College of Engineering- Center for Environmental Research & Technology

Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles

FINAL REPORT
(ARB Agreement No. 13-301)

Prepared for:

California Air Resources Board and the California Environmental Protection Agency

By:

Kanok Boriboonsomsin, Kent Johnson, George Scora, Daniel Sandez, Alexander Vu, Tom Durbin, and Yu (Jade) Jiang

College of Engineering - Center for Environmental Research and Technology
University of California at Riverside

and

Andrew Burnette

infoWedge

May 2017

Disclaimer

The statements and conclusions in this Report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

Acknowledgements

The research team acknowledges the funding support from the California Air Resources Board (CARB). We are thankful for the program support from Seungju Yoon, John Collins, Don Chernich, Mark Burnitski, Kathy Jaw, Zhen Dai, and Sam Pournazeri, of CARB during the course of the project.

The research team also acknowledges the technical support and supplementary resources received through the Cooperative Research and Development Agreement with the U.S. Environmental Protection Agency. We would also like to acknowledge the supplemental funding from the University of California Institute of Transportation Studies.

In addition, the research team acknowledges the contribution of many individuals in this research effort, including:

- Carl Fulper of the U.S. Environmental Protection Agency
- Sandeep Kishan and Michael Sabisch of Eastern Research Group, Inc.
- Don Pacocha, Mark Villela, and Michael Todd of the College of Engineering – Center for Environmental Research and Technology, University of California at Riverside

Finally, the research team would like to thank several anonymous fleets from both public and private sectors for their participation in this research.

Table of Contents

List of Tables

List of Figures

List of Acronyms

Caltrans	California Department of Transportation
CARB	California Air Resources Board
CAN	Controller Area Network
CNG	Compressed natural gas
CRADA	Cooperative Research and Development Agreement
CSV	Comma-separated values
ECU	Electronic Control Unit
EMFAC	EMission FACtor (model)
EPA	(U.S.) Environmental Protection Agency
GB	Gigabytes
GPS	Global Positioning System
GVWR	Gross vehicle weight rating
HHDT	Heavy heavy-duty trucks
HHDDT	Heavy heavy-duty diesel truck
JSAD	Joint speed-acceleration distribution
MHDT	Medium heavy-duty trucks
MSE	Mean squared error
NO_x	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
OBD	On-Board Diagnostic
OEM	Original equipment manufacturer
OMD	Operating mode bin distribution
OpMode	(Vehicle) operating mode
PM	Particulate matter
PTO	Power take off
SAE	Sum squared error
SCAB	South Coast Air Basin
SCR	Selective catalytic reduction
STP	Scaled tractive power
UCR	University of California at Riverside
UDDS	Urban Dynamometer Driving Schedule
VMT	Vehicle miles traveled
VSP	Vehicle specific power

Executive Summary

An accurate characterization of vehicle activity is crucial to the construction of regional emissions inventory of on-road mobile sources. However, it is a challenging task given the limited availability of vehicle activity data at a large scale. Compared to light-duty vehicles, the availability of vehicle activity data for heavy-duty vehicles are even more limited. In addition, heavy-duty vehicles are comprised of a variety of vocations, each of which may have different operational requirements resulting in different vehicle activity patterns. Therefore, it is important to understand the extent of those differences so that appropriate emission control and mitigation strategies can be developed.

Vehicle activity patterns have significant implication for heavy-duty vehicles that employ selective catalytic reduction (SCR) to meet the new 2010 nitrogen oxides (NO_x) emission standards. Typically, SCR needs to be at least 200 °C before significant NO_x reduction is achieved, but there are times when this temperature requirement may not be met such as right after engine start and during low engine loads. Thus, understanding the heavy-duty diesel vehicle activity profiles are fundamental to the quantification of real-world NO_x emissions from vehicles meeting the new 2010 NO_x emission standards and to the construction of NO_x emission inventories for these vehicles.

There have been improvements in data collection tools over the past decade. GPS receivers have continued to be smaller and more accurate. ECU data loggers have become cheaper and can now be integrated with GPS and wireless communication modems. This has resulted in a powerful data logging tool used in this research that can simultaneously collect data about vehicle position, speed, as well as engine parameters, and then transmit the data to a data server remotely in real time. This allows more data to be collected at a lower cost. The availability of ECU data in the collected vehicle activity data also allows for more accurate analysis of vehicle activity patterns. For example, in this research engine speed data was used to differentiate engine-on events from key-on events, which makes the resulting engine start and engine soak period statistics more accurate.

In this research, vehicle and engine activity data were collected from 90 heavy-duty vehicles that make up 19 different groups defined by a combination of vocational use, GVWR, and geographic region. Almost all of the vehicles are of model year 2010 or newer and are equipped with SCR technology. Due to the large amount of data items that were collected from both GPS and ECU, the size of the data for each group ranges from 0.7 to 12.1 GB. These data went through several steps of data processing and quality assurance to identify road type, filter and correct erroneous data, and protect fleet confidentiality. The processed data were then used to analyze a number of vehicle activity statistics related to engine start, engine soak, idle activity, SCR temperature, and others.

The vehicle activity analysis results reveal new findings about how the vehicle samples in each vocation operated during the data collection period. Some of the findings are as expected while some others are not intuitive or even surprising. Key findings include:

- The average speed values for the different vocations are mostly as expected. The average speed for line haul - out of state trucks is the highest at 41.1 mph while the average speed for drayage trucks in Northern California is the lowest at 8.9 mph. The vocations that have a low average speed value tend to spend a significant portion of time on non-freeway roads, for example, drayage trucks in Southern California, airport shuttles, refuse trucks, and urban buses.

- Line haul - in state trucks are found to have a much lower average speed value than line haul - out of state trucks (32.4 mph vs. 41.1 mph) as they spend much less time on freeways (53.7% vs. 68.2%), and almost double the amount of time idling (28.3% vs. 16.0%).

- The contrasts between urban buses and express buses are as expected. Express buses have twice as high an average speed than urban buses (20.5 mph vs. 10.1 mph)as they spend much more time on freeways (25.0% vs. 1.5%). On the other hand, urban buses have a higher percentage of time in brake mode (10.3% vs. 5.9%) as they have to make more stops and experience more congestion.

- It is also interesting to see the contrast between food distribution and beverage distribution trucks. Food distribution trucks have three times higher average speed (34.6 mph vs. 11.6 mph) as they spend significantly more time on freeways (62.9% vs. 8.3%) and less time idling (13.2% vs. 39.3%) than beverage distribution trucks. This could be partly because the food distribution trucks recruited in this research operate throughout Southern California while the beverage distribution trucks operate solely in the inner Los Angeles metropolitan area where traffic is generally more congested.

- Vehicles in most of the vocations spend about a third or more of their time in idle mode, irrespective of the percentage of time spent on non-freeway roads. The only exceptions are line haul - out of state trucks, line haul - in state trucks, food distribution trucks, and municipal work trucks. This is surprising for municipal work trucks because they spend 81.1% of their time on non-freeway roads but only 26.3% in idle mode. It would be interesting to examine whether the fleet implements any idle reduction technology or policy.

- The vocation with the highest percentage of time in idling mode is cement mixers. This is not surprising as these vehicles do their jobs while idling, which often involves the use of PTO. The same is true for utility repair trucks.

- As expected, the average speed values after excluding idle trips and extended idling events are higher across all vocations. The increases are greater for the vocations with a significant amount of idling time such as cement mixers, freeway work trucks, and utility repair trucks.

Key findings from the SCR temperature analysis include:

- The frequency distributions of SCR temperature for both out-of-state and in-state line haul trucks have two peaks. One of the peaks is around 260-280 °C, which is probably when driving on highways. The other one is around 100 °C, which is probably when idling.

- The Drayage - Northern California group consists of only one truck, which comes from the same fleet as the out-of-state line-haul trucks. This truck has the same engine make/model/year as one of the out-of-state line-haul trucks, but has a significantly different frequency distribution of SCR temperature where the distribution peaks at around 100-110 °C. This is a strong evidence of how the differences in vehicle activity patterns affect the SCR temperatures of the vehicles, and likely their real-world NO_x emissions.

- The SCR temperatures of agricultural trucks are found to be surprisingly low despite these trucks having similar operating patterns to line haul - in state trucks. One potential reason is that the engine size may be too large for the type of load and weight that they carry. Another potential reason may have to do with the specific engines and SCR systems used in these trucks as there is a distinct peak in the frequency distribution of SCR temperature at 100-110 °C.

- The SCR temperature frequency distribution for construction trucks and the one for cement mixers are similar to each other. They have the shape of Gaussian distribution with a single peak at around 190-210 °C. Both frequency distributions look unique as compared to the frequency distributions of the other vocation types.

- The SCR temperature frequency distribution for food distribution trucks and the one for beverage distribution trucks are similar to each other. They have the shape of Gaussian distribution with a major peak at around 220-250 °C and a minor peak at around 40-80 °C. One notable difference between them is that the distribution for food distribution trucks has more frequency at the temperature higher than 250 °C. This may be due to the food distribution trucks having a significantly higher fraction of time driving at freeway speeds.

- The SCR temperature frequency distribution for local moving trucks also has a major peak at around 220-250 °C. However, a minor peak at around 40-80 °C is so substantial that the distribution looks like a bi-modal Gaussian distribution.

- Sweeping trucks are able to maintain higher SCR temperatures than freeway work trucks despite having similar engine size and vehicle activity characteristics. This may be because freeway work trucks spend a higher fraction of idle time (54% vs. 33%) than sweeping trucks.

- Overall, it is found that on average the vehicles in this study operate with SCR temperature lower than 250 °C for 42-91% of the time and lower than 200 °C for 11-87% of the time, depending on their vocation. These portions of vehicle operation with low SCR temperature have a significant implication on the vehicles' real-world NO_x emission. By assuming a generic NO_x reduction curve as a function of SCR temperature for all the vehicles, the weighted average %reduction in engine-out NO_x emission ranges from 16% for agricultural trucks to 69% for refuse trucks. This would have a significant impact on the NO_x emission inventory of heavy-duty diesel vehicles in California.

The processed data were used to develop representative drive cycles for each of the 19 vocations. These vocation-specific drive cycles can be used for emission testing of a variety of heavy-duty vehicles in California. Since these drive cycles reflect real-world operating characteristics of the vehicles based on their vocational uses, they would better capture real-world emissions of heavy-duty vehicles in the different vocation types than the one-size-fits-all approach that is based on the existing emission certification test cycle.

In addition to the key findings summarized above, this research has resulted in additional valuable products that can be used for CARB air quality planning and heavy-duty emissions reduction planning purposes. The research team has developed a database containing vehicle and engine activity data at the time resolution of 1 Hz. This database includes a large number of ECU and GPS data fields that can be analyzed to improve our understanding of real-world, in-use performance of vehicle, engine, and emission control system. The processing and quality assurance of ECU data is being conducted by Eastern Research Group with support from the U.S. EPA through the CRADA with UCR. The research team has also developed data processing and analysis scripts that can be used in similar efforts in the future. Lastly, the experiences gained during the conduct of this research, from recruiting truck fleets to protecting fleet confidentiality to handling and processing Big Data of vehicle activity, can serve as best practices for conducting large-scale vehicle activity studies in the future.

1. Introduction

1.1. Background

For the State of California to meet upcoming ambient air quality standards for ozone and particulate matter (PM), considerable reductions in nitrogen oxides (NO_x) emissions are needed. To help achieve some of these required reductions, the NO_x emission standards for heavy-duty on-road engines were reduced by 90 percent in 2010. Diesel engine manufacturers have in most cases been using advanced engine exhaust aftertreatment, specifically Selective Catalytic Reduction (SCR), to meet the new standards.

SCR reduces NO_x in the exhaust stream but requires adequate temperatures for the reduction to take place effectively. Typically, SCR needs to be at least 200 °C before significant NO_x reduction is achieved. Figure 1-1 shows NOx reduction curve of an example SCR system where a 40% NO_x reduction is achieved at the SCR temperature of 200 °C. However, there are times when this temperature requirement may not be met, such as right after engine start and during low engine load operations experienced when the engine is idling or when the vehicle is moving slowly on flat terrain.

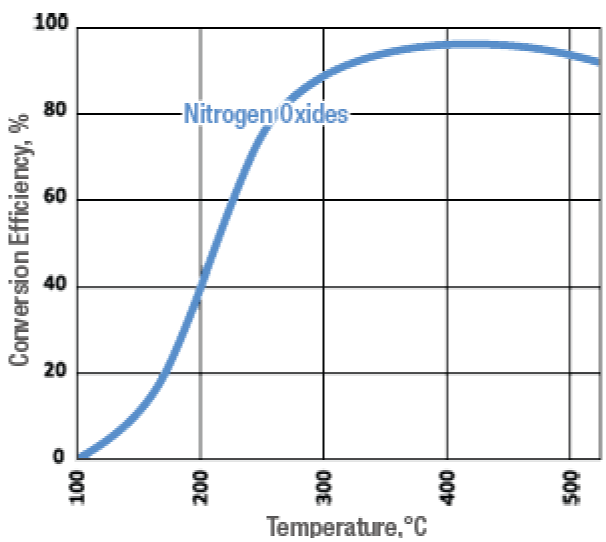


Figure 1-1. NO_x reduction curve of an example SCR system[1]

As an example, Figure 1-2 shows the vehicle speed profile (blue line) and SCR temperature profile (red line) of a heavy-duty diesel vehicle during a trip. The green horizontal line indicates the SCR temperature of 200 °C. As can be seen in the figure, there are multiple instances when the SCR temperature is below 200 °C. These include

[1] Nett Technology Inc. (2016). BlueMAX™ Selective Catalytic Reduction (SCR) System. https://www.nettinc.com/products/selective-catalytic-reduction-scr/bluemax, accessed April 2016.

at the beginning of the trip where it takes about 30 minutes for the SCR temperature to get above 200 °C. As marked in the figure, there is one long period of idling (about 30 minutes) where the SCR temperature drops from 350 °C to around 120 °C. Also, a sustained period of low-load operation where the vehicle creeps mostly below 10 mph also causes a sharp drop in the SCR temperature from 400 °C to 200 °C.

Figure 1-2. Vehicle speed and SCR temperature profiles of a heavy-duty diesel vehicle during a trip

The frequency of engine starts (especially after a long period of soak) and low-load operations, and thus low SCR temperatures, for a vehicle depends partly on its vocation type. For instance, in line-haul application a vehicle operates mostly at highway cruising speeds, and thus maintain high engine loads for most of its operation. On the other hand, a vehicle in local delivery application operates with frequent stops and idles, and thus involves with frequent low engine load operations.

A change in vehicle activity would result in a change in SCR temperature. This change has significant implications in establishing NO_x control strategies for regional air quality planning purposes. Therefore, it is critical to characterize heavy-duty diesel vehicle activity profiles including duty cycles, number of engine starts, and engine soak time distributions, for these vehicles by vocation. Understanding the heavy-duty diesel vehicle activity profiles are fundamental to the quantification of real-world NO_x emissions from vehicles meeting the 2010 NO_x emission standard and to the construction of NO_x emission inventories for these vehicles.

1.2. Objectives

This research project has two primary objectives. One is to characterize the activity profiles of heavy-duty diesel vehicles in different types of vocation (e.g., line haul, drayage, delivery, etc.), and the other is to identify the fraction of vehicle operation that SCR may not control NO_x effectively. The characterization of vehicle activity profiles includes analyzing the vehicles' engine start, engine soak time, and other statistics as well as developing duty cycles for different vocations. Some of the vehicle activity statistics can be used to update assumptions in the California Air Resources Board (CARB)'s Emission Factor (EMFAC) model, while the duty cycles can inform the representativeness of the existing emission certification test cycle in reflecting real-world NO_x emissions of heavy-duty diesel vehicles in different vocations. Therefore, the results from this research project can be used by CARB to improve NO_x emission inventories and to support emission reduction strategies for heavy-duty diesel vehicles in California.

