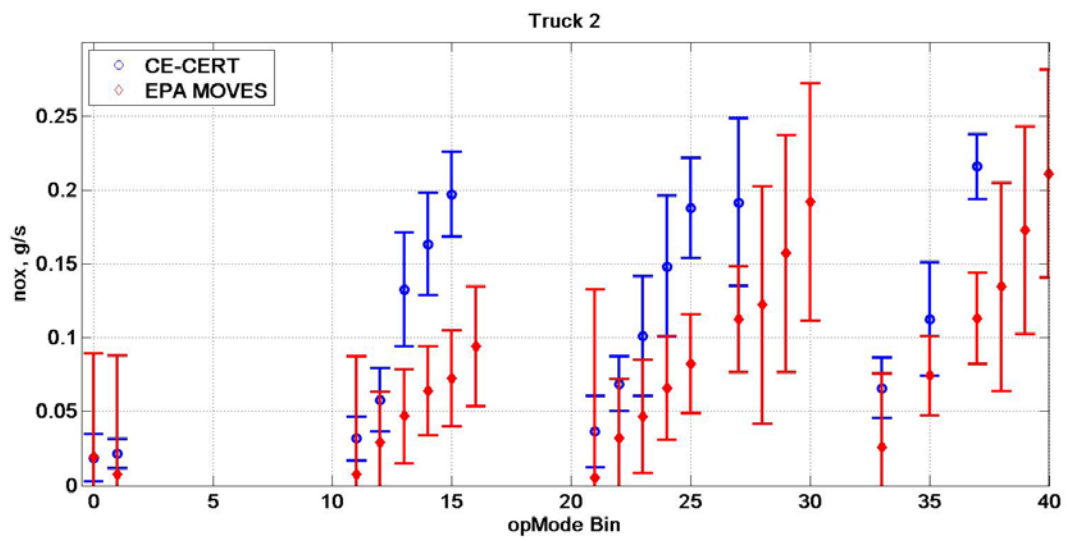
Figure 5-13. NOx emission rates for Truck 2 versus MOVES' rates
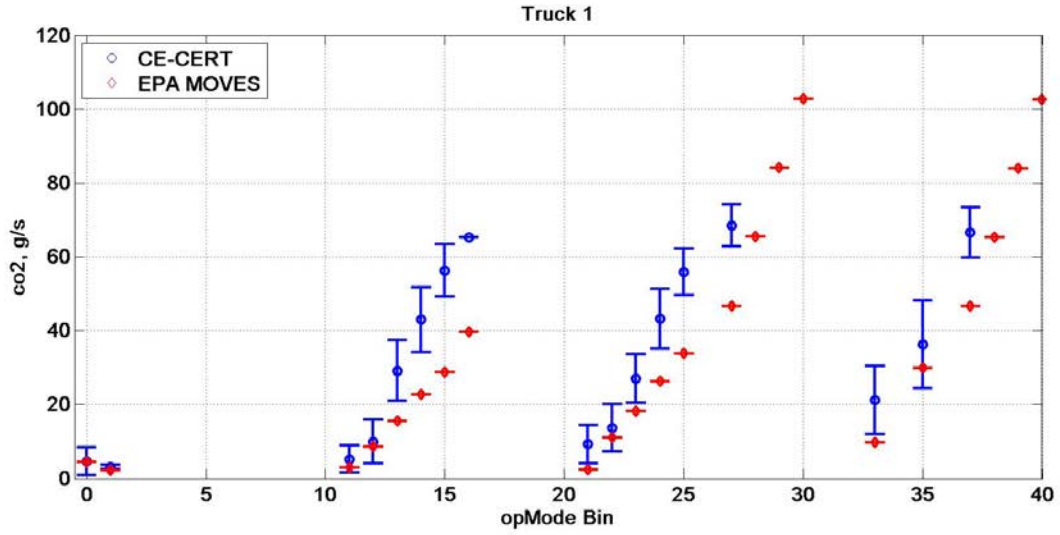
Figure 5-14. CO2 emission rates for Truck 1 versus MOVES' rates
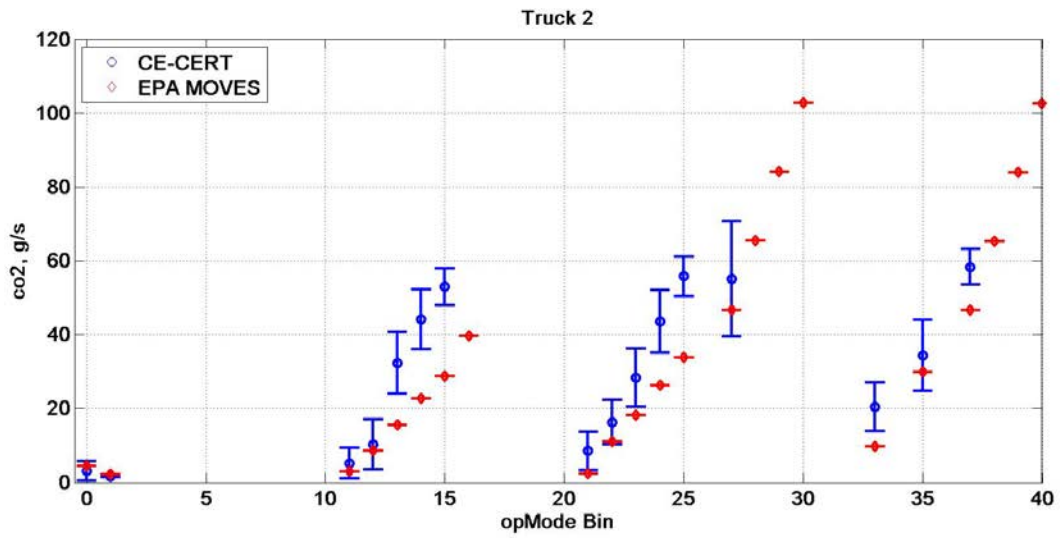
Figure 5-15. CO2 emission rates for Truck 2 versus MOVES' rates

5.4. Concluding remarks

To date, the effect of loaded weight on HDT emissions has not received much attention. However, it is an important topic, especially for areas with freight terminals or freight corridors. For example, some seaports may have unbalanced import and export freight traffic. Therefore, the average weight of HDTs traveling around those seaports may deviate from the typical HDT weight at which emissions are measured.

In this research, HDDT emissions were measured from two trucks at three different weight scenarios that represent a bobtail, a half loaded, and a fully loaded truck. It is observed that the increasing weight increases NOx and CO2 emissions proportionally. For HC and CO, the measured emission data are so noisy that no trend can be observed. This is not too surprising as HDDTs generally produce low HC and CO emissions, which makes them more prone to measurement errors and noise. In addition, it is found that PM emissions from these trucks cannot be confidently measured as most of them are lower than the detection limit of the measurement instrument. This finding attests the effectiveness of the DPF at reducing PM emissions from HDDTs.

The two trucks tested are of model years 2008 and 2009, which means they meet the 2007 emission standards. These trucks were purposefully selected because they were not available by the time MOVES was developed. In the current version of MOVES, these emission data "holes" are filled with placeholder emission values that are determined by factoring two emission standards. The measured NOx and CO2 emissions in this study show that the placeholder emission values for HDDTs meeting the 2007 emission standards are underestimated in most of the vehicle operating mode bins. These measured emission data may be used to update the emission tables in MOVES.

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Appendix A:

Sample Vehicle and Engine Characteristics

Table A-1. VIN and vehicle/engine characteristics for 100 light-duty vehicles

#	Vehicle Type	Year	Make	Model	VIN Number	Mileage	MPG (City/Highway)	Drive Type	Transmission	Engine	Hauling Capacity [Towing (lbs)/Cargo (ft)/Payload(lbs)]	Fuel Capacity (gal)	Base Engine Displacement
1	Conv	2000	Ford	Mustang		88663	17/25	RWD	Auto	4.6L V8	1000/7.7	15.7	4L
2	Conv	2007	BMW	M6		34737	19-Dec	RWD	Auto	5L V10	12.4ft/849lbs	18.5	5L
3	Conv	2008	Audi	TT 2.0T		29092	22/29	FWD	Auto	2L I4	8.8ft	14.5	2L
4	Conv	2003	BMW	Z4 Roadster		94749	21/29	RWD	Manual	3.0L I6	Payload: 551/9.2 ft Cargo	14.5	3L
5	Conv	2007	Volvo	C70		44312	21/29	FWD	Auto	2.5L I5	2000/12.8	15.9	5L
6	Conv	2007	VW	Beetle		26156	23/32	FWD	Auto	2.5L I5	27.1/772	14.5	2L
7	Conv	2007	Porsche	Boxter		36623	23/32	RWD	Auto	2.7L H6	9.9ft	16.9	2L
8	Conv	1999	Porsche	Boxter		34310	19/26	RWD	Manual	2.5L H6	11.2 ft	17	2L
9	Conv	2006	Mercedes-Benz	SL 500		45141	16/24	RWD	Auto	5L V8	10.2 ft	21.1	5L
10	Conv	2007	Mercedes-Benz	SLK 280		44249	20/27	RWD	Auto	3L V6	9.8 ft	18.5	3L
11	Conv	2008	Bentley	Continental GTC		111	11…18	AWD	Auto	6L W12	9.2ft	23.8	6L
12	Conv	2005	Nissan	350Z		55405	20/26	RWD	Manual	3L V6	6.8 ft	20	3L
13	Conv	2007	Honda	S2000		24326	20/26	RWD	Manual	2.2L I4	5ft	13.2	2L
14	Coupe	2007	Honda	Civic LX		45921	30/40	FWD	Auto	1.8L I4	1000/11.5ft	13.2	1L
15	Coupe	2005	Honda	RSX Type S		63119	23/31	FWD	Manual	2L I4	25.3ft	13.2	2L
16	Coupe	2001	Honda	Prelude		83408	22/27	FWD	Manual	2.2L I4	8.7ft	15.9	2L
17	Coupe	2006	Ford	Mustang GT		31810	19/28	RWD	Auto	4.6L V8	1000/13.1FT	16	4L
18	Coupe	2007	BMW	328i		34362	20/30	RWD	Auto	3L I6	Payload: 926/11.1 ft Cargo	16.1	3L
19	Coupe	2002	Honda	Accord EX-L		128742	20/28	FWD	Auto	3L V6	13.6ft	17.1	3L
20	Coupe	2001	Pontiac	Grand Prix GTP		64891	18/28	FWD	Auto	3.8L V6	16ft	17.5	3L
21	Coupe	2000	Acura	NSX-T		58154	17/24	RWD	Manual	3.2L V6	5ft	18.5	3L
22	Coupe	2006	Toyota	Camry Solara SLE		71961	23/33	FWD	Auto	2.4L I4	13.8ft	18.5	2L
23	Coupe	2008	Scion	TC		7882	21/29	FWD	Manual	2.4 I4	12.8ft	14.5	2L
24	Coupe	2006	Mercedes-Benz	CLS 4dr Coupe		42656	16/22	RWD	Auto	5L V8	15.8ft	21.1	5L
25	Coupe	2005	Chevrolet	Corvette		23701	18/28	RWD	Auto	6LV8	22.4ft	18	6L
26	Hatchback	2008	Dodge	Caliber SXT		28209	24/29	FWD	Auto	2L I4	2000/48ft	13.6	1L
27	Hatchback	2000	Ford	Focus ZX3		48237	25/33	FWD	Auto	2L I4	42.5ft Payload: 990lbs	13.2	2L
28	Hatchback	2009	Toyota	Venza		3677	19/26	FWD	Auto	3.5L V6	3500/70.1/825	17.7	3.5L
29	Hatchback	2008	Chevrolet	Aveo LS		46357	24/34	FWD	Auto	1.6L I4	42ft	11	1L
30	Hatchback	2008	Honda	Fit 4dr		12466	27/34	FWD	Auto	1.5L I4	41.9ft	10.8	1L
31	Hatchback	2007	Nissan	Versa		45413	28/35	FWD	Auto	1.8L I4	50.4ft	13.2	1L
32	Hatchback	2008	Volvo	C30 2DR T5		20067	19/28	FWD	Auto	2.5L I5	Towing: 1985/Payload: 882	15.9	2L
33	Hatchback	2008	Toyota	Matrix 5dr		43718	25/31	FWD	Auto	1.8L I4	1500/53.2	13.2	1L
34	Hatchback	2004	Mini	Cooper		77682	28/37	FWD	Auto	1.6L I4	Payload: 816/25 ft Cargo	13.2	1L
35	Hatchback	2008	Saturn	Astra		7453	24/32	FWD	Auto	1.8L I4	44.8ft	12	1L
36	Hatchback	2002	VW	Golf GLS		60512	24/31	FWD	Manual	2L I4	Payload: 902/41.8 ft Cargo	14.5	2L
37	Minivan	2008	Nissan	Quest		27366	16/24	FWD	Auto	3.5L V6	3500/148.1/1203lbs payload	20	3L
38	Minivan	2003	VW	Euro		92339	17/20	FWD	Auto	2.8L V6	1387lbs payload	21.1	2L
39	Minivan	2008	Dodge	Grand Caravan SXT		43013	16/23	FWD	Auto	3.8L V6	3600/140.6	20	3L
40	Minivan	2005	Chevrolet	Venture LS		142945	19/26	FWD	Auto	3.4L V6	140.7ft/1457lbs payload	25	3L
41	Minivan	2007	Honda	Odyssey EX-L w/DVD		34161	18/25	FWD	Auto	3.5L V6	3500/147.4/1349lbs payload	21	3L
42	Minivan	2005	Saturn	Relay RF2		53625	18/24	FWD	Auto	3.5L V6	3500/136.5	25	3L
43	Minivan	2007	Kia	Sedona		24986	18/25	FWD	Auto	3.8L V6	3500/141.5	21.1	3L
44	Minivan	1995	Nissan	Quest		86836	17/23	FWD	Auto	3L V6	3500 Towing Capacity	20	3L
45	Minivan	2010	Chrysler	Town and Country LWB LX			17/24	FWD	Auto	3.3L V6	3600/143.8/1200lbs payload	20	3.3L
46	Minivan	2010	Toyota	Sienna XLE			17/23	FWD	Auto	3.5L V6	3500/148.9/1380lbs payload	20	3.5L
47	Minivan	2006	Honda	Odyssey EX-L w/DVD RES		47028	20/28	FWD	Auto	3.5L V6	3500/147.4/1322lbs payload	21	3L
48	Minivan	2008	Toyota	Sienna CE		43236	19/26	FWD	Auto	3.5L V6	3500/148.9/1515lbs payload	20	3L
49	Sedan	2006	Bentley	Continental Flying Spur Sedan		10608	11….18	AWD	Auto	6L W12	16.7ft	23.8	6L
50	Sedan	2008	Mercedes-Benz	S63 AMG		40065	11…17	RWD	Auto	6.2L V8	16.3ft	23.8	6L

#	Vehicle Type	Year	Make	Model	VIN Number	Mileage	MPG (City/Highway)	Drive Type	Transmission	Engine	Hauling Capacity (Towing (lbs)/Cargo (ft)/Payload(lbs))	Fuel Capacity (gal)	Base Engine Displacement
51	Sedan	2008	Mazda	6i		44952	21/28	FWD	Auto	2.3L I4	58.7	18	2L
52	Sedan	2002	Nissan	Sentra SE-R		103002	27/33	FWD	Manual	2.5L I4	1001/11.6	13.2	1L
53	Sedan	2010	Mercedes-Benz	C300		4047	18/26	RWD	Auto	3L V6	12.4ft	17.4	3L
54	Sedan	2007	Jaguar	X-Type		25708	18/24	AWD	Auto	3L V6	16ft	16`	3L
55	Sedan	2008	Acura	TL		18904	18/27	FWD	Auto	3.2L V6	1000/12.5ft	17.1	3L
56	Sedan	2006	Nissan	Altima 2.5		21076	24/31	FWD	Auto	2.5L I4	1000/15.6ft	20	2L
57	Sedan	2006	Infiniti	M35x		69236	17/24	AWD	Auto	3.5L V6	1000/14.9	20	3L
58	Sedan	2004	Hyundai	Accent GL		74576	26/35	FWD	Auto	1.6L I4	11.8ft	11.9	1L
59	Sedan	2009	Chevrolet	Malibu LS		36661	22/30	FWD	Auto	2.2L I4	15.1ft	16	2.4L
60	Sedan	2002	Honda	Civic Ex		139423	32/37	FWD	Manual	1.7L I4	12.9ft	13.2	1L
61	Sedan	2009	Ford	Fusion S		43739	20/29	FWD	Auto	2.3L I4	15.8ft	17.5	2L
62	Sedan	2005	Subaru	Legacy GT Limited		54526	22/30	AWD	Auto	2.5L H4	11.4ft	16.9	2L
63	Sedan	1997	Lexus	ES 300		119487	19/26	FWD	Auto	3L V6	2000/13ft	18.5	3L
64	SUV	1998	Mercury	Mountaineer		96397	15/20	RWD	Auto	5L V8	4500/80.2	21	4L
65	SUV	2004	Lexus	GX470		98741	15/18	AWD	Auto	4.7L V8	6500/77.5	23	4L
66	SUV	2003	GMC	YUKON XL 1500		84578	13/17	RWD	Auto	5.3L V8	8400/131.6/2053	32.5	5L
67	SUV	2008	Audi	Q7		27866	14/19	AWD	Auto	3.6L V6	6600/88.7/1279	26.4	3L
68	SUV	2009	Jeep	Wrangler Unlimited 4x4 Sahara		2300	15/19	4WD	Auto	3.8L V6	3500/86.8/1150	22.5	3.8L
69	SUV	2001	Honda	CR-V EX		157907	22/25	AWD	Auto	2L I4	1000/67.2	15.3	2L
70	SUV	2006	Land Rover	Range Rover Sport Supercharged		26814	13/18	4WD	Auto	5L V8	7716/71	23.3	4L
71	SUV	2007	Lexus	RX350		83525	20/25	FWD	Auto	3.5L V6	3500/85ft	19.2	3L
72	SUV	2007	Ford	Edge		38901	18/25	FWD	Auto	3.5L V6	3500/69.6/1023lbs	19	3L
73	SUV	2007	Honda	Pilot EX-L		66324	18/24	FWD	Auto	3.5L V6	3500/87.6/1322	20.4	3L
74	SUV	2001	Honda	CR-V EX		157907	22/25	4WD	Auto	2L I4	1000/67.2	15.3	2L
75	SUV	2009	BMW	X5 3.0ix		8358	15/21	AWD	Auto	3L I6	6000/61.8/1290	22.5	3L
76	SUV	1997	Nissan	Pathfinder		79881	16/20	4X4	Auto	3.3L V6	3500/85/1175	21.1	3L
77	SUV	2007	Toyota	FJ Cruiser		19686	17/21	4WD	Auto	4L V6	5000/66.8/1325	19	4L
78	SUV	2003	Toyota	Rav4		48485	24/29	FWD	Auto	2L I4	1500/68.3/1169	14.7	2L
79	Truck	1999	GMW	Sierra 1500 Standard Cab		93335	15/19	4X4	Auto	5L V8	5000/40.5/2027	25	5L
80	Truck	2007	Ford	F-150 Supercrew Style Side		30739	15/19	RWD	Auto	5.4L V8	8000/47.9/1770	30	5L
81	Truck	2004	Nissan	Frontier LB Crew Cab XE		92158	17/20	RWD	Manual	3.3L V6	3500/1102	19.4	3L
82	Truck	2006	Honda	Ridgeline Standard Cab WB RTS		59805	16/21	4WD	Auto	3.5L V6	5000/41.4/1558	22	4L
83	Truck	2007	Chevrolet	Avalanche 1500 4X2		33972	15/21	RWD	Auto	5.3L V8	7200/1258	31	5L
84	Truck	2006	Toyota	Tundra Double Cab Limited		58020	16/19	RWD	Auto	4.7L V8	6800/1835	26.4	4L
85	Truck	2008	Dodge	Ram Quad Cab		40357	13/17	4WD	Auto	4.7L V8	6800/41/1280	35	4L
86	Truck	2008	GMC	Canyon Crew Cab SLE1		46169	18/24	RWD	Auto	2.9L I4	5500/1316	19	2
87	Truck	2002	Chevrolet	Avalanche 2500		117878	n/a	4WD	Auto	8.1L V8	11900/1957	37.5	8L
88	Truck	2004	Toyota	Tundra Double Cab Limited		60309	14/18	RWD	Auto	4.7L V8	6800/1820	26.4	4L
89	Van	2008	Ford	E-150 Cargo Van		29481	n/a	RWD	Auto	4.6L V8	6100/256.5/2650	35	4L
90	Van	2008	Ford	E-150 Cargo Van		25507	n/a	RWD	Auto	4.6L V8	6100/256.5/2650	35	4L
91	Van	2009	Ford	E-350 Cargo Extended Van XLT		19444	n/a	RWD	Auto	5.4L V8	6400/309.4/2990	35	5.4L
92	Van	2006	Ford	E-150 Cargo Van		62243	15/19	RWD	Auto	4.6L V8	8700/256.5/2275	35	4L
93	Van	2008	Ford	E-350 Cargo Super Duty Extended Van		45439	n/a	RWD	Auto	5.4L V8	6700/309.4/3000	35	5L
94	Wagon	2006	Ford	Freestar Wagon SE		70935	18/24	FWD	Auto	3.9L V6	3500/134.3/1200	26	3L
95	Wagon	2004	Volvo	V70 Turbo		80881	22/30	FWD	Auto	2.4L I5	3300/71.4ft	18.5	2L
96	Wagon	2004	Volvo	V70 Turbo		82465	22/30	FWD	Auto	2.4L I5	3300/71.4ft	18.5	2L
97	Wagon	2008	Scion	xB		21389	22/28	FWD	Auto	2.4L I5	69.9ft	14	2L
98	Wagon	2007	Volvo	V50		30401	22/29	FWD	Auto	2.4L I5	2000/62.9/992	15.9	2L
99	Wagon	2005	Volvo	XC70 T5		67645	18/24	AWD	Auto	2.5L I5	3300/71.4/1100	18	2L
100	Wagon	2007	Dodge	Magnum RT		38801	17/25	RWD	Auto	5.7L V8	3800/71.6/1150	19	5L

Table A-2. VIN and vehicle/engine characteristics for 50 heavy-duty trucks

#	Year	Make	Model	VIN	Odometer	Gross Vehicle Weight (lbs)	Engine Manufacturer	Engine Model	Engine Horsepower	Transmission Type	Drivetrain	Axle Count	Axle Capacity-Front (lbs)	Axle Capacity-Rear (lbs)	Rear Axle Ratio
1	2009	Volvo	780		154753	N/A	Volvo	D-16	500	Auto	RWD	3	14,600	38K	3.25
2	2003	Peterbilt	378		820550	48000	Caterpillar	C-12	445	13 Speed Manual	RWD	3	12K	36K	3.55
3	2002	Freightliner	Conventional FLD 120		832109	33001+	Cummins	N 14	435	10 Speed Manual	Twin Drive	3	12K	40K	3.73
4	2004	Peterbilt	387		674,893	48,000	Caterpillar	C-12	525	10 Speed Manual	RWD	3	12K	36K	3.55
5	2005	Kenworth	Construct W900		600070	33001+	Caterpillar	C-15	435	13 Speed Manual	Twin Drive	3	12K	36K	3.25
6	1993	Freightliner	FLD12064ST		401,364	33001+	Cummins	N-14		9 Speed Manual	Twin Drive	3	12K	38K	3.58
7	1997	Volvo	Aero WIA		1020407	33001+	Cummins	N-14		10 Speed Manual	Twin Drive	3	12K	38K	3.9
8	2007	Freightliner	Conventional ST120		330021	33000	Mercedes-Benz	MBE4000	410	Auto	RWD	2	12K	21K	3.58
9	2007	Freightliner	M2 112		329664	26001-33000	Mercedes-Benz	MBE4000	350	10 Speed Manual	FWD	2	12K	21K	3.42
10	2007	Peterbilt	357		20954	33001+	Caterpillar	C-13	335	10 Speed Manual	Twin Drive	3	20K	46K	NA
11	2007	Volvo	VNL64T-670		531813	50350	Volvo	VE-D12	465	13 Speed Manual	RWD	3	12.5K	38K	3.58
12	2005	International	4300		107241	25,500	International	DT466	220	Auto	RWD	2	8K	17.5K	5.57
13	2006	International	9400I		380487	52000	Cummins	ISX	475	10 Speed Manual	RWD	3	12K	40K	3.73
14	2007	Ford			83172	16,001 - 19,500	Ford	4.6L	200	Auto	Single Drive	2	7K	13.5K	4.88
15	2009	Western Star	4900FA		126181	50000	Mercedes-Benz	4000	450	Auto	RWD	3	12K	38K	3.42
16	2007	Peterbilt	Conventional 335		50899	60000	Cummins	ISC315	315	10 Speed Manual	RWD	3	20K	40K	4.63
17	2002	International	9200I		219709	52000	Cummins	ISM	330	10 Speed Manual	RWD	3	12K	40K	3.9
18	2001	Peterbilt	379 119		34210	33001+	Caterpillar	C15	475	18 Speed Manual	Single Drive	3	12K	40K	3.25
19	1999	Ottawa			43536	31730	Cummins	C8.3-C	215	Auto	RWD	2	11346	20384	N/A
20	2009	Peterbilt	386		246,929		Cummins	ISX	485	18 Speed Manual	Twin Drive	3	12K	38K	3.55
21	2005	International	4200		34150	26001-33,001	International	VT365	200	Auto	RWD	2			
22	2009	Volvo	VT830		162773	33001+	Cummins	ISX	500	13 Speed Manual	RWD	3	13200	38K	3.36
23	2007	Freightliner	CC132064T		319003	33001+	Detroit Diesel	S-60	515	13 Speed Manual	Twin Drive	3	12K	40K	3.58
24	2006	Peterbilt	379 127		504696	33,001+	Caterpillar	C-15 ACERT	475	18 Speed Manual	Twin Drive	3	12K	38K	3.36
25	2002	Freightliner	FL70		366789	27K	Caterpillar	3126B	330	6 Speed Manual	Single Drive	2	8K	19K	4.11
26	2005	Mack	600 CXN		298121	52000	Mack	AC-355/380	355	6 Speed Manual	RWD	2	12K	40K	3.86
27	2008	Chevrolet	CC5C042		13938	19500	GM	6.6L	330	Auto	RWD	2	7K	13500	4.56
28	2007	International	4000 Series 4400 LP		71371	19501-26000	IHC	D310	310	Auto	RWD	2			
29	2006	Ford	F650 Super Duty		154966		Cummins	ISO	260	Auto	RWD	3.9			
30	2005	International	7500		439917	46000	International	HT570	310	Auto	RwD	3	12K	34K	4.63
31	2007	Freightliner	Conventional Columbia		573062	52000	Detroit Diesel	S-60	470	10 Speed Manual	RWD	3	12K	40K	3.42
32	2007	GMC	C5500 C5E042		27733	16001-19500	Duramax	8.1L	225	Auto	Single Drive	2	7K	13.5K	
33	1997	Ford			944124	52000	Cummins	N 14	500	13 Speed Manual	Twin Drive	3	12K	40K	3.78
34	2004	Kenworth	T-600		690488		Caterpillar	C15	475	13 Speed Manual	RWD	3			3.7
35	2004	Volvo	780		663184	33001+	Cummins	ISX	450	10 Speed Manual	Twin Drive	3	12.5K	40K	3.58
36	2003	Kenworth	Construct T600		884513	52000	Caterpillar	3406/C15/C16	450	13 Speed Manual	RWD	3	12K	40K	
37	2003	Volvo	VNL64T		789509	33001+	Volvo	VE-D12	465	13 Speed Manual	Twin Drive	3	12K	38K	3.58
38	2005	Peterbilt	379 127		659713	33001+	Caterpillar	C15	550	13 Speed Manual	Twin Drive	3	12K	36K	3.55
39	2005	Western Star	4900EX		731912	33001+	Detroit Diesel	S-60	515	10 Speed Manual	Twin Drive	3	12K	40K	3.58
40	2005	International	4300		206810	26001-33000	International	DT466	225	6 Speed Manual	RWD	2	12K	21K	4.11
41	2003	Freightliner	FLD12042ST		392264	33001+	Detroit Diesel	60-12.7L	500	Manual	Twin Drive	3	12K	40K	3.58
42	2008	Peterbilt	389 127		426093		Cummins	ISX	450	10 Speed Manual	Twin Drive	3	12K	40K	3.36
43	2007	Freightliner	Conventional Columbia		330135	33001+	Caterpillar	C15	435	10 Speed Manual	RWD	3	12K	40K	3.42
44	2007	Freightliner	Conventional Columbia		277204	33001+	Detroit Diesel	DDC 60	455	10 Speed Manual	Twin Drive	3	12K	40K	3.58
45	2007	Frieghtliner	Conventional FLD120		44901	33001+	Mercedes-Benz	MBE4000	370	Auto	Twin Drive	3	20K	46K	4.89
46	2007	International	9400I		412457	52000	Cummins	ISX	475	10 Speed Manual	RWD	3	12K	40K	3.73
47	2007	Mack	CTP713B		100016	33001+	Mack	MP7-405M	370	Auto	3 Drive Axels	4	20K	44K	4.64
48	2007	Peterbilt	387		510625	33001+	Caterpillar	C-15	475	18 Speed Manual	Twin Drive	3	12K	36K	3.58
49	1998	International	9100		820896	5200	cummins	M11	350	10 Speed Manual	Twin Drive	3	12K	20K	2.93
50	1998	International	9200		958773	33001+	Cummins	M11	370	9 Speed Manual	Twin Drive	3	12K	40K	3.9

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Table A-2. VIN and vehicle/engine characteristics for 50 heavy-duty trucks (continued)