1.3. Report Organization

To achieve the project objectives, the research team at the University of California at Riverside (UCR) set out to collect real-world activity data from 100 heavy-duty diesel trucks (HHDTs) in California for use in several analyses. This report presents every aspect of the research activities that have been conducted during the course of the project. It is organized as follows:

- Chapter 2 presents the processes to identify vehicle categories that likely contribute the most to the state's NO_x emission inventories and to develop vehicle sampling plan for data collection accordingly.
- Chapter 3 describes data collection activities from the recruitment of participating vehicles to the configuration and installation of data loggers.
- Chapter 4 describes data processing and analysis procedures.
- Chapter 5 presents and discusses the results.
- Finally, Chapter 6 provides conclusions of this research and recommendations for future research.
- Additionally, the report contains several appendices at the end that provide supplemental information regarding the methods and results of the research.

2. Vehicle Sampling

Before the data collection from 100 heavy-duty diesel vehicles could take place, a plan for sampling vehicles from different specific vocations was needed. First, vehicle categories that contribute the most to the state's NO_x emission inventories were selected. Then, major vocation types within the selected vehicle categories were identified, and vehicle activity data from these vocation types collected and analyzed. This chapter describes the process to identify what vehicle categories and vocations should be targeted.

2.1. Analysis of EMFAC2011 Data

EMFAC2011 was the latest version of EMFAC at the time of conducting this research. In this version, the medium-heavy duty trucks (MHDTs) and HHDTs are subdivided into multiple categories based on vocation, geographical area, place of registration, weight, etc. Table 2-1 provides a list of MHDT and HHDT categories in EMFAC2011 and how they correspond to commercial truck classification based on gross vehicle weight rating (GVWR). These are the vehicle categories that are of interest in this project.

EMFAC2011 was run to extract data related to the MHDT and HHDT categories shown in Table 2-1. The extracted data include statewide vehicle population, vehicle miles traveled (VMT) per day, and NO_x emissions for each vehicle category in calendar year 2014. These data were for vehicles of model years 2010 and newer since these vehicles are typically equipped with SCR technologies. The statewide vehicle population, percent of statewide VMT, and percent of statewide mobile source NO_x inventory are plotted in a descending order in Figure 2-1, Figure 2-2, and, Figure 2-3, respectively. These figures allow for a quick identification of major MHDT and HHDT categories in California in terms of population, miles traveled, and NO_x emissions.

Table 2-1. MHDT and HHDT vehicle categories in EMFAC2011

EMFAC2007 Vehicle Category	EMFAC2011 Vehicle Category	EMFAC2011 Vehicle Category Description	Commercial Truck Classification
Medium heavy-duty trucks (MHDT)	T6 Ag	Medium-Heavy Duty Diesel Agriculture Truck	Class 4 (GVWR 14,001-16,000 lbs) Class 5 (GVWR 16,001-19,500 lbs) Class 6 (GVWR 19,501-26,000 lbs) Class 7 (GVWR 26,001-33,000 lbs)
	T6 CAIRP heavy	Medium-Heavy Duty Diesel CA International Registration Plan Truck with GVWR>26000 lbs	
	T6 CAIRP small	Medium-Heavy Duty Diesel CA International Registration Plan Truck with GVWR<=26000 lbs	
	T6 instate construction heavy	Medium-Heavy Duty Diesel instate construction Truck with GVWR>26000 lbs	
	T6 instate construction small	Medium-Heavy Duty Diesel instate construction Truck with GVWR<=26000 lbs	
	T6 instate heavy	Medium-Heavy Duty Diesel instate Truck with GVWR>26000 lbs	
	T6 instate small	Medium-Heavy Duty Diesel instate Truck with GVWR<=26000 lbs	
	T6 OOS heavy	Medium-Heavy Duty Diesel Out-of-state Truck with GVWR>26000 lbs	
	T6 OOS small	Medium-Heavy Duty Diesel Out-of-state Truck with GVWR<=26000 lbs	
	T6 Public	Medium-Heavy Duty Diesel Public Fleet Truck	
	T6 utility	Medium-Heavy Duty Diesel Utility Fleet Truck	
	T6TS	Medium-Heavy Duty Gasoline Truck	
Heavy heavy-duty trucks (HHDT)	T7 Ag	Heavy-Heavy Duty Diesel Agriculture Truck	Class 8 (GVWR > 33,000 lbs)
	T7 CAIRP	Heavy-Heavy Duty Diesel CA International Registration Plan Truck	
	T7 CAIRP construction	Heavy-Heavy Duty Diesel CA International Registration Plan Construction Truck	
	T7 NNOOS	Heavy-Heavy Duty Diesel Non-Neighboring Out-of-state Truck	
	T7 NOOS	Heavy-Heavy Duty Diesel Neighboring Out-of-state Truck	
	T7 other port	Heavy-Heavy Duty Diesel Drayage Truck at Other Facilities	
	T7 POAK	Heavy-Heavy Duty Diesel Drayage Truck in Bay Area	
	T7 POLA	Heavy-Heavy Duty Diesel Drayage Truck near South Coast	
	T7 Public	Heavy-Heavy Duty Diesel Public Fleet Truck	
	T7 Single	Heavy-Heavy Duty Diesel Single Unit Truck	
	T7 single construction	Heavy-Heavy Duty Diesel Single Unit Construction Truck	
	T7 SWCV	Heavy-Heavy Duty Diesel Solid Waste Collection Truck	
	T7 tractor	Heavy-Heavy Duty Diesel Tractor Truck	
	T7 tractor construction	Heavy-Heavy Duty Diesel Tractor Construction Truck	
	T7 utility	Heavy-Heavy Duty Diesel Utility Fleet Truck	
	T7IS	Heavy-Heavy Duty Gasoline Truck	
	PTO	Power Take Off	

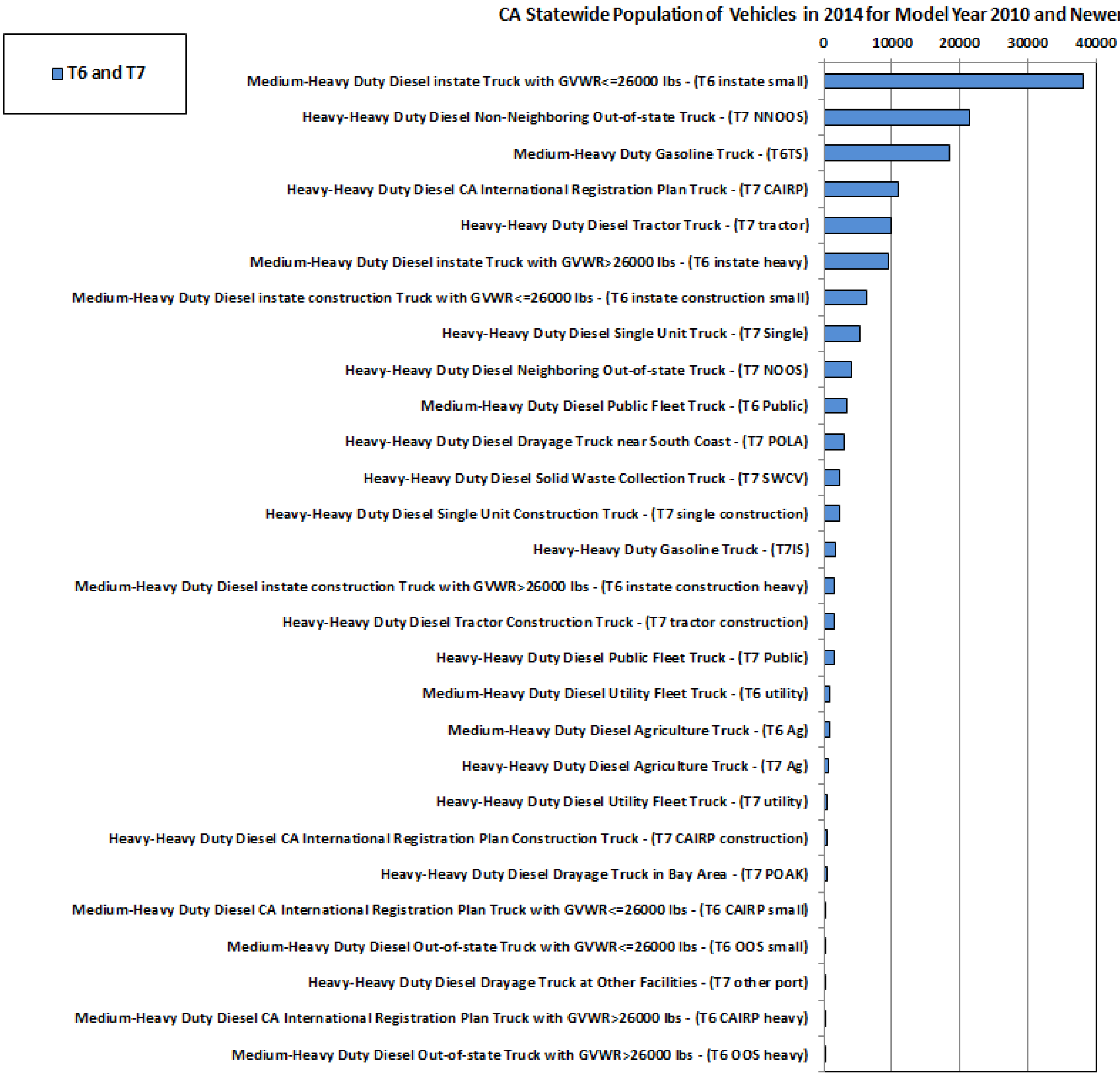


Figure 2-1. Vehicle population in 2014 for model years 2010+

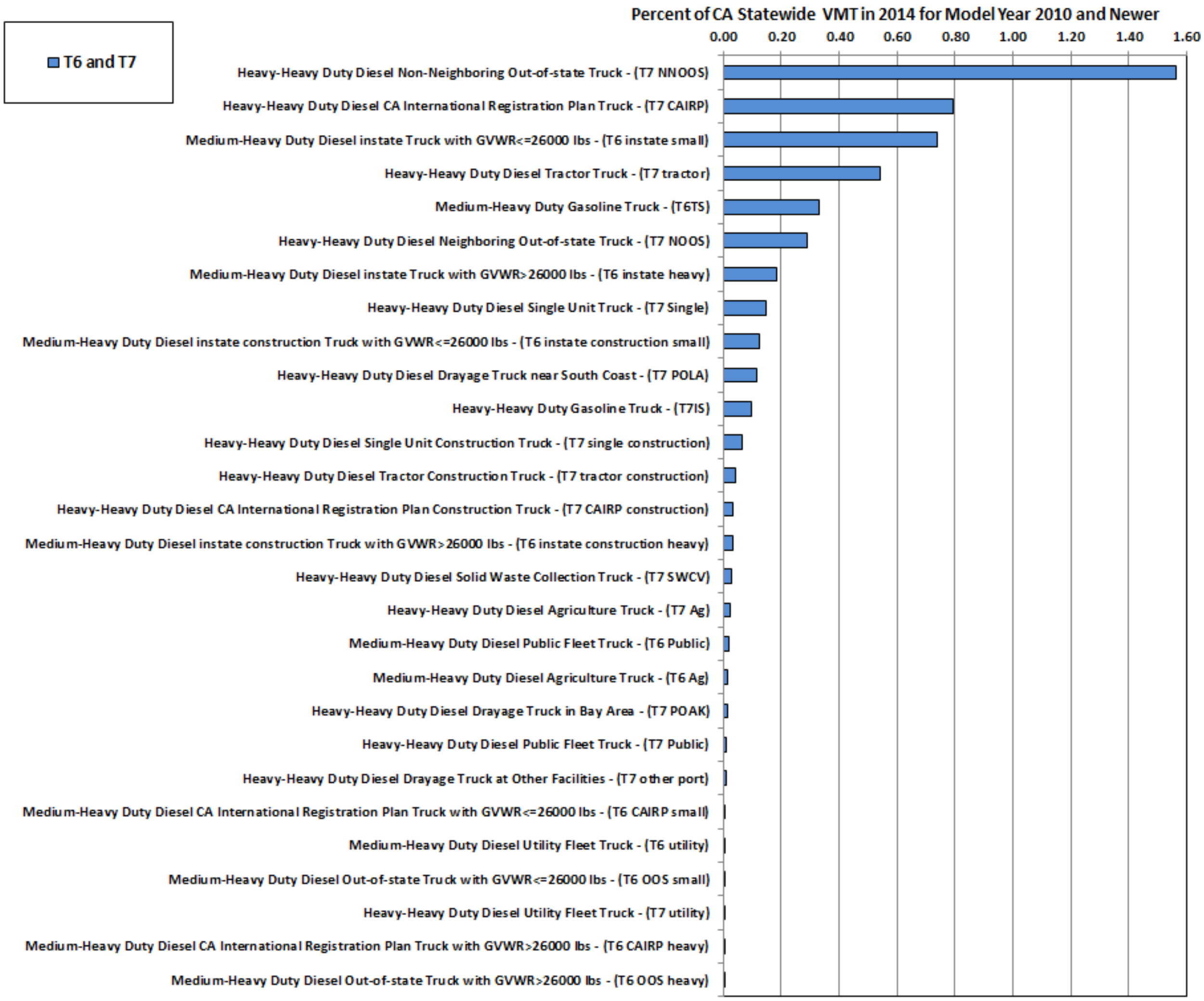


Figure 2-2. Percent of statewide vehicle miles traveled per day in 2014 for model years 2010+

As shown in Figure 2-3, heavy-heavy duty diesel non-neighboring out-of-state trucks are responsible for almost 20% of California statewide NO_x inventory in 2014, which is the highest among all the MHDT and HHDT categories in EMFAC2011. This is partly because they have the second most population (see Figure 2-1) and travel the most miles per day (see Figure 2-2). Other vehicles categories in the top five NO_x emitters are heavy-heavy duty diesel CA International Registration Plan trucks, heavy-heavy duty diesel tractor trucks, heavy-heavy duty diesel neighboring out-of-state trucks, and medium-heavy duty diesel instate trucks with GVWR less than or equal to 26,000 lbs. Together, these top five categories account for about 80% of the statewide NO_x inventory contributed by all MHDT and HHDT categories, or about 44% of the statewide mobile source NO_x inventory. All of them either have a significantly larger number of vehicle population or travel many more miles per day as compared to other MHDT and HHDT categories. These vehicle categories should be included in subsequent tasks of this study as any change in NO_x emission rates of these vehicle categories due to the ineffectiveness of SCR would have a major impact on the total statewide mobile source NO_x inventory.