#	Suspension Type	Wheelbase (in)	Brake Type	Brakes-ABS	Retarder (Jake)	Sleeper Model	Fuel Tank Count	Fuel Tank Capacity	5th Wheel Type	Exhaust Type	Exhaust Location	Power Takeoff	Refrigerator	Air Conditioning	Body Type	Engine Type	Engine Cylinder Count
1	Air Ride	300	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Single	Under Chassis	No	Yes	Both		Diesel	6
2	Air Ride	248	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Dual	Cab Sides	No	No	Both	Tractor/Truck	Diesel	6
3	Air Ride	232	Air	Yes	Yes	High Roof	2	290	Air Slide	Single	Behind Cab	Yes	No	Both	Tractor/Truck	Diesel	6
4	Air Ride	238	Air	Yes	Yes	High Roof	2	300	Fixed	Single	Behind Cab	No	No	Both	Tractor/Truck	Diesel	6
5	Air Ride	262	Air	Yes	Yes	Mid Roof	2	240	Air Slide	Dual	Cab Sides	No	No	Both	Tractor/Truck	Diesel	6
6		179					2	200								Diesel	6
7		214					2	160								Diesel	6
8	Air Ride	300	Air	Yes	Yes	High Roof	2	200	N/A	Single	Behind Cab	No	Yes	Both	Conventional Cab/Truck	Diesel	6
9	Air Ride	210	Air	Yes	Yes	Flat Top	2	200	N/A	Single	Under Chassis	No	No	Cab	Conventional Cab/Truck	Diesel	6
10	Pete Air Trac	314	Air	Yes	Yes	N/A	1	99	N/A	Dual	Besides Cab	Yes	No	Cab	Tandem Truck	Diesel	6
11	Air Ride	220	Air	Yes	Yes	High Roof	2	250	Air Slide	Single	Behind Cab	No	Yes	Both	Tractor/Truck	Diesel	6
12	Spring	250	Hydraulic	Yes	No	Day Cab	1	55	N/A	Single	Under Chassis	No	Yes	Missing	Conventional Cab/Truck	Diesel	6
13	Air Ride	232	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Single	Behind Cab	No	No	Both	Tractor/Truck	Diesel	6
14	Spring	186	Hydraulic	Yes	No	Day Cab	1	33	N/A	Single	Under Chassis	No	No	Cab	Tilt Cab/Truck	Diesel	6
15	Air Ride	265	Air	Yes	Yes	High Roof	2	250	Air Slide	Dual	Cab Sides	No	Yes	Both	N/A	Diesel	6
16	Spring	210	Air	Yes	Yes	Day Cab	2	134	N/A	Dual	Cab Sides	Yes	No	N/A	Tandem	Diesel	6
17	Air Ride	171	Air	Yes	Yes	Day Cab	2	200	Air Slide	Single	Behind Cab	No	No	Cab	N/A	Diesel	6
18	Air Ride	276	Air	Yes	Yes	Flat Top	2	240	Air Slide	Dual	Cab Sides	Yes	N/A	Both	Tractor/Truck	Diesel	6
19	Spring	114	Air	N/A	No	Day Cab	1	50	Fixed	Single	Cab Sides	Yes	No	Cab	N/A	Diesel	6
20	Air Ride	241	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Dual	Behind Cab	No	Yes	Both	Tractor/Truck	Diesel	6
21	Spring	156	Hydraulic	Yes	No	Day Cab	1	55	N/A	Single	Under Chassis	Yes	No	Cab	Conventional Cab/Truck	Diesel	8
22	Air Ride	257	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Dual	Behind Cab	No	No	Both	Tractor/Truck	Diesel	6
23	Air Ride	265	Air	Yes	Yes	High Roof	2	300	Air Slide	Single	Under Chassis	No	Yes	Both	Tractor/Truck	Diesel	6
24	Air Ride	280	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Dual	Cab Sides	No	No	Both	Tractor/Truck	Diesel	6
25	Air Ride	252	Air	Yes	No		2	90	N/A	Single	Under Chassis	No	No	Cab	Conventional Cab/Truck	Diesel	6
26	Air Ride	187	Air	Yes	No	Day Cab	2	160	Manual	Single	Behind Cab	No	No	Cab	Tractor/Truck	Diesel	6
27	Spring	152	Hydraulic	N/A	No	Day Cab	2	40	NA	Single	Under Chassis	Yes	No	Cab	Single Axle Dump	Diesel	8
28	Air Ride	190	Air	Yes	No	N/A	2	100	NA	Single	Under Chassis	No	No	Cab	Conventional Cab/Truck	Diesel	6
29	Air Ride	218	Air	Yes	No		1	100	Missing	Single	Under Chassis	No	No	Cab	Incomplete Chassis Truck	Diesel	6
30	Air Ride	293	Air	Yes	Yes	Mid Roof	2	146		Single	Under Chassis	No	Yes	Both	Conventional Cab/Truck	Diesel	6
31	Air Ride	232	Air	Yes	Yes	High Roof	2	260	Air Slide	Single	Behind Cab	No	No	Both	Tractor/Truck	Diesel	6
32	Spring	236	Air/Hydraulic	Yes	Yes	N/A	2	40	N/A	Single	Under Chassis	Yes	No	Cab	Crew Chassis/Truck	Diesel	8
33	Air Ride	253	Air	Yes	Yes	High Roof	2	300	Air Slide	Single	Under Chassis	No	Yes	Both	Tandem/Truck	Diesel	6
34	Air Ride	246	Air	Yes	Yes	High Roof	2	300	Air Slide	Dual	Behind Cab	No	Yes	Both		Diesel	6
35	Air Ride	238	Air	Yes	Yes	High Roof	2	240	Air Slide	Single	Behind Cab	No	No	Both	Tandem/Truck	Diesel	6
36	Air Ride	232	Air	Yes	Yes	Mid Roof	2	240	Air Slide	Single	Behind Cab	No	No	Both	Tractor/Truck	Diesel	6
37	Air Ride	230	Air	Yes	Yes	High Roof	2	318	Air Slide	Single	Behind Cab	No	No	Both	Tractor/Truck	Diesel	6
38	Air Ride	262	Air	Yes	Yes	High Roof	2	300	Air Slide	Dual	Cab Sides	No	Yes	Both	Tractor/Truck	Diesel	6
39	Air Ride	280	Air	Yes	Yes	Mid Roof	2	284	Air Slide	Dual	Cab Sides	No	Yes	Both	Tractor/Truck	Diesel	6
40	Spring	273	Air	Yes	No	Day Cab	2	110	N/A	Single	Under Chassis	No	No	Cab	Conventional Cab/Truck	Diesel	6
41	Air Ride	259	Air	Yes	Yes	High Roof	2	280	Air Slide	Dual	Cab Sides	No	No	Both	Tractor/Truck	Diesel	6
42	Air Ride	264	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Dual	Cab Sides	No	No	Both	Tractor/Truck	Diesel	6
43	Air Ride	224	Air	Yes	Yes	Mid Roof	1	100	Air Slide	Single	Behind Cab	No		Both	Tractor/Truck	Diesel	6
44	Air Ride	239	Air	Yes	Yes	High Roof	4	400	Air Slide	Single	Behind Cab	NO	Yes	Both	Tractor/Truck	Diesel	6
45	Spring	240	Air	Yes	Yes	Day Cab	1	60	N/S	Single	Behind Cab	No		Cab	Cement Truck	Diesel	6
46	Air Ride	232	Air	Yes	Yes	Mid Roof	2	300	Air Slide	Single	Behind Cab	NO	NO	Both	Tractor/Truck	Diesel	6
47	Air Ride	213	Air	Yes	Yes	Day Cab	2	150	N/A	Single	Behind Cab	Yes	NO	Cab	Dump Truck	Diesel	6
48	Air Ride	236	Air	Yes	Yes	High Roof	2	262	Air Slide	Dual	Behind Cab	NO	Yes	Both	Tractor/Truck	Diesel	6
49	Air Ride	168	Air	Yes	Yes	Day Cab	2	200	Air Slide	Single	Behind Cab	NO	No	Cab	Tandem/Truck	Diesel	6
50	Air Ride	238	Air	Yes	Yes	Mid Roof	2	200	Air Slide	Single	Under Chassis	No	No	Both	Tandem/Truck	Diesel	6

Appendix B:
Guidance on Conducting License Plate Survey

Introduction

In the development of on-road mobile source emission inventories, reliable data on vehicle fleet characteristics such as age distribution and alternative vehicle fuels and technologies fraction are as important as accurate data concerning vehicle activity and emission rates. For example, fleets with a higher percentage of older vehicles will have higher emissions for two reasons. First, older vehicles have typically been driven more miles and have experienced more deterioration in emission control systems. Second, a higher percentage of older vehicles also means that there are more vehicles in the fleet that do not meet newer, more stringent emissions standards. Studies have shown that the class and age distributions of vehicle fleets can vary significantly from area to area[1]. Therefore, for state implementation plan (SIP) and transportation conformity purposes, the U.S. Environmental Protection Agency (EPA) recommends that agencies develop local vehicle class and age distributions[2].

The current practice in developing vehicle fleet data relies heavily on the use of vehicle registration database. This practice is sufficient for creating base vehicle fleet characteristics for an area, but it also has certain limitations. For instance, a significant fraction of vehicle miles traveled (VMT), and thus emissions, for an area could be attributable to vehicles registered outside the area[3]. This is usually the case for, for instance, tourist areas and areas with major transportation hubs such as international airports and seaports. Applying inaccurate vehicle fleet characteristics could have significant impacts on the resulting emission inventories.

Furthermore, some vehicle emission and air quality studies may benefit from careful characterization of vehicle fleet at a more refined scale. For example, a project-level analysis of vehicle emissions may be performed using vehicle fleet data localized to the project. In another example, a modeling of regional air quality during ozone episodes may be based on emissions estimated using vehicle fleet data specific to the modeling period. Yet, in another example, a measurement of pollutant concentration near roadways for dispersion model development or validation may be conducted in conjunction with vehicle fleet characterization during the measurement in order to reduce biases in the emission estimates.

The need for better vehicle fleet data mentioned above can be met by conducting vehicle license plate survey. The survey is aimed at collecting the license plate numbers of vehicles that are present at the location of interest during the survey period. There are two types of license plate survey that may be conducted—on-road survey and parking lot survey. This guidance is focused on the on-road survey. It provides guidelines for selecting survey sites, videotaping vehicular traffic in the field, and extracting license plate numbers from videos.

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[1] Malcolm, C., Younglove, T., Barth, M., and Davis, N. (2003). Mobile-source emissions: analysis of spatial variability in vehicle activity patterns and vehicle fleet distributions. *Transportation Research Record*, 1842, 91-98.

[2] U.S. Environmental Protection Agency (2009). *Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity*. Report No. EPA-420-B-09-042, December.

[3] Lutsey, N. (2009). Assessment of out-of-state truck activity in California. *Transport Policy*, 16(1), 12-18.

Selecting Survey Sites

There are two aspects to the selection of license plate survey sites—the general area where the survey will be conducted and the location of the camera set up and videotaping. These two aspects should be considered together. The considerations include:

- The general area where the survey will be conducted should be selected according to the purpose of the study. For example, for a project-level emission analysis the survey sites should be at or within the vicinity of the project. For a regional emission inventorying purpose, the survey sites should be on major roadways in the region. Figure B-1 shows an example of survey sites that are appropriate for a study to examine the characteristics of out-of-region vehicles. In this example, areas on major highways that carry traffic into and out of the region around the boundary of the region are selected.

Figure B-1. Survey sites for out-of-region vehicles study

- If there are multiple roadways in the general area that has been selected for conducting license plate survey, the roadways that carry high volume of traffic are preferred for two reasons. First, having high volume of traffic means more number of license plates can be captured within the same amount of time. Second, vehicles on a roadway with high volume of traffic are more likely to travel at a slower speed, which makes it easier to read the license plate numbers.

- The location of the camera set up and videotaping can be on roadside or on a bridge overcrossing the roadway. If available and suitable, the latter is preferred for two reasons.

First, it is safer. Second, unlike a roadside location from which the view of the traffic in the inner lanes may be occluded, a location on a bridge allows for the traffic in any of the lanes to be captured.

- In the case of a bridge, the surveyor should find one with a wide shoulder lane or sidewalk that provides enough working space for setting up video cameras and other equipment (see the left photo in Figure B-2). Also, most bridges have fences on either or both sides of the bridge. These fences may be made of wire mesh, steel bar, or similar material. A bridge without fences or with ones that have large opening spaces is preferred (see the right photo in Figure B-2).

Figure B-2. Location of camera set up and videotaping

- In the case of roadside, the surveyor should find a section of the roadway with a sidewalk, an elevated bank, a wide median, or a safe spot away from the traffic.

- Depending on the survey location, a permit may be required in order to occupy the site and videotape the traffic. The permit may be acquired from the responsible agency such as the City (for city streets), the County (for county roads), and the state department of transportation (for highways). The permit application and approval process may take days or weeks. Therefore, the surveyor should apply for it as soon as the survey location has been identified.

Videotaping Vehicular Traffic

Equipment

The equipment required to perform a successful on-road license plate survey can vary by survey site, but the necessary items are listed below:

- *Video Cameras* – Choice of cameras is especially important when videotaping vehicular traffic. A high definition (HD) camera gives better resolution of the images than a standard definition (SD) one. A strong optical zoom (as opposed to digital zoom) is needed to get a clear view of the license plates. Storage space is another consideration, as cameras may have to hold multiple hours of video at any point in time.

- *12V Marine Battery* – When using the videotaping mode with the highest quality (typically the standard play or SP mode), stock camera batteries provide approximately 45-60 minutes of filming time. If the survey session(s) for the day is longer than that, additional power will be needed. A marine battery can provide sufficient, stable power to run two HD cameras in SP mode for at least eight hours.

- *12V to 120V DC-AC Converter* – This adapter is required to connect the cameras to the marine battery. It is still recommended to leave the stock batteries in the camera in the event that this adapter fails.

- *Tripods* – A standard tripod is acceptable, but tripods with thicker, sturdier legs are preferred. Smaller tripods are at risk of being blown over, necessitating careful observation or heavy anchors.

- *Safety Vests* – Reflective safety vests help to ensure the safety of the surveyors on site.

- *Permits* – An on-road survey requires the appropriate encroachment or filming permit approved by the city, county, or state.

In addition to the necessary items above, the following optional items may also be useful:

- *Digital Multimeter* – This is useful for keeping track of the 12V charge level.

- *12V Batter Charger* – This is needed to recharge the 12V battery after the filming.

- *Extension Cords* – They allow for optimal positioning of the cameras.

- *Traffic Cones* – They are helpful for guarding the working space.

- *Personal Supplies* – The surveyor may need to perform the filming for several hours at a time. This means that matters such as hydration, food, and shade should be prepared for before the start of the survey.

Procedures

The procedures for videotaping vehicular traffic vary by circumstances. Below are some basic procedures and considerations that may be used as a general guideline.

- *Survey Period* – The videotaping should be performed during peak hours for the same reasons as performing it on roadways with high traffic volume. First, the number of vehicles is high so more license plates can be captured. Second, the traffic is more likely to be congested, allowing the license plate numbers to be clearly seen on the video playback.

- *Initial Setup* – At least 15 minutes for setting up and taking down the equipment should be allotted on both ends of the planned filming interval. Place the 12 V marine battery and the connecting DC-AC adapter in the center of the working space. Use extension cords, if necessary, to help provide flexibility of camera placement. Also, tie down each tripod to a centered weight between their legs to provide stability. However, tying cameras to a fence is not a good idea, especially in the wind, as it will cause video shaking and stuttering. If possible, the initial setup should be tested prior to the planned filming day to ensure that all the equipment is working properly.

- *Camera Angle and Zoom Level* – One of the most critical aspects to capturing good license plate footages is the shooting angle of the video camera. On an overpass, the camera should be as close to the ground as possible and zoomed to a point on one lane of traffic so that the camera view is between 30 and 45 degree angle with the road surface. Conversely, while filming on roadside, the tripods should be set at their maximum heights to properly record the plates.

  Another critical aspect is the camera's zoom level. Adjust the camera such that the lane markers of one lane are on the edges of the screen (use maximum zoom if necessary). The license plate must be visible in the camera view for at least two full seconds to be properly processed. It is recommended that a trial-and-error approach be used to find an optimal shooting angle and zoom level.

  During a survey session, cameras should be checked every 15-30 minutes for shooting angle, zoom level, as well as power. As the lens is set to near its maximum zoom, any slight adjustment can take the focus completely off of the license plates. In some cases, the surveyor may contact the camera or the tripod accidentally, which can make the shooting angle and zoom level no longer optimal.

- *Camera Glare and Heat* – Morning and late afternoon glare can be very problematic to an on-road license plate survey. The most effective solution is manual readjustment of the "exposure" setting on the camera. This could almost entirely eliminate glare, but needs to be checked every 15-20 minutes as the position of the sun changes.

  In addition, video cameras can be prone to overheating if being used in the sun unprotected. This is generally not a problem, but in particularly hot areas, cameras can get too hot and temporarily shut down. If this happens, try to provide shade protection for the camera (draping a towel above or over the camera suffices).

- *Camera Rotation* – Depending on the number of lanes being surveyed, length of the survey, and the number of available cameras, a camera rotation scheme may be required. An example is given below.

4 Hours of Survey with 2 Video Cameras	
For 3-Lane Highways	**For 4-lane Highways**
First 80 minutes – Lanes 1 and 2 Next 80 minutes – Lanes 2 and 3 Last 80 minutes – Lanes 3 and 1	First 2 hours – Lanes 1 and 3 Last 2 hours – Lanes 2 and 4

After each survey session, there are a few routines that should be performed to prepare for the next day of survey. It is important that these routines are performed immediately after each session, especially if multiple sessions are planned for the same day.

- *Battery Charging* – Each camera should be fully charged as the stock battery serves to protect against any accidental shutdowns of the main power source. Each 12V marine battery should also be charged overnight to provide enough power for the next day of filming (charging mid-day is not necessary).

- *Unloading Data* – Even cameras with high capacity data storage have a fairly limited recording time. Every time the equipment is packed up, the data stored on the camera should be unloaded onto an available computer or external hard drive.

Extracting License Plate Numbers

Due to the high costs of automated license plate recognition systems, manual extraction of license plate numbers can prove to be a viable alternative. A typical setup involves a team of data technicians; each assigned a set of videos from the survey. The process is straightforward; going through the tape, pausing at each vehicle, and recording the vehicle information on a spreadsheet. If possible, a dual-computer or dual-monitor setup such as that shown in Figure B-3 is desirable as it will help make the processing faster.
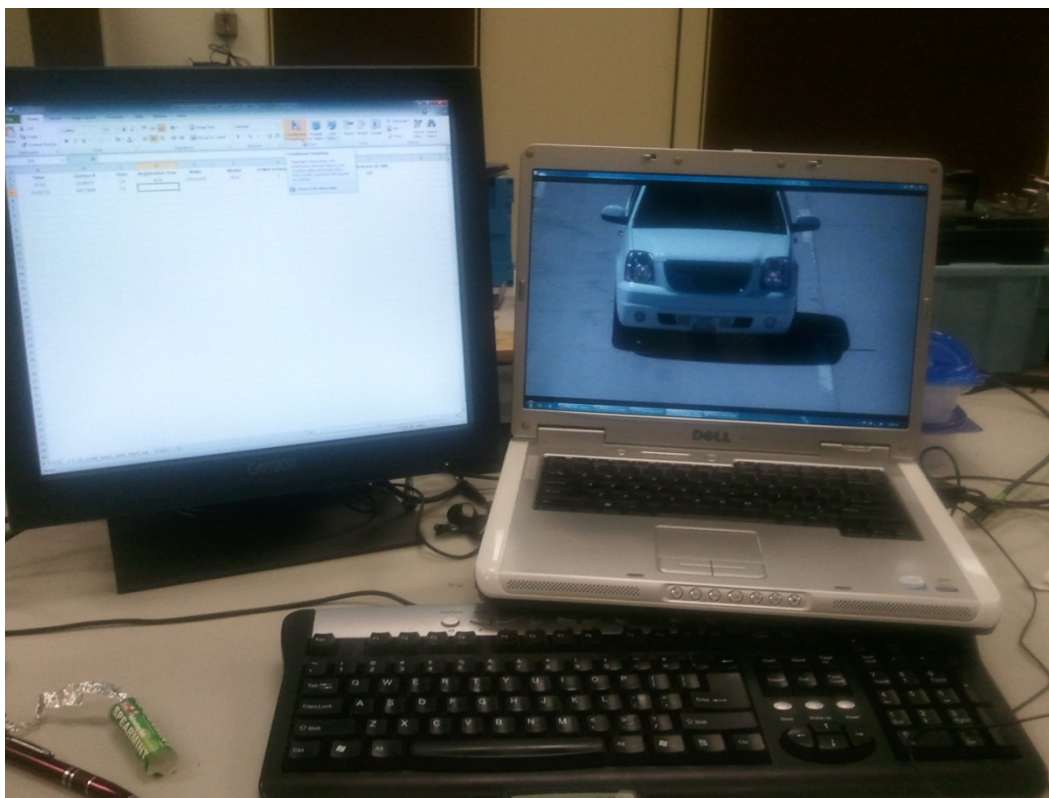
Figure B-3. Dual-computer setup for license plate number extraction

The main advantage of manual extraction is the interpretation ability of the data technician. Due to the relatively ad hoc nature of the data collection process, the size of a license plate number, the amount of lighting on the plate, and the amount of time the plate is captured on film can vary greatly from one video to another. The human eye, however, is quick to adjust and able to interpret license plates. Moreover, the manual extraction technique allows for the collection of more vehicle attributes than just the license plate number, for example, state of registration, vehicle class, or even vehicle make and model in some cases.

On the other hand, manual extraction takes time. Even with a dual-monitor setup, the amount of time to process one hour of video can take between two and four hours depending on the traffic volume and the quality of the video images.

Appendix C:

Results of Vehicle License Plate Surveys
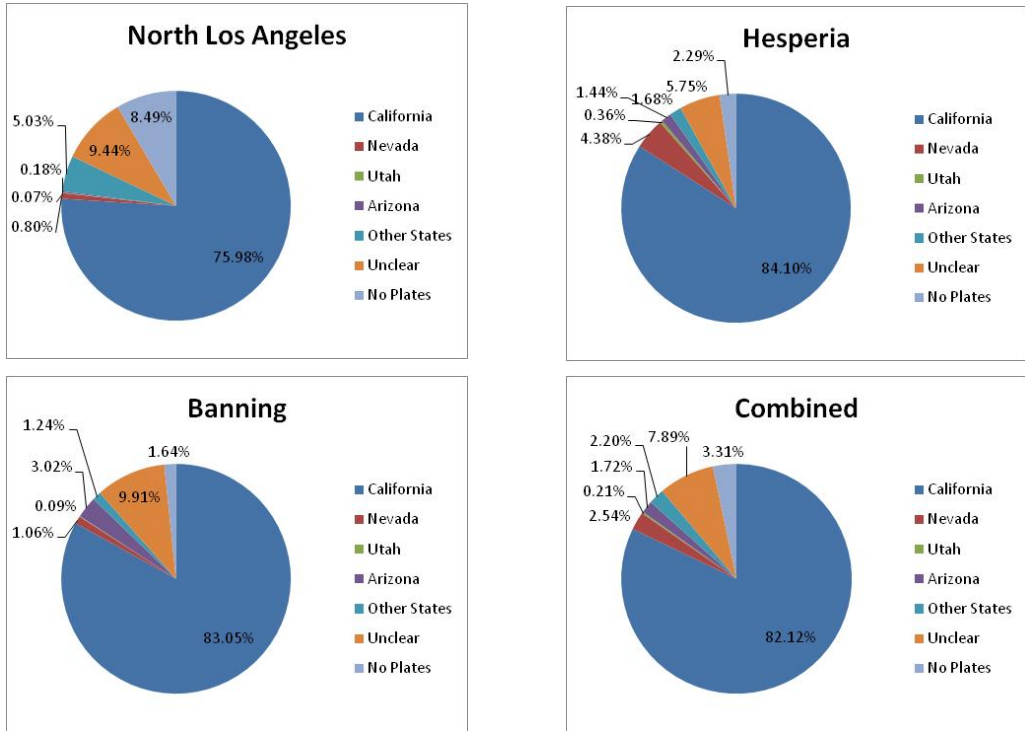
Figure C-1. State of registration – Los Angeles, weekday

Figure C-2. State of registration – Los Angeles, weekend

North Las Vegas

2.66%
22.39%
22.45%
2.25%
1.61%
4.40%
44.24%

- From California
- From Nevada
- From Utah
- From Arizona
- Other States
- Unclear
- No Plates

East Las Vegas

0.94%
9.08%
1.23%
11.29%
0.84%
7.03%
69.59%

- California
- Nevada
- Utah
- Arizona
- Other States
- Unclear
- No Plates

South Las Vegas

1.44%
2.48%
1.55%
1.51%
9.31%
32.15%
51.56%

- California
- Nevada
- Utah
- Arizona
- Other States
- Unclear
- No Plates

Combined

1.49%
1.85%
13.27%
4.10%
1.87%
19.21%
58.21%

- California
- Nevada
- Utah
- Arizona
- Other States
- Unclear
- No Plates

Figure C-3. State of registration – Las Vegas, weekday

North Las Vegas

2.85%
35.92%
5.50%
11.52%
5.74%
6.73%
31.74%

- California
- Nevada
- Utah
- Arizona
- Other States
- Unclear
- No Plates

East Las Vegas

0.85%
13.51%
0.88%
18.52%
5.75%
0.68%
59.80%

- California
- Nevada
- Utah
- Arizona
- Other States
- Unclear
- No Plates

South Las Vegas

3.85%
5.43%
2.27%
2.18%
45.97%
4.83%
35.46%

- California
- Nevada
- Utah
- Arizona
- Other States
- Unclear
- No Plates

Combined

1.71%
2.78%
13.39%
4.82%
27.45%
3.24%
46.61%

- California
- Nevada
- Utah
- Arizona
- Other States
- Unclear
- No Plates

Figure C-4. State of registration – Las Vegas, weekend
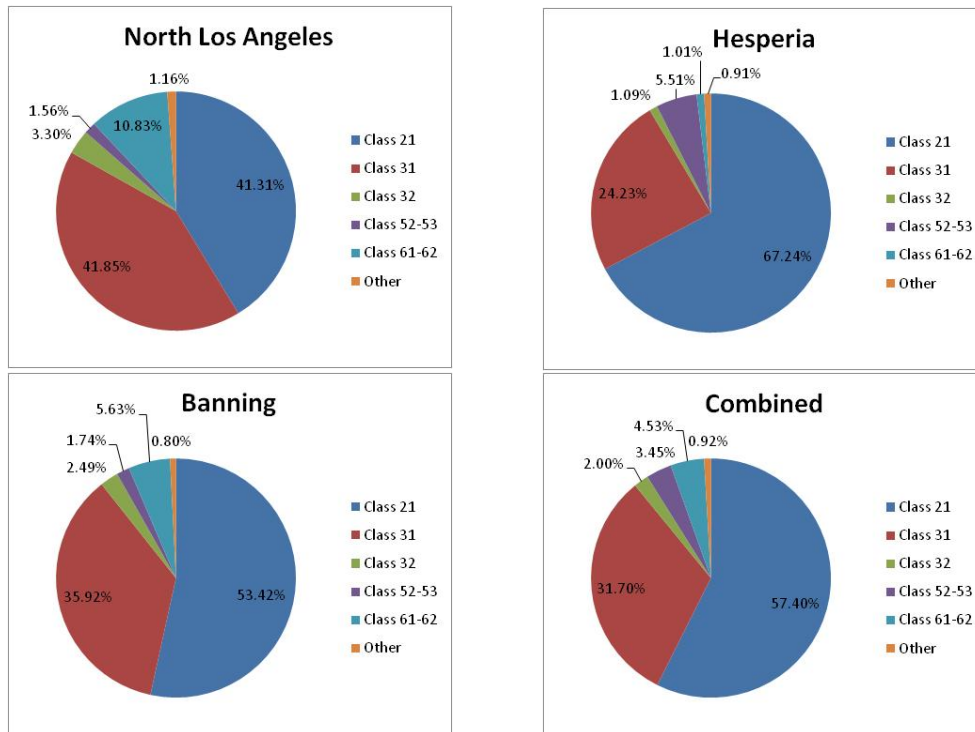
Figure C-5. MOVES SourceType – Los Angeles, weekday
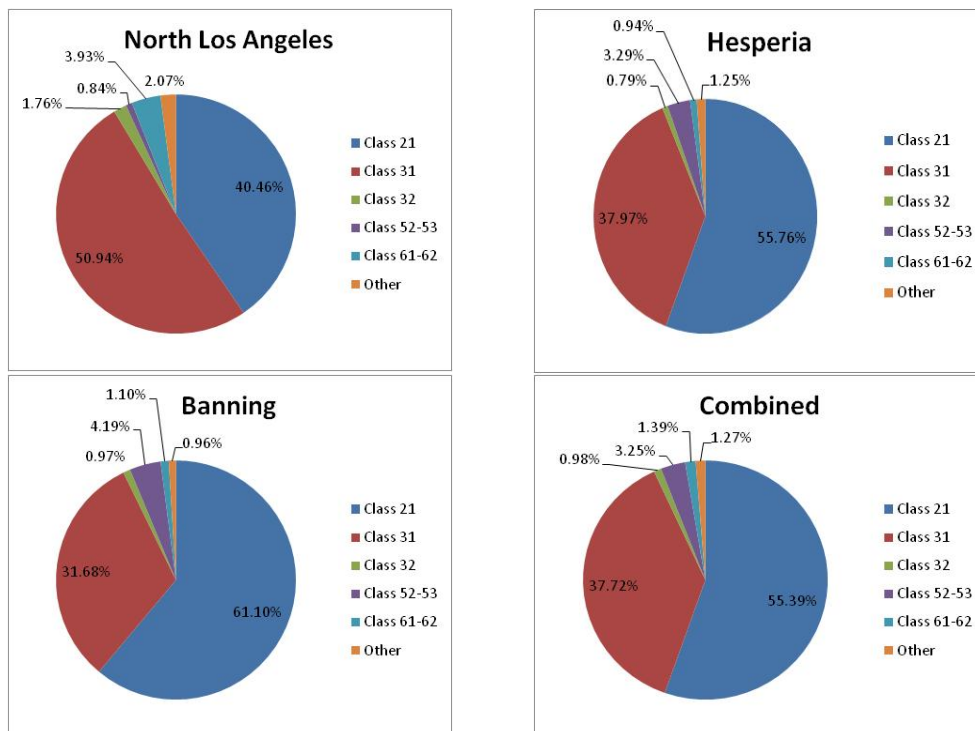
Figure C-6. MOVES SourceType – Los Angeles, weekend

North Las Vegas

- Class 21 — 46.70%
- Class 31 — 29.84%
- Class 32 — 2.07%
- Class 52-53 — 11.53%
- Class 61-62 — 6.61%
- Other — 3.25%

East Las Vegas

- Class 21 — 53.73%
- Class 31 — 38.15%
- Class 32 — 1.48%
- Class 52-53 — 4.52%
- Class 61-62 — 0.34%
- Other — 1.78%

South Las Vegas

- Class 21 — 45.29%
- Class 31 — 41.82%
- Class 32 — 3.06%
- Class 52-53 — 1.40%
- Class 61-62 — 6.57%
- Other — 1.86%

Combined

- Class 21 — 49.55%
- Class 31 — 37.38%
- Class 32 — 2.10%
- Class 52-53 — 5.16%
- Class 61-62 — 3.68%
- Other — 2.14%

Figure C-7. MOVES SourceType – Las Vegas, weekday

North Las Vegas

- Class 21 — 35.04%
- Class 31 — 34.47%
- Class 32 — 15.60%
- Class 52-53 — 5.64%
- Class 61-62 — 4.49%
- Other — 4.76%

East Las Vegas

- Class 21 — 56.88%
- Class 31 — 37.00%
- Class 32 — 0.27%
- Class 52-53 — 3.70%
- Class 61-62 — 0.15%
- Other — 2.00%

South Las Vegas

- Class 21 — 45.74%
- Class 31 — 47.98%
- Class 32 — 1.01%
- Class 52-53 — 0.28%
- Class 61-62 — 2.72%
- Other — 2.27%

Combined

- Class 21 — 48.65%
- Class 31 — 39.26%
- Class 32 — 3.28%
- Class 52-53 — 4.19%
- Class 61-62 — 1.88%
- Other — 2.74%

Figure C-8. MOVES SourceType – Las Vegas, weekend
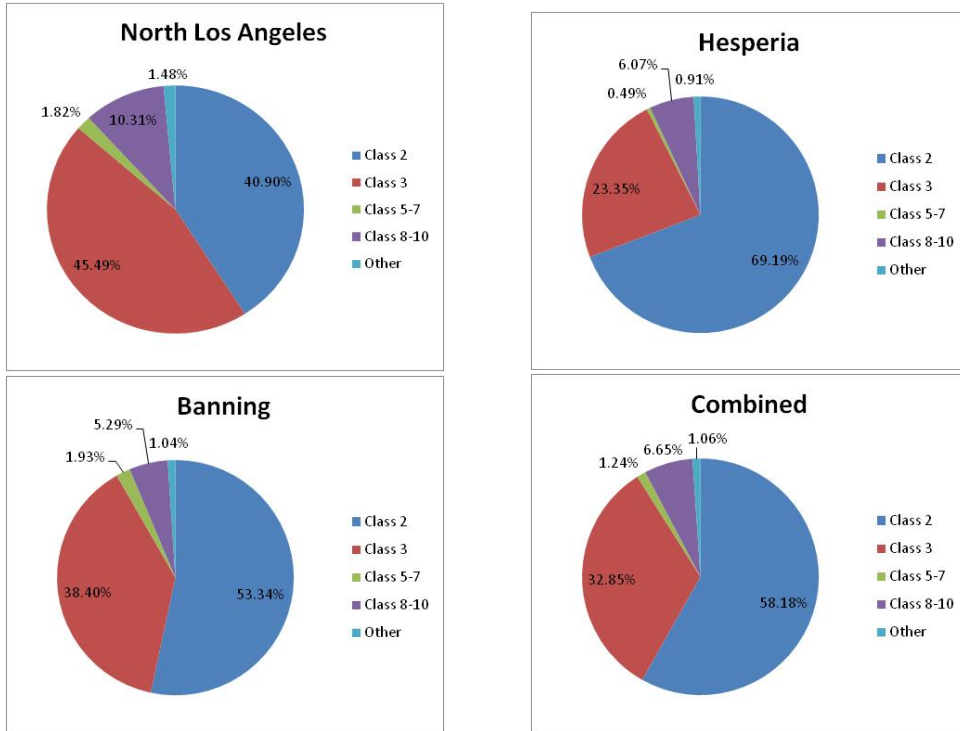
Figure C-9. FHWA vehicle class – Los Angeles, weekday
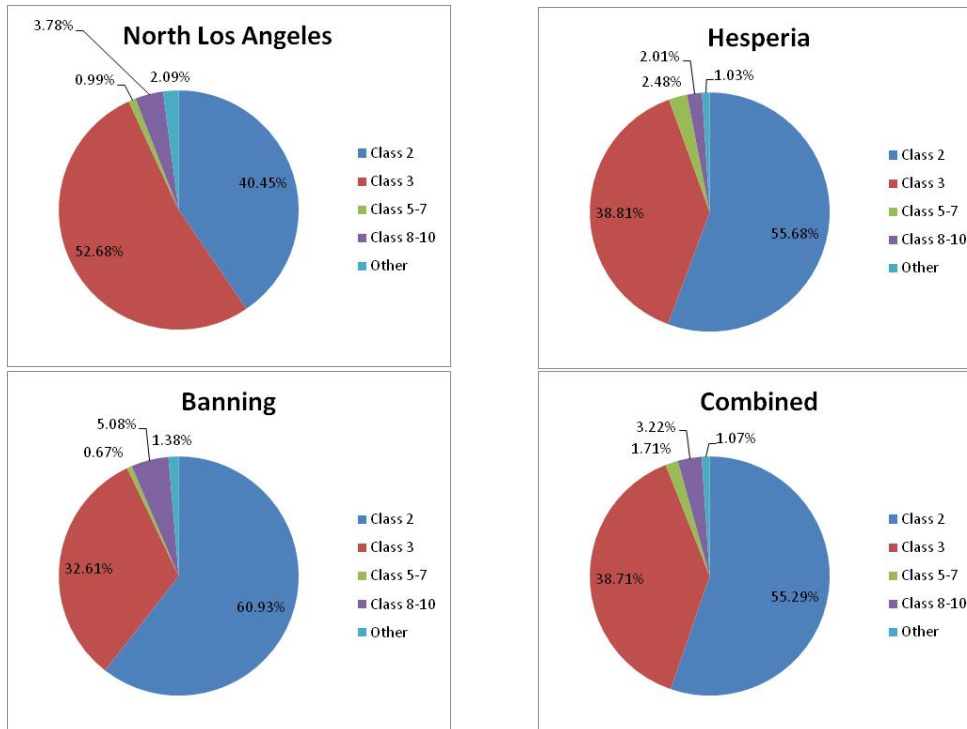
Figure C-10. FHWA vehicle class – Los Angeles, weekend

North Las Vegas

46.43% Class 2
31.02% Class 3
13.72% Class 5-7
6.82% Class 8-10
2.01% Other

East Las Vegas

53.76% Class 2
39.55% Class 3
2.69% Class 5-7
3.18% Class 8-10
0.82% Other

South Las Vegas

45.26% Class 2
44.47% Class 3
1.55% Class 5-7
6.42% Class 8-10
2.30% Other

Combined

49.47% Class 2
39.10% Class 3
4.87% Class 5-7
5.01% Class 8-10
1.55% Other
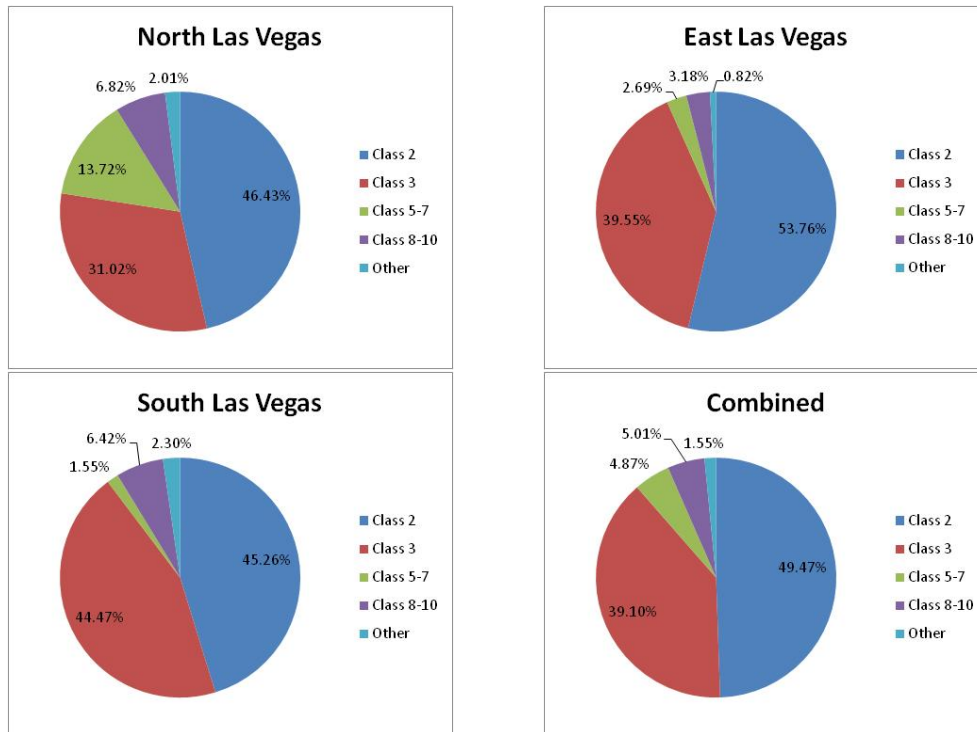
Figure C-11. FHWA vehicle class – Las Vegas, weekday

North Las Vegas

36.08% Class 2
35.45% Class 3
15.62% Class 5-7
9.55% Class 8-10
3.30% Other

East Las Vegas

56.91% Class 2
37.20% Class 3
3.47% Class 5-7
1.37% Class 8-10
1.05% Other

South Las Vegas

45.72% Class 2
49.01% Class 3
0.41% Class 5-7
2.72% Class 8-10
2.15% Other

Combined

49.02% Class 2
39.90% Class 3
5.54% Class 5-7
3.66% Class 8-10
1.87% Other

Figure C-12. FHWA vehicle class – Las Vegas, weekend

Appendix D:

Results of Truck Telematics Data Analysis

Table D-1. RoadTypeDistribution – U.S.