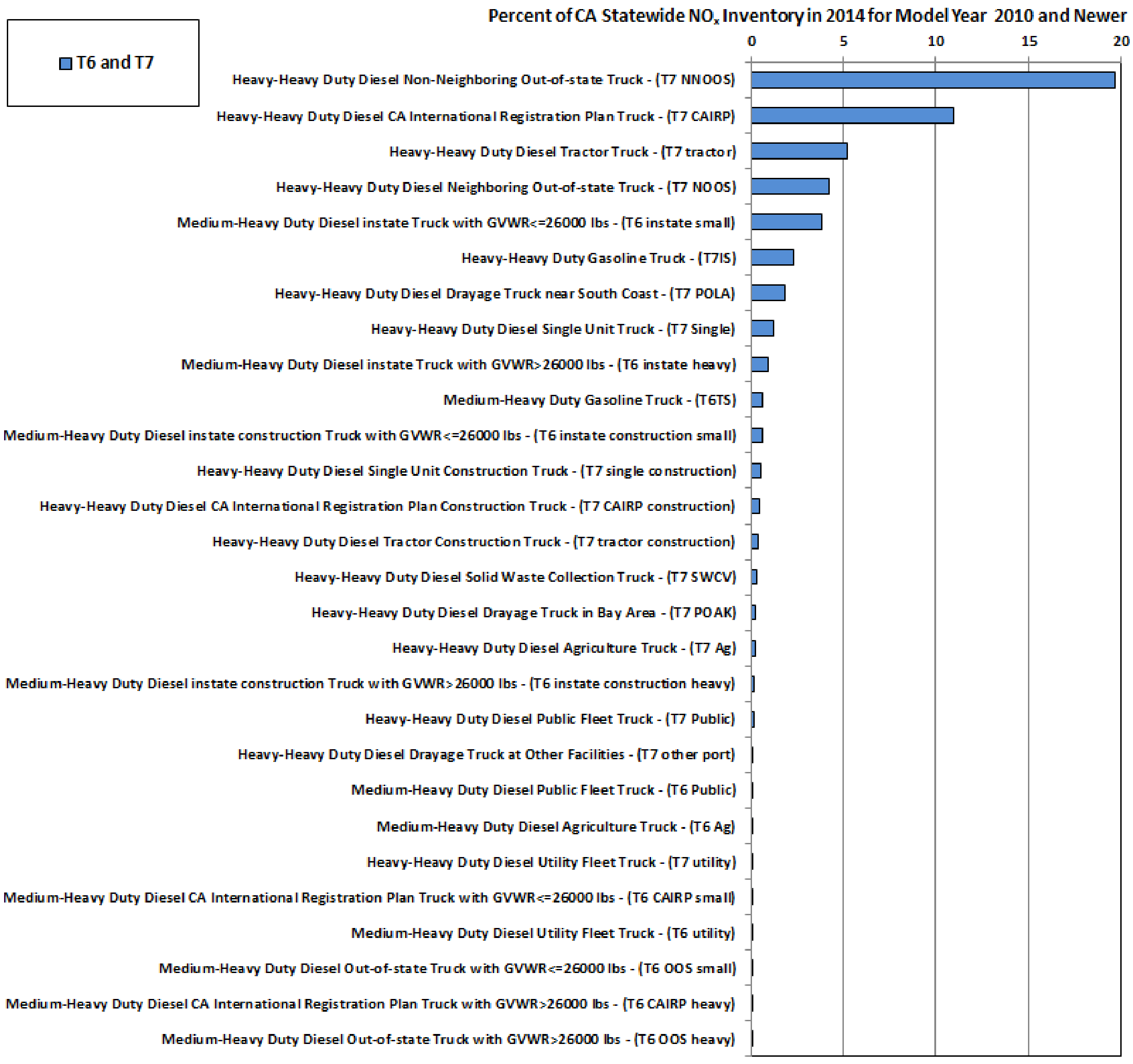


Figure 2-3. Contribution to statewide mobile source NO_x inventory in 2014 for model years 2010+

The data extracted from EMFAC2011 were also used to calculate an annual average VMT per day per vehicle for each vehicle category in calendar year 2014. This metric provides a first glance at vehicle activity patterns for the different vehicle categories. The results are plotted in a descending order as shown in Figure 2-4. According to Figure 2-4, several vehicle categories have the same VMT per day per vehicle. This is due to the lack of category-specific data on their usage or activity patterns. In general, the vehicle categories can be broadly grouped into four applications based on their activity patterns.

1. ***Long Haul*****:** Long haul trucks typically travel more than 200 miles per day. The majority is interstate or interregional (within the state) travel, therefore, most of the miles occur on highways.

2. ***Short Haul*****:** Short haul trucks generally travel between 100 and 200 miles per day where the majority of them are intraregional or local travel. Therefore, they have more travel miles on city streets and low volume roads than long haul trucks.

3. ***Pick-up and Delivery*****:** These trucks pick up and deliver a variety of goods, usually in and around urban areas. Their activity includes a lot of travel on city streets and involves a significant amount of stop time for loading and unloading.

4. ***Service-oriented*****:** This group consists mainly of public and utility trucks. They have low VMT per day because they make few trips per day where each trip involves a long stop to perform service. Some trucks may also require power take off (PTO) during the period that they perform the service.

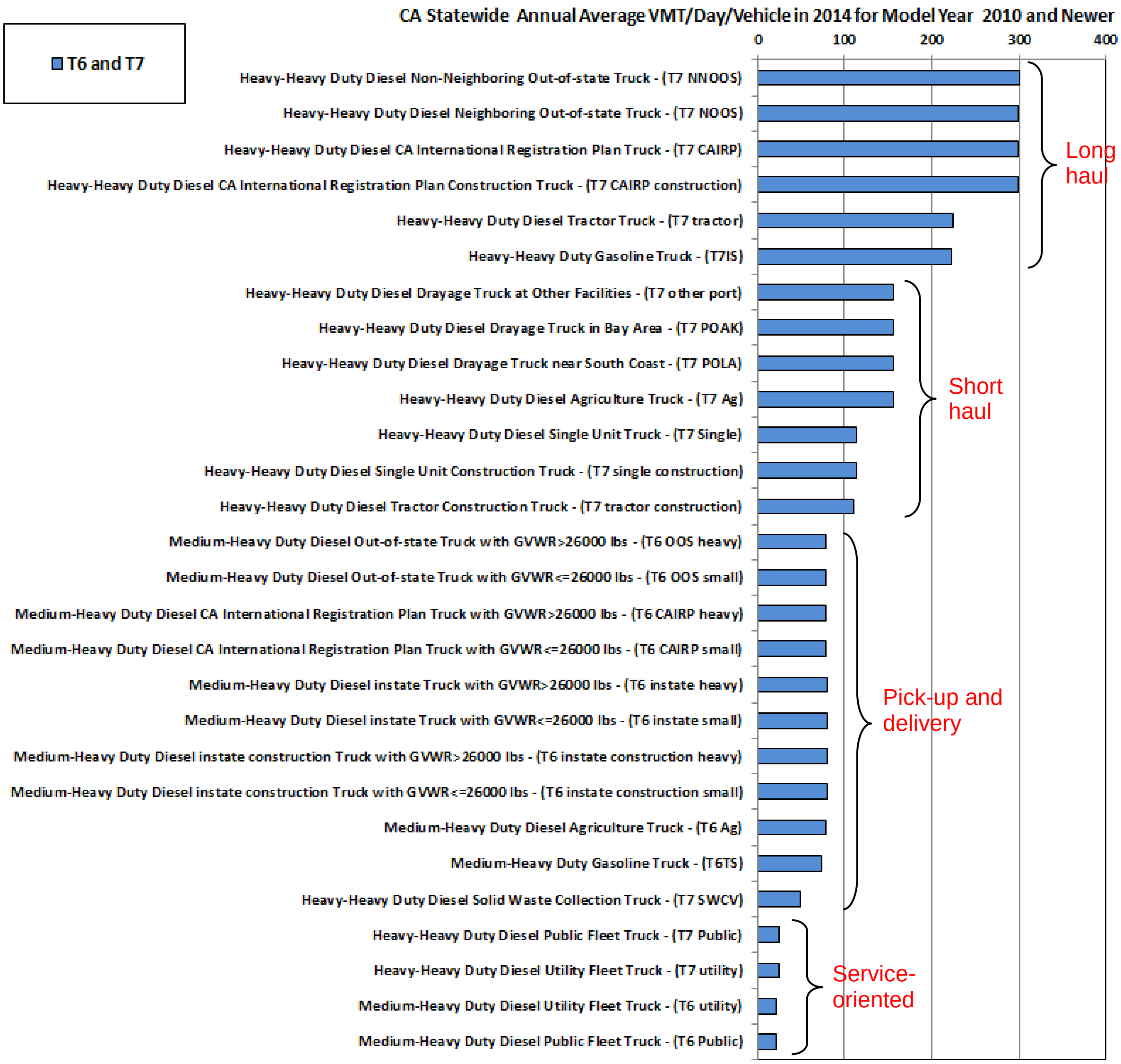


Figure 2-4. Annual average vehicle miles traveled per day per vehicle in 2014 for model years 2010+

2.2. Vehicle Sampling Strategy

Based on the results from the analysis of EMFAC2011 data in Section 2.1, the research team came up with a first draft of vehicle sampling strategy for the vehicle activity data collection portion of this project. In this first draft, the sampling strategy is based on the following rationales:

- Since data would be logged from 100 vehicles, we initially targeted 10 data logging groups where each group would include 10 vehicles with the same or similar activity pattern. We felt that this allocation would provide a good balance between the number of vehicle vocations that would be studied and the number of vehicle samples required to provide representative data for each group.

- We allocated at least one data logging group to each of the four usage patterns in Figure 2-4 (i.e., long haul, short haul, pick-up and delivery, and service-oriented) so that all unique activity patterns would be represented.

- For long haul trucks, we assumed that the place of registration—whether they are non-neighboring out-of-state, neighboring out-of-state, California and in International Registration Plan, or California but not in International Registration Plan—was likely to have minimal impact on their activity pattern. Therefore, we only allocated one data logging group for all long haul trucks.

- For short haul trucks, we allocated three data logging groups for three different vocations. These were drayage trucks, agricultural trucks, and construction trucks. We believed that trucks in these three vocations would have different usage patterns that warrant their own data logging group.

- Similar to the long haul truck, we assumed that the place of registration was likely to have minimal impact on the activity patterns of pick-up and delivery vehicles. On the other hand, the activity patterns of pick-up and delivery vehicles vary by vocation as evident in the NREL study. Based on the recommendation in the NREL study, we then planned to collect data from four vocations, which are food distribution, airport shuttle, refuse hauler, and transit bus.

- For service-oriented trucks which consist of public and utility trucks, we allocated one data logging group to public trucks and another data logging group to utility trucks.

Table 2-2 summarizes the 10 proposed vehicle data logging groups and the EMFAC2011 vehicle categories that they represent.

Table 2-2. First draft of the proposed vehicle sample allocation

Group No.	Usage Pattern	Vocation	No. of Samples	EMFAC2011 Vehicle Categories Represented
1	Long haul	Long haul	10	T7 CAIRP T7 CAIRP construction T7 NNOOS T7 NOOS T7 tractor
2	Short haul	Drayage	10	T7 other port T7 POAK T7 POLA
3	Short haul	Agriculture	10	T7 Ag T6 Ag
4	Short haul	Construction	10	T7 single construction T7 tractor construction T6 instate construction heavy T6 instate construction small
5	Pick-up and delivery	Food distribution	10	T6 CAIRP heavy T6 CAIRP small T6 instate heavy T6 instate small T6 OOS heavy T6 OOS small
6	Pick-up and delivery	Airport shuttle	10	
7	Pick-up and delivery	Refuse	10	
8	Pick-up and delivery	Transit	10	
9	Service-oriented	Public	10	T7 Public T6 Public
10	Service-oriented	Utility	10	T7 utility T6 utility
		Total	*100*	

For each group, we would try to recruit five of the 10 vehicles from Northern California and the other five from Southern California to provide a balanced geographical representation. For example, we would try to recruit five drayage trucks that operate at the port of Oakland and another five that operate at the ports of Los Angeles and Long Beach. The first draft of the proposed vehicle sampling strategy was reviewed by CARB and discussed in the CARB-UCR meeting on August 5th, 2014. A summary of comments and the corresponding adjustments to the vehicle sampling strategy is provided below.

- ***Group 3*:** T6 Ag trucks may have similar activity patterns to T6 instate construction small trucks. Thus, all 10 samples in this group should be focused on T7 Ag trucks.

- ***Group 4*:** T7 single construction, T7 tractor construction, and T6 instate construction heavy trucks should be considered as one subgroup while T6 instate construction small trucks should be considered as another subgroup. Also, T7 CAIRP construction trucks in Group 1 should be part of the first subgroup in this Group 4.

- ***Group 7*:** Since most refuse trucks in Southern California are now fueled by compressed natural gas (CNG), the number of samples for this group should be reduced to 5 with a focus on refuse trucks in other regions.

- ***Group 8*:** Since most urban transit buses are now fueled by CNG, the number of samples for this group should be reduced to 5 with a focus on intercity buses.

- ***Group 9*:** T6 and T7 public trucks are trucks owned and operated by public agencies. These trucks may involve multiple vocational uses. Thus, the number of samples for this group is increased to 20 where they are distributed equally across four vocational uses, including towing, sweeping, watering, and catch basin cleaning.

- ***Group 10*:** T6 and T7 utility trucks are trucks owned and operated by utility companies. While these trucks may involve multiple vocational uses, the majority of them are used for repairs of electrical poles and wires. Thus, the number of samples for this group is kept at 10 with all of them focusing on utility repair trucks.

On August 19th, 2014, the project team further discussed with ARB staff on fine-tuning vehicle categories by vocation. A summary of the discussion and the corresponding refinements to the vehicle sampling strategy is provided below.

- ***Group 1*:** T7 CAIRP, T7 NNOOS, and T NOOS trucks should be considered as one subgroup while T7 tractors as another subgroup. Trucks in the former subgroup can travel out-of-state while trucks in the latter subgroup cannot.

- ***Group 2*:** Five samples should be from ports in Northern California (e.g., Port of Oakland) while the other five samples from ports in Southern California (i.e., Ports of Los Angeles and Long Beach).

- ***Group 3*:** Most agricultural activities in California occur in the Central Valley. Thus, all truck samples would likely come from this region. If possible, five of the 10 samples should be from the northern part of the Central Valley while the other five from the southern part.

- ***Group 4*:** There should be separate subgroups for heavy construction trucks (e.g., those operating a crane) and small construction trucks (e.g., cement mixers) as their activity patterns may be different.

- ***Group 6*:** Similar to refuse trucks, most airport shuttle buses in Southern California are now fueled by CNG. Therefore, the number of samples for this group was reduced to 5 with a focus on airport shuttle buses in the other regions.

- ***Group 8*:** Intercity buses can be further categorized into: 1) motor coaches and tour buses, and 2) express buses. It was decided to increase the number of samples in this group back to 10 where each subgroup is allocated five samples.

- ***Group 9*:** The four vocational uses should be tentative. The final vocational uses should be determined based on fleet information from participating public agencies. If possible, it would be desirable to recruit truck samples from more than one agency.

- ***Group 10*:** In addition to work trucks that are used for repairs of electrical poles and wires, it would be desirable to have another set of utility trucks with a different vocational use. The other vocational use should be determined based on fleet information from participating utility companies.

Later, during a further discussion between CARB and UCR on September 18th, 2014, it was jointly decided that vehicle samples in Group 5 should be divided equally between food distribution and beverage distribution. Table 2-3 shows the final draft of vehicle sample allocation. The final draft consisted of 20 data logging groups with 5 truck samples in each group. While the data logging groups are defined by a combination of vocational use, GVWR, and geographic region, in this report we also generically refer to these data logging groups as vocations.

The final draft of vehicle sample allocation was used as a starting point for recruiting trucks with the view that the truck sample allocation may need to be adjusted during the recruitment stage as necessary, for example, when new information is obtained regarding the activity pattern of some truck vocations or when it is not possible to recruit trucks of certain vocations. A significant amount of effort was made to recruit vehicles according to the vehicle sample allocation shown in Table 2-3. The research team was able to successfully recruit vehicles in some vocations while finding it challenging to recruit vehicles in some other vocations. During the course of the project, the vehicle sample allocation was occasionally updated to reflect the circumstances. A few vocations were replaced by other vocations as necessary, as described below:

- We were not able to recruit motor coaches & tour buses albeit having successfully made an initial contact and numerous follow ups thereafter. In consultation with CARB, this vocation was replaced by urban buses. Note that these urban buses have diesel hybrid electric powertrain.

- Watering and catch basin cleaning trucks were included in the original vehicle sample allocation. However, these two vocations were not the most common in the public fleets that we worked with. Therefore, they were replaced by the most common types of heavy-duty vehicles in those fleets, which are freeway work trucks and municipal work trucks.

- Due to difficulty recruiting another vocation of utility trucks, we removed the second vocation of utility trucks and replaced it with local moving trucks.