Road Type	Description	January 2010			July 2010		
		VMT	Fraction w/ Off-Network	Fraction w/o Off-Network	VMT	Fraction w/ Off-Network	Fraction w/o Off-Network
2	Rural Restricted	993,986	0.2201	0.3350	1,343,507	0.1169	0.2373
3	Rural Unrestricted	904,069	0.2002	0.3047	1,641,084	0.1428	0.2898
4	Urban Restricted	554,439	0.1228	0.1869	880,417	0.0766	0.1555
5	Urban Unrestricted	514,375	0.1139	0.1734	1,797,233	0.1564	0.3174
	Total	*4,516,445*	*1.0000*	*1.0000*	*11,494,802*	*1.0000*	*1.0000*

Table D-2. DayVMTFraction – U.S.

Day	January 2010				July 2010			
	Rural		Urban		Rural		Urban	
	VMT	Fraction	VMT	Fraction	VMT	Fraction	VMT	Fraction
Weekday	1,557,755	0.8207	918,509	0.8594	2,377,805	0.7967	2,308,367	0.8621
Weekend	340,301	0.1793	150,304	0.1406	606,786	0.2033	369,283	0.1379
Total	*1,898,055*	*1.0000*	*1,068,814*	*1.0000*	*2,984,590*	*1.0000*	*2,677,650*	*1.0000*

Table D-3. HourVMTFraction – U.S.

Hour	January 2010				July 2010			
	Rural		Urban		Rural		Urban	
	VMT	Fraction	VMT	Fraction	VMT	Fraction	VMT	Fraction
0	42,621	0.0225	33,077	0.0309	133,188	0.0446	116,442	0.0435
1	50,158	0.0264	21,606	0.0202	182,173	0.0610	85,107	0.0318
2	42,453	0.0224	33,334	0.0312	84,906	0.0284	78,670	0.0294
3	44,564	0.0235	45,805	0.0429	127,104	0.0426	66,751	0.0249
4	49,868	0.0263	42,866	0.0401	122,534	0.0411	71,281	0.0266
5	79,080	0.0417	52,986	0.0496	93,768	0.0314	73,889	0.0276
6	64,261	0.0339	47,519	0.0445	116,445	0.0390	103,341	0.0386
7	67,952	0.0358	59,630	0.0558	113,418	0.0380	172,478	0.0644
8	90,058	0.0474	43,207	0.0404	122,946	0.0412	198,188	0.0740
9	93,097	0.0490	46,247	0.0433	123,309	0.0413	108,690	0.0406
10	80,437	0.0424	75,294	0.0704	115,075	0.0386	127,307	0.0475
11	119,447	0.0629	75,225	0.0704	113,189	0.0379	135,157	0.0505
12	101,580	0.0535	59,788	0.0559	128,211	0.0430	123,367	0.0461
13	115,288	0.0607	57,441	0.0537	116,164	0.0389	96,863	0.0362
14	91,525	0.0482	67,897	0.0635	151,740	0.0508	117,605	0.0439
15	99,921	0.0526	60,050	0.0562	110,995	0.0372	124,697	0.0466
16	110,154	0.0580	46,954	0.0439	110,209	0.0369	108,586	0.0406
17	118,824	0.0626	28,128	0.0263	119,925	0.0402	144,395	0.0539
18	77,938	0.0411	42,518	0.0398	134,994	0.0452	113,801	0.0425
19	75,211	0.0396	28,098	0.0263	147,026	0.0493	91,358	0.0341
20	87,174	0.0459	31,448	0.0294	123,255	0.0413	120,465	0.0450
21	65,563	0.0345	24,105	0.0226	148,974	0.0499	90,411	0.0338
22	67,377	0.0355	27,039	0.0253	144,956	0.0486	102,781	0.0384
23	63,502	0.0335	18,553	0.0174	100,086	0.0335	106,021	0.0396
Total	*1,898,055*	*1.0000*	*1,068,814*	*1.0000*	*2,984,590*	*1.0000*	*2,677,650*	*1.0000*

Table D-4. AvgSpeedDistribution, rural restricted, weekday, January 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.0149	0.0014	0.0025	0.0057	0.0036	0.0050	0.0124	0.0256	0.0434	0.0539	0.0470	0.1076	0.1877	0.4374	0.0348	0.0173	1.0000
1	0.0225	0.0012	0.0038	0.0047	0.0026	0.0067	0.0158	0.0252	0.0429	0.0589	0.0379	0.0860	0.1708	0.4529	0.0479	0.0202	1.0000
2	0.0185	0.0006	0.0018	0.0022	0.0018	0.0043	0.0129	0.0219	0.0505	0.0661	0.0436	0.0925	0.1705	0.4321	0.0561	0.0248	1.0000
3	0.0186	0.0011	0.0012	0.0068	0.0025	0.0073	0.0166	0.0267	0.0493	0.0625	0.0461	0.1012	0.1590	0.4091	0.0707	0.0212	1.0000
4	0.0192	0.0005	0.0007	0.0032	0.0037	0.0056	0.0128	0.0220	0.0440	0.0603	0.0495	0.0918	0.1479	0.4352	0.0817	0.0218	1.0000
5	0.0193	0.0008	0.0018	0.0015	0.0020	0.0061	0.0147	0.0247	0.0439	0.0581	0.0470	0.0977	0.1551	0.4086	0.0929	0.0260	1.0000
6	0.0270	0.0007	0.0010	0.0011	0.0025	0.0056	0.0140	0.0249	0.0460	0.0595	0.0476	0.0978	0.1471	0.4035	0.0856	0.0362	1.0000
7	0.0381	0.0010	0.0026	0.0018	0.0055	0.0061	0.0139	0.0249	0.0440	0.0578	0.0413	0.0837	0.1332	0.4112	0.0979	0.0369	1.0000
8	0.0309	0.0011	0.0021	0.0032	0.0023	0.0071	0.0127	0.0237	0.0425	0.0546	0.0436	0.0750	0.1268	0.4034	0.1188	0.0523	1.0000
9	0.0343	0.0012	0.0020	0.0038	0.0028	0.0053	0.0127	0.0210	0.0392	0.0478	0.0491	0.0840	0.1337	0.4043	0.1128	0.0460	1.0000
10	0.0336	0.0011	0.0025	0.0035	0.0033	0.0049	0.0108	0.0237	0.0421	0.0489	0.0400	0.0873	0.1381	0.3921	0.1189	0.0491	1.0000
11	0.0343	0.0013	0.0022	0.0034	0.0026	0.0056	0.0115	0.0193	0.0395	0.0482	0.0388	0.0857	0.1612	0.3846	0.1123	0.0495	1.0000
12	0.0279	0.0020	0.0031	0.0030	0.0017	0.0040	0.0106	0.0198	0.0399	0.0501	0.0376	0.0870	0.1500	0.4063	0.1110	0.0461	1.0000
13	0.0322	0.0011	0.0017	0.0027	0.0028	0.0055	0.0116	0.0190	0.0409	0.0468	0.0316	0.0769	0.1551	0.4246	0.1001	0.0474	1.0000
14	0.0346	0.0010	0.0030	0.0037	0.0027	0.0054	0.0114	0.0214	0.0404	0.0494	0.0343	0.0822	0.1552	0.4133	0.0994	0.0426	1.0000
15	0.0366	0.0011	0.0025	0.0032	0.0020	0.0064	0.0125	0.0209	0.0401	0.0514	0.0362	0.0875	0.1526	0.4129	0.0815	0.0526	1.0000
16	0.0444	0.0017	0.0028	0.0036	0.0034	0.0061	0.0163	0.0255	0.0456	0.0516	0.0418	0.0901	0.1461	0.3988	0.0745	0.0477	1.0000
17	0.0329	0.0027	0.0035	0.0035	0.0039	0.0086	0.0188	0.0280	0.0476	0.0618	0.0484	0.0973	0.1823	0.3851	0.0452	0.0305	1.0000
18	0.0243	0.0009	0.0022	0.0029	0.0052	0.0073	0.0173	0.0238	0.0469	0.0652	0.0446	0.0958	0.1721	0.4261	0.0360	0.0293	1.0000
19	0.0168	0.0010	0.0010	0.0034	0.0035	0.0060	0.0150	0.0192	0.0432	0.0608	0.0468	0.0954	0.1778	0.4523	0.0314	0.0263	1.0000
20	0.0209	0.0009	0.0026	0.0029	0.0025	0.0072	0.0139	0.0235	0.0418	0.0589	0.0434	0.0927	0.1709	0.4647	0.0323	0.0210	1.0000
21	0.0152	0.0006	0.0025	0.0035	0.0028	0.0060	0.0158	0.0239	0.0433	0.0570	0.0445	0.1009	0.1782	0.4688	0.0261	0.0108	1.0000
22	0.0159	0.0007	0.0017	0.0055	0.0028	0.0066	0.0142	0.0218	0.0447	0.0604	0.0470	0.1036	0.1843	0.4625	0.0155	0.0129	1.0000
23	0.0155	0.0015	0.0031	0.0049	0.0045	0.0042	0.0128	0.0223	0.0432	0.0505	0.0403	0.0933	0.1846	0.4809	0.0223	0.0162	1.0000

Table D-5. AvgSpeedDistribution, rural restricted, weekend, January 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.0277	0.0008	0.0013	0.0039	0.0033	0.0068	0.0176	0.0246	0.0545	0.0706	0.0399	0.0649	0.1693	0.4865	0.0187	0.0096	1.0000
1	0.0285	0.0022	0.0000	0.0014	0.0036	0.0048	0.0167	0.0254	0.0547	0.0662	0.0385	0.0826	0.1521	0.4789	0.0295	0.0150	1.0000
2	0.0354	0.0012	0.0018	0.0048	0.0028	0.0054	0.0165	0.0316	0.0542	0.0663	0.0385	0.1018	0.1348	0.4549	0.0372	0.0127	1.0000
3	0.0326	0.0001	0.0008	0.0037	0.0024	0.0117	0.0175	0.0264	0.0550	0.0647	0.0521	0.1020	0.1297	0.4338	0.0455	0.0221	1.0000
4	0.0243	0.0006	0.0003	0.0017	0.0017	0.0063	0.0155	0.0302	0.0512	0.0754	0.0591	0.1068	0.1618	0.3971	0.0506	0.0173	1.0000
5	0.0297	0.0008	0.0022	0.0015	0.0035	0.0104	0.0234	0.0308	0.0468	0.0626	0.0567	0.1134	0.1571	0.3952	0.0522	0.0137	1.0000
6	0.0179	0.0003	0.0014	0.0007	0.0026	0.0049	0.0202	0.0296	0.0459	0.0619	0.0453	0.1077	0.1503	0.4576	0.0396	0.0142	1.0000
7	0.0187	0.0006	0.0018	0.0010	0.0009	0.0046	0.0144	0.0216	0.0383	0.0489	0.0365	0.1017	0.1382	0.4885	0.0586	0.0257	1.0000
8	0.0147	0.0000	0.0008	0.0047	0.0047	0.0072	0.0110	0.0280	0.0389	0.0514	0.0523	0.1029	0.1359	0.4503	0.0682	0.0290	1.0000
9	0.0241	0.0002	0.0010	0.0060	0.0032	0.0041	0.0147	0.0305	0.0504	0.0596	0.0523	0.0979	0.1223	0.4412	0.0605	0.0320	1.0000
10	0.0318	0.0017	0.0015	0.0033	0.0028	0.0043	0.0109	0.0243	0.0410	0.0417	0.0341	0.0777	0.1307	0.4850	0.0613	0.0479	1.0000
11	0.0262	0.0011	0.0016	0.0030	0.0021	0.0062	0.0114	0.0252	0.0406	0.0444	0.0316	0.0894	0.1439	0.4503	0.0578	0.0654	1.0000
12	0.0158	0.0003	0.0020	0.0026	0.0030	0.0044	0.0109	0.0233	0.0439	0.0575	0.0348	0.0862	0.1415	0.4542	0.0420	0.0774	1.0000
13	0.0114	0.0015	0.0037	0.0046	0.0024	0.0042	0.0126	0.0224	0.0429	0.0492	0.0300	0.0758	0.1184	0.4619	0.0519	0.1071	1.0000
14	0.0190	0.0010	0.0012	0.0043	0.0025	0.0066	0.0122	0.0248	0.0419	0.0492	0.0316	0.0779	0.1323	0.4480	0.0556	0.0919	1.0000
15	0.0180	0.0018	0.0011	0.0028	0.0030	0.0039	0.0155	0.0213	0.0348	0.0544	0.0385	0.0983	0.1400	0.4275	0.0470	0.0920	1.0000
16	0.0153	0.0010	0.0016	0.0022	0.0015	0.0093	0.0143	0.0302	0.0577	0.0653	0.0460	0.0981	0.1359	0.4187	0.0326	0.0704	1.0000
17	0.0059	0.0033	0.0053	0.0042	0.0045	0.0078	0.0221	0.0334	0.0688	0.0770	0.0535	0.0998	0.1514	0.3813	0.0207	0.0610	1.0000
18	0.0080	0.0008	0.0010	0.0052	0.0035	0.0077	0.0222	0.0334	0.0555	0.0729	0.0469	0.1052	0.1570	0.4118	0.0236	0.0452	1.0000
19	0.0059	0.0004	0.0020	0.0031	0.0034	0.0098	0.0153	0.0292	0.0506	0.0655	0.0538	0.1046	0.1937	0.4119	0.0234	0.0275	1.0000
20	0.0151	0.0000	0.0013	0.0028	0.0033	0.0073	0.0164	0.0348	0.0520	0.0655	0.0484	0.0968	0.1944	0.4141	0.0154	0.0325	1.0000
21	0.0180	0.0000	0.0011	0.0045	0.0026	0.0077	0.0227	0.0299	0.0498	0.0643	0.0507	0.1164	0.1869	0.4149	0.0131	0.0175	1.0000
22	0.0279	0.0019	0.0041	0.0065	0.0020	0.0063	0.0189	0.0292	0.0604	0.0802	0.0419	0.0923	0.1799	0.4241	0.0166	0.0078	1.0000
23	0.0250	0.0000	0.0051	0.0046	0.0022	0.0108	0.0272	0.0399	0.0706	0.0840	0.0477	0.1059	0.1555	0.3945	0.0194	0.0076	1.0000

Table D-6. AvgSpeedDistribution, rural unrestricted, weekday, January 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
0	0.2377	0.0097	0.0113	0.0116	0.0094	0.0196	0.0372	0.0520	0.1089	0.1180	0.0698	0.1196	0.0935	0.0938	0.0052	0.0025	1.0000
1	0.2806	0.0078	0.0127	0.0081	0.0137	0.0255	0.0360	0.0508	0.0927	0.1071	0.0731	0.1087	0.0854	0.0887	0.0067	0.0025	1.0000
2	0.1003	0.0079	0.0106	0.0128	0.0056	0.0206	0.0542	0.0679	0.1226	0.1330	0.0896	0.1339	0.1178	0.1095	0.0062	0.0076	1.0000
3	0.0695	0.0062	0.0071	0.0140	0.0085	0.0209	0.0443	0.0735	0.1091	0.1266	0.1019	0.1475	0.1417	0.1111	0.0144	0.0036	1.0000
4	0.0977	0.0095	0.0091	0.0080	0.0265	0.0192	0.0453	0.0731	0.1117	0.1264	0.1080	0.1455	0.1166	0.0876	0.0122	0.0035	1.0000
5	0.0903	0.0068	0.0090	0.0097	0.0152	0.0197	0.0449	0.0825	0.1201	0.1378	0.0991	0.1343	0.1202	0.0817	0.0152	0.0137	1.0000
6	0.0936	0.0072	0.0121	0.0122	0.0158	0.0203	0.0556	0.0803	0.1339	0.1468	0.1112	0.1317	0.0930	0.0683	0.0119	0.0061	1.0000
7	0.1337	0.0197	0.0249	0.0227	0.0245	0.0363	0.0551	0.0781	0.1207	0.1310	0.0882	0.1211	0.0782	0.0524	0.0081	0.0056	1.0000
8	0.1114	0.0228	0.0290	0.0274	0.0283	0.0401	0.0515	0.0857	0.1233	0.1358	0.0954	0.1184	0.0705	0.0463	0.0081	0.0060	1.0000
9	0.1450	0.0321	0.0316	0.0309	0.0324	0.0388	0.0567	0.0806	0.1105	0.1170	0.0823	0.1107	0.0769	0.0417	0.0079	0.0051	1.0000
10	0.1421	0.0204	0.0323	0.0300	0.0272	0.0369	0.0621	0.0849	0.1133	0.1236	0.0841	0.1062	0.0777	0.0428	0.0095	0.0070	1.0000
11	0.1243	0.0217	0.0295	0.0299	0.0296	0.0346	0.0598	0.0892	0.1116	0.1213	0.0842	0.1114	0.0894	0.0490	0.0077	0.0066	1.0000
12	0.1239	0.0250	0.0315	0.0290	0.0345	0.0399	0.0624	0.0846	0.1129	0.1205	0.0822	0.1119	0.0776	0.0466	0.0094	0.0081	1.0000
13	0.1442	0.0245	0.0335	0.0319	0.0375	0.0413	0.0559	0.0748	0.1010	0.1101	0.0780	0.1120	0.0873	0.0519	0.0097	0.0065	1.0000
14	0.1407	0.0266	0.0328	0.0431	0.0352	0.0387	0.0526	0.0673	0.1023	0.1120	0.0723	0.1257	0.0850	0.0514	0.0085	0.0059	1.0000
15	0.1603	0.0298	0.0407	0.0320	0.0351	0.0466	0.0516	0.0669	0.1028	0.1121	0.0794	0.1033	0.0784	0.0485	0.0079	0.0046	1.0000
16	0.1636	0.0351	0.0469	0.0366	0.0454	0.0411	0.0720	0.0603	0.0831	0.0889	0.0639	0.1192	0.0797	0.0492	0.0092	0.0057	1.0000
17	0.1982	0.0397	0.0415	0.0364	0.0474	0.0475	0.0608	0.0676	0.0953	0.0907	0.0708	0.0954	0.0591	0.0380	0.0041	0.0075	1.0000
18	0.1908	0.0448	0.0319	0.0312	0.0412	0.0382	0.0487	0.0626	0.0862	0.0940	0.0763	0.1009	0.0763	0.0619	0.0076	0.0076	1.0000
19	0.1626	0.0248	0.0304	0.0223	0.0210	0.0283	0.0494	0.0673	0.1021	0.0995	0.0811	0.1280	0.0946	0.0784	0.0064	0.0037	1.0000
20	0.2065	0.0090	0.0155	0.0107	0.0230	0.0169	0.0364	0.0572	0.0927	0.1091	0.0848	0.1269	0.1090	0.0931	0.0054	0.0039	1.0000
21	0.1710	0.0088	0.0132	0.0201	0.0098	0.0190	0.0342	0.0654	0.1062	0.1125	0.0856	0.1364	0.1092	0.1017	0.0060	0.0007	1.0000
22	0.1740	0.0147	0.0096	0.0110	0.0155	0.0221	0.0305	0.0536	0.0965	0.1241	0.0889	0.1308	0.1005	0.1212	0.0037	0.0031	1.0000
23	0.1948	0.0062	0.0103	0.0076	0.0122	0.0171	0.0372	0.0568	0.1042	0.1241	0.0804	0.1256	0.0960	0.1189	0.0055	0.0030	1.0000

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Table D-7. AvgSpeedDistribution, rural unrestricted, weekend, January 2010 – U.S.

Hour	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
Average Speed (mph)																	
0	0.0969	0.0020	0.0027	0.0194	0.0129	0.0227	0.0433	0.0745	0.1524	0.1649	0.0868	0.0863	0.0853	0.1411	0.0037	0.0052	1.0000
1	0.1805	0.0034	0.0091	0.0097	0.0156	0.0216	0.0372	0.0553	0.1108	0.1241	0.0762	0.1207	0.0979	0.1241	0.0078	0.0059	1.0000
2	0.0192	0.0041	0.0026	0.0010	0.0265	0.0237	0.0574	0.0744	0.1453	0.1496	0.0969	0.1515	0.1221	0.1127	0.0094	0.0037	1.0000
3	0.0678	0.0037	0.0024	0.0030	0.0061	0.0135	0.0668	0.0882	0.1140	0.1503	0.1068	0.1372	0.1207	0.1122	0.0067	0.0007	1.0000
4	0.0748	0.0099	0.0054	0.0063	0.0109	0.0232	0.0484	0.0803	0.1304	0.1572	0.1132	0.1221	0.1064	0.0956	0.0119	0.0039	1.0000
5	0.0510	0.0014	0.0021	0.0054	0.0039	0.0233	0.0597	0.0924	0.1417	0.1538	0.1135	0.1555	0.1119	0.0740	0.0065	0.0038	1.0000
6	0.0198	0.0022	0.0070	0.0051	0.0094	0.0239	0.0566	0.1107	0.1564	0.1614	0.1097	0.1374	0.1042	0.0852	0.0089	0.0021	1.0000
7	0.0571	0.0079	0.0087	0.0114	0.0115	0.0270	0.0606	0.0887	0.1309	0.1516	0.1173	0.1383	0.1010	0.0787	0.0060	0.0033	1.0000
8	0.0530	0.0112	0.0226	0.0298	0.0258	0.0263	0.0520	0.0778	0.1324	0.1521	0.1130	0.1518	0.0793	0.0657	0.0055	0.0017	1.0000
9	0.0650	0.0196	0.0252	0.0204	0.0212	0.0399	0.0678	0.1064	0.1329	0.1411	0.0993	0.1341	0.0719	0.0516	0.0022	0.0014	1.0000
10	0.0587	0.0168	0.0215	0.0143	0.0254	0.0447	0.0784	0.1068	0.1393	0.1402	0.0924	0.1152	0.0833	0.0526	0.0065	0.0040	1.0000
11	0.0532	0.0084	0.0133	0.0255	0.0230	0.0376	0.0710	0.1132	0.1561	0.1442	0.0991	0.1190	0.0767	0.0495	0.0053	0.0050	1.0000
12	0.0619	0.0104	0.0112	0.0183	0.0270	0.0423	0.0824	0.1068	0.1330	0.1374	0.0903	0.1342	0.0810	0.0544	0.0054	0.0039	1.0000
13	0.0493	0.0097	0.0180	0.0112	0.0225	0.0465	0.0611	0.0868	0.1234	0.1375	0.0987	0.1550	0.0967	0.0660	0.0065	0.0113	1.0000
14	0.0666	0.0130	0.0132	0.0100	0.0170	0.0298	0.0574	0.0740	0.1182	0.1231	0.0857	0.1734	0.1192	0.0822	0.0084	0.0087	1.0000
15	0.0387	0.0110	0.0430	0.0091	0.0114	0.0187	0.0485	0.0616	0.1036	0.1277	0.1155	0.1992	0.1100	0.0821	0.0063	0.0134	1.0000
16	0.0591	0.0058	0.0092	0.0177	0.0093	0.0196	0.0436	0.0637	0.1281	0.1324	0.1087	0.1990	0.0938	0.0867	0.0090	0.0143	1.0000
17	0.0534	0.0032	0.0045	0.0068	0.0303	0.0178	0.0417	0.0653	0.1349	0.1471	0.1337	0.1964	0.0885	0.0654	0.0014	0.0095	1.0000
18	0.0544	0.0058	0.0068	0.0081	0.0102	0.0242	0.0567	0.0722	0.1345	0.1513	0.1051	0.1846	0.0999	0.0781	0.0044	0.0036	1.0000
19	0.0702	0.0261	0.0078	0.0071	0.0106	0.0206	0.0523	0.0871	0.1187	0.1375	0.0959	0.1353	0.1283	0.0924	0.0041	0.0059	1.0000
20	0.1440	0.0014	0.0056	0.0116	0.0072	0.0202	0.0527	0.0666	0.0975	0.1223	0.0985	0.1241	0.1273	0.1100	0.0039	0.0070	1.0000
21	0.0685	0.0028	0.0022	0.0063	0.0054	0.0329	0.0497	0.0770	0.1197	0.1381	0.1124	0.1813	0.1091	0.0881	0.0015	0.0050	1.0000
22	0.0259	0.0107	0.0078	0.0086	0.0080	0.0291	0.0475	0.0797	0.1591	0.1626	0.0963	0.1271	0.1121	0.1158	0.0027	0.0069	1.0000
23	0.0781	0.0000	0.0053	0.0058	0.0204	0.0508	0.0503	0.0807	0.1600	0.1841	0.0810	0.1035	0.1016	0.0754	0.0015	0.0016	1.0000

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Table D-8. AvgSpeedDistribution, urban restricted, weekday, January 2010 – U.S.