Table 2-3. Final draft of the proposed vehicle sample allocation

Group No.	Usage Pattern	Vocation	No. of Samples	EMFAC2011 Vehicle Categories Represented
1a	Long haul	Long haul – out of state	5	T7 CAIRP T7 NNOOS T7 NOOS
1b	Long haul	Long haul – in state	5	T7 tractor
2a	Short haul	Drayage – Northern California	5	T7 other port T7 POAK
2b	Short haul	Drayage – Southern California	5	T7 POLA
3a	Short haul	Agriculture – North Central Valley	5	T7 Ag
3b	Short haul	Agriculture – South Central Valley	5	T7 Ag
4a	Short haul	Construction	5	T7 CAIRP construction T7 single construction T7 tractor construction T6 instate construction heavy T6 instate construction small
4b	Short haul	Cement mixers	5	
5a	Pick-up and delivery	Food distribution	5	T6 CAIRP heavy T6 CAIRP small T6 instate heavy T6 instate small T6 OOS heavy T6 OOS small
5b	Pick-up and delivery	Beverage distribution	5	
5c	Pick-up and delivery	Local moving	5	
6	Pick-up and delivery	Airport shuttle	5	
7	Pick-up and delivery	Refuse	5	
8a	Pick-up and delivery	Urban buses	5	
8b	Pick-up and delivery	Express buses	5	
9a	Service-oriented	Public – freeway work	5	T7 Public T6 Public
9b	Service-oriented	Public – sweeping	5	
9c	Service-oriented	Public – municipal work	5	
9d	Service-oriented	Public – towing	5	
10	Service-oriented	Utility – repair	5	T7 utility T6 utility
		Total	*100*	

3. Data Collection

3.1. Overview

There are several methods of collecting vehicle activity data. Travel diary survey has traditionally been used due to its low cost, thus allowing for vehicle activity data from a large sample size to be collected. In this method, truck drivers are asked to record the information about their trips such as start and end times, start and end odometer, etc. for a period of time (typically 1-2 weeks), after which the diaries are collected and transcribed for data analyses. This method has been known to be prone to human errors where trips are often underreported. It can provide trip-level data (e.g., number of trips per day, distribution of trip start time) but not vehicle or engine operation data.

Since the late 1990s, GPS data loggers have increasingly been used in vehicle activity studies as their cost has become lower and their accuracy continued to improve. In GPS-based vehicle activity studies, GPS data loggers are instrumented on vehicles to record the vehicles' position (latitude, longitude, and altitude), speed, and the associated timestamp. These data are recorded at high frequency, typically ranging from 0.5 to 10 Hz. Since a GPS data logger can be powered by the vehicle, either through the cigarette lighter or the On-Board Diagnostic (OBD) port, it can record vehicle activity data for a long period of time (several months).

Recently, on-board ECU data loggers have emerged as a useful tool for vehicle and engine performance studies. Once connected to the vehicle's Controller Area Network (CAN) bus through the OBD port (for most light-duty vehicles) or the J1939 port (for most heavy-duty vehicles), an ECU data logger can record engine parameters such as wheel speed, engine speed, fuel rate, etc. at high frequency. Since the data logger is powered through this connection, it can record vehicle and engine activity data for a long period of time.

Table 3-1 provides a summary of pros and cons for each vehicle activity data collection method described above. It is worth noting that many advanced data loggers are capable of logging both GPS and ECU data, which allows capturing detailed vehicle activity, engine operation, and geographic location data. This is particularly useful for analyzing the spatial and temporal context of vehicle activity patterns, for example, locations of idling hot spots, distribution of engine start time, etc. Some advanced data loggers offer an option to be equipped with a cellular modem, so that the recorded data can be wirelessly transmitted to a data server in real-time.

Table 3-1. Pros and cons of different vehicle activity data collection methods

Method	Pros	Cons
Travel diary survey	• Lowest cost per sample, thus allowing for larger sample size • Least invasive, which may make truck recruitment easier • Provide qualitative data (e.g., trip purpose) in addition to quantitative data	• Short data collection period (typically 1-2 weeks) • Semi-subjective and prone to human errors (e.g., underreported trips) • Only provide trip-related data; no detailed vehicle or engine operation data
GPS data logging	• Provide vehicle location data in addition to vehicle speed, thus enabling spatial analyses (e.g., road type identification) • High resolution data (e.g., 1 Hz) for long period (several months) • Inexpensive data logger	• GPS "tracking" sometime leads to privacy concerns. • Cannot directly identify when the engine is turned on and when it is turned off.
ECU data logging	• Provide vehicle speed and engine operation data (e.g., engine RPM, fuel rate, etc.), including exhaust temperature, which is the key parameter of interest • High resolution data (e.g., 1 Hz) for long period (several months)	• Expensive data logger • Most invasive as the data logger needs to be connected to the vehicle's J1939 port

After considering the pros and cons as well as the cost of each data collection method and the feedback from CARB staff, the research team decided not to use the travel diary survey. This is partly because all quantitative trip information that can be derived from travel diary data, such as the number of engine starts per day and soak time distribution per day, can also be derived from GPS and ECU data. Also, we felt that the qualitative trip information that can be obtained from travel diary data such as trip purpose is less important for meeting the objectives of this research. In addition, it is difficult to encourage or incentivize truck drivers to record their travel diaries over a long period in order to obtain a sufficient amount of data that represent typical vehicle activity patterns of their trucks. While the costs for conducting travel diary survey are lower than doing vehicle instrumentation, the derived trip information will be less accurate as they are subject to human errors.

Therefore, in this project the research team decided to collect vehicle activity data exclusively through vehicle instrumentation. The vehicle instrumentation program was designed to include the following elements:

- ***Using combined GPS&ECU data loggers***: It was desirable to take advantage of advanced data loggers that combine GPS and ECU data logging capabilities to collect detailed vehicle and engine operation data along with the location and time information associated with those data.

- ***Using dual data transfer mechanisms*****:** It was desirable to use data loggers that have both on-board data storage and cellular modem. The on-board data storage will allow recorded data to be stored on the data logger, which can be downloaded to a computer once the data loggers are retrieved at the end of the data collection period. The cellular modem will allow recorded data to be sent wirelessly to the data server either periodically or in real-time. This wireless data transfer provides a way to quickly identify issues associated with the data loggers or the data quality.

- ***Collecting data for at least one month*****:** It was desirable to collect data from each vehicle sample for at least one month to obtain enough data to be representative of its operation.

During the project, the research team at UCR entered into a Cooperative Research and Development Agreement with the U.S. Environmental Protection Agency (EPA) on portable vehicle measurement research. Through this CRADA, the U.S. EPA has provided various resources in support of this project, for example, lending combined GPS&ECU data loggers for use in the data collection. This allowed the research team to collect both GPS and ECU data from all the truck samples rather than just from a subset of them. This CRADA support also allowed us to extend the data collection period for some of the truck samples well beyond one month.

3.2. Data Loggers

The research team surveyed the market for combined GPS&ECU data loggers that would meet the project needs. After a thorough consideration of the survey result, we decided to choose the J1939 Mini Logger™ produced by HEM Data. This data logger was just introduced at the time of conducting this research and was made to order. It consists mainly of a CAN reader capable of acquiring CAN bus data in SAE J1939 standard and an on-board data storage. A GPS receiver and antenna as well as communication modems (cellular and/or WiFi) can be added as optional. The data logger can be configured to acquire any number of J1939 parameters on a vehicle's J1939 network through the companion DawnEdit™ software.

In this project, the research team used two versions of the J1939 Mini Logger™. One was equipped with WiFi modem, which was used mostly in the initial stages of the data collection when a version with cellular modem was not yet available. The WiFi version was also used on trucks whose owners requested not to be tracked in real time. Although the WiFi-capable data loggers can transfer recorded data to the data server over a WiFi connection, we did not utilize that feature as there was often not a free WiFi connection available at the fleet locations. These data loggers were exclusively used to store the recorded data on-board for later download after they were retrieved. The other version of J1939 Mini Logger™ that was used in this project was equipped with cellular modem and was set up to transfer recorded data over the cellular network to the data server periodically during the data collection period. Figure 3-1 show the J1939 Mini Logger™ used in this research.

Figure 3-1. J1939 Mini Logger™ used in this research

3.3. Vehicle Recruitment and Data Logger Installation

Vehicle recruitment was one of the most challenging aspects of this project since we targeted vehicles in specific vocations as listed in Table 2-3. Given the anticipated long lead time for vehicle recruitment, parallel recruiting efforts were made as described below.

- ***Recruiting from UCR contacts***: The research team has several direct contacts at heavy-duty vehicle fleets, original equipment manufacturers (OEMs), air quality management districts, and public agencies in California. Inquiries were made to these contacts to solicit participation or referral as appropriate. UCR's vehicle recruitment and data logger installation efforts were focused on fleets in Southern California including the southern part of the Central Valley.

- ***Recruiting through consultants***: We hired a private consultant, infoWedge, to assist with acquiring fleet contacts, negotiating data logging requirements (e.g., number of trucks, data logging period, etc.), and coordinating data logger installation based on vehicle availability. The consultant is based in the Greater Sacramento area, and thus, was tasked with recruiting vehicles from and coordinating installation efforts with fleets in Northern California including the northern part of the Central Valley.

- ***Recruiting from CARB contacts***: CARB provided several heavy-duty vehicle fleet contacts obtained from heavy-duty inspection programs and offered assistance in vehicle recruitment and data logger installation.

It has been the research team's experience that collecting GPS data may be an issue with some fleets due to privacy concerns, which could impact our ability to recruit vehicles. Therefore, we offered ways to protect any confidential information for the participating fleets and the privacy of the drivers without compromising our ability to obtain vehicle activity patterns of interest (e.g., number of engine starts and soak time). For instance, we only used WiFi-capable data loggers for fleets that were concerned about real-time tracking of their vehicles and drivers. We also agreed to remove the latitude and longitude information for the first and last miles of each trip in the data files to prevent identifying the origin and destination locations.

At the time of vehicle recruitment, we asked potential fleets for vehicles that meet specific criteria: 1) being commercial class 4 (GVWR 14,001-16,000 lbs) or higher, 2) being conventional diesel vehicles, and 3) being model year 2010 or newer. The first criterion was to ensure that the vehicles fall into the T6 (medium heavy-duty trucks) or T7 (heavy heavy-duty trucks) categories in EMFAC2011, which are the target vehicle categories in this research. The T6 category corresponds with commercial classes 4-7 while the T7 category corresponds with commercial class 8 (see Table 2-1). The third criterion was used as a proxy for identifying vehicles with SCR technology. Due to the difficulty in recruiting vehicles in some vocations, we had to accept a small number of vehicles that do not meet the second or the third criterion, as described in Section 2.2.

Once vehicles had been recruited, an installation date and time was scheduled and the preparation work followed. This included gathering data loggers and miscellaneous supplies and configuring them. The data loggers were configured to log more than 170 ECU parameters as listed in Appendix A at the frequency of 1 Hz. In the case of cellular-capable data loggers, the preparation work also included activating SIM cards and registering them with the data server. Finally, each data logger went through a final test in house before being deployed in the field. The installation of data loggers followed the procedures given in Appendix B. At the time of data logger installation, we also collected vehicle and engine information including vehicle manufacturer/model/model year, engine manufacturer/model/model year, rated horsepower, GVWR, etc. to examine whether there are any differences in vehicle and engine characteristics by vocation. Originally, we used a paper survey form to record these information on site. The survey form is attached at the end of Appendix B. Later, we employed a more efficient method where we took photos of sticker labels that contain these information, and then extracted the information from the photos at a later time. This method significantly reduced the downtime of the vehicles.

3.4. Final Vehicle Samples

Table 3-2 summarizes the final vehicle samples obtained in this research. For each vocation, the table lists the number of vehicle samples targeted, the number of vehicles actually installed with data loggers, and the number of samples that completed the data collection. Figure 3-2 shows pictures of an example vehicle from each vocation. The vehicle and engine information of the individual vehicles are provided in Appendix C.

Table 3-2. Final vehicle samples in this research

No.	Vocation	No. of Vehicles			No. of Fleets	Region	Comment
		Tar-geted	Install ed	Com-pleted			
1a	Line haul - out of state	5	3	3	1	No. Cal.	-
1b	Line haul - in state	5	4	3	1	So. Cal.	1 WiFi logger lost
2a	Drayage - No. Cal.	5	4	1	1	No. Cal.	3 WiFi loggers lost
2b	Drayage - So. Cal.	5	7	5	1	So. Cal.	2 cellular loggers lost
3a	Agricultural - No. CV	5	2	0	1	No. Cal.	2 cellular loggers lost
3b	Agricultural - So. CV	5	8	8	1	So. Cal.	1 cellular logger removed
4a	Construction	5	6	6	3	Both	-
4b	Cement mixers	5	5	5	2	Both	-
5a	Food distribution	5	5	5	1	So. Cal.	1 cellular logger lost
5b	Beverage distribution	5	10	6	1	So. Cal.	4 WiFi loggers lost
5c	Local moving	5	1	1	1	So. Cal.	-
6	Airport shuttle	5	5	5	1	No. Cal.	-
7	Refuse	5	6	6	1	No. Cal.	-
8a	Urban buses	5	6	6	1	No. Cal.	-
8b	Express buses	5	5	5	1	So. Cal.	-
9a	Freeway work	5	5	5	1	Both	-
9b	Sweeping	5	5	5	1	Both	-
9c	Municipal work	5	3	3	1	So. Cal.	-
9d	Towing	5	7	7	2	Both	-
10	Utility repair	5	5	5	1	No. Cal.	-
	Total	*100*	*102*	*90*	*24*	-	-

Notes: No. Cal. = Northern California; So. Cal. = Southern California; CV = Central Valley

- Thirteen data loggers were lost where eight of them were WiFi-capable data loggers. The data on these eight data loggers were not retrievable, and thus, the data collection with these data loggers was deemed incomplete. For example, four WiFi-capable data loggers were installed on four drayage trucks in Northern California. Only one of them completed the data collection as the other three were lost. Out of the five cellular-capable data loggers that were lost, two in Group 2b and two in Group 3a were lost before any meaningful data were sent to the server. Therefore, the data collection with these four data loggers were considered incomplete.

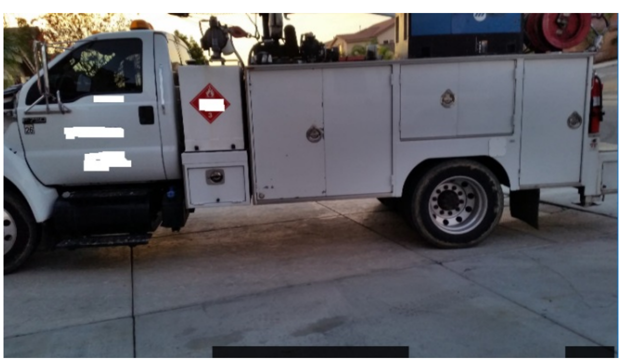
- One cellular-capable data logger in Group 3b was removed during the data collection period as the vehicle needed to be repaired, and the fleet returned the data logger to the research team. One cellular-capable data logger in Group 5a was also removed during the data collection period, but the fleet was not able to locate and return it to the research team. In both cases, however, the data had already been uploaded onto the data server.

Line haul – out of state

Line haul – in state

Drayage – Southern California

Agricultural – Southern Central Valley



Construction

Cement mixers

Figure 3-2. Example of vehicle sample in each data logging group


Food distribution

Beverage distribution

Local moving

Airport shuttle


Refuse


Urban buses

Figure 3-2. Example of vehicle sample in each data logging group (continued)

Express buses

Freeway work

Sweeping

Municipal work

Towing

Utility repair

Figure 3-2. Example of vehicle sample in each data logging group (continued)

4. Data Processing and Analysis

4.1. Overview

Data recorded by the J1939 Mini Logger™ are separated into individual files where a file includes data from the "key-on" event to the "key-off" event, as illustrated in Figure 4-1. The key-on event is when the ignition key is switched on, which powers on the electrical system of the vehicle. The data logger receives an electrical signal, prompting it to create a new data file and start recording the data. The key-on event is usually followed by an "engine-on" event when the engine is turned on. This engine-on event represents the start of a trip in the context of this research as it has implication on the vehicle's start emissions. After a certain period of engine operation, the engine is turned off, which represents the end of the trip. This "engine-off" event is then usually followed by a key-off event when the data logger stops recording the data and closes the data file. The amount of time from an engine-off event to the next engine-on event is called a soak period, which also has impact on the vehicle's start emissions and evaporative emissions. For heavy-duty vehicles, any engine start with the preceding soak period longer than 12 hours is considered a "cold" start.