Hour	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.0464	0.0015	0.0028	0.0011	0.0037	0.0092	0.0247	0.0392	0.0577	0.0591	0.0497	0.1622	0.1859	0.3312	0.0129	0.0129	1.0000
1	0.0171	0.0022	0.0016	0.0042	0.0051	0.0111	0.0260	0.0557	0.0716	0.0674	0.0439	0.1514	0.1836	0.3126	0.0269	0.0196	1.0000
2	0.0160	0.0017	0.0059	0.0038	0.0044	0.0127	0.0279	0.0445	0.0634	0.0618	0.0423	0.1439	0.1985	0.3298	0.0247	0.0186	1.0000
3	0.0189	0.0023	0.0032	0.0037	0.0040	0.0136	0.0285	0.0419	0.0571	0.0611	0.0421	0.1371	0.2075	0.3236	0.0386	0.0169	1.0000
4	0.0179	0.0030	0.0011	0.0025	0.0037	0.0072	0.0254	0.0415	0.0522	0.0492	0.0391	0.1492	0.2489	0.2970	0.0405	0.0217	1.0000
5	0.0183	0.0025	0.0047	0.0015	0.0032	0.0084	0.0260	0.0385	0.0565	0.0493	0.0466	0.1697	0.2459	0.2566	0.0415	0.0309	1.0000
6	0.0209	0.0024	0.0027	0.0030	0.0064	0.0186	0.0272	0.0461	0.0559	0.0559	0.0557	0.1653	0.2371	0.2332	0.0397	0.0300	1.0000
7	0.0576	0.0094	0.0120	0.0125	0.0159	0.0255	0.0407	0.0500	0.0657	0.0675	0.0580	0.1241	0.1887	0.1920	0.0337	0.0467	1.0000
8	0.0498	0.0108	0.0138	0.0180	0.0211	0.0288	0.0488	0.0622	0.0709	0.0682	0.0527	0.1095	0.1593	0.1831	0.0378	0.0652	1.0000
9	0.0505	0.0061	0.0079	0.0100	0.0126	0.0189	0.0375	0.0545	0.0638	0.0546	0.0517	0.1238	0.1935	0.2148	0.0433	0.0567	1.0000
10	0.0571	0.0035	0.0045	0.0064	0.0084	0.0172	0.0331	0.0534	0.0591	0.0519	0.0402	0.1328	0.2213	0.2184	0.0402	0.0525	1.0000
11	0.0407	0.0050	0.0052	0.0053	0.0090	0.0168	0.0313	0.0460	0.0542	0.0565	0.0515	0.1237	0.2328	0.2262	0.0420	0.0539	1.0000
12	0.0416	0.0018	0.0035	0.0052	0.0088	0.0162	0.0286	0.0470	0.0565	0.0570	0.0515	0.1310	0.2162	0.2317	0.0411	0.0625	1.0000
13	0.0478	0.0047	0.0047	0.0061	0.0073	0.0155	0.0290	0.0437	0.0515	0.0528	0.0445	0.1180	0.2294	0.2446	0.0366	0.0638	1.0000
14	0.0437	0.0068	0.0061	0.0077	0.0094	0.0183	0.0368	0.0506	0.0557	0.0534	0.0470	0.1221	0.2200	0.2288	0.0389	0.0546	1.0000
15	0.0418	0.0081	0.0095	0.0125	0.0133	0.0338	0.0474	0.0563	0.0630	0.0659	0.0495	0.1148	0.1857	0.2051	0.0299	0.0636	1.0000
16	0.0455	0.0114	0.0149	0.0187	0.0247	0.0361	0.0461	0.0589	0.0681	0.0616	0.0561	0.1085	0.1578	0.1983	0.0281	0.0651	1.0000
17	0.0417	0.0168	0.0227	0.0258	0.0294	0.0364	0.0531	0.0613	0.0760	0.0736	0.0638	0.1183	0.1274	0.1895	0.0154	0.0486	1.0000
18	0.0378	0.0092	0.0169	0.0176	0.0192	0.0295	0.0483	0.0559	0.0687	0.0622	0.0671	0.1370	0.1566	0.2244	0.0120	0.0378	1.0000
19	0.0203	0.0044	0.0043	0.0048	0.0093	0.0168	0.0341	0.0451	0.0604	0.0586	0.0671	0.1647	0.2025	0.2611	0.0119	0.0345	1.0000
20	0.0180	0.0039	0.0152	0.0052	0.0051	0.0114	0.0316	0.0444	0.0539	0.0568	0.0558	0.1852	0.2319	0.2506	0.0098	0.0211	1.0000
21	0.0268	0.0023	0.0020	0.0018	0.0047	0.0104	0.0266	0.0422	0.0494	0.0481	0.0622	0.1862	0.2411	0.2757	0.0091	0.0113	1.0000
22	0.0208	0.0012	0.0018	0.0010	0.0034	0.0103	0.0250	0.0455	0.0544	0.0599	0.0541	0.1652	0.2182	0.3230	0.0050	0.0112	1.0000
23	0.0255	0.0030	0.0026	0.0037	0.0091	0.0086	0.0247	0.0370	0.0610	0.0657	0.0586	0.1422	0.1817	0.3459	0.0092	0.0215	1.0000

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Table D-9. AvgSpeedDistribution, urban restricted, weekend, January 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.0192	0.0000	0.0016	0.0055	0.0011	0.0146	0.0364	0.0527	0.0642	0.0607	0.0382	0.1179	0.2015	0.3643	0.0114	0.0107	1.0000
1	0.0242	0.0032	0.0076	0.0061	0.0079	0.0201	0.0404	0.0561	0.0789	0.0604	0.0332	0.0767	0.1428	0.4075	0.0206	0.0144	1.0000
2	0.0158	0.0000	0.0007	0.0048	0.0089	0.0109	0.0343	0.0548	0.0723	0.0566	0.0361	0.0693	0.1354	0.4415	0.0182	0.0404	1.0000
3	0.0989	0.0002	0.0040	0.0026	0.0065	0.0121	0.0359	0.0383	0.0597	0.0570	0.0352	0.0760	0.1549	0.3900	0.0194	0.0092	1.0000
4	0.0255	0.0009	0.0070	0.0073	0.0074	0.0159	0.0490	0.0574	0.0805	0.0718	0.0387	0.0879	0.1719	0.3498	0.0189	0.0101	1.0000
5	0.0174	0.0055	0.0038	0.0013	0.0021	0.0132	0.0430	0.0543	0.0697	0.0651	0.0427	0.1398	0.1843	0.3208	0.0279	0.0092	1.0000
6	0.0201	0.0011	0.0019	0.0012	0.0027	0.0162	0.0357	0.0620	0.0737	0.0622	0.0395	0.1310	0.2127	0.3056	0.0198	0.0146	1.0000
7	0.0177	0.0031	0.0017	0.0029	0.0036	0.0152	0.0378	0.0557	0.0678	0.0607	0.0323	0.1044	0.2134	0.3414	0.0261	0.0161	1.0000
8	0.0174	0.0005	0.0004	0.0026	0.0054	0.0148	0.0419	0.0536	0.0728	0.0590	0.0317	0.0996	0.2148	0.3389	0.0311	0.0156	1.0000
9	0.0157	0.0008	0.0009	0.0023	0.0019	0.0158	0.0416	0.0653	0.0710	0.0730	0.0438	0.0948	0.1955	0.3184	0.0272	0.0321	1.0000
10	0.0354	0.0006	0.0050	0.0015	0.0045	0.0119	0.0279	0.0501	0.0645	0.0547	0.0368	0.0935	0.1673	0.3638	0.0238	0.0587	1.0000
11	0.0262	0.0000	0.0011	0.0034	0.0047	0.0159	0.0397	0.0530	0.0602	0.0562	0.0379	0.0980	0.1755	0.3598	0.0249	0.0434	1.0000
12	0.0299	0.0019	0.0031	0.0064	0.0064	0.0139	0.0350	0.0541	0.0623	0.0474	0.0297	0.0872	0.1872	0.3689	0.0237	0.0430	1.0000
13	0.0247	0.0010	0.0027	0.0033	0.0043	0.0205	0.0330	0.0480	0.0604	0.0526	0.0410	0.0813	0.1565	0.4174	0.0280	0.0254	1.0000
14	0.0266	0.0026	0.0046	0.0023	0.0056	0.0181	0.0763	0.0556	0.0615	0.0540	0.0334	0.0706	0.1253	0.3912	0.0224	0.0498	1.0000
15	0.0252	0.0007	0.0041	0.0034	0.0086	0.0231	0.0464	0.0685	0.0860	0.0717	0.0261	0.0739	0.1547	0.3558	0.0203	0.0315	1.0000
16	0.0165	0.0002	0.0033	0.0057	0.0084	0.0229	0.0587	0.0705	0.0911	0.0652	0.0278	0.0908	0.1380	0.3405	0.0126	0.0478	1.0000
17	0.0089	0.0011	0.0040	0.0091	0.0173	0.0204	0.0645	0.0790	0.0991	0.0701	0.0446	0.0988	0.1674	0.2755	0.0071	0.0330	1.0000
18	0.0104	0.0554	0.0051	0.0055	0.0095	0.0303	0.0500	0.0677	0.0871	0.0664	0.0371	0.0897	0.1464	0.2894	0.0096	0.0404	1.0000
19	0.0129	0.0035	0.0019	0.0073	0.0056	0.0185	0.0545	0.0742	0.0906	0.0742	0.0427	0.0985	0.1518	0.3232	0.0076	0.0330	1.0000
20	0.0085	0.0018	0.0019	0.0046	0.0085	0.0167	0.0433	0.0558	0.0670	0.0624	0.0491	0.1122	0.1873	0.3311	0.0106	0.0391	1.0000
21	0.0604	0.0025	0.0009	0.0012	0.0053	0.0110	0.0438	0.0618	0.0778	0.0637	0.0407	0.1105	0.1727	0.3134	0.0098	0.0245	1.0000
22	0.0061	0.0015	0.0018	0.0009	0.0059	0.0127	0.0348	0.0500	0.0664	0.0666	0.0389	0.1008	0.1788	0.4196	0.0078	0.0075	1.0000
23	0.0116	0.0016	0.0025	0.0043	0.0013	0.0151	0.0358	0.0532	0.0753	0.0578	0.0431	0.1022	0.2048	0.3705	0.0162	0.0047	1.0000

Table D-10. AvgSpeedDistribution, urban unrestricted, weekday, January 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
0	0.1753	0.0154	0.0303	0.0200	0.0368	0.0488	0.1157	0.1243	0.1205	0.0843	0.0316	0.0696	0.0575	0.0639	0.0014	0.0046	1.0000
1	0.1599	0.0050	0.0165	0.0230	0.0268	0.0493	0.1141	0.1281	0.1323	0.0864	0.0411	0.0752	0.0656	0.0665	0.0037	0.0065	1.0000
2	0.1818	0.0244	0.0113	0.0325	0.0275	0.0418	0.1092	0.1550	0.1178	0.0671	0.0410	0.0581	0.0625	0.0614	0.0047	0.0038	1.0000
3	0.1410	0.0074	0.0048	0.0181	0.0229	0.0582	0.1349	0.1397	0.1241	0.0877	0.0339	0.0565	0.0897	0.0674	0.0096	0.0043	1.0000
4	0.1505	0.0065	0.0100	0.0186	0.0208	0.0457	0.1283	0.1361	0.1151	0.0688	0.0432	0.0734	0.0985	0.0684	0.0091	0.0071	1.0000
5	0.1751	0.0107	0.0090	0.0131	0.0278	0.0480	0.1201	0.1304	0.1043	0.0609	0.0366	0.0833	0.0969	0.0634	0.0094	0.0110	1.0000
6	0.1610	0.0122	0.0126	0.0169	0.0258	0.0585	0.1283	0.1187	0.1000	0.0673	0.0453	0.0763	0.1001	0.0579	0.0100	0.0094	1.0000
7	0.2903	0.0210	0.0164	0.0182	0.0313	0.0530	0.0950	0.1050	0.1019	0.0634	0.0333	0.0554	0.0541	0.0382	0.0059	0.0177	1.0000
8	0.2135	0.0271	0.0240	0.0352	0.0406	0.0701	0.1137	0.1184	0.1113	0.0696	0.0316	0.0445	0.0450	0.0319	0.0068	0.0164	1.0000
9	0.2135	0.0279	0.0254	0.0258	0.0375	0.0622	0.0956	0.1238	0.1193	0.0716	0.0368	0.0475	0.0583	0.0357	0.0057	0.0135	1.0000
10	0.2231	0.0304	0.0211	0.0260	0.0350	0.0577	0.0918	0.1077	0.1204	0.0743	0.0402	0.0553	0.0607	0.0369	0.0063	0.0130	1.0000
11	0.2406	0.0240	0.0202	0.0255	0.0364	0.0585	0.0935	0.1037	0.1144	0.0763	0.0360	0.0483	0.0642	0.0364	0.0076	0.0143	1.0000
12	0.2304	0.0262	0.0173	0.0238	0.0328	0.0549	0.0949	0.1092	0.1180	0.0783	0.0366	0.0516	0.0616	0.0415	0.0069	0.0159	1.0000
13	0.2342	0.0294	0.0221	0.0276	0.0345	0.0540	0.0863	0.1070	0.1128	0.0777	0.0351	0.0521	0.0608	0.0414	0.0082	0.0167	1.0000
14	0.2124	0.0260	0.0230	0.0277	0.0427	0.0608	0.0975	0.1154	0.1193	0.0729	0.0347	0.0504	0.0569	0.0376	0.0073	0.0153	1.0000
15	0.2342	0.0300	0.0244	0.0367	0.0433	0.0651	0.0937	0.1061	0.1023	0.0692	0.0352	0.0463	0.0555	0.0383	0.0055	0.0143	1.0000
16	0.2558	0.0323	0.0323	0.0344	0.0396	0.0628	0.0998	0.1005	0.0976	0.0617	0.0321	0.0464	0.0493	0.0364	0.0051	0.0137	1.0000
17	0.2268	0.0302	0.0323	0.0335	0.0552	0.0682	0.1182	0.1099	0.0942	0.0601	0.0357	0.0498	0.0379	0.0338	0.0043	0.0102	1.0000
18	0.2034	0.0277	0.0347	0.0243	0.0322	0.0628	0.1222	0.1064	0.0942	0.0628	0.0423	0.0668	0.0571	0.0471	0.0034	0.0124	1.0000
19	0.1918	0.0193	0.0190	0.0200	0.0322	0.0488	0.1071	0.1155	0.0987	0.0715	0.0453	0.0848	0.0803	0.0531	0.0031	0.0096	1.0000
20	0.1661	0.0169	0.0134	0.0294	0.0243	0.0425	0.0958	0.1114	0.1208	0.0754	0.0424	0.1048	0.0915	0.0546	0.0039	0.0068	1.0000
21	0.1298	0.0194	0.0159	0.0315	0.0309	0.0476	0.1096	0.1143	0.1217	0.0706	0.0396	0.0966	0.1040	0.0612	0.0021	0.0052	1.0000
22	0.1547	0.0127	0.0133	0.0207	0.0280	0.0420	0.1016	0.1244	0.1215	0.0866	0.0440	0.0953	0.0831	0.0672	0.0011	0.0037	1.0000
23	0.1241	0.0247	0.0257	0.0262	0.0218	0.0492	0.1011	0.1333	0.1363	0.0853	0.0400	0.0742	0.0798	0.0708	0.0010	0.0065	1.0000

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Table D-11. AvgSpeedDistribution, urban unrestricted, weekend, January 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.1728	0.0118	0.0047	0.0189	0.0250	0.0521	0.1171	0.1497	0.1561	0.0909	0.0255	0.0423	0.0404	0.0643	0.0023	0.0260	1.0000
1	0.1874	0.0074	0.0078	0.0220	0.0283	0.0512	0.1153	0.1383	0.1565	0.0936	0.0253	0.0279	0.0480	0.0796	0.0030	0.0087	1.0000
2	0.1113	0.0064	0.0066	0.0317	0.0148	0.0422	0.1316	0.1835	0.1662	0.1016	0.0360	0.0320	0.0315	0.0817	0.0058	0.0169	1.0000
3	0.1136	0.0042	0.0069	0.0310	0.0389	0.0459	0.1203	0.1809	0.1511	0.0734	0.0445	0.0488	0.0646	0.0683	0.0054	0.0023	1.0000
4	0.0963	0.0182	0.1067	0.0175	0.0152	0.0379	0.1285	0.1636	0.1371	0.0752	0.0297	0.0340	0.0575	0.0715	0.0068	0.0043	1.0000
5	0.1096	0.0037	0.0065	0.0134	0.0339	0.0684	0.1525	0.1699	0.1319	0.0799	0.0347	0.0589	0.0630	0.0649	0.0065	0.0023	1.0000
6	0.1188	0.0031	0.0044	0.0198	0.0284	0.0715	0.1275	0.1315	0.1324	0.0844	0.0420	0.0616	0.0835	0.0769	0.0059	0.0083	1.0000
7	0.1336	0.0073	0.0197	0.0138	0.0261	0.0606	0.1440	0.1539	0.1215	0.0721	0.0332	0.0399	0.0787	0.0825	0.0047	0.0084	1.0000
8	0.1188	0.0105	0.0223	0.0205	0.0285	0.0636	0.1145	0.1443	0.1166	0.0690	0.0264	0.0498	0.1003	0.1032	0.0080	0.0039	1.0000
9	0.2669	0.0098	0.0074	0.0173	0.0279	0.0525	0.1136	0.1216	0.1099	0.0740	0.0316	0.0403	0.0599	0.0560	0.0045	0.0068	1.0000
10	0.1599	0.0160	0.0254	0.0287	0.0329	0.0529	0.1132	0.1362	0.1228	0.0810	0.0350	0.0507	0.0547	0.0746	0.0034	0.0126	1.0000
11	0.1624	0.0121	0.0117	0.0177	0.0220	0.0563	0.1371	0.1401	0.1290	0.0753	0.0318	0.0540	0.0676	0.0706	0.0043	0.0080	1.0000
12	0.0747	0.0066	0.0076	0.0106	0.0293	0.0667	0.1348	0.1840	0.1364	0.0942	0.0295	0.0460	0.0790	0.0821	0.0062	0.0124	1.0000
13	0.0648	0.0102	0.0138	0.0343	0.0279	0.0542	0.1401	0.1772	0.1412	0.0775	0.0388	0.0416	0.0723	0.0944	0.0053	0.0064	1.0000
14	0.1286	0.0069	0.0094	0.0183	0.0361	0.0722	0.1568	0.1512	0.1366	0.0740	0.0326	0.0436	0.0501	0.0702	0.0043	0.0092	1.0000
15	0.0797	0.0053	0.0099	0.0213	0.0277	0.0725	0.1520	0.1842	0.1425	0.0861	0.0281	0.0461	0.0551	0.0791	0.0035	0.0067	1.0000
16	0.0950	0.0097	0.0111	0.0122	0.0358	0.0578	0.1619	0.1686	0.1505	0.0838	0.0293	0.0480	0.0609	0.0673	0.0012	0.0070	1.0000
17	0.0832	0.0061	0.0140	0.0369	0.0309	0.0769	0.1660	0.1674	0.1425	0.0677	0.0368	0.0466	0.0645	0.0530	0.0008	0.0066	1.0000
18	0.0615	0.0135	0.0124	0.0234	0.0371	0.0641	0.1465	0.1510	0.1484	0.0867	0.0415	0.0526	0.0570	0.0646	0.0019	0.0380	1.0000
19	0.0717	0.0101	0.0116	0.0217	0.0401	0.0643	0.1356	0.1525	0.1828	0.0838	0.0351	0.0416	0.0490	0.0604	0.0026	0.0371	1.0000
20	0.0728	0.0074	0.0249	0.0218	0.0365	0.0579	0.1269	0.1278	0.1383	0.0846	0.0284	0.0801	0.0817	0.0712	0.0008	0.0389	1.0000
21	0.0992	0.0130	0.0113	0.0167	0.0360	0.0593	0.1221	0.1470	0.1377	0.0757	0.0318	0.0681	0.0843	0.0678	0.0020	0.0280	1.0000
22	0.1298	0.0080	0.0116	0.0227	0.0328	0.0476	0.1047	0.1696	0.1486	0.0855	0.0429	0.0468	0.0546	0.0669	0.0000	0.0278	1.0000
23	0.0888	0.0073	0.0086	0.0420	0.0421	0.0491	0.1276	0.1540	0.1484	0.0896	0.0432	0.0533	0.0495	0.0658	0.0022	0.0284	1.0000

Table D-12. AvgSpeedDistribution, rural restricted, weekday, July 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
0	0.0267	0.0010	0.0023	0.0041	0.0045	0.0071	0.0153	0.0227	0.0352	0.0524	0.0387	0.0910	0.1937	0.4220	0.0328	0.0505	1.0000
1	0.0322	0.0016	0.0028	0.0053	0.0029	0.0100	0.0127	0.0195	0.0397	0.0544	0.0408	0.0833	0.1626	0.4455	0.0329	0.0539	1.0000
2	0.0235	0.0013	0.0028	0.0074	0.0037	0.0055	0.0118	0.0220	0.0398	0.0541	0.0380	0.0886	0.1635	0.4427	0.0409	0.0544	1.0000
3	0.0386	0.0021	0.0040	0.0054	0.0036	0.0061	0.0193	0.0214	0.0417	0.0524	0.0353	0.0877	0.1477	0.4103	0.0579	0.0665	1.0000
4	0.0335	0.0014	0.0046	0.0029	0.0018	0.0072	0.0200	0.0210	0.0399	0.0568	0.0386	0.0983	0.1473	0.3959	0.0702	0.0606	1.0000
5	0.0375	0.0011	0.0020	0.0059	0.0049	0.0106	0.0169	0.0254	0.0429	0.0550	0.0428	0.0979	0.1682	0.3421	0.0755	0.0714	1.0000
6	0.0260	0.0015	0.0052	0.0028	0.0039	0.0093	0.0158	0.0239	0.0378	0.0562	0.0428	0.0846	0.1690	0.3567	0.0931	0.0713	1.0000
7	0.0350	0.0017	0.0031	0.0048	0.0038	0.0096	0.0164	0.0190	0.0348	0.0481	0.0334	0.0897	0.1621	0.3719	0.0887	0.0778	1.0000
8	0.0526	0.0015	0.0023	0.0039	0.0040	0.0064	0.0130	0.0192	0.0322	0.0430	0.0354	0.0803	0.1369	0.3932	0.0961	0.0799	1.0000
9	0.0700	0.0012	0.0012	0.0017	0.0046	0.0063	0.0111	0.0191	0.0343	0.0392	0.0369	0.0863	0.1441	0.3821	0.0909	0.0709	1.0000
10	0.0522	0.0025	0.0028	0.0037	0.0047	0.0071	0.0129	0.0216	0.0370	0.0473	0.0421	0.0898	0.1552	0.3695	0.0892	0.0624	1.0000
11	0.0483	0.0019	0.0031	0.0056	0.0044	0.0068	0.0154	0.0219	0.0395	0.0464	0.0409	0.0914	0.1420	0.3711	0.0976	0.0636	1.0000
12	0.0477	0.0039	0.0045	0.0059	0.0068	0.0079	0.0143	0.0220	0.0408	0.0494	0.0460	0.0912	0.1422	0.3538	0.0956	0.0680	1.0000
13	0.0415	0.0020	0.0057	0.0067	0.0083	0.0084	0.0146	0.0265	0.0424	0.0503	0.0405	0.0918	0.1558	0.3447	0.0919	0.0689	1.0000
14	0.0420	0.0045	0.0054	0.0060	0.0048	0.0104	0.0178	0.0226	0.0423	0.0451	0.0385	0.0948	0.1639	0.3417	0.0933	0.0670	1.0000
15	0.0513	0.0033	0.0051	0.0064	0.0081	0.0089	0.0174	0.0235	0.0445	0.0499	0.0400	0.0928	0.1754	0.3356	0.0808	0.0569	1.0000
16	0.0540	0.0040	0.0039	0.0081	0.0067	0.0107	0.0186	0.0251	0.0406	0.0512	0.0411	0.0932	0.1670	0.3374	0.0810	0.0575	1.0000
17	0.0477	0.0040	0.0059	0.0061	0.0074	0.0086	0.0176	0.0253	0.0403	0.0484	0.0384	0.0897	0.1711	0.3454	0.0765	0.0674	1.0000
18	0.0462	0.0039	0.0061	0.0057	0.0058	0.0079	0.0145	0.0253	0.0395	0.0513	0.0399	0.0965	0.1935	0.3233	0.0663	0.0742	1.0000
19	0.0375	0.0013	0.0026	0.0043	0.0045	0.0082	0.0158	0.0247	0.0363	0.0420	0.0398	0.1095	0.1965	0.3479	0.0579	0.0710	1.0000
20	0.0323	0.0013	0.0035	0.0033	0.0027	0.0066	0.0123	0.0181	0.0321	0.0469	0.0447	0.1030	0.1837	0.3776	0.0654	0.0666	1.0000
21	0.0342	0.0012	0.0034	0.0033	0.0040	0.0060	0.0114	0.0185	0.0319	0.0462	0.0390	0.1055	0.1928	0.3944	0.0530	0.0553	1.0000
22	0.0300	0.0018	0.0038	0.0037	0.0041	0.0090	0.0170	0.0181	0.0291	0.0482	0.0456	0.1086	0.1888	0.4098	0.0411	0.0413	1.0000
23	0.0296	0.0021	0.0018	0.0033	0.0030	0.0113	0.0168	0.0271	0.0340	0.0512	0.0429	0.0969	0.1926	0.4048	0.0399	0.0425	1.0000

Table D-13. AvgSpeedDistribution, rural restricted, weekend, July 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.0236	0.0021	0.0030	0.0041	0.0056	0.0059	0.0133	0.0251	0.0443	0.0565	0.0415	0.0783	0.1597	0.4612	0.0452	0.0306	1.0000
1	0.0081	0.0007	0.0034	0.0048	0.0030	0.0049	0.0111	0.0251	0.0422	0.0538	0.0410	0.0902	0.1572	0.4951	0.0257	0.0337	1.0000
2	0.0079	0.0030	0.0022	0.0028	0.0042	0.0044	0.0166	0.0298	0.0423	0.0611	0.0415	0.0967	0.1324	0.4950	0.0283	0.0320	1.0000
3	0.0204	0.0063	0.0007	0.0046	0.0025	0.0048	0.0135	0.0285	0.0440	0.0583	0.0346	0.0897	0.1397	0.4827	0.0284	0.0414	1.0000
4	0.0080	0.0000	0.0032	0.0046	0.0035	0.0097	0.0134	0.0261	0.0504	0.0561	0.0332	0.0795	0.1704	0.4496	0.0434	0.0487	1.0000
5	0.0226	0.0006	0.0027	0.0065	0.0030	0.0093	0.0219	0.0228	0.0430	0.0599	0.0424	0.1005	0.1794	0.4131	0.0512	0.0212	1.0000
6	0.0137	0.0003	0.0037	0.0090	0.0076	0.0046	0.0145	0.0220	0.0434	0.0625	0.0413	0.0910	0.1702	0.4452	0.0534	0.0176	1.0000
7	0.0230	0.0000	0.0011	0.0018	0.0011	0.0054	0.0115	0.0229	0.0374	0.0551	0.0401	0.0943	0.1559	0.4410	0.0836	0.0256	1.0000
8	0.0185	0.0004	0.0005	0.0030	0.0045	0.0036	0.0159	0.0239	0.0341	0.0541	0.0379	0.1006	0.1390	0.4518	0.0738	0.0384	1.0000
9	0.0164	0.0025	0.0036	0.0066	0.0025	0.0042	0.0139	0.0172	0.0307	0.0429	0.0422	0.0863	0.1529	0.4437	0.0794	0.0548	1.0000
10	0.0257	0.0021	0.0015	0.0047	0.0015	0.0097	0.0080	0.0148	0.0367	0.0376	0.0334	0.0761	0.1319	0.4562	0.1021	0.0581	1.0000
11	0.0222	0.0002	0.0063	0.0025	0.0040	0.0044	0.0182	0.0178	0.0400	0.0452	0.0412	0.0825	0.1524	0.4329	0.0793	0.0511	1.0000
12	0.0126	0.0027	0.0016	0.0070	0.0040	0.0039	0.0145	0.0202	0.0398	0.0438	0.0431	0.0856	0.1674	0.4388	0.0698	0.0454	1.0000
13	0.0124	0.0023	0.0021	0.0070	0.0073	0.0062	0.0171	0.0225	0.0368	0.0468	0.0439	0.0970	0.1606	0.3961	0.0695	0.0724	1.0000
14	0.0154	0.0033	0.0037	0.0116	0.0081	0.0087	0.0140	0.0225	0.0366	0.0450	0.0334	0.0884	0.1729	0.3690	0.0792	0.0881	1.0000
15	0.0105	0.0019	0.0036	0.0064	0.0052	0.0073	0.0205	0.0220	0.0399	0.0496	0.0411	0.0848	0.1677	0.3676	0.0859	0.0860	1.0000
16	0.0185	0.0014	0.0013	0.0026	0.0065	0.0049	0.0154	0.0198	0.0354	0.0480	0.0403	0.0855	0.1653	0.4012	0.0695	0.0844	1.0000
17	0.0172	0.0011	0.0025	0.0025	0.0048	0.0059	0.0148	0.0195	0.0389	0.0499	0.0359	0.0775	0.1493	0.4322	0.0719	0.0762	1.0000
18	0.0078	0.0033	0.0029	0.0076	0.0077	0.0066	0.0142	0.0185	0.0488	0.0599	0.0518	0.0973	0.1532	0.3927	0.0578	0.0698	1.0000
19	0.0092	0.0022	0.0027	0.0033	0.0047	0.0048	0.0189	0.0191	0.0355	0.0562	0.0387	0.0957	0.1757	0.3879	0.0699	0.0756	1.0000
20	0.0161	0.0003	0.0006	0.0039	0.0050	0.0071	0.0195	0.0168	0.0340	0.0405	0.0385	0.0951	0.1779	0.4330	0.0446	0.0670	1.0000
21	0.0068	0.0005	0.0051	0.0031	0.0044	0.0086	0.0153	0.0211	0.0387	0.0494	0.0390	0.0978	0.1751	0.4358	0.0451	0.0541	1.0000
22	0.0251	0.0013	0.0035	0.0050	0.0053	0.0083	0.0185	0.0211	0.0343	0.0525	0.0357	0.1082	0.1743	0.4174	0.0347	0.0547	1.0000
23	0.0159	0.0008	0.0041	0.0107	0.0016	0.0077	0.0144	0.0195	0.0419	0.0578	0.0439	0.0894	0.1777	0.4442	0.0353	0.0349	1.0000

Table D-14. AvgSpeedDistribution, rural unrestricted, weekday, July 2010 – U.S.

Hour	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.2124	0.0237	0.0441	0.0181	0.0211	0.0280	0.0467	0.0432	0.0796	0.0912	0.0614	0.1074	0.1061	0.0907	0.0057	0.0205	1.0000
1	0.2774	0.0152	0.0221	0.0211	0.0229	0.0193	0.0316	0.0444	0.0759	0.0899	0.0609	0.1060	0.1012	0.0908	0.0073	0.0140	1.0000
2	0.1912	0.0194	0.0333	0.0224	0.0188	0.0388	0.0529	0.0529	0.0929	0.1064	0.0607	0.0908	0.0960	0.1076	0.0063	0.0098	1.0000
3	0.2329	0.0199	0.0199	0.0217	0.0223	0.0276	0.0397	0.0550	0.0931	0.0939	0.0684	0.0998	0.0989	0.0851	0.0102	0.0117	1.0000
4	0.2343	0.0158	0.0189	0.0295	0.0236	0.0283	0.0465	0.0532	0.0819	0.1013	0.0688	0.0917	0.0892	0.0829	0.0137	0.0205	1.0000
5	0.1656	0.0179	0.0236	0.0204	0.0212	0.0320	0.0494	0.0607	0.0872	0.0964	0.0691	0.1007	0.1122	0.1003	0.0210	0.0223	1.0000
6	0.1666	0.0139	0.0277	0.0271	0.0401	0.0272	0.0575	0.0661	0.0849	0.0955	0.0691	0.1007	0.1017	0.0887	0.0170	0.0161	1.0000
7	0.2028	0.0227	0.0377	0.0287	0.0402	0.0367	0.0474	0.0613	0.0811	0.0800	0.0612	0.0984	0.1073	0.0704	0.0127	0.0113	1.0000
8	0.1975	0.0242	0.0330	0.0353	0.0361	0.0436	0.0544	0.0636	0.0772	0.0818	0.0604	0.1053	0.1037	0.0639	0.0106	0.0093	1.0000
9	0.1740	0.0292	0.0485	0.0454	0.0421	0.0539	0.0580	0.0669	0.0877	0.0896	0.0659	0.0948	0.0751	0.0498	0.0091	0.0099	1.0000
10	0.1625	0.0339	0.0361	0.0341	0.0400	0.0384	0.0563	0.0703	0.0932	0.1018	0.0792	0.1098	0.0788	0.0481	0.0081	0.0096	1.0000
11	0.1476	0.0275	0.0276	0.0346	0.0395	0.0463	0.0770	0.0791	0.0983	0.1025	0.0791	0.1007	0.0769	0.0432	0.0097	0.0103	1.0000
12	0.1744	0.0296	0.0364	0.0411	0.0413	0.0508	0.0594	0.0774	0.1013	0.0986	0.0750	0.0894	0.0678	0.0388	0.0086	0.0102	1.0000
13	0.1880	0.0308	0.0424	0.0383	0.0443	0.0564	0.0694	0.0793	0.0942	0.0905	0.0664	0.0821	0.0630	0.0334	0.0092	0.0121	1.0000
14	0.1925	0.0302	0.0394	0.0403	0.0382	0.0554	0.0703	0.0775	0.0964	0.0947	0.0706	0.0834	0.0589	0.0335	0.0073	0.0112	1.0000
15	0.1933	0.0293	0.0352	0.0386	0.0384	0.0513	0.0595	0.0713	0.0904	0.0955	0.0714	0.0925	0.0742	0.0387	0.0070	0.0134	1.0000
16	0.1968	0.0360	0.0387	0.0390	0.0360	0.0458	0.0564	0.0689	0.0928	0.0934	0.0690	0.0908	0.0696	0.0425	0.0073	0.0168	1.0000
17	0.1938	0.0404	0.0365	0.0381	0.0354	0.0510	0.0514	0.0679	0.0932	0.0942	0.0683	0.0955	0.0709	0.0408	0.0087	0.0138	1.0000
18	0.1855	0.0479	0.0404	0.0467	0.0354	0.0422	0.0613	0.0667	0.0879	0.0941	0.0646	0.0925	0.0763	0.0403	0.0074	0.0109	1.0000
19	0.1904	0.0367	0.0349	0.0362	0.0362	0.0369	0.0531	0.0641	0.0850	0.0917	0.0591	0.0999	0.0939	0.0597	0.0138	0.0083	1.0000
20	0.1940	0.0130	0.0161	0.0257	0.0215	0.0271	0.0552	0.0572	0.0809	0.0915	0.0768	0.1182	0.1194	0.0771	0.0132	0.0132	1.0000
21	0.2156	0.0209	0.0150	0.0248	0.0165	0.0299	0.0415	0.0461	0.0732	0.0857	0.0722	0.1274	0.1247	0.0820	0.0103	0.0142	1.0000
22	0.2467	0.0176	0.0142	0.0200	0.0179	0.0269	0.0340	0.0448	0.0734	0.0868	0.0692	0.1206	0.1204	0.0820	0.0072	0.0182	1.0000
23	0.2343	0.0235	0.0159	0.0233	0.0136	0.0275	0.0332	0.0566	0.0885	0.1007	0.0636	0.1047	0.1073	0.0864	0.0063	0.0147	1.0000