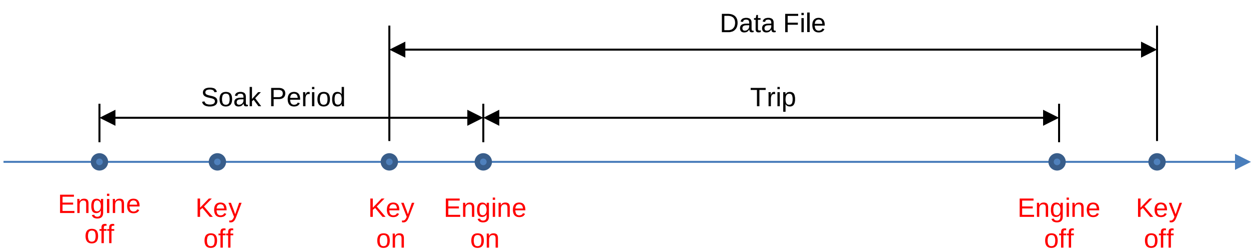


Figure 4-1. Illustration of events associated with a data file

It should be noted that the events discussed above do not always occur in the order presented in Figure 4-1. Sometime a key-on event may be followed by a key-off event, for instance, when a driver switches the key on to charge cell phone and then switches it off without turning on the engine. In this case, a data file will be created by the J1939 Mini Logger™ but it will not be considered a trip in the context of this research. As another example, an engine-off event may be followed by an engine-on event without key-off. In this case, the data file will contain more than one trip.

4.2. Data Processing

There are multiple steps of processing the collected data. The steps are described below.

1. ***Data Conversion***: The J1939 Mini Logger™ creates two binary files for each trip—a .GSP file that logs the GPS data and a .IOS file that logs the ECU data.

DawnEdit software was used to convert the two data files into a comma-separated values (CSV) file before the following processing and analysis steps. During the conversion, the software time-aligned the GPS and ECU data streams and created a single CSV file.

2. ***Map Matching*:** In this research, it is of interest to understand vehicle activity patterns on different road types. In order to identify the road type for each data point, map matching was performed on a GIS analysis platform with the collected data. Using latitude, longitude, and heading information, the map matching algorithm assigned each data point to a road link in the digital road network based on its proximity (a data point usually belongs to the closest road link), orientation (a data point heads into the same direction as the road link), and history (a data point is more likely to be on the same road type as the few previous data points than not). The map matching resulted in each data point being assigned to one of the three broad categories of road type: 1) freeway, 2) non-freeway, and 3) ramp. A "Road Type" data field was added to the CSV file to store the road type of each data point.

3. ***Data Quality Assurance*:** The vocation master data files went through several data quality assurance procedures with the primary focus on timestamp and vehicle speed data fields. There are two sources of timestamp data: 1) GPS and 2) internal clock of the data logger. The data logger's internal clock only reports timestamp down to minutes. While the GPS reports timestamp down to seconds, there were parts in the data where the GPS timestamp was obviously incorrect or missing. For those parts in the data, the timestamp from the data logger's internal clock was used to estimate the timestamps for the data records.

   In terms of vehicle speed data, there are two sources: GPS-based speed and ECU-based speed. The speed reported by GPS is based on a distance the vehicle travels in a given time (one second in this case) that was determined from the satellite signals. The accuracy of the speed depends on the number of satellites and the quality of satellite signal. The speed reported by ECU is based on rotational speed of the wheels, which could be affected by general wear and tear of the wheels. The ECU-based speed data could also be incorrect if the wheel size is changed without a proper calibration of the wheel speed calculation. Figure 4-2 shows an example of questionable ECU-based speed data where the values are unreasonably high for long periods. The linear interpolation applied to correct the unreasonably high values results in unrealistic vehicle speed profile, such as around the seconds 170-300. Figure 4-3 show another example of questionable ECU-based speed data. In this case, there are sporadic offsets of ECU-based speed from the GPS-based speed that cannot be explained. In general, the GPS-based speed data is more accurate, and therefore, was used as the primary source of vehicle speed in this research. The ECU-based speed data was used to supplement or replace the GPS-based speed data as needed, for example, when the GPS-based speed was not available or unrealistic. A "Composite Speed" data field was added to the master data files to store the vehicle speed data that had gone through the data quality assurance described above.

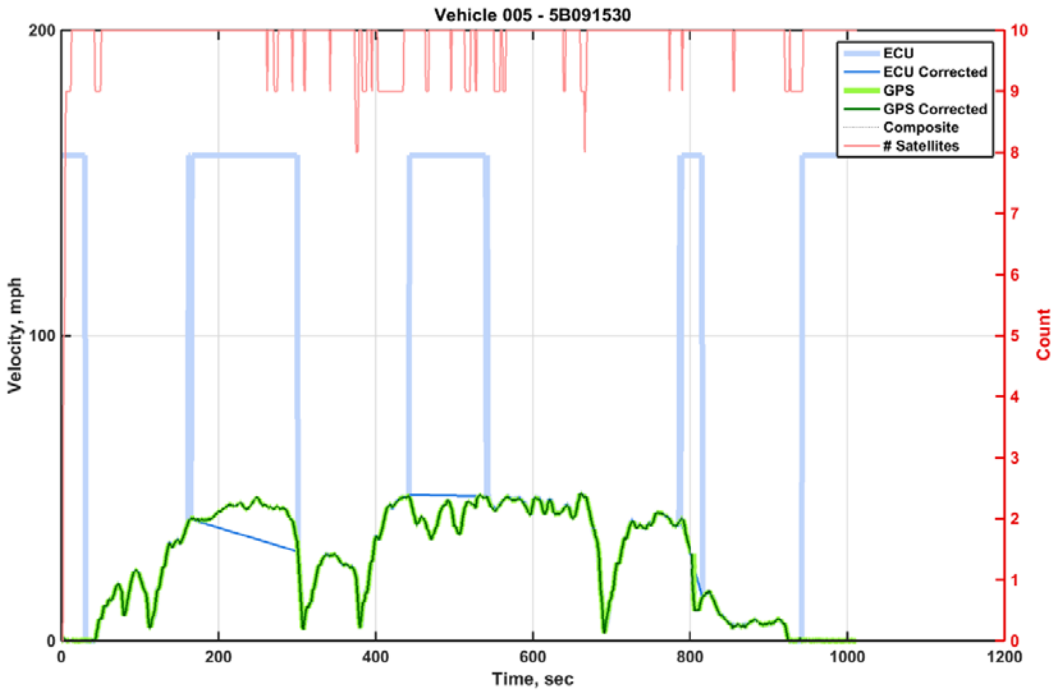


Figure 4-2. Example of questionable ECU-based speed data with periods of unreasonably high values

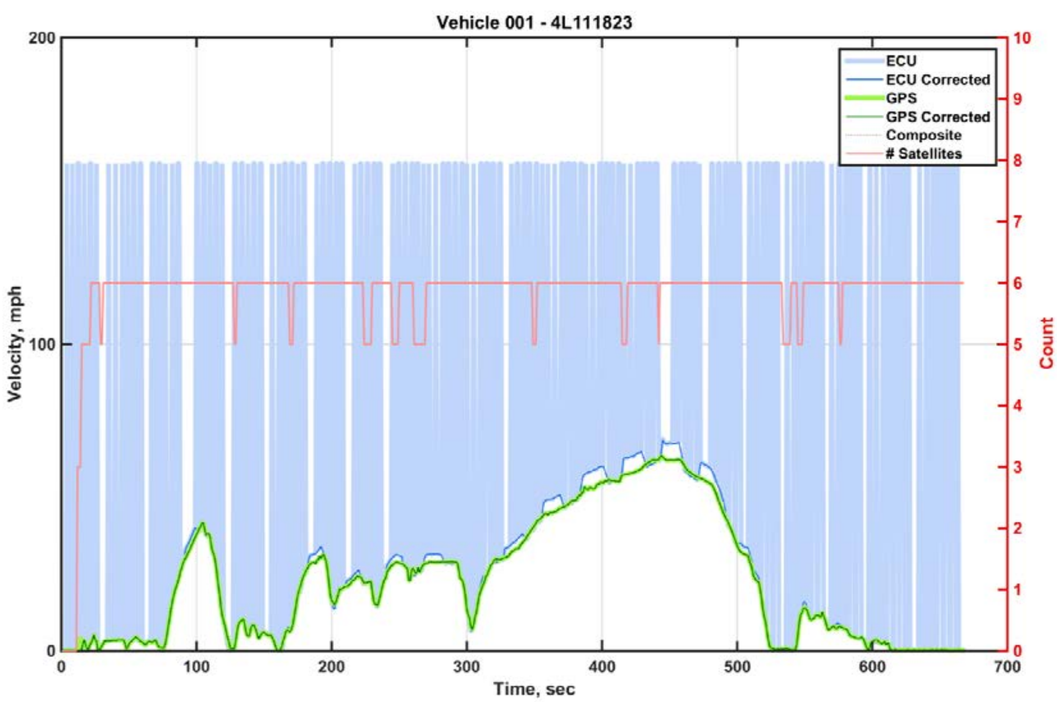


Figure 4-3. Example of questionable ECU-based speed data with sporadic offsets

Figure 4-4 shows an example of vehicle speed data where there is a good match between GPS-based speed and ECU-based speed. Figure 4-5 shows an example where the GPS-based speed data from the seconds 1-18 are questionable due to having no satellite, and thus, are replaced by the corrected ECU-based speed data.

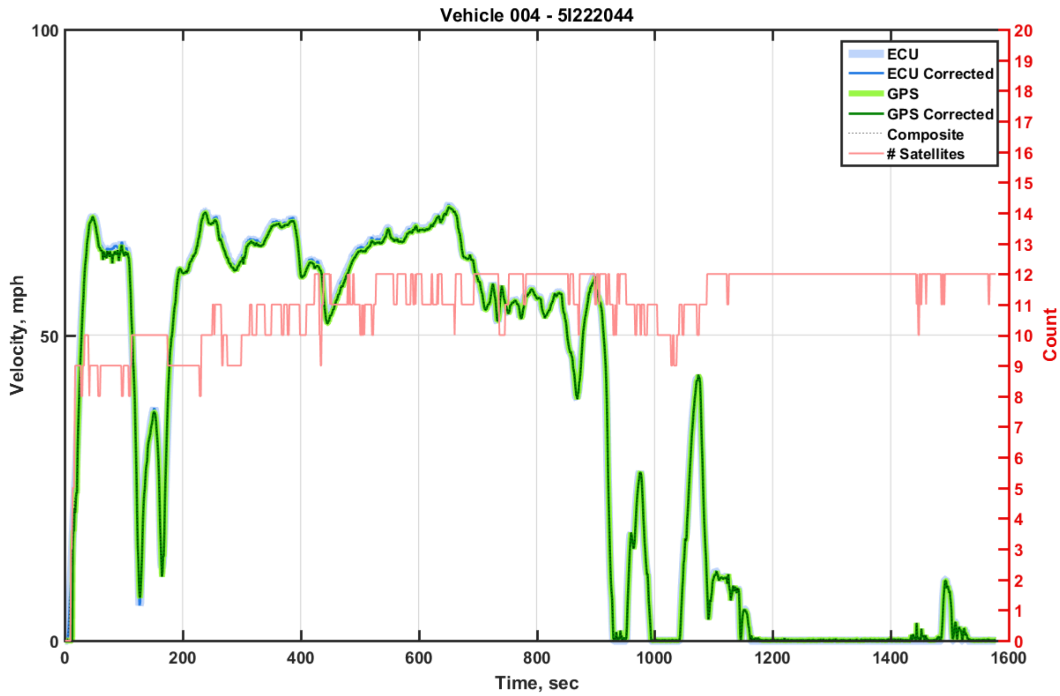


Figure 4-4. Example of a good match between GPS-based speed and ECU-based speed data

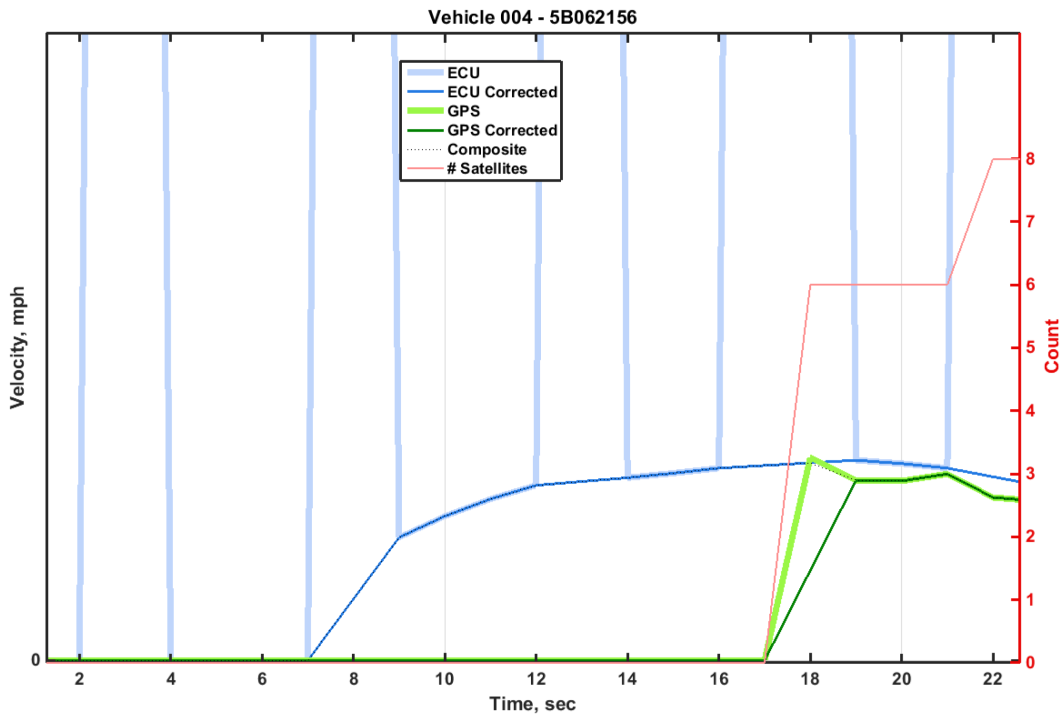


Figure 4-5. Example of replacing questionable GPS-based speed with ECU-based speed

4. ***Trip Identification*:** As noted in Section 4.1, a trip in the context of this research is from an engine-on event to an engine-off event. Therefore, trips needed to be identified and indexed in the master data files before they could be used for analyses. Engine speed was used to identify engine-on and engine-off events. An engine off event was defined as having engine speed below 300 rpm. This threshold value was selected based on our observation that there was some noise in the engine speed data. A "Trip ID" data field was added to identify each unique trip in the master data files. Sometimes, a key-on event was followed by a key-off event, resulting in a data file being created by the J1939 Mini Logger™ although it is not a trip. In this case, a Trip ID was not assigned to this portion of the data. In other times, an engine-off event was followed by an engine-on event without key-off, resulting in the data file containing more than one trip. In this case, each trip was assigned a unique Trip ID.

   It was discovered during the project that some data files were incorrectly created by the data loggers because of interruption to data connection with the ECU. Typically, the J1939 Mini Logger™ takes less than one second after the ignition key has been switched on to create a data file and start recording data. When the ignition key is switched off, the data messages on the ECU stop being transmitted. The data logger stops recoding data when there are no more messages. Thus, an interruption to data connection during vehicle operation would cause the data logger to misunderstand that the ignition key has been switched off, and so it would stop recording and close the data file. A reconnection of data stream would then cause the data logger to misunderstand that the ignition key has been switched on, and so it would create a new data file and start recording data. An example is given in Figure 4-6, which shows vehicle speed and engine speed data in two consecutive data files. It can be seen that the first data file ended when the vehicle speed was around 10 mph and the engine speed was around 1,100 rpm. The following data file started when the vehicle speed was around 10 mph and the engine speed was around 1,100 rpm. The time gap between the two files was less than 30 seconds. Under these conditions, it is reasonably to assume that the vehicle had been moving and the two files should be merged into a single file.

Therefore, a data file merging step was performed prior to trip identification. First, the starting and ending values of vehicle speed, engine speed, latitude, longitude, and timestamp in each data files were compiled. Then, the lapsed time and distance between the end of one file to the start of the next file in chronological order were calculated. Next, two consecutive trips were merged if all of the followings were true: a) ending engine speed of the first file > 300 rpm; b) starting engine speed of the second file > 300 rpm; and c) lapsed time < 60 seconds. Of all the cases where conditions a) and b) are true, 99.4% have a lapsed time of fewer than 60 seconds, indicating that the data interruptions were usually brief. The remaining cases were manually examined to determine whether the trips should be merged or not. The decision was made based on the ending vehicle speed in the first file, the starting vehicle speed in the second file, and the estimated travel speed calculated as lapsed distance divided by lapsed time.

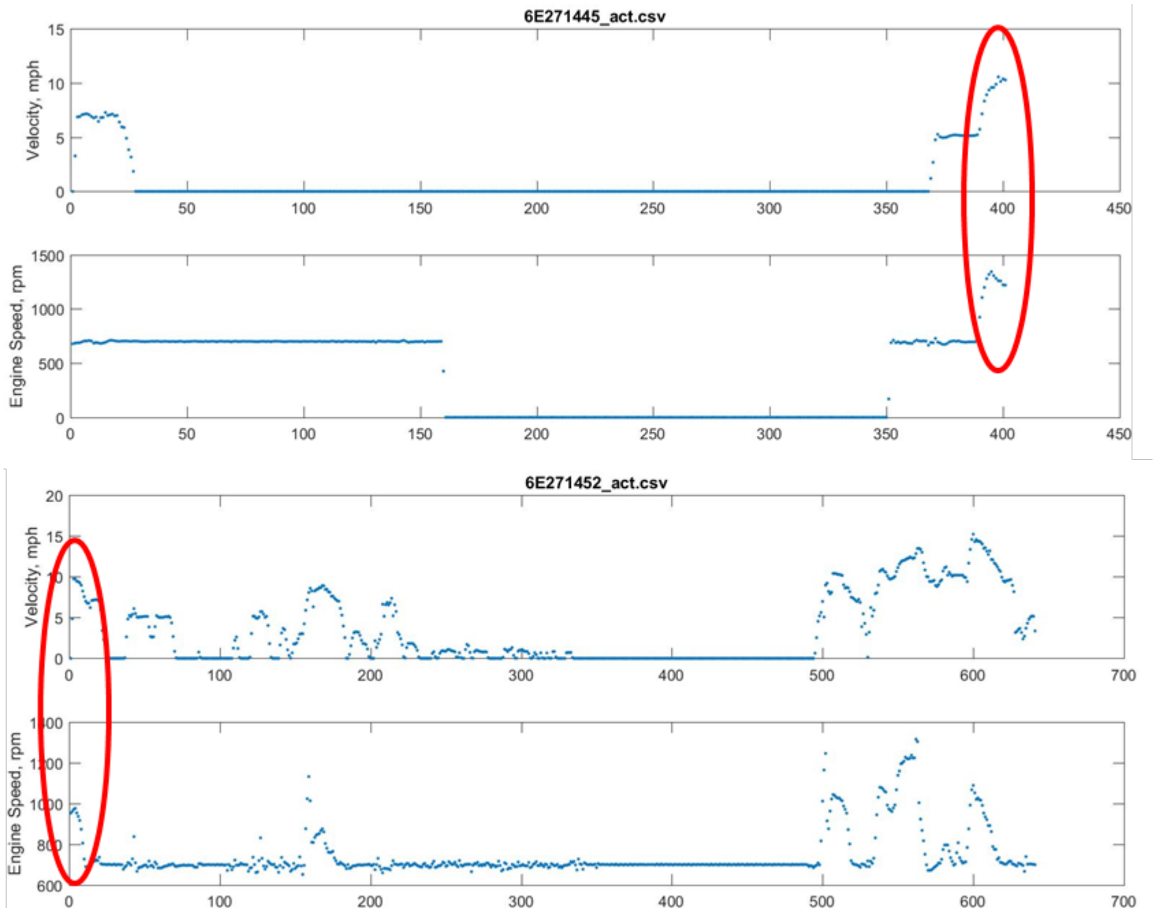


Figure 4-6. Vehicle and engine speed of two consecutive data files showing data interruption

5. ***Trip Origin and Destination Cloaking*:** To protect the identity of the participating fleets, the latitude and longitude information were removed for the first and last miles of each trip in the data files. Other GPS data fields such as timestamp and speed and all ECU data fields were retained.

6. ***Data Aggregation*:** As data for a vehicle consists of many data files, these individual data files were concatenated in chronological order into a single data file. Then, data files of all the vehicles in a data logging group were aggregated into a master data file for the group. A "Vehicle ID" field was added to this master data file to identify which data records belong to which vehicle. Due to the large amount of data that were collected, the size of a group's master data file ranges from 0.7 gigabytes (GB) to 12.1 GB. Each master data file is essentially a very large data table where the columns include all the data fields in the GPS and ECU data plus additional data fields that were added such as Vehicle ID. Some columns are empty as the data for those data fields are not available. Each row in the data table represents one second of data. Every second of data can be uniquely identified by a combination of Vehicle ID and timestamp. Vehicle ID can also be used to associate vehicle activity data in these master data files with the vehicle and engine information that are stored in a different data table.

4.3. Vehicle Activity Analysis

Once the collected data had been processed through the steps described above, there were a total of 19 master data files for the 19 data logging groups. [Note that there was no data for Group 3a - Agricultural trucks in North Central Valley.] These data files were used to calculate a number of statistics related to vehicle activity, which are presented in Chapter 5 of this report. While some statistics are self-explanatory, other statistics are not as they involve unique vehicle activity metrics and concepts. Below describes those unique vehicle activity metrics and concepts.

Scaled Tractive Power

Scaled tractive power (STP) is a metric used in the U.S. EPA's Motor Vehicle Emission Simulator (MOVES) to describe emissions from heavy-duty vehicles. Vehicle specific power (VSP) is a similar metric in MOVES used for light-duty vehicles. STP and VSP describe the power required at the wheel to propel the vehicle against tire rolling resistance, mechanical rotating friction, aerodynamic drag, and if applicable, gravitational force due to road slope. They can be expressed as:

$$VSP = \left(\frac{A}{M}\right) \cdot v + \left(\frac{B}{M}\right) \cdot v^2 + \left(\frac{C}{M}\right) \cdot v^3 + (a + g \cdot \sin\theta) \cdot v$$

$$STP = \frac{Av + Bv^2 + Cv^3 + M \cdot v \cdot (a + g \cdot \sin\theta)}{F_{scale}}$$

where *A*, *B*, and *C* are road load coefficients in kw·s/m, kw·s^2/m^2, and kw·s^3/m^3, respectively. *A* is associated with tire rolling resistance, *B* with mechanical rotating friction as well as higher order rolling resistance losses, and *C* with aerodynamic drag. *M* is mass of the vehicle (metric tons), *g* gravitational acceleration (9.8 m/s^2), *v* instantaneous vehicle speed (m/s), *a* instantaneous vehicle acceleration (m/s^2), and θ angle of road slope (degree). F_{scale} is a scaling factor that helps keep STP in the same range of VSP. STP can indicate the level of load placed on the engine, and thus, may imply the level of SCR temperature. A vehicle operating at high STP states is likely to have a higher SCR temperature than the same vehicle operating at low STP states. Also, STP is needed to determine the vehicle operating mode (OpMode) as defined by MOVES and described below.

Vehicle Operating Mode

MOVES defines 23 vehicle OpMode bins for calculating running exhaust emissions. These OpMode bins are defined by a combination of instantaneous vehicle speed and STP as shown in Table 4-1. It has been shown that the OpMode bins have strong correlation with the trends of running exhaust emissions for both light-duty and heavy-duty vehicles. As an example, Figure 4-7 shows NO_x and PM emission rates for heavy-duty diesel vehicles (with GVWR > 33,000 lbs) that were obtained from MOVES by OpMode bins. In this research, the concept of vehicle OpMode was heavily used in the development of drive cycles to be described in Section 4.5.

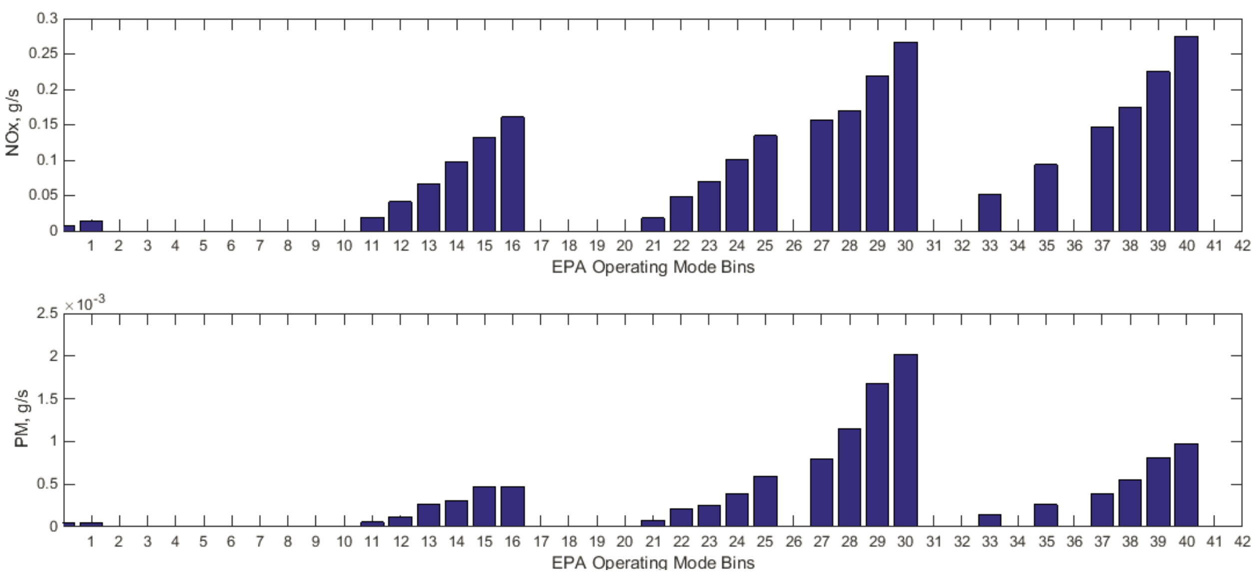


Figure 4-7. Emission rates of 2009 heavy-duty diesel vehicles from MOVES

Table 4-1. Vehicle operating mode bins in MOVES

Operating Mode Bin	Description	Scaled Tractive Power (kW/tonne)	Instantaneous Speed (mph)	Instantaneous Acceleration (mph/s)
0	Decelerate/brake	-	-	$a_t \leq -2.0$ or ($a_t < -1.0$ and $a_{t-1} < -1.0$ and $a_{t-2} < -1.0$)
1	Idle		$-1.0 \leq v < 1.0$	-
11	Coast	STP < 0	$0 \leq v < 25$	-
12	Cruise/accelerate	0 ≤ STP < 3	$0 \leq v < 25$	-
13	Cruise/accelerate	3 ≤ STP < 6	$0 \leq v < 25$	-
14	Cruise/accelerate	6 ≤ STP < 9	$0 \leq v < 25$	-
15	Cruise/accelerate	9 ≤ STP < 12	$0 \leq v < 25$	-
16	Cruise/accelerate	12 ≤ STP	$0 \leq v < 25$	-
21	Coast	STP < 0	$25 \leq v < 50$	-
22	Cruise/accelerate	0 ≤ STP < 3	$25 \leq v < 50$	-
23	Cruise/accelerate	3 ≤ STP < 6	$25 \leq v < 50$	-
24	Cruise/accelerate	6 ≤ STP < 9	$25 \leq v < 50$	-
25	Cruise/accelerate	9 ≤ STP < 12	$25 \leq v < 50$	-
27	Cruise/accelerate	12 ≤ STP < 18	$25 \leq v < 50$	-
28	Cruise/accelerate	18 ≤ STP < 24	$25 \leq v < 50$	-
29	Cruise/accelerate	24 ≤ STP < 30	$25 \leq v < 50$	-
30	Cruise/accelerate	30 ≤ STP	$25 \leq v < 50$	-
33	Cruise/accelerate	STP < 6	$50 \leq v$	-
35	Cruise/accelerate	6 ≤ STP < 12	$50 \leq v$	-
37	Cruise/accelerate	12 ≤ STP < 18	$50 \leq v$	-
38	Cruise/accelerate	18 ≤ STP < 24	$50 \leq v$	-
39	Cruise/accelerate	24 ≤ STP < 30	$50 \leq v$	-
40	Cruise/accelerate	30 ≤ STP	$50 \leq v$	-

Note the second column of Table 4-1 that the 23 OpMode bins can be grouped into four general operating modes: 1) deceleration/braking, 2) idling, 3) coasting, and 4) cruising/accelerating. In this research, the calculated vehicle activity statistics include the percentage of total vehicle operating time (and distance) in each of these four operating modes. When a vehicle decelerates, idles, or coasts, it usually requires less power than when it cruises or accelerates. The engine load would be lower under these circumstances. Thus, a vehicle that spends a significant portion of its time in the operating modes with low engine load will likely have lower SCR temperatures.

Idle Activities

There are two idle activities that were specifically analyzed in this research per CARB's request. They are defined below.

- ***Idle Trip*****:** A trip (engine on to engine off) with the average vehicle speed of lower than 5 mph and the trip distance of less than 5 miles.

- ***Extended Idling Event*****:** A continuous segment of vehicle activity with all the instantaneous vehicle speeds being lower than 5 mph, the total distance of less than 1 mile, and the total duration of more than 5 minutes.

These idling activities occur at trip origins or destinations, rest stops, or work sites. They do not include idling while en route such as being in traffic jam or stopping at traffic lights. It should be noted that the two idle activities are interrelated, but do not always overlap. An idle trip may contain zero, one, or multiple extended idling events. On the other hand, an extended idling event may form part of an idle trip or a regular trip. Thus, these two idle activities were analyzed separately.

Per Day Statistics

Several vehicle activity statistics are expressed on a per day basis, including: 1) number of starts per day, 2) number of cold starts per day, 3) number of idle trips per day, 4) number of extended idling events per day, and 5) idle time per day. Starts here are referred to engine-on events so the number of starts is essentially the same as the number of trips (see Figure 4-1). Cold starts are engine-on events with the preceding soak period longer than 12 hours. Idle trips and extended idling events are defined earlier. Lastly, idle time is the total duration of both idle trips and extended idling events. Note that idle time here does not include the duration of any idle activities that do not meet the definition of either idle trip or extended idling event, such as a one-minute idle while stopping at a traffic light.

Since EMFAC is designed to estimate emissions on an average weekday, only data from trips that started on weekdays (00:00:00 of Monday through 23:59:59 of Friday) were used in the calculation of these per day statistics. In other words, all weekend trips were excluded. Taking number of starts per day as an example, to obtain the numerator we counted the total number of trips that started on weekdays during the data collection period. To obtain the denominator, we counted the total number of weekdays during the data collection period. Note that a vehicle may not be operated on every single weekday so we also counted the number of operating weekdays and calculated statistics per operating weekdays. Also note that the counting of number of trips and number of weekdays was done separately for each vehicle in a data logging group. This is because not every vehicle in a group has the same data collection period. For example, to determine the number of starts per days for the group, we divided the total number of starts for all vehicles in the group by the total number of weekdays for all vehicles in the group. The same calculation method was applied to the other per day statistics.

Hour of Day

Several statistics involves diurnal distribution by hour of day. The format of hour of day used in this report is from Hour 0 to Hour 23 where Hour 0 represents 00:00:00 - 00:59:59 and Hour 23 represents 23:00:00 - 23:59:59.

Idle Temporal Distribution

Idle temporal distribution is the percentage of idle time by hour of day. It is calculated as the duration of idle in a specific hour divided by the total duration of idle in the day. Note that idle time here includes only idle activities that fall under the definition of idle trips or extended idling events.