Table D-15. AvgSpeedDistribution, rural unrestricted, weekend, July 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.1401	0.0032	0.0048	0.0240	0.0319	0.0337	0.0572	0.0662	0.1053	0.1282	0.0919	0.1037	0.0846	0.1064	0.0074	0.0112	1.0000
1	0.1832	0.0065	0.0353	0.0201	0.0098	0.0148	0.0556	0.0604	0.0959	0.1186	0.0793	0.1218	0.0916	0.0986	0.0027	0.0057	1.0000
2	0.1041	0.0224	0.0181	0.0072	0.0087	0.0184	0.0791	0.0687	0.1127	0.1331	0.0618	0.1152	0.0915	0.1318	0.0071	0.0201	1.0000
3	0.2436	0.0034	0.0146	0.0219	0.0064	0.0228	0.0416	0.0401	0.0999	0.1195	0.0724	0.0970	0.0766	0.1251	0.0056	0.0095	1.0000
4	0.2031	0.0270	0.0079	0.0111	0.0166	0.0343	0.0352	0.0513	0.0843	0.1046	0.0715	0.1356	0.1139	0.0909	0.0073	0.0056	1.0000
5	0.1799	0.0043	0.0090	0.0117	0.0262	0.0445	0.0615	0.0611	0.1087	0.1002	0.0594	0.1247	0.0955	0.0993	0.0116	0.0025	1.0000
6	0.1467	0.0121	0.0240	0.0261	0.0265	0.0235	0.0501	0.0621	0.0913	0.1091	0.1017	0.1117	0.0860	0.1081	0.0166	0.0043	1.0000
7	0.1153	0.0150	0.0105	0.0235	0.0260	0.0453	0.0490	0.0683	0.1021	0.1148	0.1013	0.1176	0.1098	0.0820	0.0115	0.0080	1.0000
8	0.1160	0.0200	0.0221	0.0405	0.0373	0.0498	0.0499	0.0644	0.0873	0.0937	0.0822	0.1169	0.1110	0.0896	0.0091	0.0102	1.0000
9	0.1523	0.0361	0.0427	0.0599	0.0409	0.0386	0.0542	0.0621	0.0851	0.0848	0.0728	0.1104	0.0847	0.0636	0.0088	0.0029	1.0000
10	0.1101	0.0354	0.0463	0.0344	0.0399	0.0397	0.0568	0.0743	0.0975	0.1107	0.1152	0.1092	0.0620	0.0531	0.0107	0.0048	1.0000
11	0.0897	0.0247	0.0382	0.0423	0.0460	0.0472	0.0768	0.0909	0.0921	0.1102	0.1019	0.1144	0.0669	0.0466	0.0096	0.0027	1.0000
12	0.1233	0.0311	0.0309	0.0319	0.0352	0.0513	0.0723	0.0992	0.1267	0.1170	0.1037	0.0832	0.0451	0.0403	0.0045	0.0043	1.0000
13	0.0731	0.0188	0.0196	0.0370	0.0353	0.0506	0.0945	0.1011	0.1200	0.1144	0.0841	0.1133	0.0816	0.0437	0.0087	0.0042	1.0000
14	0.0589	0.0172	0.0213	0.0222	0.0407	0.0586	0.0708	0.0954	0.1357	0.1397	0.1065	0.1026	0.0720	0.0390	0.0088	0.0107	1.0000
15	0.0978	0.0187	0.0148	0.0282	0.0229	0.0530	0.0655	0.0771	0.1218	0.1214	0.0924	0.1197	0.0815	0.0508	0.0131	0.0211	1.0000
16	0.0711	0.0120	0.0326	0.0216	0.0266	0.0325	0.0892	0.0851	0.0835	0.1211	0.0865	0.1309	0.0989	0.0781	0.0116	0.0186	1.0000
17	0.0927	0.0109	0.0186	0.0219	0.0214	0.0456	0.0625	0.0598	0.0999	0.1028	0.1184	0.1614	0.0789	0.0788	0.0106	0.0160	1.0000
18	0.1223	0.0065	0.0071	0.0143	0.0876	0.0221	0.0664	0.0680	0.0960	0.0898	0.0801	0.1460	0.1004	0.0575	0.0090	0.0270	1.0000
19	0.0992	0.0060	0.0064	0.0168	0.0181	0.0362	0.0364	0.0535	0.0761	0.1109	0.0831	0.1672	0.1600	0.0964	0.0183	0.0154	1.0000
20	0.0956	0.0007	0.0095	0.0469	0.0122	0.0226	0.0330	0.0519	0.0762	0.1018	0.0902	0.1451	0.1749	0.1059	0.0179	0.0155	1.0000
21	0.0933	0.0076	0.0125	0.0165	0.0049	0.0360	0.0434	0.0467	0.0804	0.0976	0.0943	0.1576	0.1521	0.1359	0.0075	0.0137	1.0000
22	0.1010	0.0047	0.0077	0.0160	0.0198	0.0493	0.0374	0.0567	0.0909	0.1016	0.0663	0.1173	0.1473	0.1436	0.0077	0.0328	1.0000
23	0.0777	0.0186	0.0140	0.0139	0.0195	0.0201	0.0631	0.0505	0.1063	0.1171	0.0780	0.1490	0.1280	0.1257	0.0076	0.0109	1.0000

Table D-16. AvgSpeedDistribution, urban restricted, weekday, July 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.0307	0.0086	0.0067	0.0070	0.0110	0.0195	0.0362	0.0513	0.0509	0.0495	0.1596	0.1183	0.1912	0.2308	0.0080	0.0206	1.0000
1	0.0518	0.0063	0.0045	0.0089	0.0095	0.0215	0.0317	0.0372	0.0493	0.0507	0.0373	0.1278	0.2250	0.3044	0.0125	0.0215	1.0000
2	0.0421	0.0025	0.0050	0.0034	0.0089	0.0251	0.0296	0.0450	0.0539	0.0546	0.0409	0.1249	0.2226	0.3068	0.0170	0.0175	1.0000
3	0.0333	0.0032	0.0021	0.0093	0.0092	0.0158	0.0357	0.0499	0.0556	0.0528	0.0286	0.1221	0.2204	0.3083	0.0284	0.0253	1.0000
4	0.0298	0.0044	0.0056	0.0068	0.0073	0.0139	0.0295	0.0415	0.0504	0.0552	0.0343	0.1278	0.2417	0.2874	0.0296	0.0347	1.0000
5	0.0318	0.0038	0.0070	0.0044	0.0089	0.0175	0.0303	0.0323	0.0404	0.0408	0.0294	0.1298	0.2975	0.2559	0.0321	0.0381	1.0000
6	0.0368	0.0058	0.0045	0.0054	0.0069	0.0165	0.0288	0.0389	0.0492	0.0391	0.0349	0.1366	0.2976	0.2165	0.0365	0.0458	1.0000
7	0.0452	0.0085	0.0141	0.0152	0.0142	0.0225	0.0342	0.0487	0.0480	0.0476	0.0426	0.1373	0.2385	0.1937	0.0353	0.0543	1.0000
8	0.0491	0.0134	0.0162	0.0198	0.0210	0.0233	0.0317	0.0443	0.0501	0.0472	0.0413	0.1129	0.2174	0.2026	0.0397	0.0701	1.0000
9	0.0531	0.0098	0.0097	0.0147	0.0179	0.0278	0.0364	0.0411	0.0548	0.0488	0.0440	0.1256	0.2421	0.1835	0.0312	0.0593	1.0000
10	0.0465	0.0073	0.0089	0.0107	0.0197	0.0215	0.0429	0.0445	0.0517	0.0516	0.0481	0.1349	0.2482	0.1747	0.0298	0.0590	1.0000
11	0.0509	0.0067	0.0073	0.0088	0.0147	0.0235	0.0361	0.0431	0.0521	0.0450	0.0415	0.1448	0.2602	0.1766	0.0320	0.0566	1.0000
12	0.0497	0.0081	0.0090	0.0118	0.0135	0.0207	0.0397	0.0472	0.0479	0.0476	0.0416	0.1398	0.2528	0.1804	0.0350	0.0550	1.0000
13	0.0492	0.0080	0.0104	0.0125	0.0174	0.0244	0.0412	0.0413	0.0499	0.0463	0.0450	0.1381	0.2398	0.1909	0.0296	0.0560	1.0000
14	0.0502	0.0103	0.0128	0.0172	0.0216	0.0300	0.0406	0.0461	0.0550	0.0481	0.0478	0.1307	0.2253	0.1859	0.0295	0.0490	1.0000
15	0.0440	0.0098	0.0165	0.0175	0.0217	0.0304	0.0397	0.0498	0.0559	0.0560	0.0470	0.1209	0.2534	0.1691	0.0247	0.0439	1.0000
16	0.0475	0.0157	0.0267	0.0253	0.0334	0.0432	0.0527	0.0555	0.0573	0.0581	0.0466	0.1181	0.1857	0.1662	0.0274	0.0406	1.0000
17	0.0336	0.0178	0.0300	0.0337	0.0317	0.0446	0.0573	0.0594	0.0686	0.0569	0.0474	0.1135	0.1811	0.1663	0.0207	0.0373	1.0000
18	0.0264	0.0144	0.0183	0.0254	0.0328	0.0389	0.0550	0.0566	0.0600	0.0576	0.0432	0.1210	0.2258	0.1741	0.0190	0.0314	1.0000
19	0.0309	0.0061	0.0095	0.0204	0.0200	0.0304	0.0512	0.0521	0.0564	0.0569	0.0400	0.1461	0.2667	0.1721	0.0176	0.0233	1.0000
20	0.0289	0.0048	0.0057	0.0085	0.0125	0.0176	0.0322	0.0426	0.0449	0.0477	0.0485	0.1841	0.2750	0.1980	0.0205	0.0285	1.0000
21	0.0335	0.0047	0.0061	0.0068	0.0121	0.0213	0.0379	0.0412	0.0439	0.0494	0.0503	0.1852	0.2710	0.1979	0.0147	0.0239	1.0000
22	0.0207	0.0071	0.0089	0.0106	0.0115	0.0164	0.0398	0.0414	0.0495	0.0473	0.0486	0.1725	0.2588	0.2308	0.0152	0.0208	1.0000
23	0.0281	0.0025	0.0085	0.0122	0.0120	0.0164	0.0451	0.0493	0.0545	0.0523	0.0446	0.1585	0.2496	0.2291	0.0134	0.0238	1.0000

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Table D-17. AvgSpeedDistribution, urban restricted, weekend, July 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.0218	0.0017	0.0061	0.0102	0.0073	0.0329	0.0538	0.0561	0.0646	0.0547	0.0346	0.1048	0.1939	0.3177	0.0239	0.0160	1.0000
1	0.0109	0.0000	0.0031	0.0038	0.0098	0.0173	0.0538	0.0510	0.0705	0.0516	0.0337	0.0953	0.1943	0.3723	0.0168	0.0159	1.0000
2	0.0187	0.0011	0.0057	0.0065	0.0084	0.0175	0.0602	0.0634	0.0855	0.0671	0.0248	0.0791	0.1594	0.3764	0.0097	0.0163	1.0000
3	0.0252	0.0027	0.0166	0.0150	0.0119	0.0192	0.0336	0.0614	0.0710	0.0548	0.0230	0.0767	0.1480	0.3962	0.0127	0.0321	1.0000
4	0.0307	0.0018	0.0076	0.0074	0.0081	0.0115	0.0575	0.0500	0.0714	0.0542	0.0217	0.0910	0.1962	0.3511	0.0174	0.0223	1.0000
5	0.0383	0.0007	0.0071	0.0039	0.0062	0.0151	0.0343	0.0363	0.0467	0.0437	0.0258	0.1081	0.2479	0.3457	0.0321	0.0080	1.0000
6	0.0233	0.0051	0.0040	0.0067	0.0080	0.0135	0.0340	0.0489	0.0543	0.0435	0.0233	0.0869	0.2892	0.3175	0.0367	0.0050	1.0000
7	0.0388	0.0026	0.0056	0.0021	0.0075	0.0218	0.0314	0.0448	0.0513	0.0505	0.0299	0.1117	0.2382	0.3170	0.0311	0.0158	1.0000
8	0.0288	0.0024	0.0058	0.0026	0.0066	0.0227	0.0283	0.0492	0.0622	0.0566	0.0368	0.1052	0.2329	0.3176	0.0273	0.0150	1.0000
9	0.0338	0.0040	0.0045	0.0025	0.0126	0.0155	0.0394	0.0391	0.0483	0.0541	0.0387	0.1410	0.2820	0.2414	0.0227	0.0205	1.0000
10	0.0183	0.0051	0.0067	0.0077	0.0087	0.0127	0.0392	0.0565	0.0601	0.0430	0.0378	0.1317	0.2888	0.2359	0.0277	0.0200	1.0000
11	0.0219	0.0073	0.0104	0.0241	0.0144	0.0276	0.0602	0.0573	0.0544	0.0514	0.0457	0.1298	0.2297	0.2132	0.0269	0.0256	1.0000
12	0.0134	0.0090	0.0081	0.0247	0.0239	0.0337	0.0513	0.0609	0.0584	0.0455	0.0397	0.1116	0.2019	0.2745	0.0174	0.0258	1.0000
13	0.0207	0.0096	0.0053	0.0172	0.0146	0.0199	0.0562	0.0508	0.0638	0.0576	0.0352	0.0977	0.2087	0.2878	0.0262	0.0286	1.0000
14	0.0226	0.0020	0.0033	0.0152	0.0121	0.0283	0.0512	0.0525	0.0640	0.0496	0.0339	0.0999	0.1927	0.3185	0.0260	0.0281	1.0000
15	0.0220	0.0055	0.0081	0.0117	0.0261	0.0347	0.0550	0.0585	0.0608	0.0494	0.0289	0.0930	0.1588	0.3245	0.0285	0.0344	1.0000
16	0.0223	0.0035	0.0041	0.0095	0.0132	0.0234	0.0375	0.0597	0.0637	0.0579	0.0223	0.0980	0.1709	0.3505	0.0239	0.0397	1.0000
17	0.0249	0.0075	0.0057	0.0124	0.0115	0.0274	0.0578	0.0658	0.0722	0.0609	0.0388	0.0796	0.1573	0.3290	0.0211	0.0281	1.0000
18	0.0224	0.0036	0.0053	0.0109	0.0207	0.0311	0.0540	0.0684	0.0744	0.0496	0.0248	0.0853	0.2105	0.2810	0.0098	0.0483	1.0000
19	0.0063	0.0027	0.0053	0.0231	0.0132	0.0254	0.0520	0.0742	0.0932	0.0650	0.0399	0.0746	0.1681	0.3010	0.0175	0.0385	1.0000
20	0.0109	0.0071	0.0027	0.0175	0.0197	0.0316	0.0455	0.0632	0.0608	0.0510	0.0263	0.0761	0.1548	0.3665	0.0137	0.0525	1.0000
21	0.0384	0.0015	0.0074	0.0128	0.0224	0.0104	0.0593	0.0576	0.0607	0.0655	0.0332	0.0886	0.1481	0.3470	0.0130	0.0338	1.0000
22	0.0163	0.0009	0.0034	0.0089	0.0201	0.0304	0.0678	0.0645	0.0820	0.0532	0.0268	0.0798	0.1570	0.3455	0.0133	0.0300	1.0000
23	0.0249	0.0036	0.0040	0.0058	0.0244	0.0247	0.0834	0.0736	0.0790	0.0449	0.0219	0.0894	0.1370	0.3434	0.0110	0.0292	1.0000

Table D-18. AvgSpeedDistribution, urban unrestricted, weekday, July 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	Sum
0	0.2783	0.0277	0.0282	0.0410	0.0362	0.0562	0.1089	0.1005	0.0843	0.0472	0.0270	0.0487	0.0667	0.0432	0.0020	0.0039	1.0000
1	0.2396	0.0318	0.0254	0.0464	0.0369	0.0473	0.1001	0.1222	0.0885	0.0568	0.0196	0.0514	0.0785	0.0489	0.0015	0.0050	1.0000
2	0.2130	0.0146	0.0202	0.0515	0.0329	0.0622	0.1080	0.1257	0.1193	0.0673	0.0236	0.0431	0.0607	0.0511	0.0020	0.0047	1.0000
3	0.1845	0.0184	0.0307	0.0328	0.0327	0.0539	0.1333	0.1160	0.1228	0.0725	0.0337	0.0458	0.0630	0.0515	0.0031	0.0052	1.0000
4	0.1812	0.0164	0.0425	0.0419	0.0389	0.0617	0.1315	0.1136	0.1168	0.0554	0.0218	0.0487	0.0703	0.0447	0.0048	0.0099	1.0000
5	0.1877	0.0138	0.0228	0.0384	0.0381	0.0672	0.1090	0.1280	0.0999	0.0603	0.0215	0.0509	0.1033	0.0430	0.0062	0.0099	1.0000
6	0.1855	0.0221	0.0302	0.0444	0.0388	0.0482	0.1108	0.1095	0.0795	0.0438	0.0252	0.0735	0.1169	0.0521	0.0071	0.0122	1.0000
7	0.2914	0.0288	0.0264	0.0330	0.0420	0.0584	0.0842	0.0897	0.0713	0.0456	0.0278	0.0566	0.0846	0.0381	0.0057	0.0164	1.0000
8	0.2582	0.0334	0.0420	0.0392	0.0489	0.0527	0.0761	0.0844	0.0797	0.0569	0.0339	0.0536	0.0731	0.0397	0.0069	0.0212	1.0000
9	0.2375	0.0322	0.0398	0.0511	0.0597	0.0725	0.0901	0.0832	0.0835	0.0581	0.0336	0.0470	0.0618	0.0309	0.0057	0.0134	1.0000
10	0.2314	0.0281	0.0396	0.0448	0.0567	0.0717	0.0953	0.0930	0.0917	0.0603	0.0304	0.0468	0.0631	0.0289	0.0052	0.0130	1.0000
11	0.2346	0.0305	0.0422	0.0423	0.0507	0.0726	0.0822	0.0904	0.0912	0.0610	0.0302	0.0513	0.0696	0.0310	0.0056	0.0145	1.0000
12	0.2312	0.0361	0.0412	0.0523	0.0519	0.0699	0.0820	0.0902	0.0865	0.0634	0.0313	0.0510	0.0635	0.0328	0.0047	0.0120	1.0000
13	0.2400	0.0340	0.0369	0.0466	0.0599	0.0768	0.0945	0.0838	0.0883	0.0593	0.0274	0.0449	0.0596	0.0301	0.0055	0.0124	1.0000
14	0.2230	0.0346	0.0354	0.0552	0.0523	0.0836	0.0962	0.0904	0.0923	0.0572	0.0294	0.0449	0.0592	0.0300	0.0051	0.0112	1.0000
15	0.2084	0.0291	0.0356	0.0508	0.0551	0.0804	0.1017	0.1014	0.0944	0.0642	0.0309	0.0467	0.0568	0.0298	0.0049	0.0099	1.0000
16	0.1911	0.0295	0.0402	0.0554	0.0632	0.0815	0.1028	0.1016	0.1060	0.0681	0.0308	0.0444	0.0470	0.0256	0.0040	0.0088	1.0000
17	0.1726	0.0305	0.0342	0.0608	0.0601	0.0841	0.1123	0.1055	0.1063	0.0701	0.0338	0.0445	0.0477	0.0264	0.0038	0.0073	1.0000
18	0.1865	0.0333	0.0420	0.0516	0.0681	0.0828	0.1026	0.1040	0.0940	0.0566	0.0267	0.0466	0.0649	0.0303	0.0036	0.0064	1.0000
19	0.1930	0.0312	0.0416	0.0523	0.0599	0.0666	0.0879	0.1012	0.0826	0.0514	0.0261	0.0676	0.0960	0.0328	0.0048	0.0049	1.0000
20	0.2023	0.0301	0.0378	0.0348	0.0442	0.0638	0.0963	0.0824	0.0857	0.0511	0.0333	0.0850	0.1038	0.0413	0.0032	0.0049	1.0000
21	0.2407	0.0252	0.0312	0.0334	0.0384	0.0491	0.0928	0.1001	0.0838	0.0491	0.0314	0.0828	0.0953	0.0389	0.0032	0.0046	1.0000
22	0.1974	0.0229	0.0299	0.0465	0.0515	0.0620	0.0983	0.0970	0.0856	0.0481	0.0338	0.0760	0.1009	0.0431	0.0025	0.0044	1.0000
23	0.2383	0.0219	0.0423	0.0481	0.0418	0.0691	0.1171	0.0928	0.0850	0.0540	0.0224	0.0542	0.0696	0.0377	0.0016	0.0042	1.0000

Table D-19. AvgSpeedDistribution, urban unrestricted, weekend, July 2010 – U.S.

Hour	Average Speed (mph)																Sum
	2.5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
0	0.1117	0.0079	0.0237	0.0446	0.0420	0.0846	0.1679	0.1384	0.1346	0.0688	0.0263	0.0338	0.0624	0.0477	0.0021	0.0033	1.0000
1	0.1420	0.0126	0.0217	0.0459	0.0482	0.0910	0.1420	0.1509	0.1311	0.0725	0.0231	0.0351	0.0359	0.0451	0.0013	0.0017	1.0000
2	0.1247	0.0141	0.0389	0.0325	0.0479	0.0563	0.1587	0.1414	0.1638	0.0633	0.0261	0.0337	0.0407	0.0545	0.0027	0.0008	1.0000
3	0.1381	0.0243	0.0172	0.0302	0.0538	0.0646	0.1487	0.1423	0.1200	0.0876	0.0240	0.0411	0.0339	0.0641	0.0027	0.0073	1.0000
4	0.1128	0.0046	0.0304	0.0609	0.0380	0.0772	0.1592	0.1569	0.1264	0.0709	0.0180	0.0315	0.0594	0.0472	0.0030	0.0037	1.0000
5	0.1579	0.0138	0.0381	0.0279	0.0344	0.0671	0.1140	0.1601	0.1209	0.0559	0.0174	0.0451	0.0791	0.0603	0.0075	0.0006	1.0000
6	0.1815	0.0100	0.0333	0.0529	0.0545	0.0714	0.1240	0.0898	0.1120	0.0442	0.0162	0.0361	0.1026	0.0617	0.0067	0.0033	1.0000
7	0.1712	0.0227	0.0226	0.0328	0.0537	0.0676	0.1154	0.0989	0.0894	0.0539	0.0228	0.0531	0.1052	0.0733	0.0098	0.0076	1.0000
8	0.2224	0.0160	0.0386	0.0361	0.0509	0.0644	0.0989	0.1013	0.0849	0.0545	0.0235	0.0436	0.0997	0.0545	0.0066	0.0041	1.0000
9	0.1681	0.0348	0.0298	0.0673	0.0610	0.0785	0.0924	0.0996	0.0891	0.0482	0.0191	0.0577	0.0883	0.0571	0.0050	0.0039	1.0000
10	0.1765	0.0239	0.0315	0.0309	0.0511	0.0736	0.1099	0.1197	0.0840	0.0539	0.0288	0.0608	0.0957	0.0504	0.0056	0.0037	1.0000
11	0.1349	0.0224	0.0272	0.0313	0.0762	0.0719	0.1079	0.1247	0.0986	0.0569	0.0349	0.0644	0.0935	0.0439	0.0049	0.0065	1.0000
12	0.1040	0.0189	0.0407	0.0858	0.0669	0.0655	0.1240	0.1061	0.1057	0.0719	0.0271	0.0570	0.0682	0.0537	0.0024	0.0021	1.0000
13	0.0971	0.0181	0.0248	0.0630	0.0581	0.0947	0.1331	0.1128	0.1088	0.0735	0.0252	0.0593	0.0716	0.0498	0.0039	0.0062	1.0000
14	0.1382	0.0125	0.0628	0.0526	0.0687	0.0952	0.1069	0.1181	0.1256	0.0602	0.0261	0.0404	0.0424	0.0422	0.0028	0.0054	1.0000
15	0.1190	0.0132	0.0267	0.0564	0.0494	0.0528	0.1373	0.1251	0.1414	0.0650	0.0251	0.0521	0.0554	0.0676	0.0042	0.0093	1.0000
16	0.1177	0.0091	0.0328	0.0598	0.0610	0.0979	0.1180	0.1584	0.1190	0.0622	0.0226	0.0336	0.0487	0.0476	0.0033	0.0084	1.0000
17	0.0666	0.0099	0.0330	0.0439	0.0517	0.1610	0.1405	0.1298	0.1098	0.0691	0.0207	0.0405	0.0582	0.0538	0.0057	0.0057	1.0000
18	0.1177	0.0136	0.0251	0.0520	0.0859	0.0987	0.1364	0.1337	0.0892	0.0587	0.0252	0.0396	0.0691	0.0420	0.0005	0.0125	1.0000
19	0.0825	0.0091	0.0350	0.0544	0.0579	0.0675	0.1367	0.1183	0.1398	0.0959	0.0255	0.0432	0.0778	0.0471	0.0041	0.0052	1.0000
20	0.1283	0.0119	0.0245	0.0448	0.0584	0.0732	0.0996	0.1371	0.1279	0.0745	0.0293	0.0307	0.0729	0.0730	0.0019	0.0119	1.0000
21	0.1592	0.0090	0.0163	0.0324	0.1017	0.0790	0.1359	0.1456	0.0917	0.0619	0.0292	0.0385	0.0403	0.0495	0.0030	0.0068	1.0000
22	0.1448	0.0168	0.0325	0.0441	0.0915	0.0725	0.1230	0.1261	0.1238	0.0709	0.0263	0.0271	0.0426	0.0498	0.0017	0.0065	1.0000
23	0.1367	0.0164	0.0146	0.0133	0.0261	0.1351	0.1597	0.1532	0.1142	0.0558	0.0293	0.0352	0.0523	0.0493	0.0006	0.0083	1.0000

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Table D-20. Trip start distribution – U.S.

Hour	January 2010				July 2010			
	Weekday		Weekend		Weekday		Weekend	
	Freq.	Fraction	Freq.	Fraction	Freq.	Fraction	Freq.	Fraction
0	738	0.0148	296	0.0289	1,402	0.0208	462	0.0386
1	708	0.0142	296	0.0289	1,207	0.0179	473	0.0395
2	759	0.0153	296	0.0289	1,225	0.0182	426	0.0356
3	1,101	0.0221	319	0.0311	1,193	0.0177	359	0.0300
4	1,220	0.0245	340	0.0332	1,415	0.0210	398	0.0333
5	1,417	0.0285	397	0.0387	1,776	0.0264	434	0.0363
6	1,709	0.0344	429	0.0418	2,130	0.0316	470	0.0393
7	2,748	0.0553	505	0.0492	3,015	0.0447	539	0.0450
8	3,370	0.0678	684	0.0667	4,031	0.0598	648	0.0541
9	3,536	0.0711	724	0.0706	4,328	0.0642	748	0.0625
10	3,599	0.0724	674	0.0657	4,447	0.0660	754	0.0630
11	3,581	0.0720	633	0.0617	4,404	0.0654	743	0.0621
12	3,387	0.0681	601	0.0586	4,309	0.0639	685	0.0572
13	3,415	0.0687	571	0.0557	4,324	0.0642	648	0.0541
14	3,337	0.0671	500	0.0488	4,149	0.0616	577	0.0482
15	2,986	0.0601	448	0.0437	4,115	0.0611	521	0.0435
16	2,853	0.0574	429	0.0418	3,817	0.0566	475	0.0397
17	2,270	0.0457	411	0.0401	3,477	0.0516	464	0.0388
18	1,609	0.0324	370	0.0361	2,988	0.0443	390	0.0326
19	1,408	0.0283	301	0.0294	2,254	0.0335	373	0.0312
20	1,178	0.0237	285	0.0278	2,129	0.0316	377	0.0315
21	1,083	0.0218	274	0.0267	1,877	0.0279	344	0.0287
22	899	0.0181	241	0.0235	1,633	0.0242	320	0.0267
23	811	0.0163	230	0.0224	1,736	0.0258	341	0.0285
Total	49,722	1.0000	10,254	1.0000	67,381	1.0000	11,969	1.0000
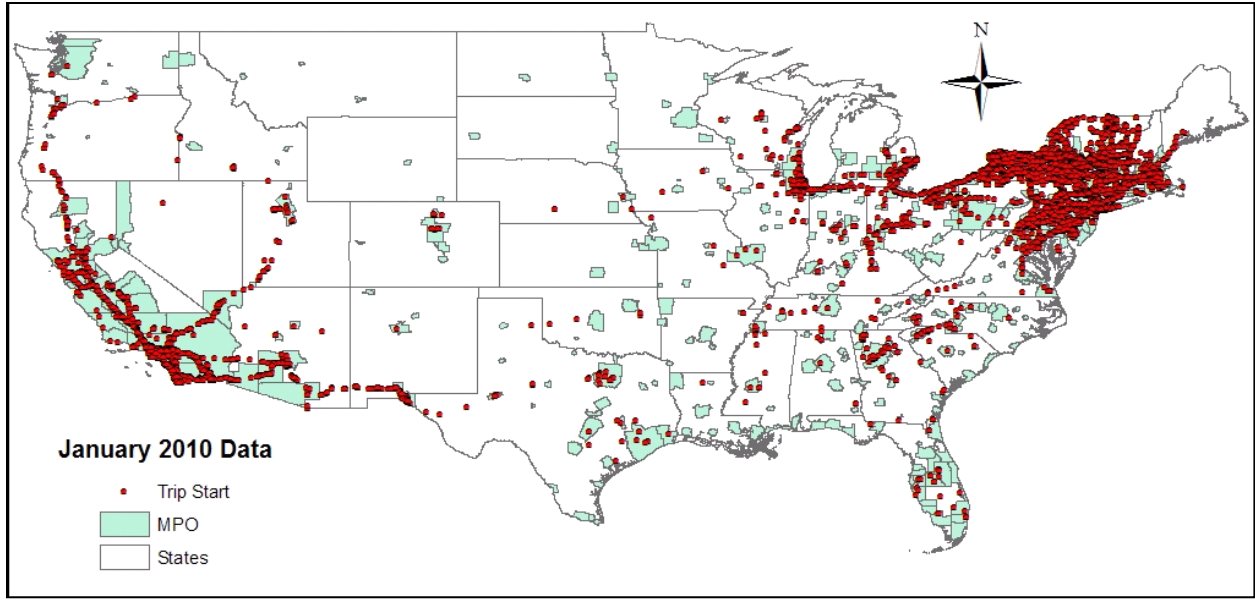
Figure D-1. Trip start locations – U.S., January 2010
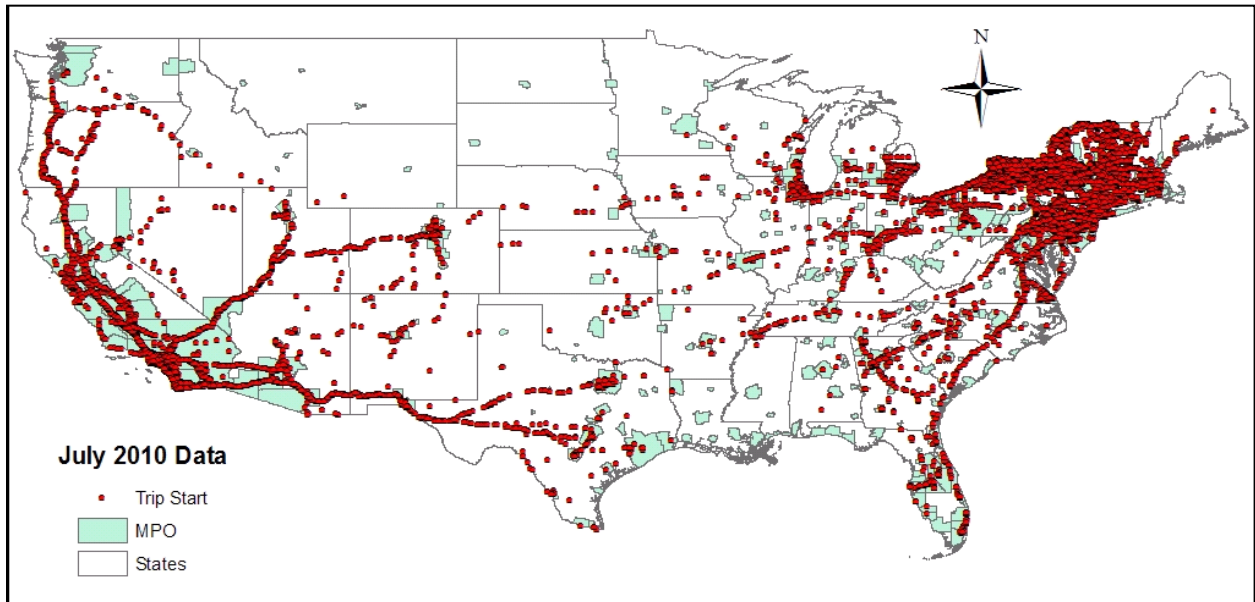
Figure D-2. Trip start locations – U.S., July 2010
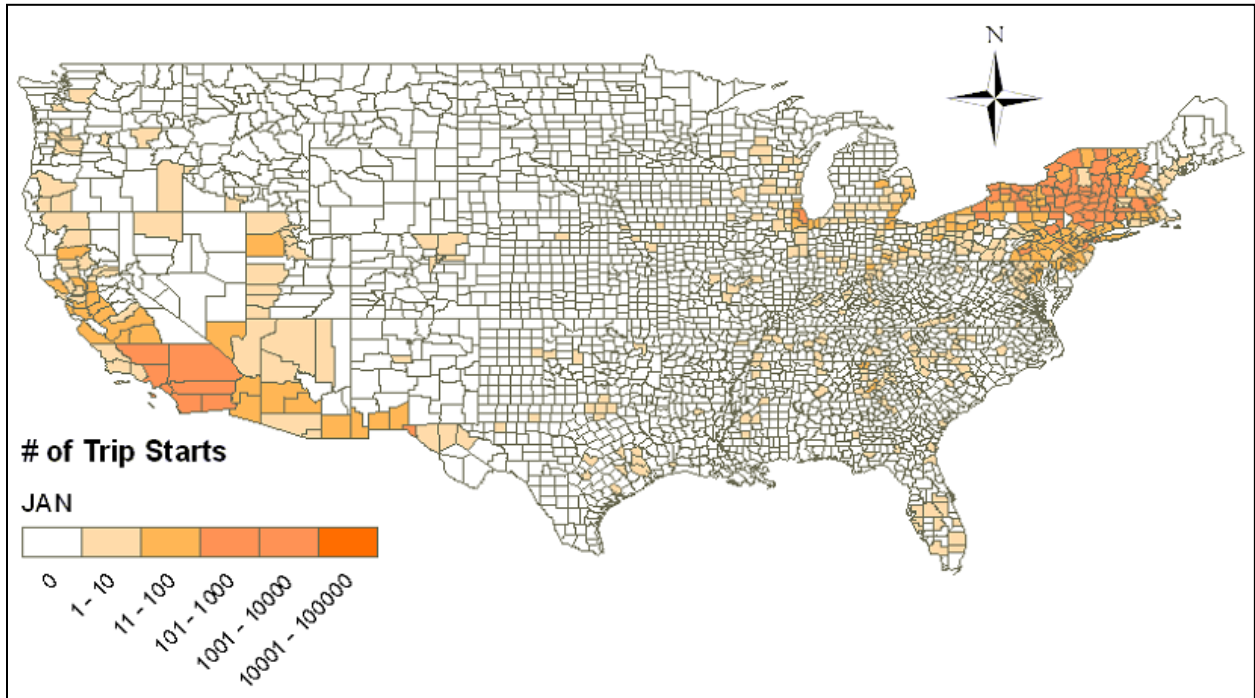
Figure D-3. StartAllocFactor – U.S., January 2010
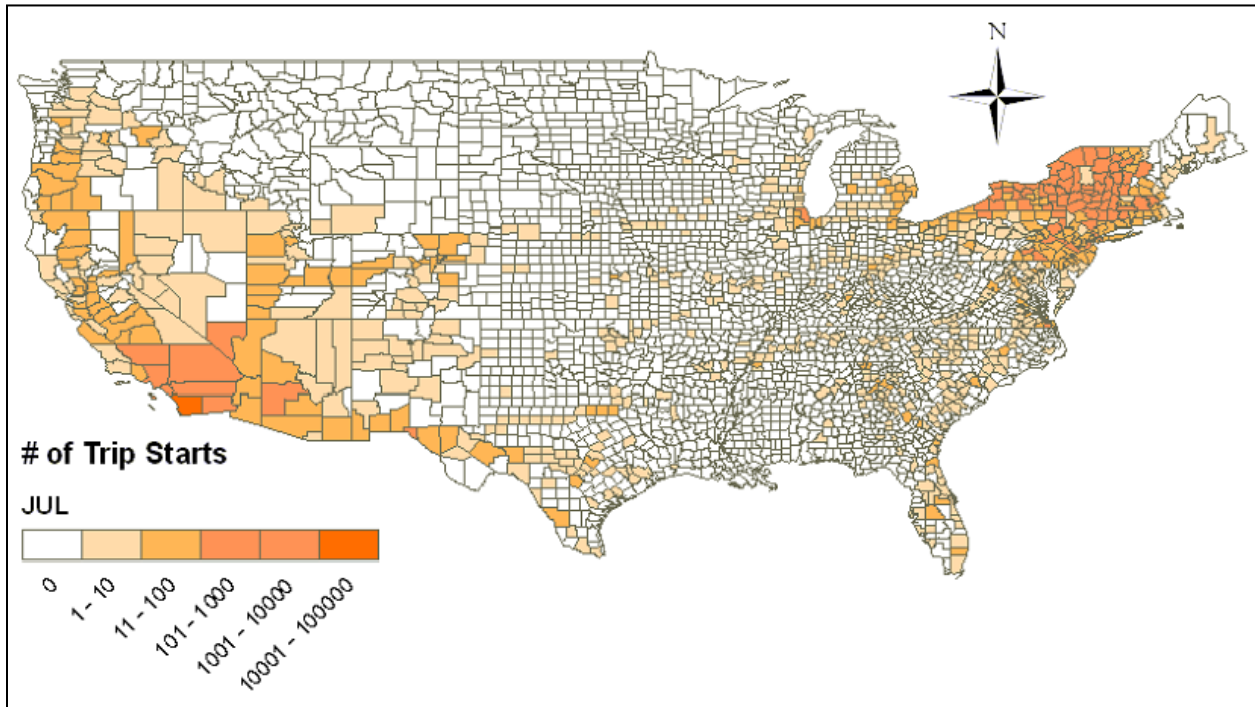
Figure D-4. StartAllocFactor – U.S., July 2010
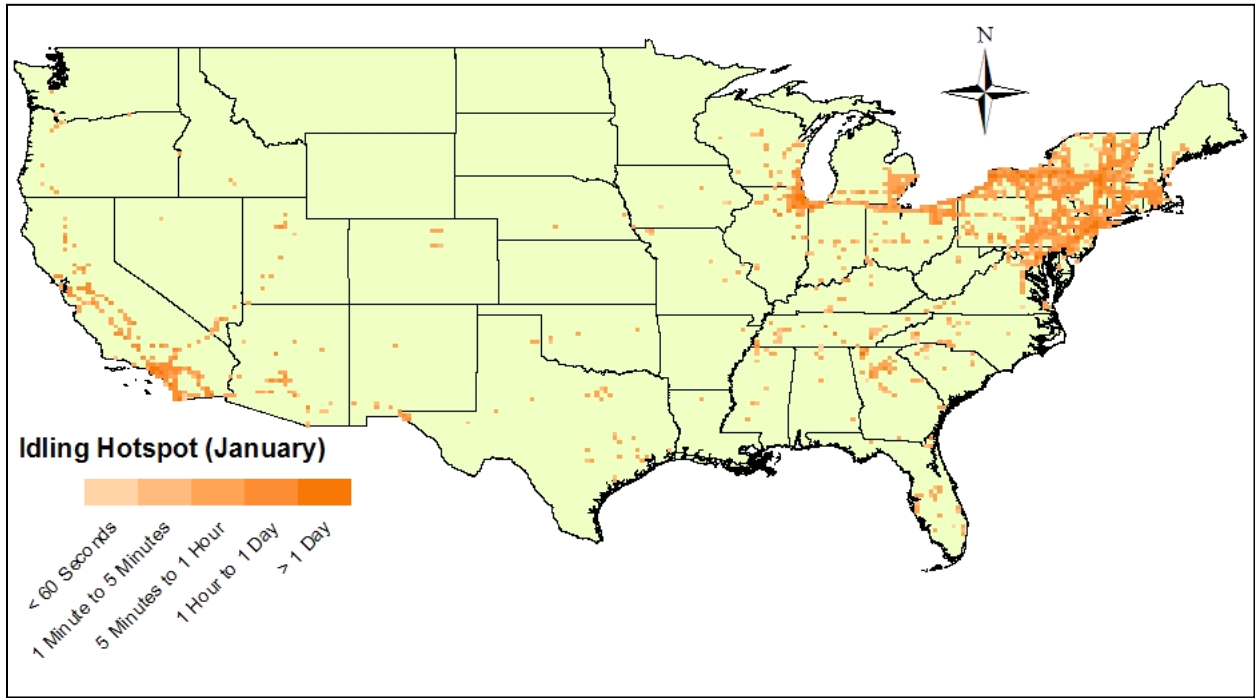
Figure D-5. Gradient map of truck idling activity and hot spots – U.S., January 2010
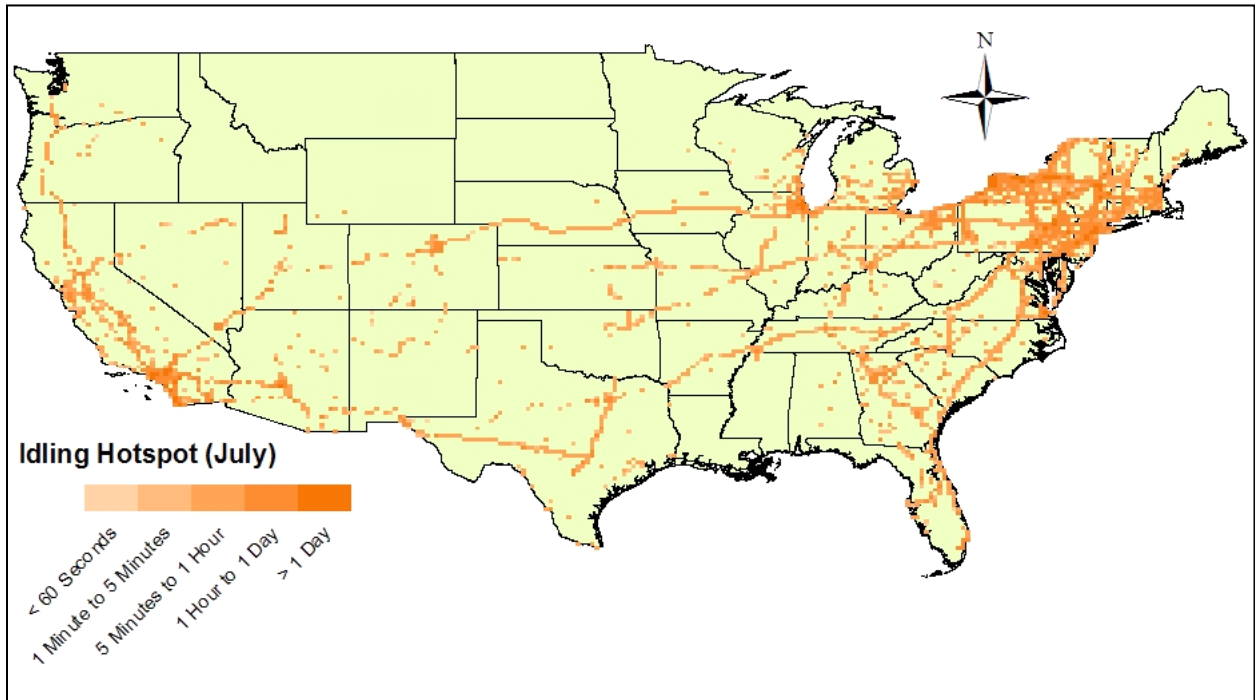
Figure D-6. Gradient map of truck idling activity and hot spots – U.S., July 2010