Start Temporal Distribution

Temporal distribution of starts is the percentage of the total number of trip (or engine) starts in each of the 24 hours of weekdays. For example, if a trip started at 3:50 PM and ended at 4:15 PM on a weekday, then the engine-on event at 3:50 PM is counted as one start applied to Hour 15. If a trip started at 9 PM on a Friday and ended at 2 AM on the following Saturday, then the engine-on event at 9 PM is counted as one start applied to Hour 21. On the other hand, if a trip started at 11 PM on a Sunday and ended at 5 AM on the following Monday, then the engine-on event at 11 PM is not counted in any of the start-related statistics.

Hourly Soak Period Distribution

Soak period represents the amount of time the engine is off prior to an engine start. At the request of CARB, engine soak events were grouped into 19 soak period bins as defined in Table 4-2. Hourly soak period distribution is the percentage of engine soak events for each 19 soak period bin by hour of day. To calculate this distribution, an engine soak event was identified and then assigned to an appropriate soak period bin based on its soak period. After that, it was subsequently assigned to the hour of day that the engine was turned on after the soak event. For example, if the engine was turned off at 9:00 PM and then restarted at 4:00 AM the next day, then the soak period for this soak event is 7 hours or 420 minutes. Therefore, a frequency count of one is applied to Soak Period Bin 420 (> 360 min and <=420 min) for Hour 4 of the day (04:00:00 - 04:59:59). As another example, the engine was turned off at 10:30 AM and then restarted at 10:32 AM, then the soak period for this soak event is 2 minutes. Therefore, a frequency count of one is applied to Soak Period Bin 5 <= 5 min) for Hour 10 of the day (10:00:00 - 10:59:59).

Table 4-2. Definition of soak period bins

Soak Period ID	Soak Period Bin	Definition
1	5	<= 5 min
2	10	>5 min and <=10 min
3	20	> 10 min and <=20 min
4	30	> 20 min and <= 30 min
5	40	> 30 min and <= 40 min
6	50	> 40 min and <= 50 min
7	60	> 50 min and <= 60 min
8	120	> 60 min and <= 120 min
9	180	> 120 min and <=180 min
10	240	> 180 min and <=240 min
11	300	> 240 min and <=300 min
12	360	>300 min and <=360 min
13	420	> 360 min and <=420 min
14	480	> 420 min and <=480 min
15	540	> 480 min and <=540 min
16	600	> 540 min and <=600 min
17	660	> 600 min and <=660 min
18	720	> 660 min and <=720 min
19	9999	> 720 min

Vehicle Miles Traveled by Speed Distribution

VMT by speed distribution represents the distance traveled by a vehicle in a single trip in different trip average speed bins and in different hours of day. CARB defines 18 speed bins according to Table 4-3. VMT by speed distribution is expressed as the percentage of the total miles traveled in each of the 18 speed bins by hour of day. The calculation of trip average speeds excludes idling trips and extended idling events.

Table 4-3. Definition of speed bins

Speed Bin	Definition
5	Speed <= 5.0 mph
10	5.0 < Speed <= 10.0 mph
15	10.0 < Speed <= 15.0 mph
20	15.0 < Speed <= 20.0 mph
25	20.0 < Speed <= 25.0 mph
30	25.0 < Speed <= 30.0 mph
35	30.0 < Speed <= 35.0 mph
40	35.0 < Speed <= 40.0 mph
45	40.0 < Speed <= 45.0 mph
50	45.0 < Speed <= 50.0 mph
55	50.0 < Speed <= 55.0 mph
60	55.0 < Speed <= 60.0 mph
65	60.0 < Speed <= 65.0 mph
70	65.0 < Speed <= 70.0 mph
75	70.0 < Speed <= 75.0 mph
80	75.0 < Speed <= 80.0 mph
85	80.0 < Speed <= 85.0 mph

90	Speed >85.0 mph

4.4. SCR Temperature Analysis

One of the primary objectives of this research is to identify the fraction of vehicle operation that SCR may not control NO_x effectively. To achieve this objective, we focused on analyzing the SCR temperature data obtained from the ECU of the vehicles. The analysis was performed by plotting the frequency distribution as well as the cumulative frequency distribution of SCR temperature. The frequency distribution allows for the identification of a range of SCR temperatures that the vehicle typically operates in. The cumulative frequency distribution makes it convenient to determine how often the SCR temperature is below a certain threshold. For instance, Figure 4-8 shows the distributions of SCR temperature of a dump truck during 440 hours of operation. The frequency distribution of SCR temperature has a shape of the Gaussian distribution. While the SCR temperature of this vehicle was typically in the range of 230 °C to 280 °C, the cumulative frequency distribution reveals that the vehicle had the SCR temperature below 200 °C for about 25% of its operating time (red line). In Chapter 5, we present the results of SCR temperature analysis for each vocation using data from the entire data collection period.

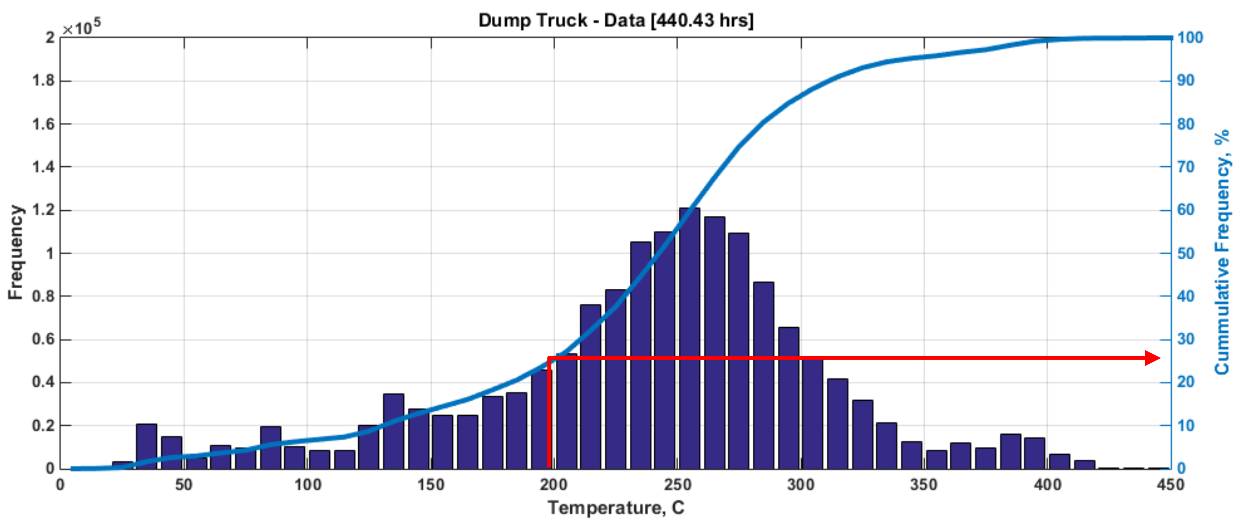


Figure 4-8. Distributions of SCR temperature of an example vehicle

4.5. Drive Cycle Development

Drive cycles play an instrumental role in emission testing with chassis dynamometer. Several drive cycles have been developed for heavy-duty vehicles such as the U.S. EPA's Urban Dynamometer Driving Schedule (UDDS) cycle, shown in Figure 4-9, and the CARB's Heavy Heavy-Duty Diesel Truck (HHDDT) cycles, shown in Figure 4-10. The HHDDT cycles include four modes: 1) idle, 2) creep, 3) transient, and 4) high speed cruise. Selected statistics of these drive cycles are provided in Table 4-4. Some of the existing drive cycles were developed for vehicles with specific vocational uses and/or in specific geographic areas, such as the Neighborhood Refuse Truck and the New York Bus cycles, due to their unique operating patterns. However, those cycles may not represent a wide spectrum of vocation-specific driving characteristics of heavy-duty vehicles in California.

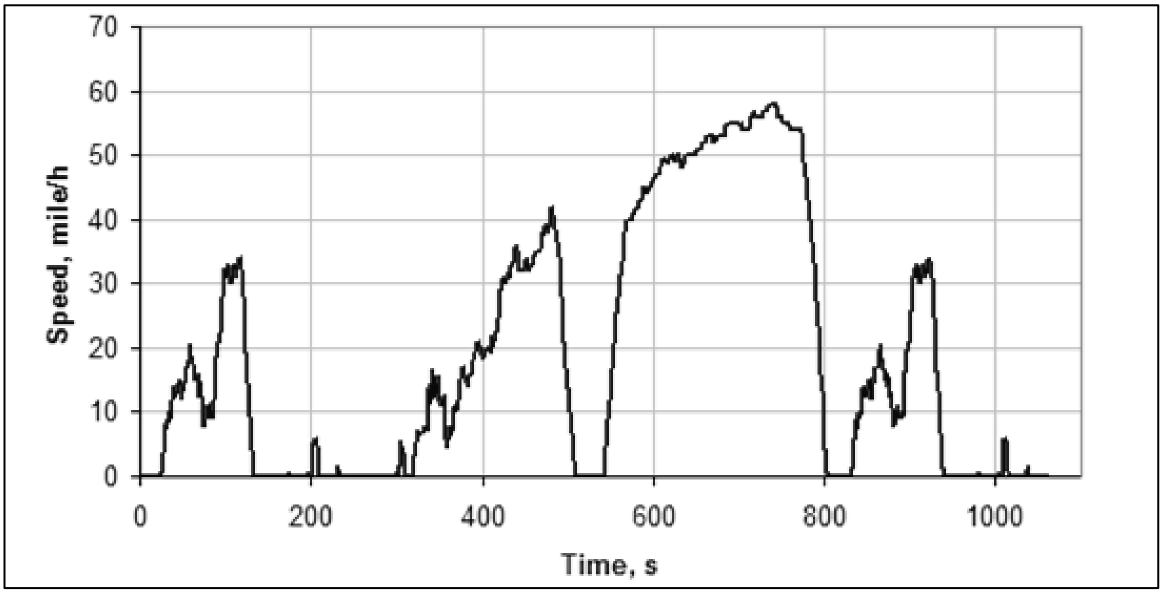


Figure 4-9. Urban Dynamometer Driving Schedule cycle

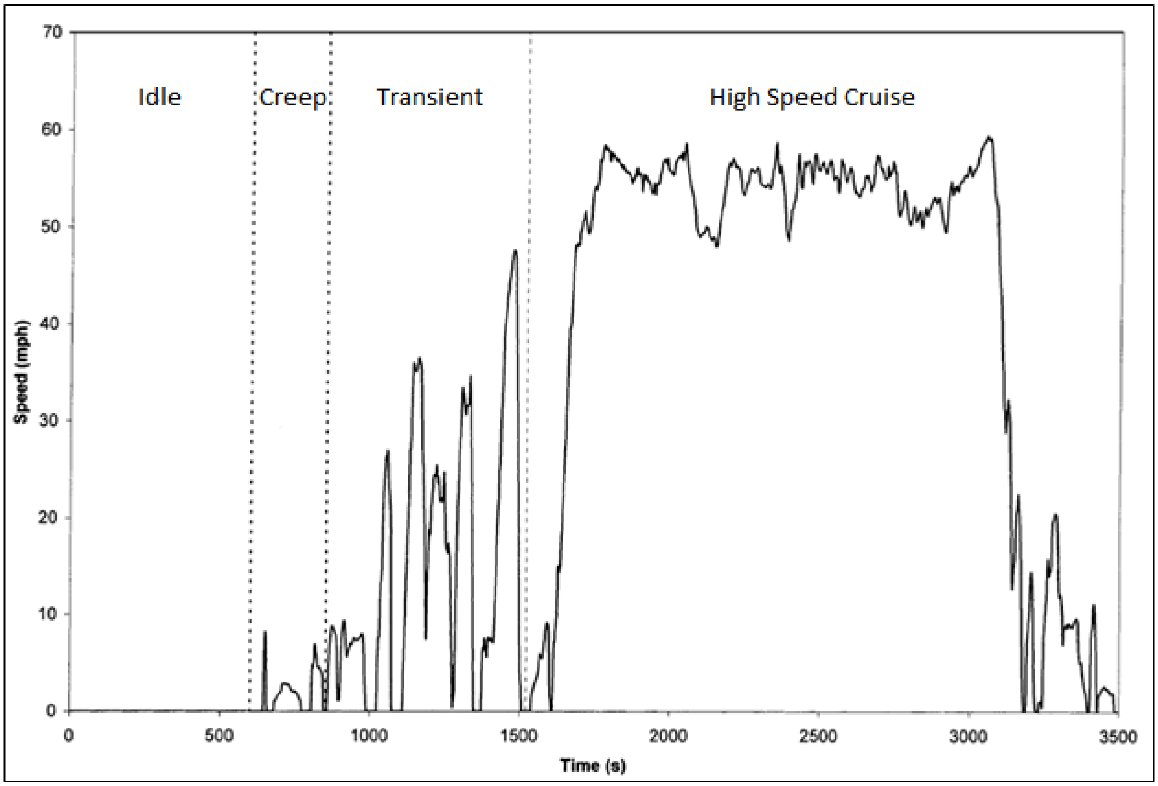


Figure 4-10. Heavy Heavy-Duty Diesel Truck cycle

Table 4-4. Selected statistics of UDDS and HHDDT cycles

Statistics	UDDS	HHDDT Creep	HHDDT Transient	HHDDT Cruise
Duration, sec	1,063	253	668	2,083
Distance, mi	5.55	0.124	2.85	23.1
Average Speed, mph	18.8	1.77	15.4	39.9
Number of Stops/Mile	2.5	24.2	1.8	0.3
Max Speed, mph	58	8.24	47.5	59.3
Max Acceleration, mph/s	4.4	2.3	3.0	2.3
Max Deceleration, mph/s	-4.6	-2.53	-2.8	-2.5
Percent Idle	33.4	42.3	16.3	8.0

In this research, different methods for developing drive cycles were reviewed and their pros and cons compared. In general, there are two categories of drive cycle development methods that have commonly been used: 1) segmentation and 2) probabilistic. The segmentation method involves cutting the entire vehicle activity data into short snippets (or microtrips), connecting different combinations of the snippets to create a pool of candidate drive cycles, and then selecting a drive cycle that is the most representative. The probabilistic method, which often involves the use of Markov Chain, defines states of vehicle activity and develops a transition matrix for these states based on the entire vehicle activity data. Then, use the transition matrix to generate drive cycles. A comparative evaluation of these two methods using a sample dataset was conducted. The results and findings are summarized in Appendix D.

In this research, we chose to use the segmentation method as the generated drive cycles are based on real vehicle activity as opposed to synthesized vehicle activity that is a result of the probabilistic method. The collected vehicle activity data were used to develop a representative drive cycle for each vocation. The procedures used to develop vocation-specific drive cycles in this research are described below.

1. ***Data Reduction*****:** As extended idling is treated as a separate mode for quantifying emissions and subject to a different set of regulations, it was requested by CARB that drive cycles developed in this research do not contain extended idling events. Therefore, the first step in the drive cycle development was to remove extended idling events from the processed data. The remaining data, referred to as *data population*, were used for drive cycle development. Note that the data population may include idle trips that do not meet the definition of extended idling event, for instance, an idle trip that only has 4 minutes of idling.

2. ***Vehicle Activity Splitting*****:** The data population contains a large number of vehicle activity *strings* where each string is made up of vehicle activity starting and ending with *idling speed*. Note that due to the noise in GPS data, the instantaneous vehicle speed is not always precisely zero when stopping or idling. Thus, idling speed is defined here as instantaneous vehicle speed of below 1 mph. In any vehicle activity string, there may be instances where the instantaneous vehicle speed may be at idling speed for a period of time, such as when stopping at traffic lights or idling at intermediate stops. Each of these instances is an idling event. Since extended idling events were removed in the previous step, all the idling events identified in this step are no longer than 5 minutes. In this research, we split a vehicle activity string into a series of *snippets* by cutting the vehicle activity data in the middle of each idling event. This created a pool of vehicle activity snippets that start and end at an idling speed. An example is shown in Figure 4-11 where a vehicle activity string is split into six snippets. Note that due to the noise in GPS data especially at low speed, we only cut idling events that have the instantaneous vehicle speed below 1 mph for at least 4 seconds to ensure that the vehicle had truly come to a full stop. If the duration of an idling duration is an even number, then the idling is split evenly between the two snippets. If it is an odd number, then the latter snippet will have one more second of idling than the former one.