Appendix E:

# MOVES Driving Cycles for Single-Unit and Combination Trucks
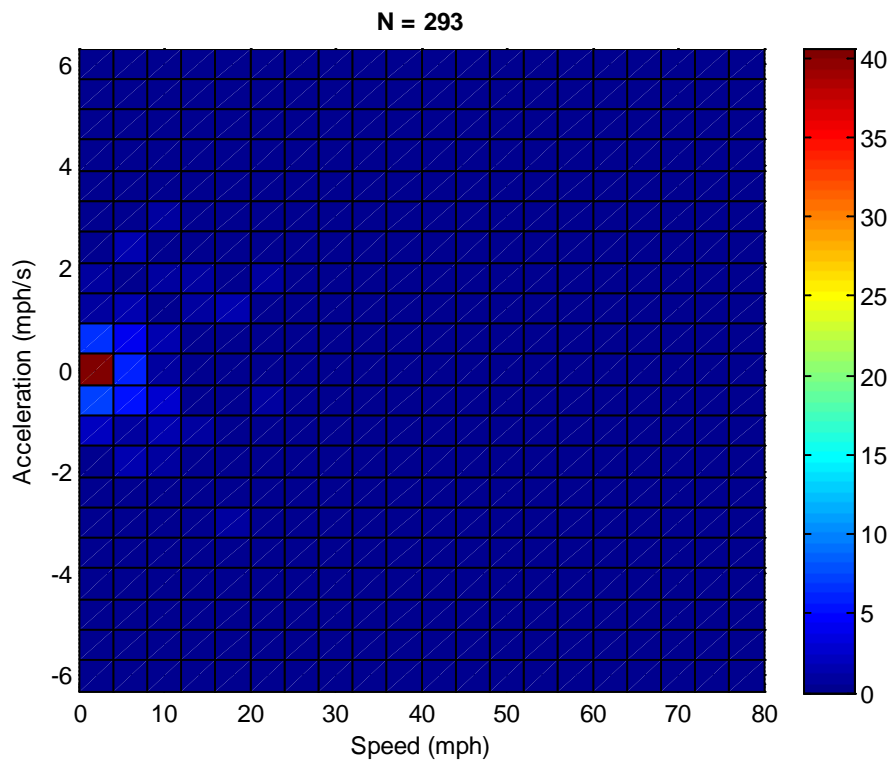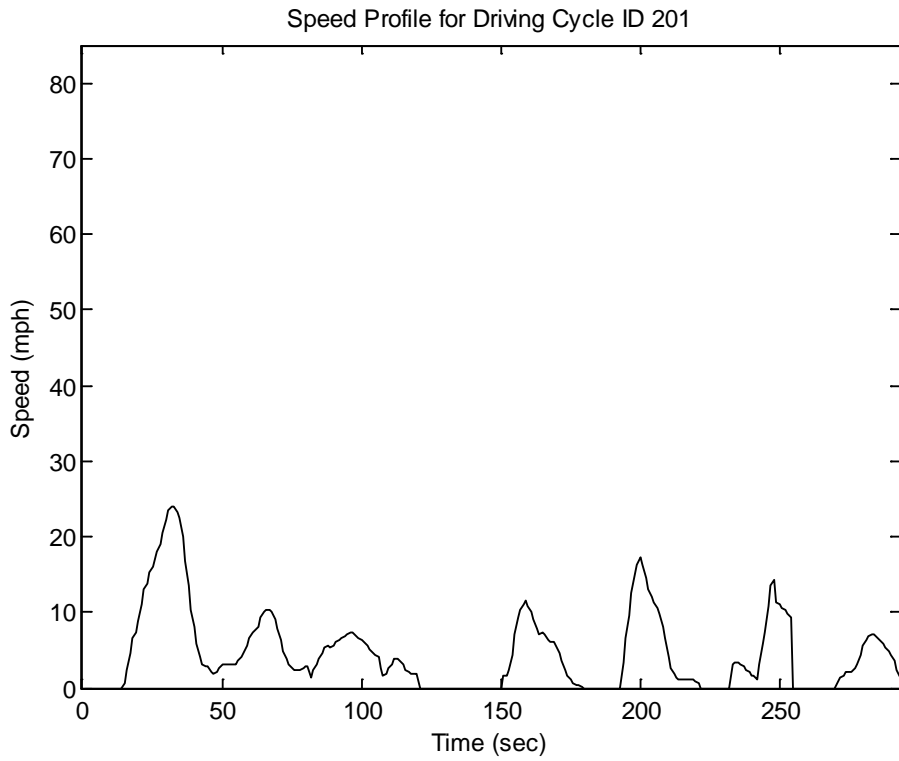
Figure E-1. MD 5mph non-freeway cycle (length = 293 seconds; average speed = 4.6 mph)
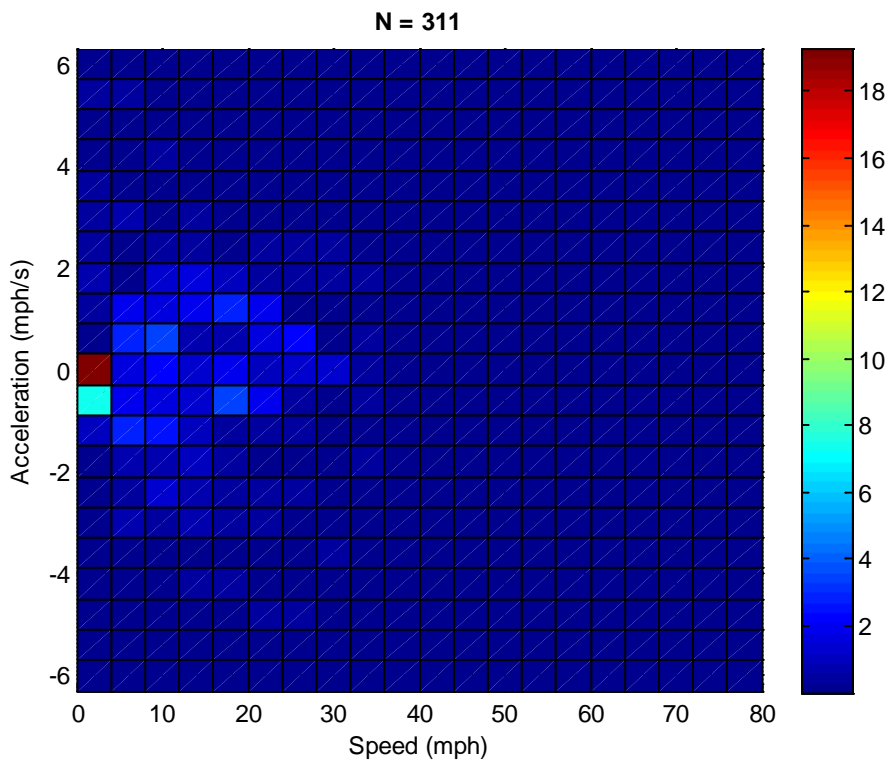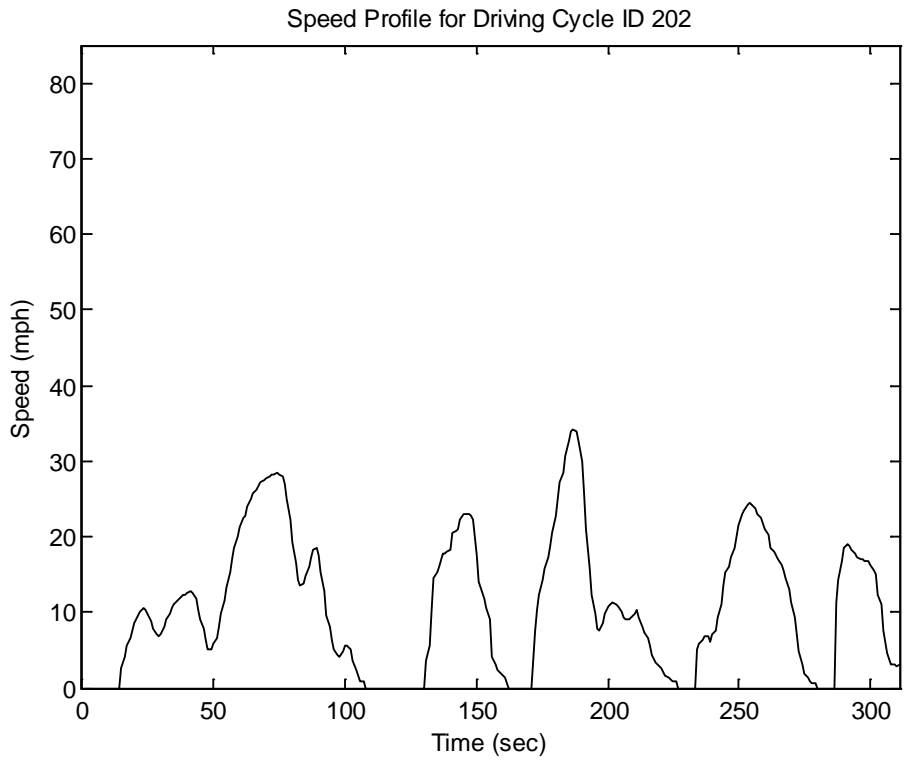
Figure E-2. MD 10mph non-freeway cycle (length = 311 seconds; average speed = 10.7 mph)
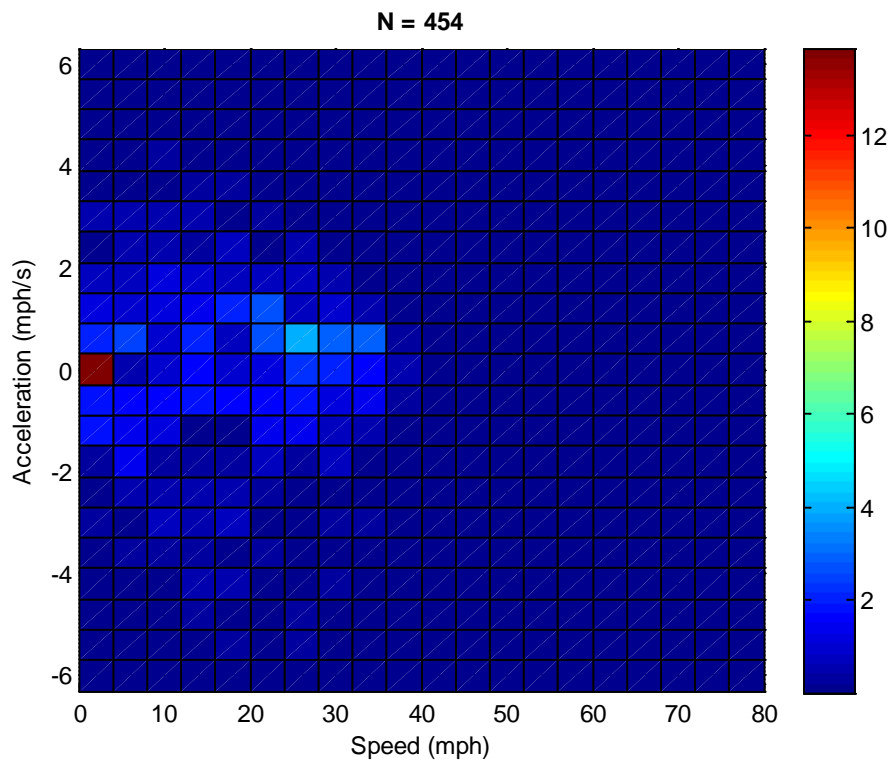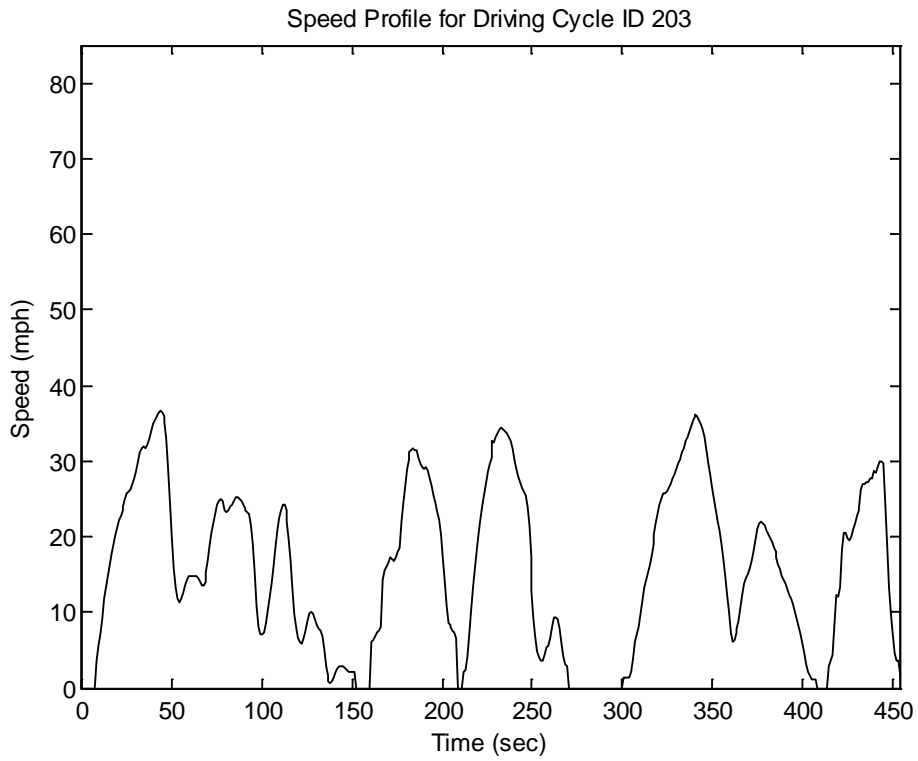
**Figure E-3. MD 15mph non-freeway cycle (length = 454 seconds; average speed = 15.6 mph)**
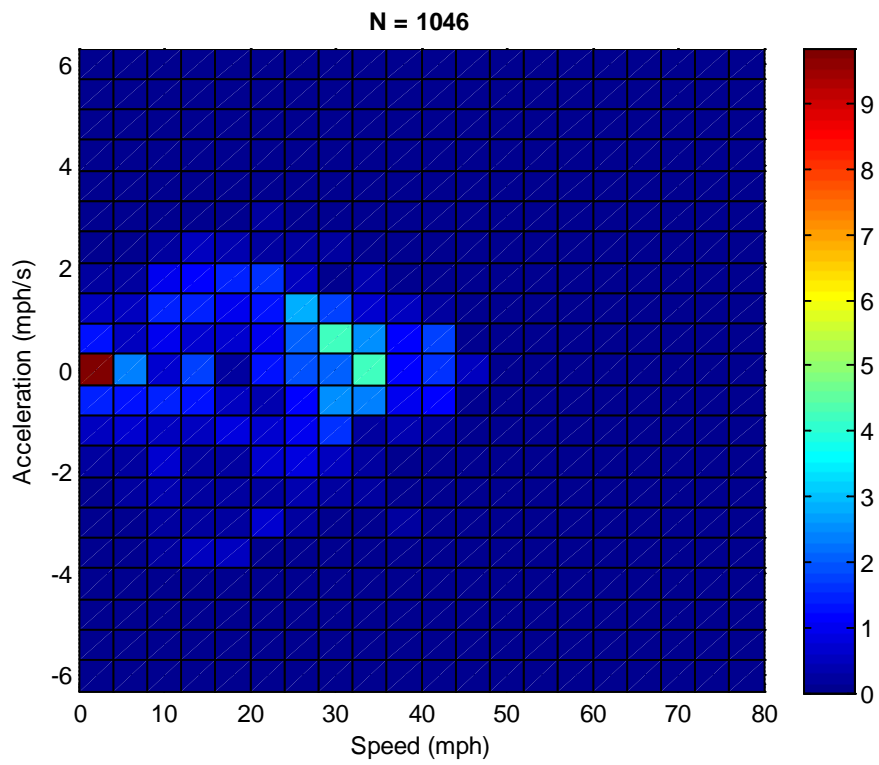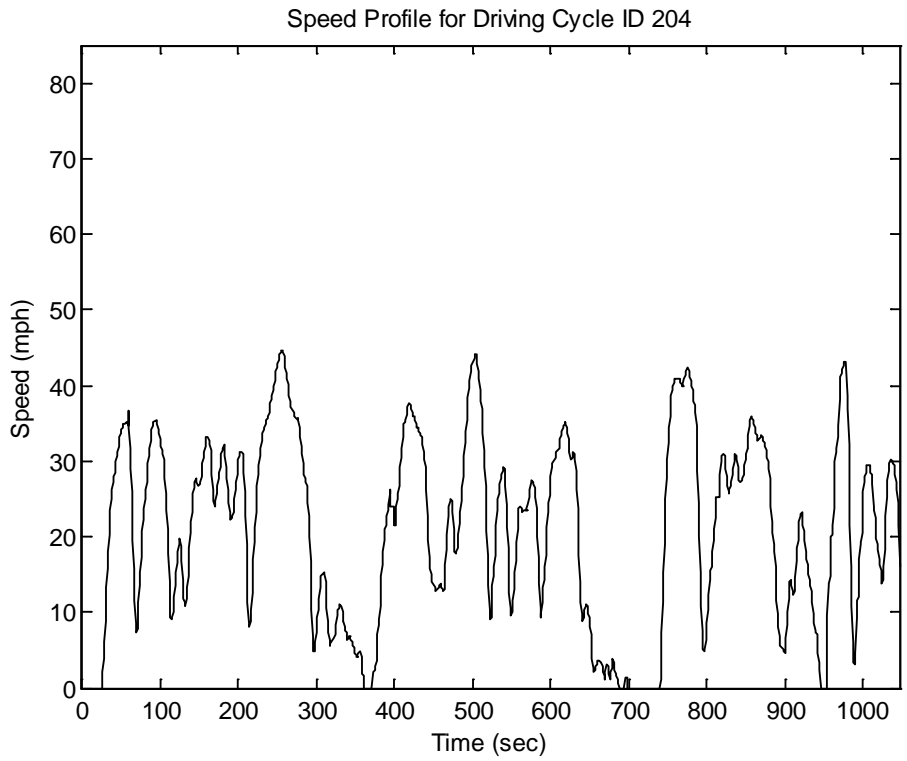
Figure E-4. MD 20mph non-freeway cycle (length = 1,046 seconds; average speed = 20.8 mph)

Speed Profile for Driving Cycle ID 205

N = 566
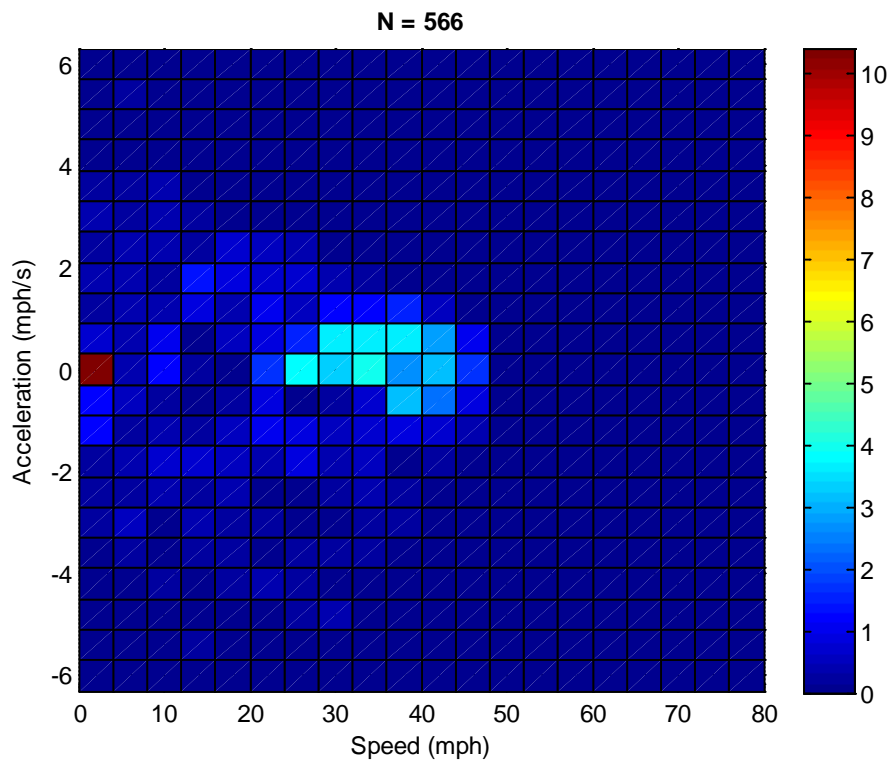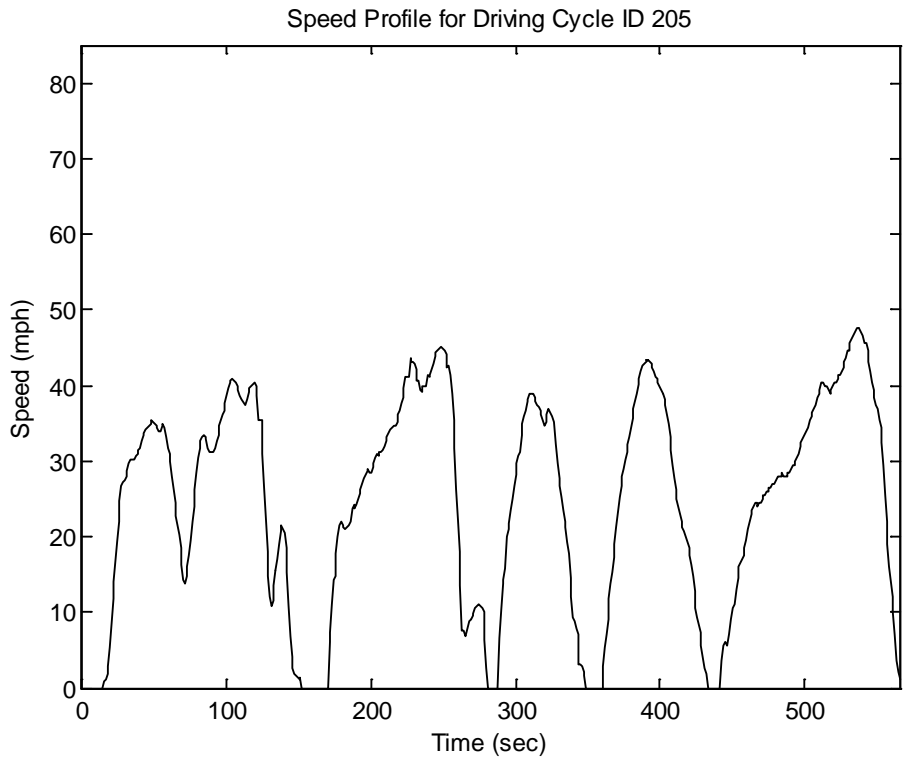
Figure E-5. MD 25mph non-freeway cycle (length = 566 seconds; average speed = 24.5 mph)
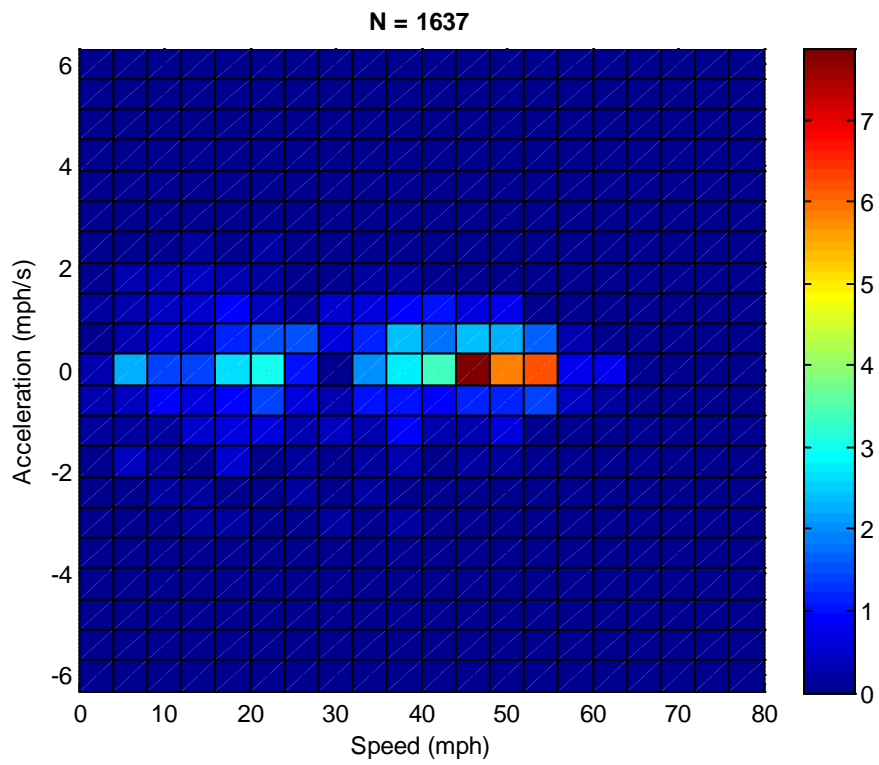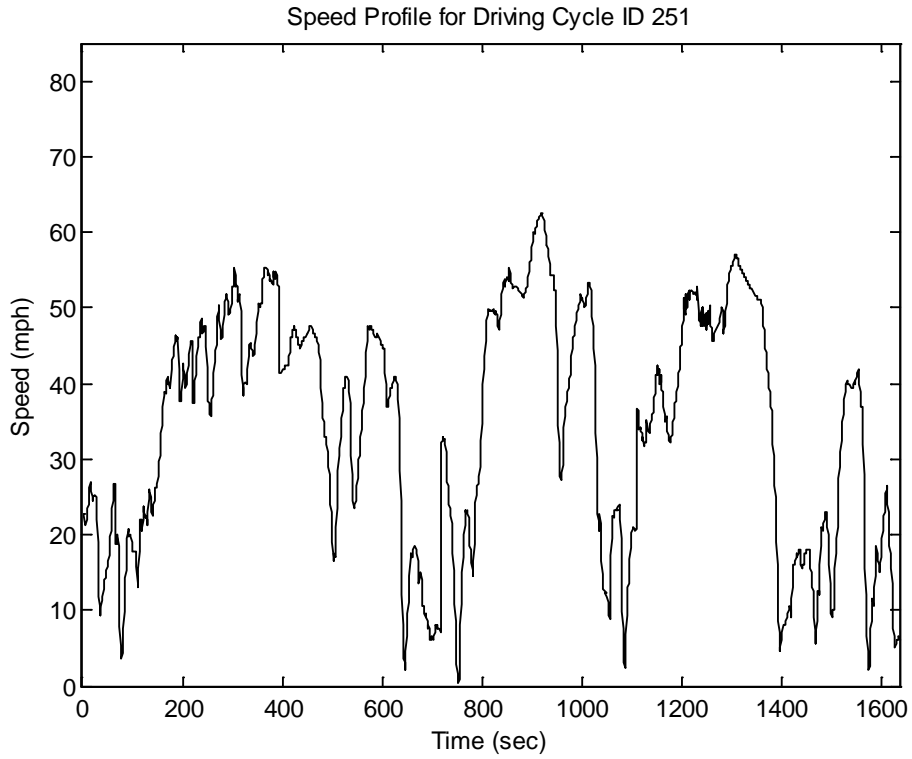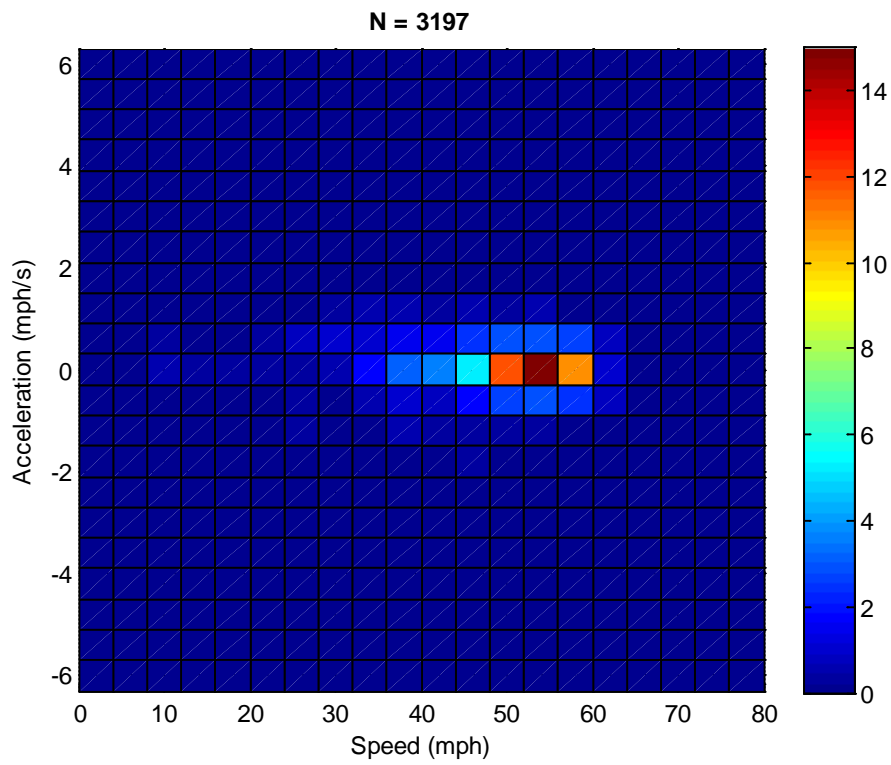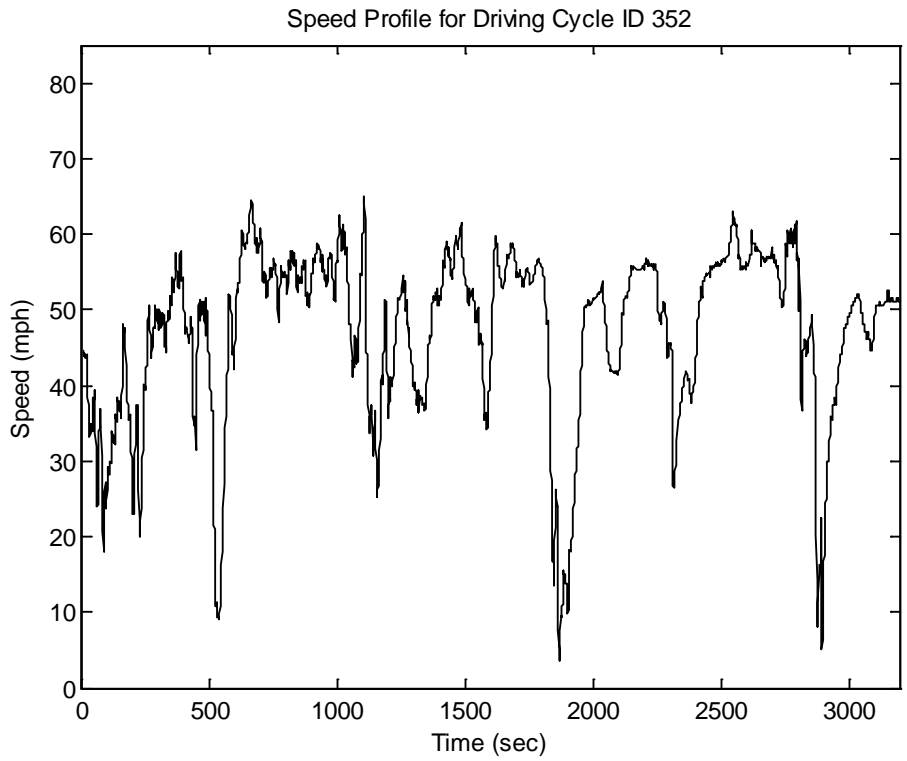
Figure E-6. MD 30mph freeway cycle (length = 1,637 seconds; average speed = 34.4 mph)
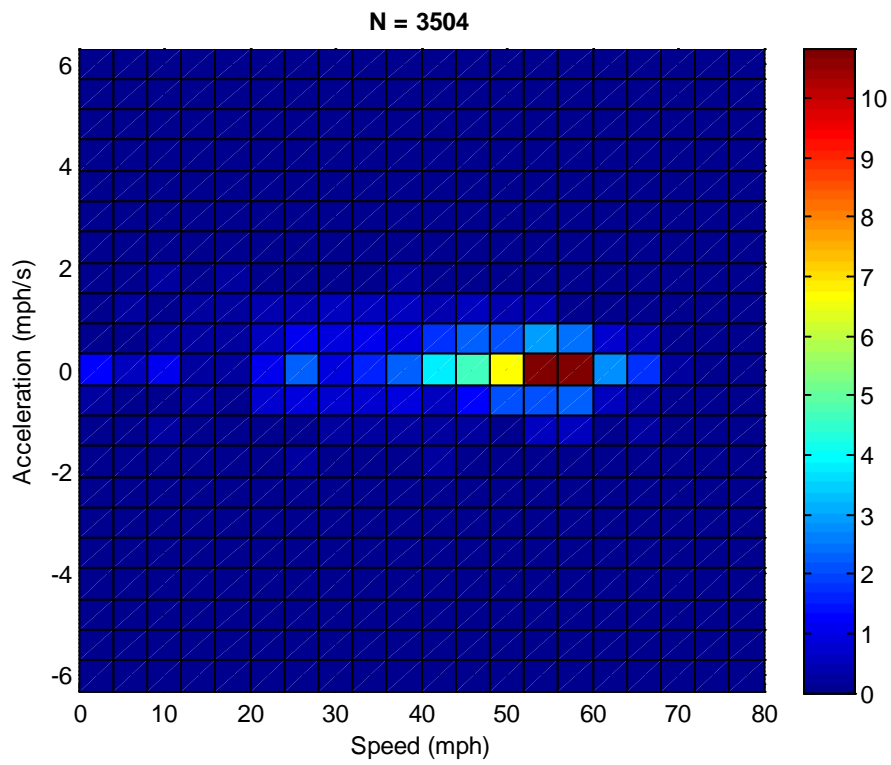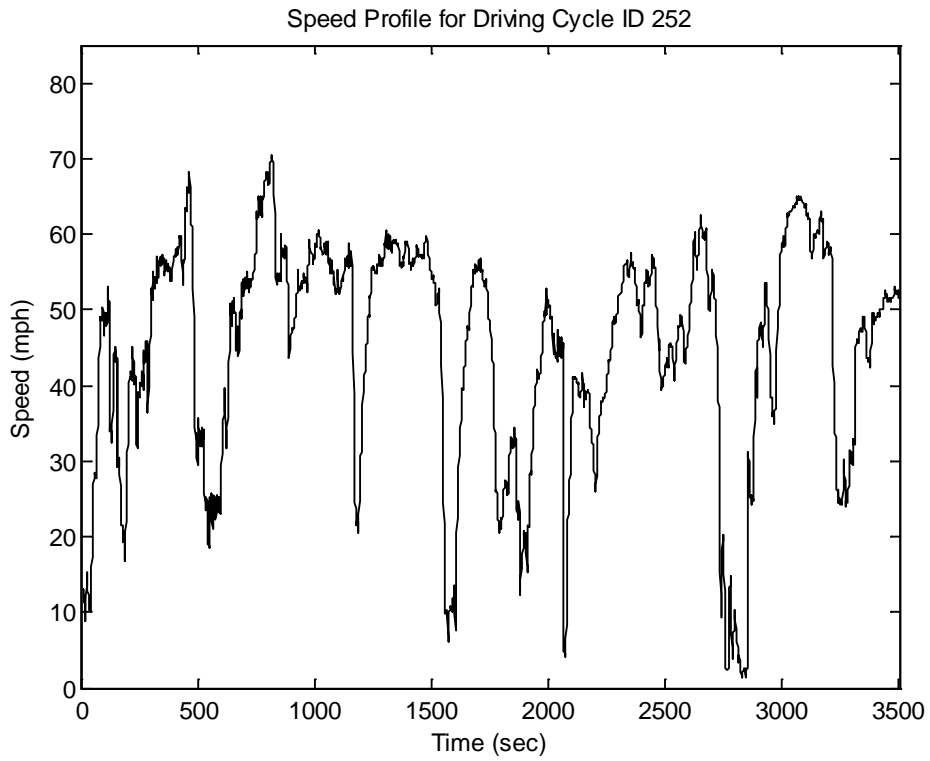
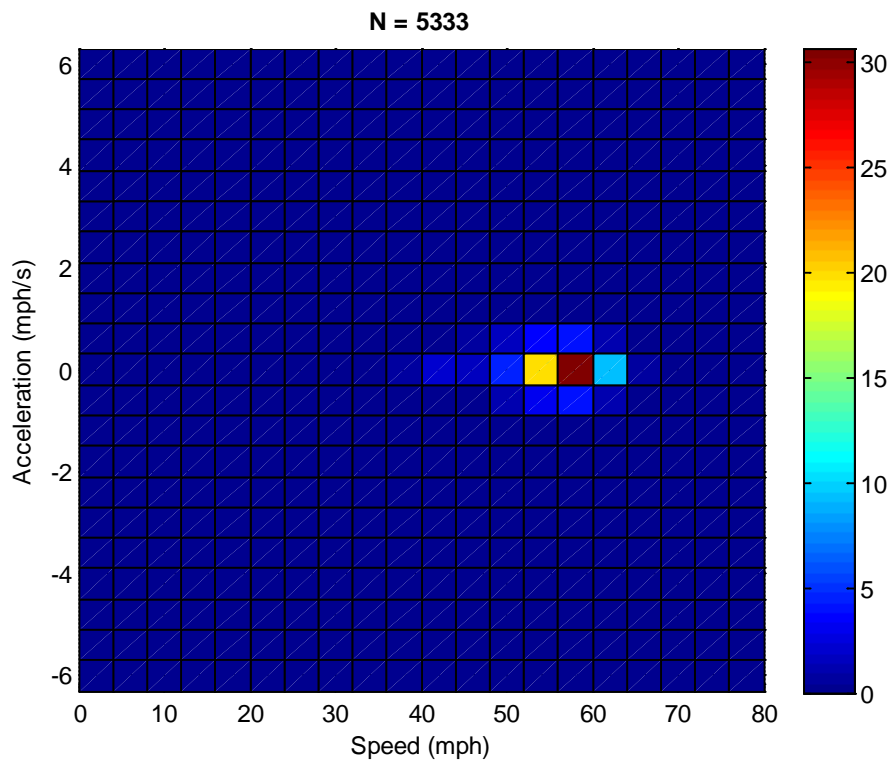**Figure E-7. MD 40mph freeway cycle (length = 3,504 seconds; average speed = 44.5 mph)**
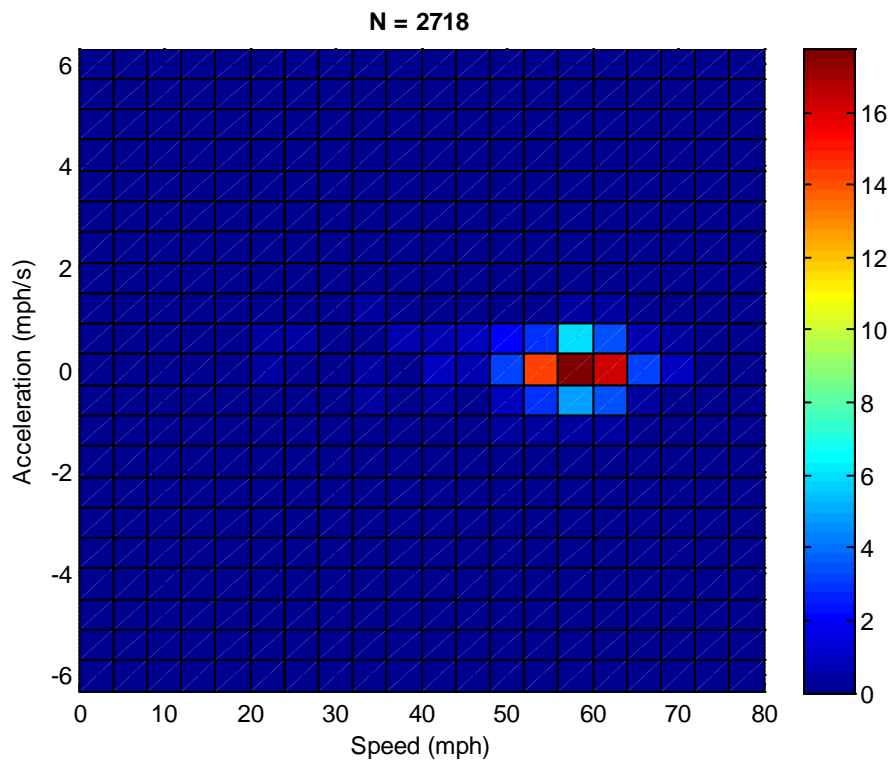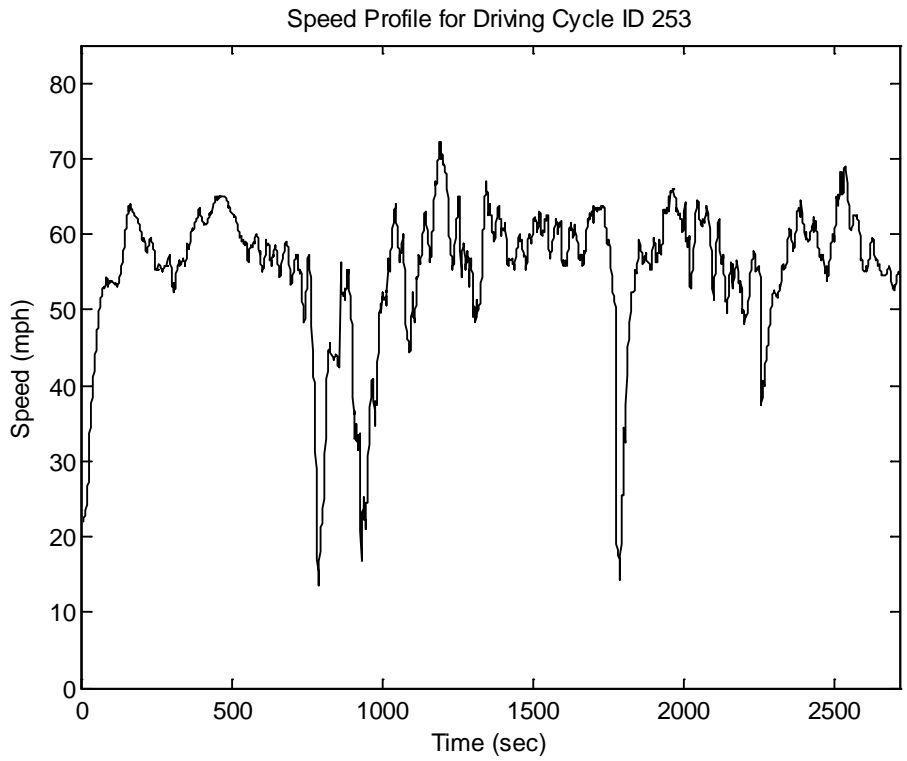
Figure E-8. MD 50mph freeway cycle (length = 2,718 seconds; average speed = 55.4 mph)

E-9

Speed Profile for Driving Cycle ID 254

N = 4866
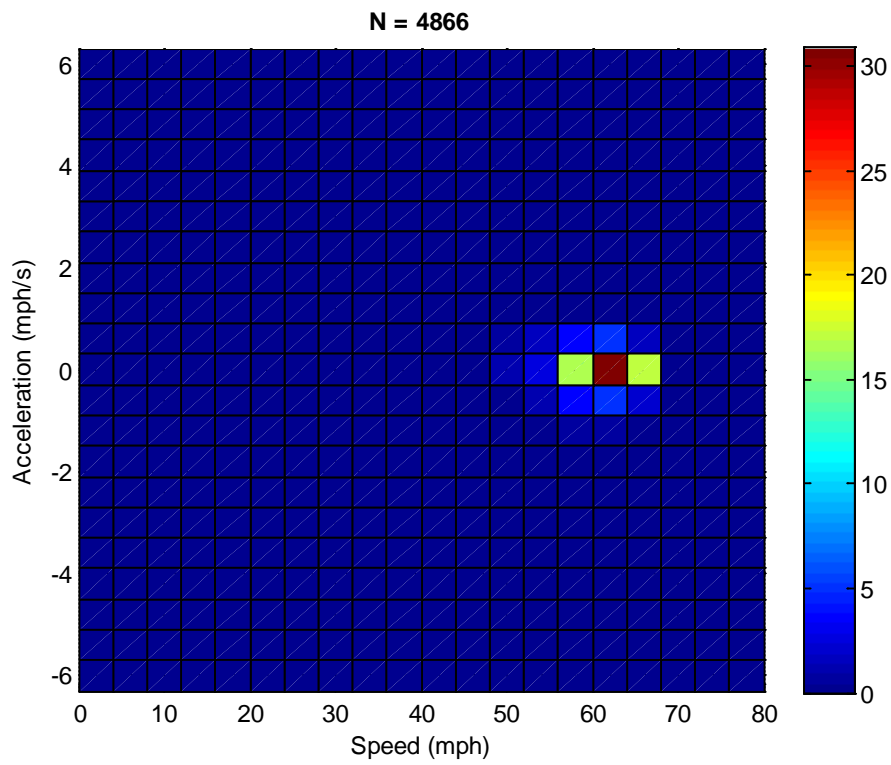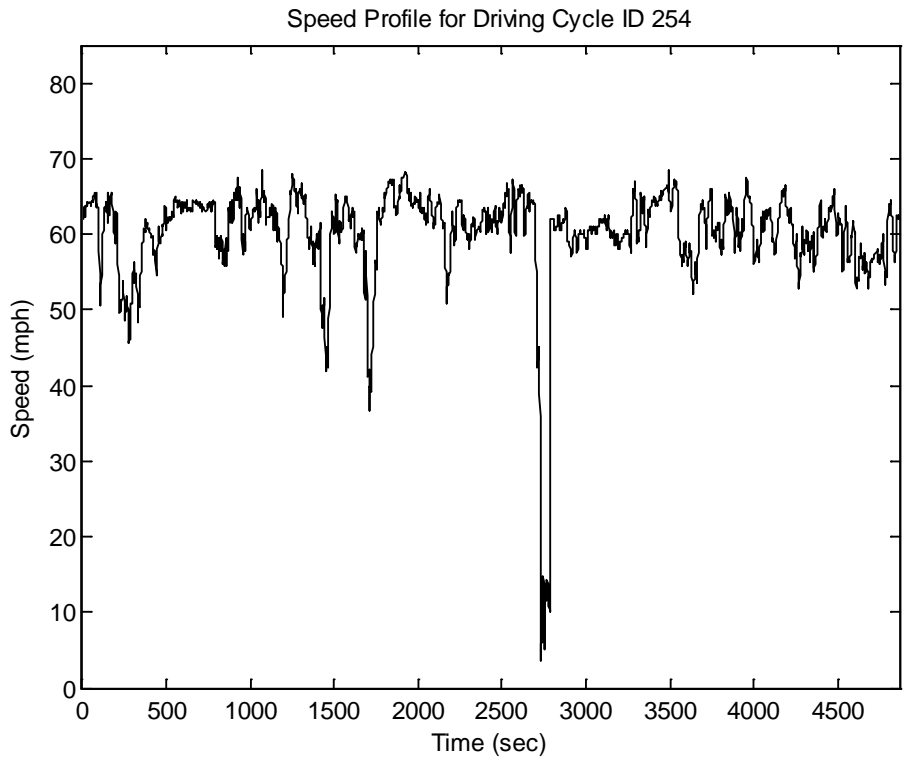
Figure E-9. MD 60mph non-freeway cycle (length = 4,866 seconds; average speed = 60.4 mph)

Speed Profile for Driving Cycle ID 255

N = 4782
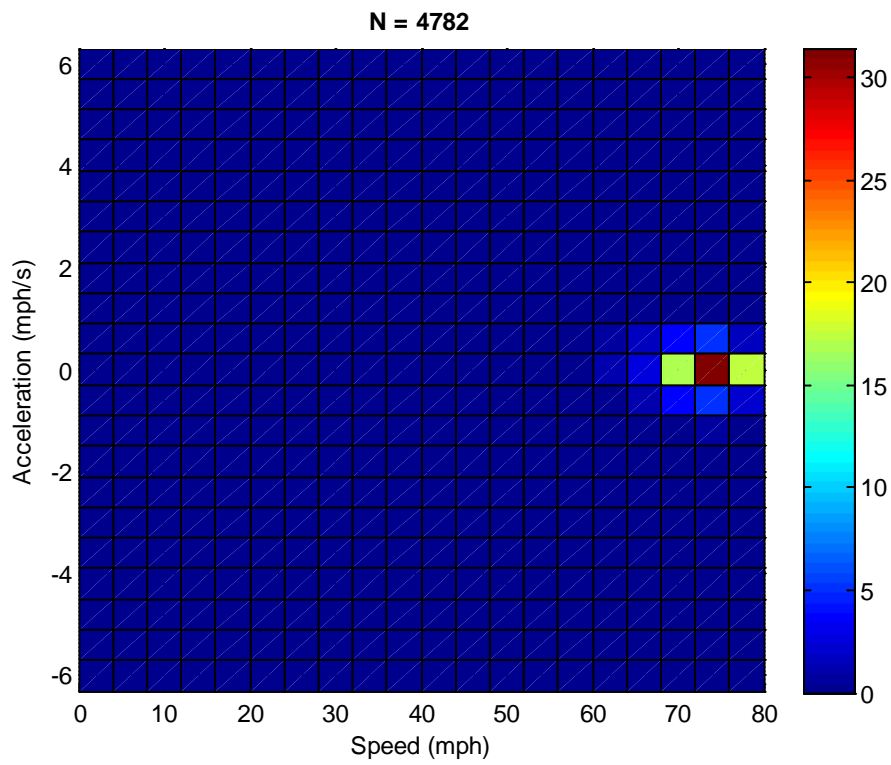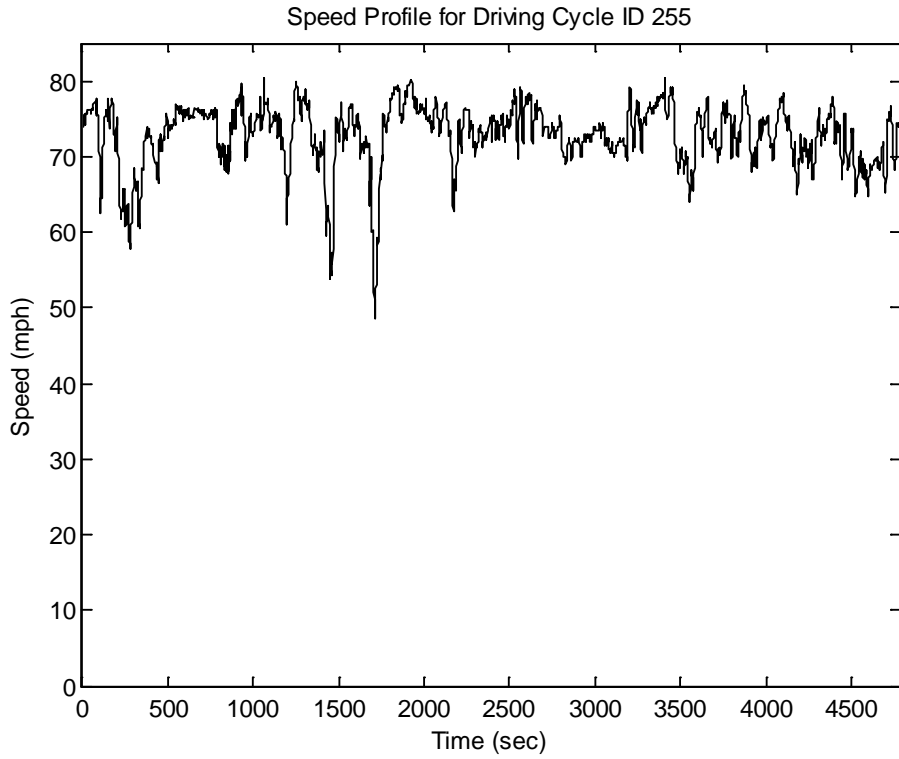
Figure E-10. MD high speed freeway cycle (length = 4,782 seconds; average speed = 72.8 mph)
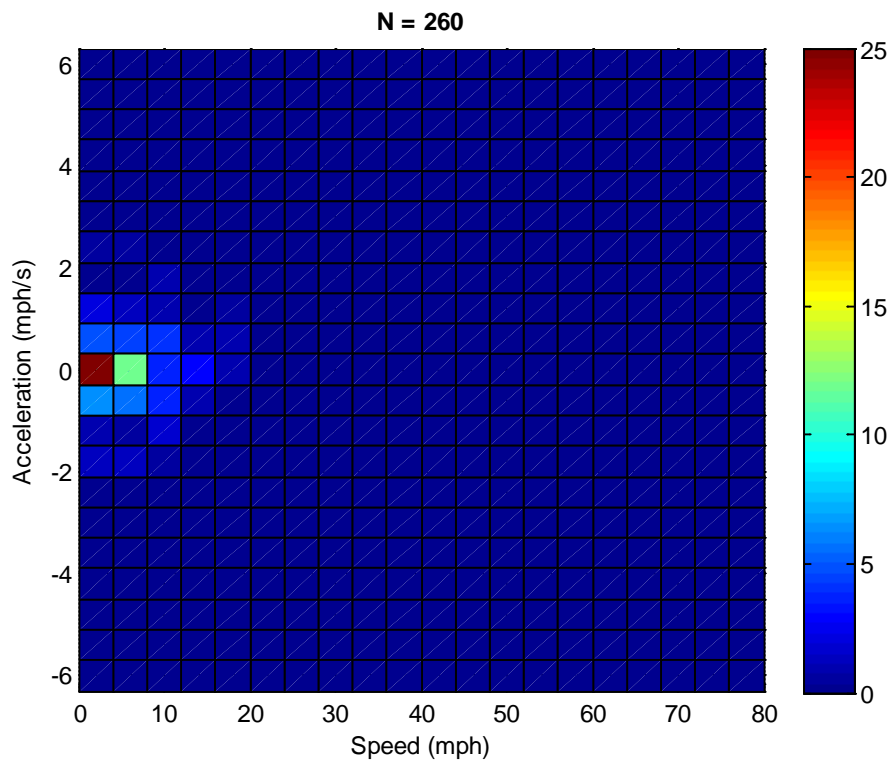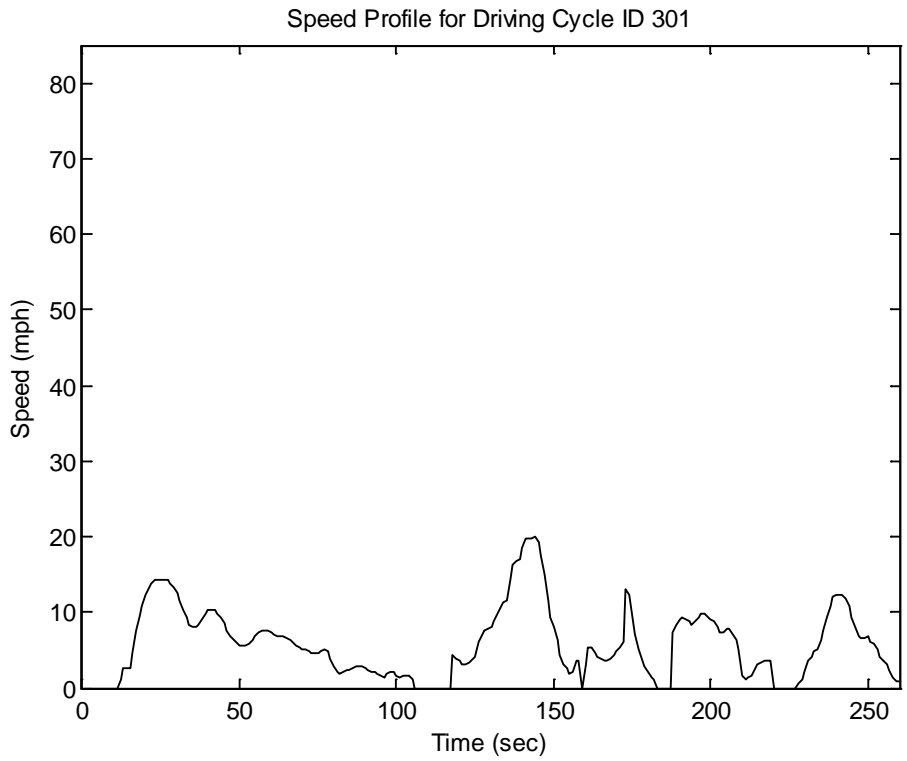
Figure E-11. HD 5mph non-freeway cycle (length = 260 seconds; average speed = 5.8 mph)
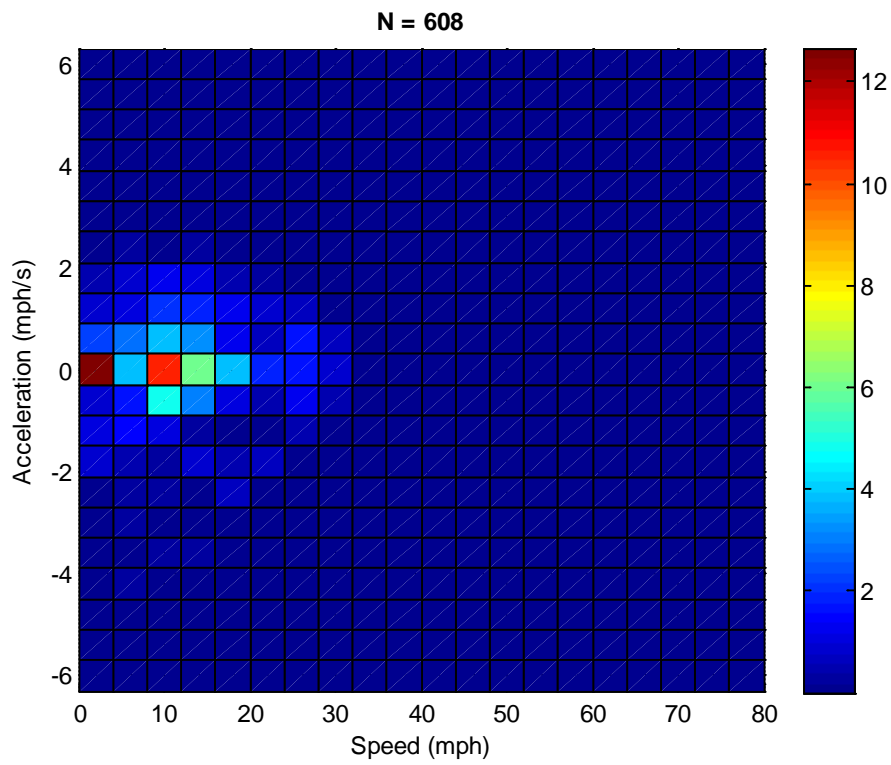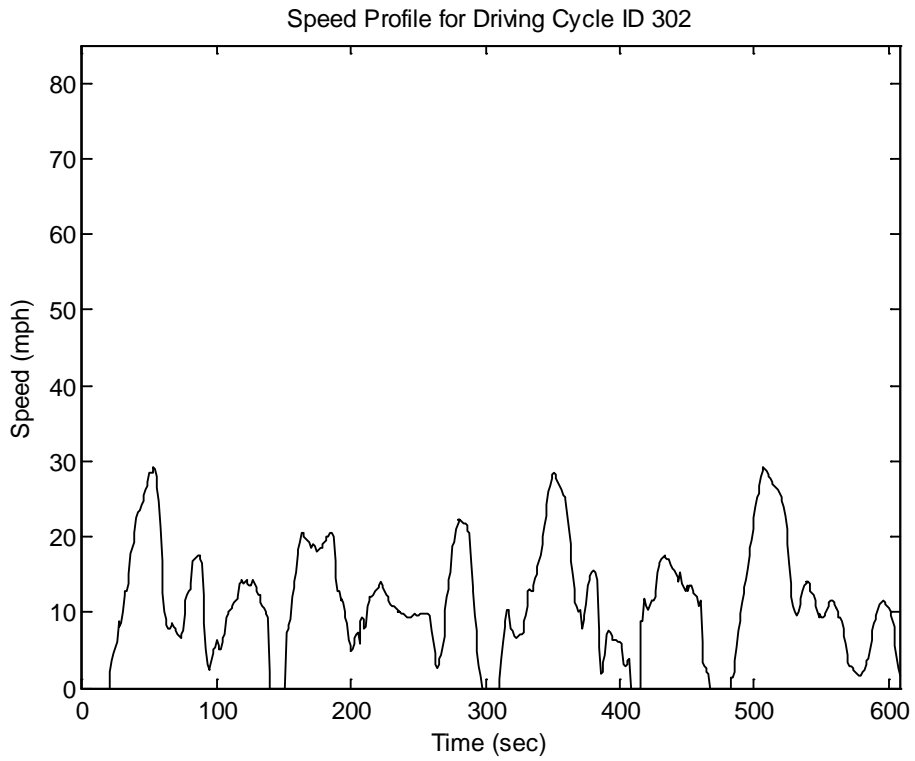
Figure E-12. HD 10mph non-freeway cycle (length = 608 seconds; average speed = 11.2 mph)

Speed Profile for Driving Cycle ID 303

N = 567
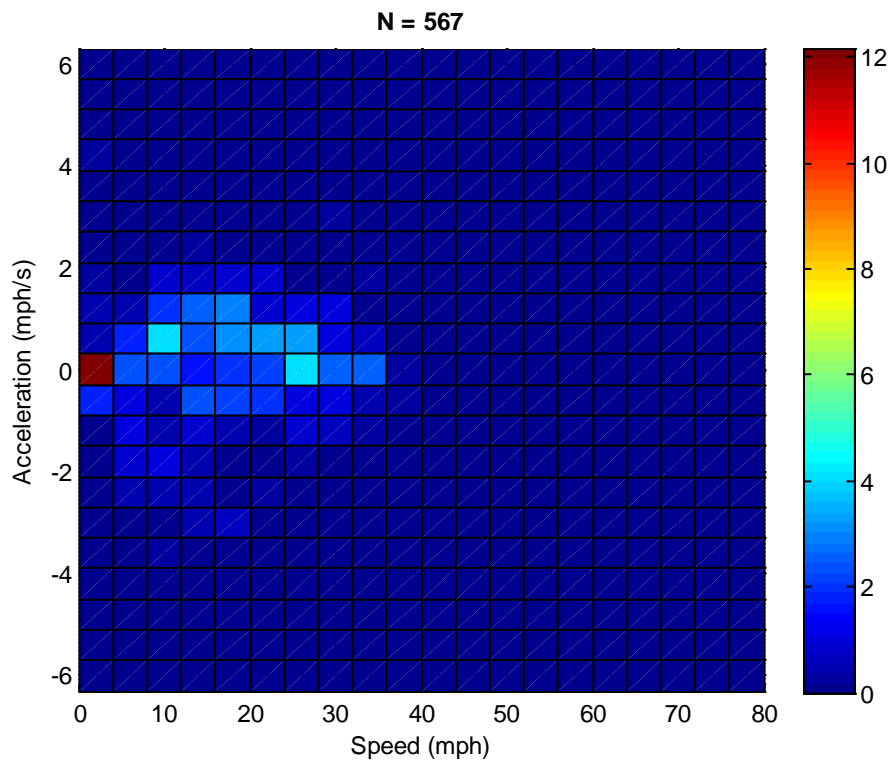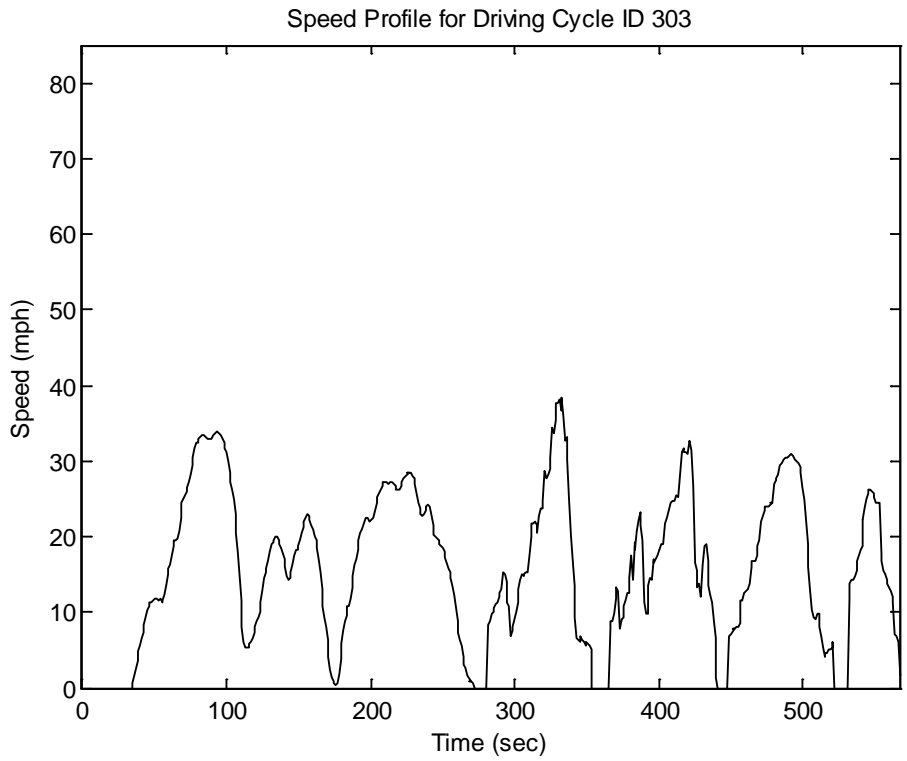
Figure E-13. HD 15mph non-freeway cycle (length = 567 seconds; average speed = 15.6 mph)

Speed Profile for Driving Cycle ID 304

N = 558
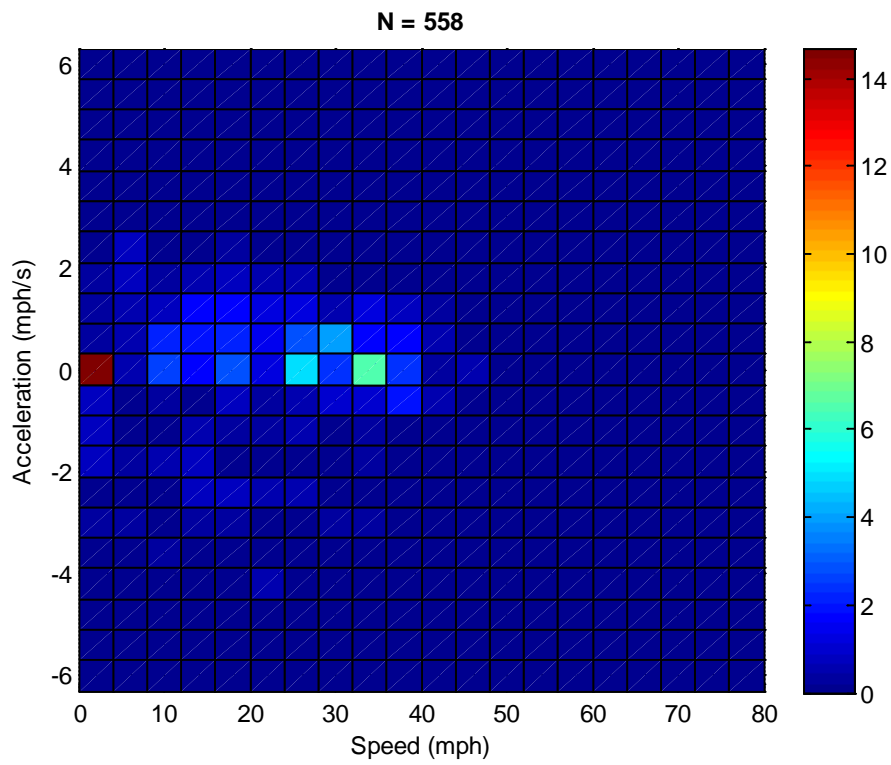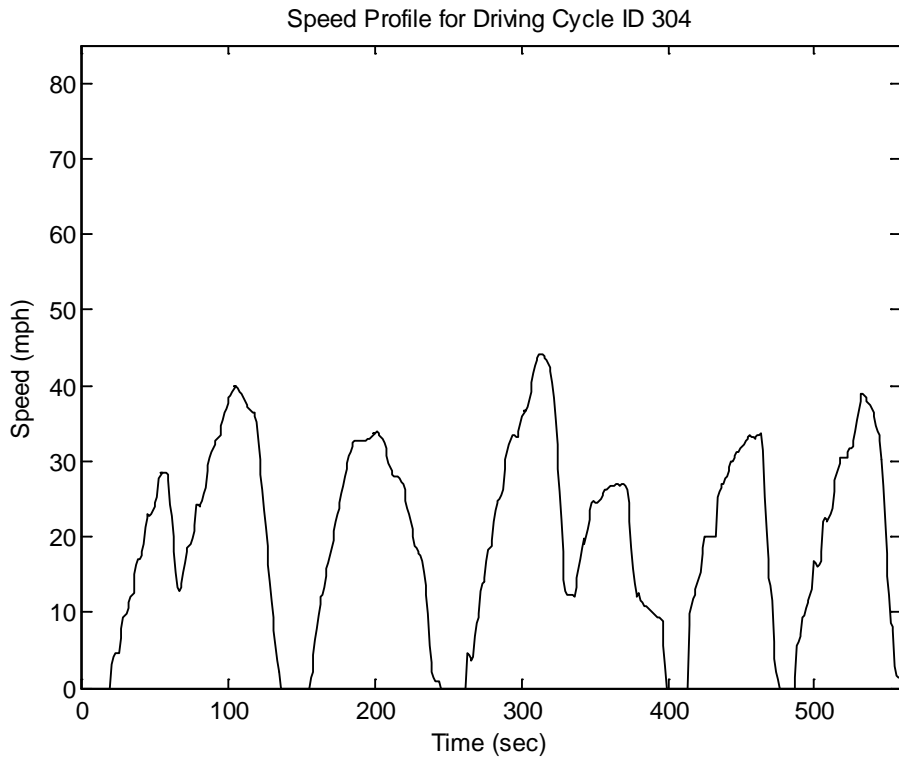
Figure E-14. HD 20mph non-freeway cycle (length = 558 seconds; average speed = 19.4 mph)

E-15
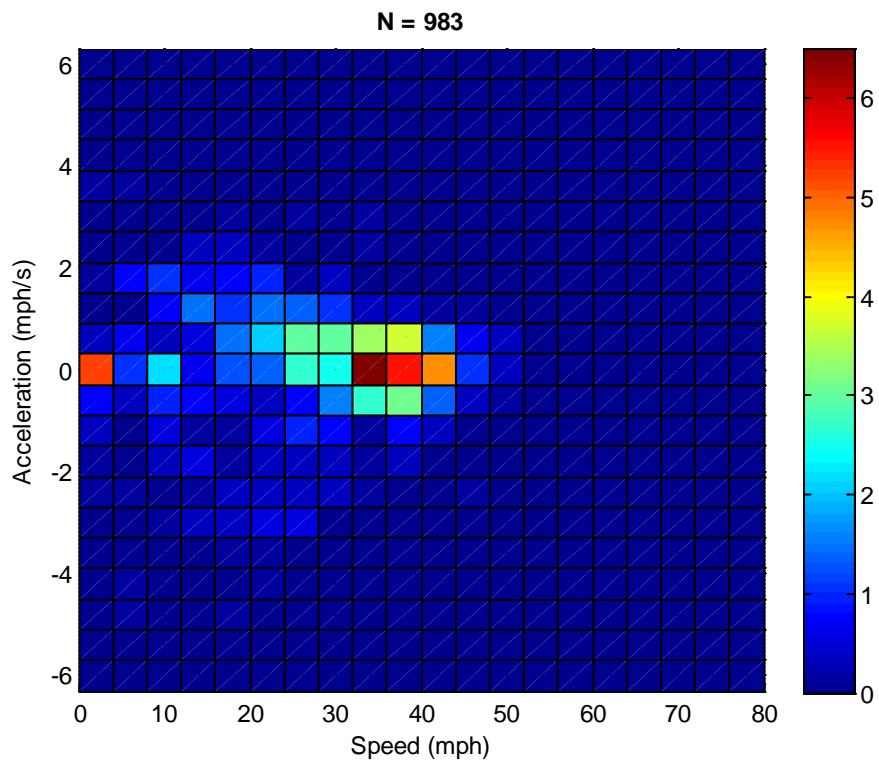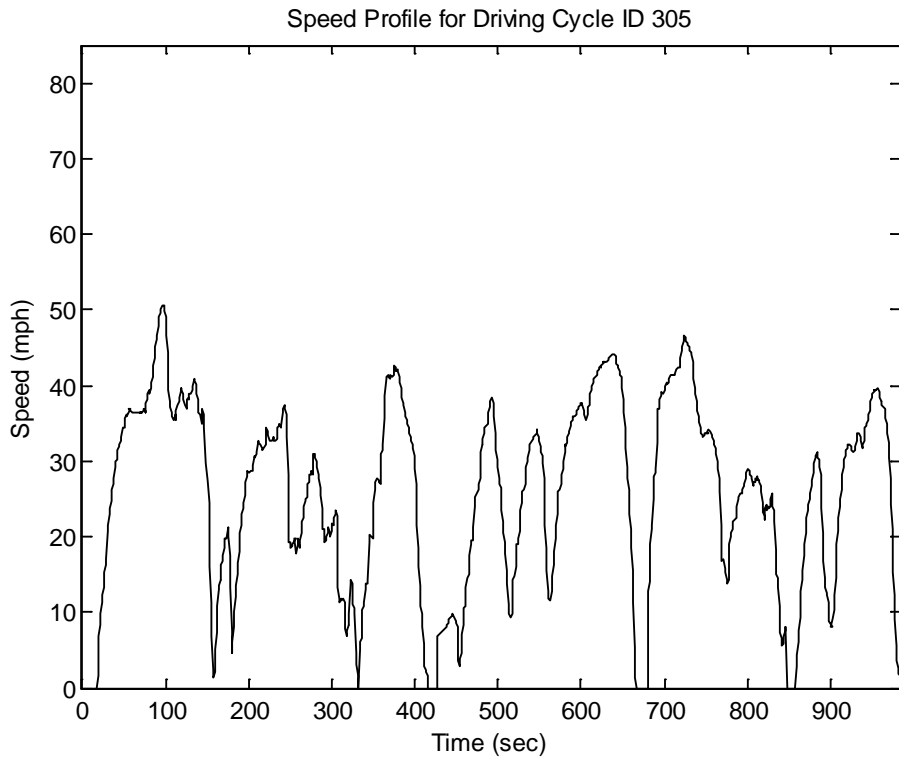
Figure E-15. HD 25mph non-freeway cycle (length = 983 seconds; average speed = 25.6 mph)
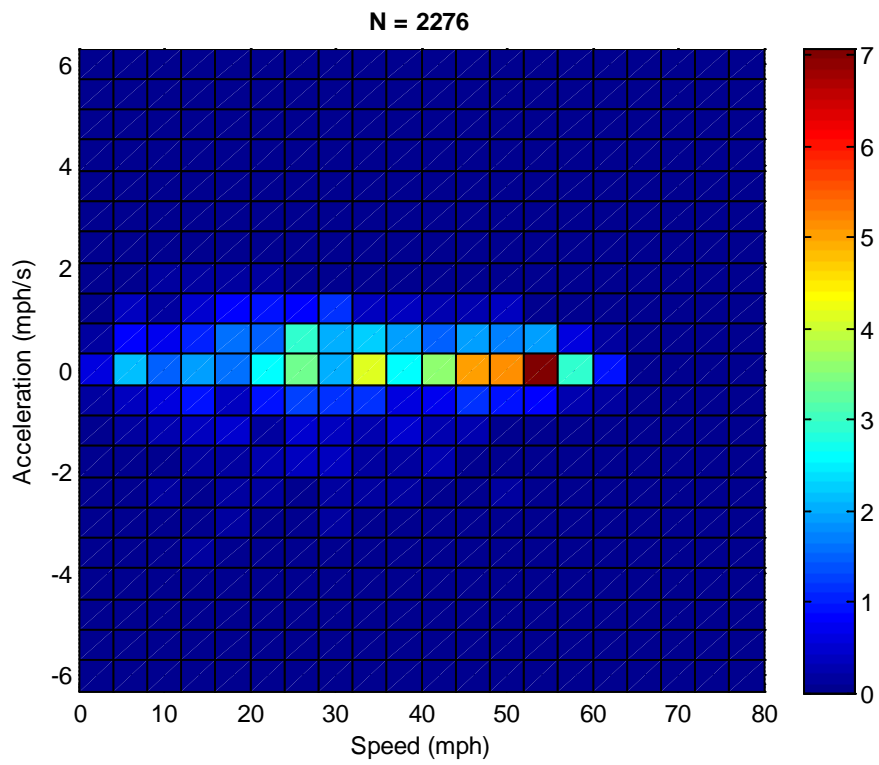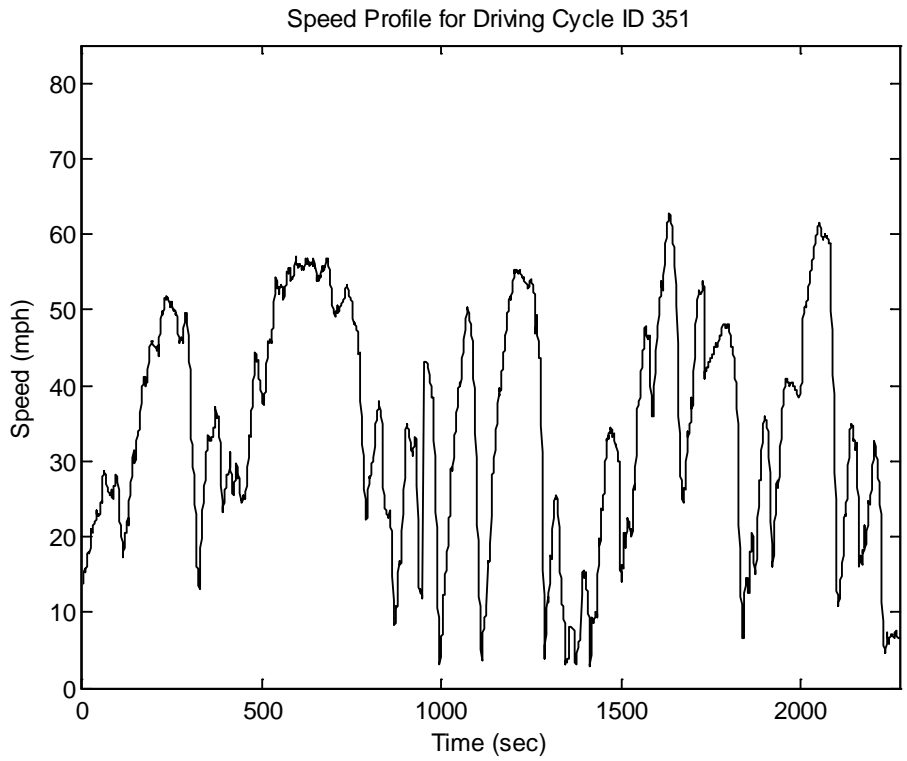
Figure E-16. HD 30mph freeway cycle (length = 2,276 seconds; average speed = 34.3 mph)

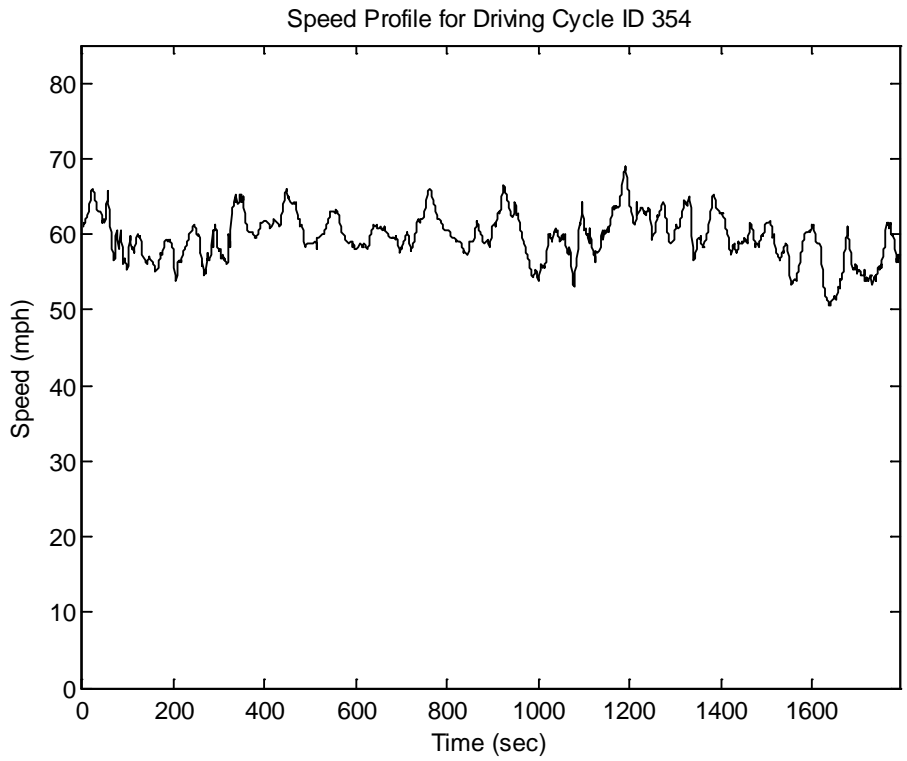**Figure E-17. HD 40mph freeway cycle (length = 3,197 seconds; average speed = 47.1 mph)**
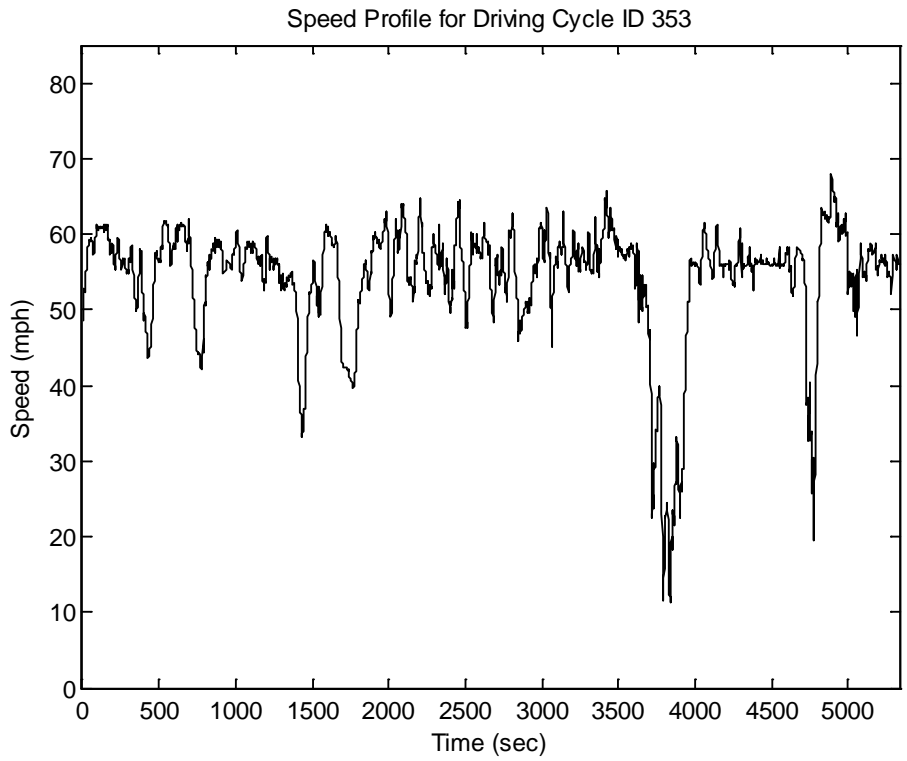
Figure E-18. HD 50mph freeway cycle (length = 5,333 seconds; average speed = 54.2 mph)
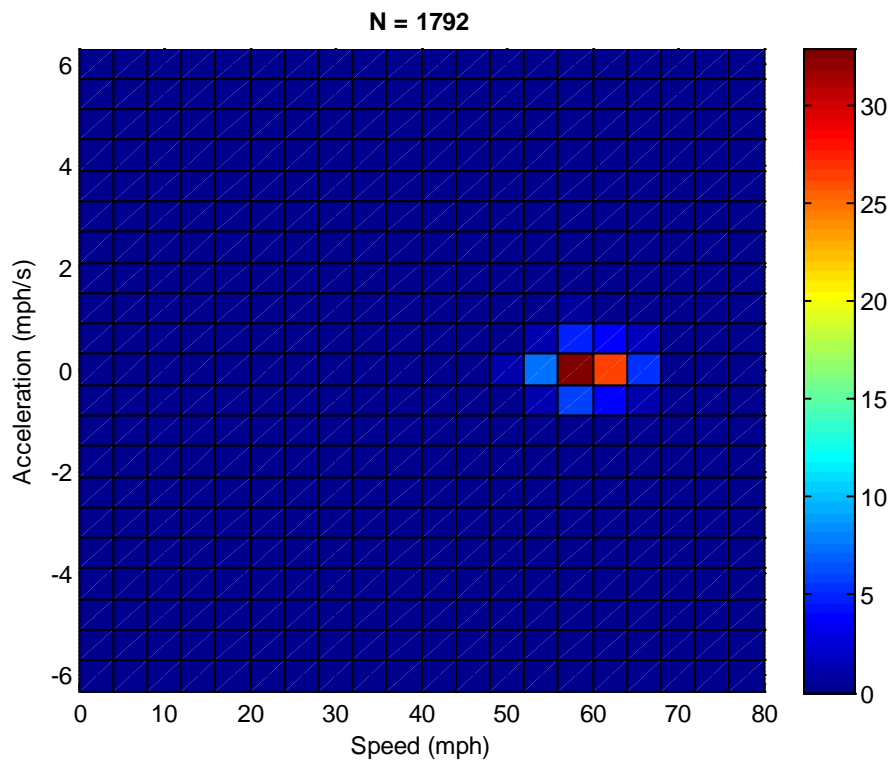
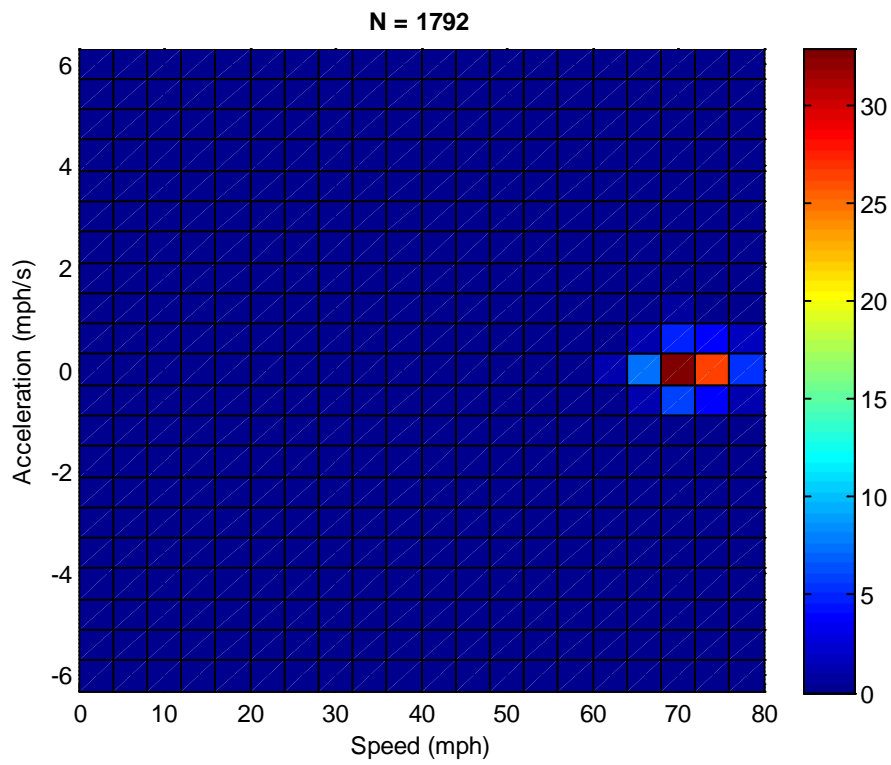**Figure E-19. HD 60mph freeway cycle (length = 1,792 seconds; average speed = 59.4 mph)**
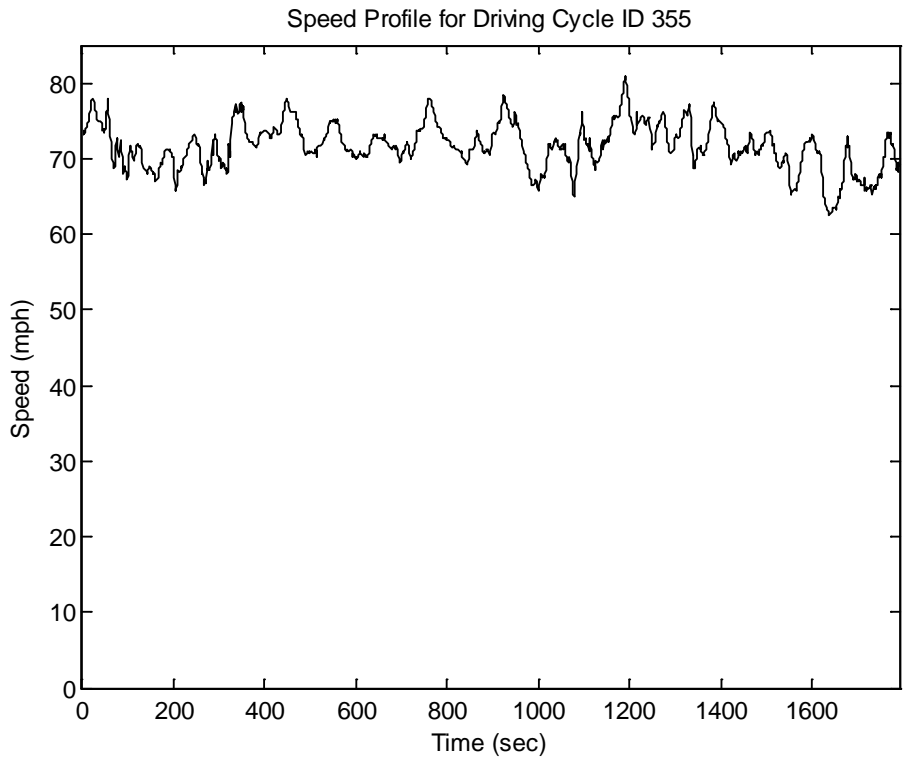
Figure E-20. HD high speed freeway cycle (length = 1,792 seconds; average speed = 71.7 mph)