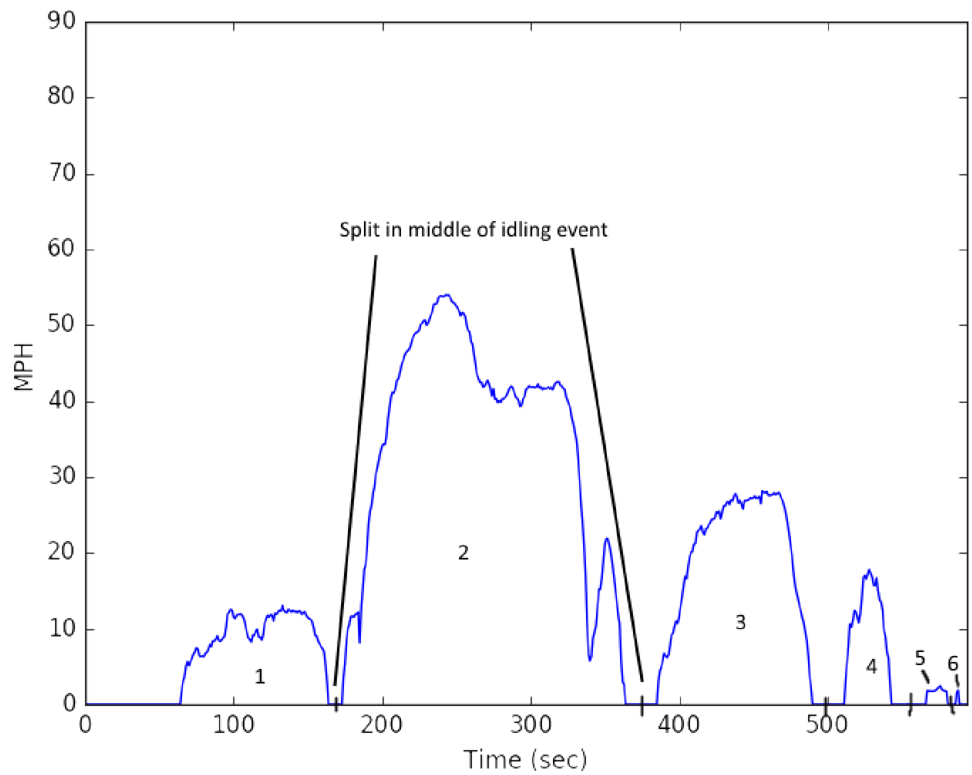


Figure 4-11. Splitting vehicle activity string into snippets

3. ***Candidate Cycle Generation***: The vehicle activity snippets resulted from the previous step can vary greatly in length. As an example, Figure 4-12 shows the frequency distribution of the length of snippets in data population of Group 1a (line haul – out of state). Each snippet can be considered as a drive cycle by itself. In addition, drive cycles can be generated by connecting two or more snippets together. All these drive cycles are referred to as *candidate cycles*. Since all the snippets start and end at an idling speed, the order of snippets in a candidate cycle is switchable. However, candidate cycles with the same set of snippets are considered to be the same irrespective of the order of the snippets in those cycles. For instance, a candidate cycle with snippets 1-2-3-4 is considered to be the same as another candidate cycle with snippets 2-3-1-4.

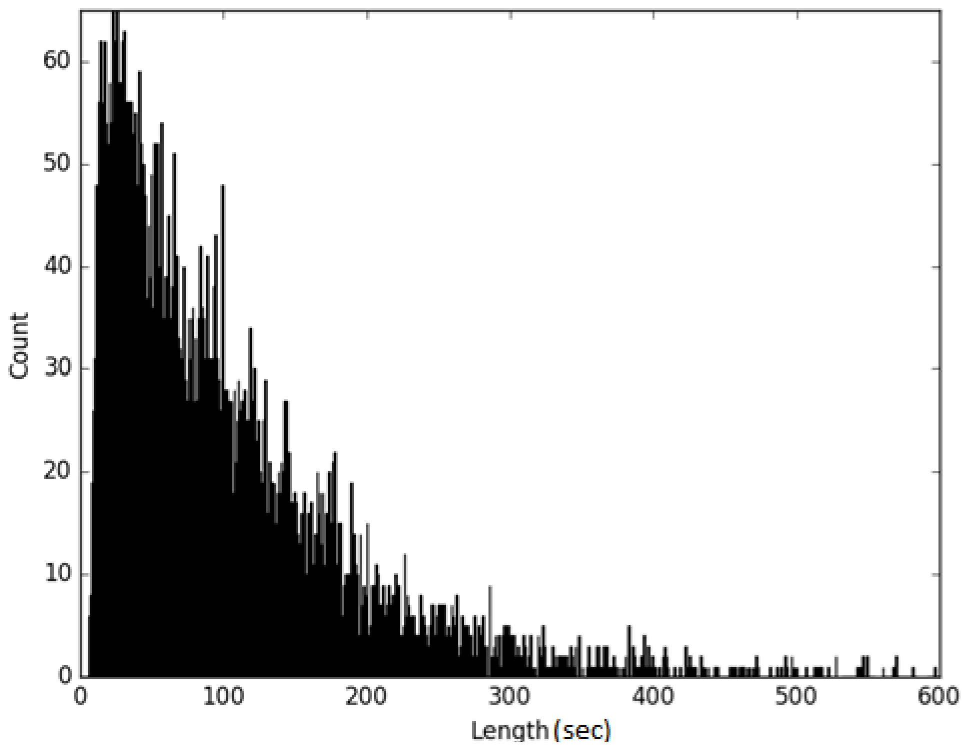


Figure 4-12. Length distribution of snippets in data population of Group 1a (Line haul – out of state)

4. ***Selection of Representative Cycle*****:** Out of the enormous pool of candidate cycles, one whose characteristics best match the characteristics of the data population is to be selected. The representativeness can be quantitatively determined by one or more selection criteria and the associated performance measures. Examples of selection criteria that were used in other studies include percent time in idle mode, mean instantaneous speed, maximum instantaneous acceleration, and joint speed-acceleration distribution (JSAD). These criteria are characteristics of the data population that we want the representative cycle to emulate as close as possible. Examples of performance measures that were used in other studies include sum absolute error (SAE) and mean squared error (MSE). They indicate how close a specific characteristic of a candidate cycle is to that of the data population. In this research, we used the distribution of vehicle OpMode bins defined in Table 4-1 as the cycle selection criterion and the MSE as the performance measure. The MSE of OpMode bin distribution (OMD) is calculated as:

$$\text{MSE of OMD} = \frac{1}{N}\sum_{i=1}^{N}\left[\left(OM_i^c - OM_i^p\right)^2\right]$$

where: OM_i^c is frequency of operating mode *i* in driving cycle
OM_i^p is frequency of operating mode *i* in data population
w_i is contribution of mode *i* to total emission in data population
N is number of operating modes (23)

The rationale for using OMD as the selection criterion is that it is a strong descriptor of running exhaust emissions. For instance, in MOVES each OpMode bin has a corresponding emission rate (per unit of time), and summing the product of emission rate and frequency count across all OpMode bins results in the total emission. This means that a drive cycle with low MSE of OMD would have a similar total emission per unit of time to that generated by the entire data population as calculated by MOVES. Thus, the selected drive cycle can be used for emission testing with chassis dynamometer to measure the amount of emission per unit of time that would be generated by heavy-duty vehicles in California represented by those sampled in this research.

To illustrate the concept, Figure 4-13 shows NO_x emission rates by OpMode bin for a 2009 heavy-duty diesel vehicle obtained from MOVES. Figure 4-14 shows two OMDs of a heavy-duty diesel vehicle. The top OMD is based on the entire vehicle activity data population while the bottom one is based on a drive cycle. If the entire vehicle activity data population consists of 100,000 seconds while the drive cycle has 1,000 seconds, and if the two OMDs are exactly the same (i.e., MSE of OMD = 0), then the total NO_x emissions (in terms of grams) for the drive cycles would be 1,000/100,000 or 1% of the total NO_x emissions for the entire data population.

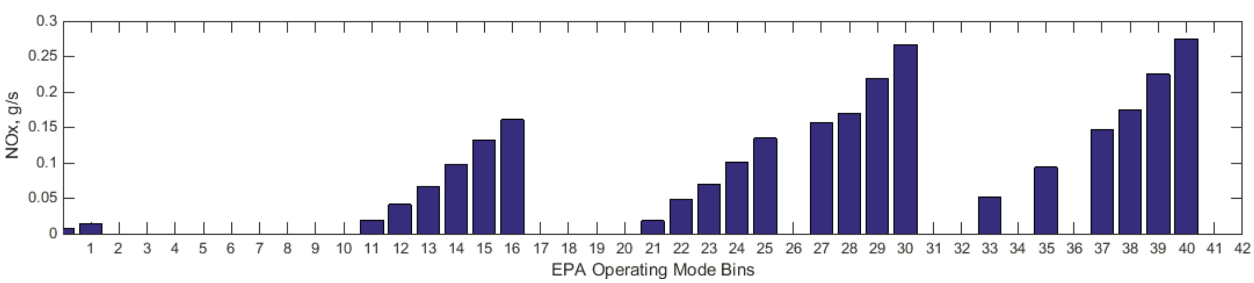


Figure 4-13. Emission rates of 2009 heavy-duty diesel vehicles from MOVES

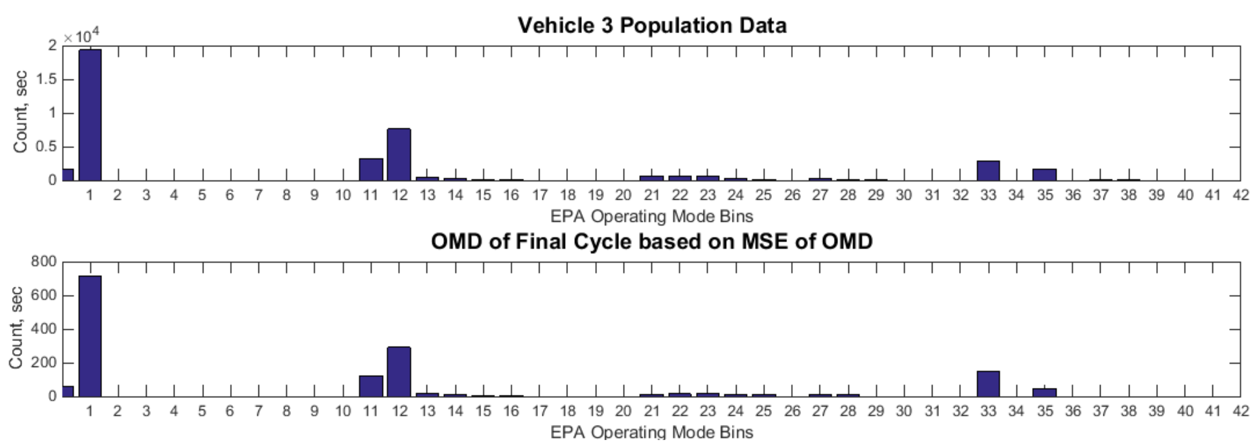


Figure 4-14. Example vehicle operating mode bin distributions

5. Results

This chapter presents the results of the vehicle activity analysis, SCR performance, and drive cycle development discussed in Chapter 4. First, a number of statistics are provided in Section 5.1 in a series of summary tables to allow for cross-comparison of vehicle activities and SCR temperatures among the different vocations. Then, plots of vehicle activity and SCR temperature patterns are presented and discussed for each of the 19 vocations in Section 5.2. [Note that there was no data for Group 3a - Agricultural trucks in North Central Valley]. Lastly, vocation-specific drive cycles and their statistics are given in Section 5.3.

5.1. Vehicle Activity Results

Table 5-1 presents general statistics about total vehicle operation time and distance in the processed data. The total time statistics reflect the amount of data collected and processed for each vocation. Also, the average speed is provided, which is calculated as the total distance divided by the total time. Additionally, the percentages of time and distance spent on each of the three road types (freeway, non-freeway, and ramp) are included. Table 5-2 presents the same statistics as those in Table 5-1 but with the exclusion of idle trips and extended idling events from the calculation.

Table 5-1. Total time and distance of collected data

No.	Vocation	Total Time (hr)	Total Dist. (mi)	Avg. Speed (mph)	% Time On			% Distance On		
					F	NF	R	F	NF	R
1a	Line haul - out of state	1,757	72,170	41.1	68.2	31.0	0.8	90.5	8.8	0.7
1b	Line haul - in state	1,301	42,012	32.4	53.7	44.6	1.7	86.3	12.4	1.3
2a	Drayage - No. Cal.	204	1,805	8.9	8.8	90.9	0.3	49.2	49.9	0.9
2b	Drayage - So. Cal.	1,739	18,343	10.5	10.5	87.9	1.6	39.5	56.7	3.8
3b	Agricultural - So. CV	1,210	35,855	30.0	46.7	52.5	0.8	84.1	15.2	0.7
4a	Construction	963	20,615	21.5	27.5	70.2	2.3	61.1	37.2	1.7
4b	Cement mixers	450	6,303	14.1	13.5	84.7	1.8	55.3	40.3	4.4
5a	Food distribution	1,765	60,814	34.6	62.9	34.4	2.7	87.2	10.5	2.3
5b	Beverage distribution	590	6,815	11.6	8.3	89.5	2.2	24.8	71.6	3.6
5c	Local moving	205	4,855	23.7	37.6	60.7	1.7	75.2	23.1	1.7
6	Airport shuttle	5,707	63,301	11.1	0.0	99.9	0.1	0.0	99.9	0.1
7	Refuse	2,329	25,506	11.0	1.2	98.5	0.3	6.2	93.1	0.7
8a	Urban buses	2,734	27,496	10.1	1.5	97.8	0.7	7.4	90.5	2.1
8b	Express buses	1,516	31,147	20.5	25.0	71.5	3.5	65.8	29.9	4.3
9a	Freeway work	964	12,359	12.8	52.0	34.3	13.7	74.9	18.4	6.7
9b	Sweeping	1,063	11,142	10.5	53.2	43.9	2.9	72.0	25.9	2.1
9c	Municipal work	373	9,230	24.9	17.8	81.1	1.1	33.7	65.1	1.2
9d	Towing	2,269	59,266	26.2	38.5	56.1	5.4	67.1	29.2	3.7
10	Utility repair	903	11,440	12.7	7.3	91.2	1.5	27.5	69.3	3.2

Note: F = Freeway; NF = Non-Freeway; R = Ramp

Table 5-2. Total time and distance of collected data excluding idle trips and extended idling events

No.	Vocation	Total Time (hr)	Total Dist. (mi)	Avg. Speed (mph)	% Time On			% Distance On		
					F	NF	R	F	NF	R
1a	Line haul - out of state	1,472	71,774	48.8	81.1	17.9	1.0	91.0	8.3	0.7
1b	Line haul - in state	1,155	41,941	36.4	60.0	38.1	1.9	86.4	12.3	1.3
2a	Drayage - No. Cal.	123	1,672	13.8	14.7	84.9	0.4	53.2	45.9	0.9
2b	Drayage - So. Cal.	885	17,165	19.4	20.4	76.6	3.0	42.1	53.8	4.1
3b	Agricultural - So. CV	814	35,639	44.6	68.4	30.6	1.0	84.6	14.6	0.8
4a	Construction	681	20,427	30.1	36.8	61.2	2.0	61.6	36.7	1.7
4b	Cement mixers	247	6,270	25.6	24.6	72.3	3.1	55.6	40.0	4.4
5a	Food distribution	1,648	60,584	37.0	67.2	30.0	2.8	87.6	10.1	2.3
5b	Beverage distribution	454	6,636	14.6	10.8	86.5	2.7	25.5	70.8	3.7
5c	Local moving	145	4,813	33.3	53.1	44.5	2.4	75.8	22.5	1.7
6	Airport shuttle	4,060	63,007	15.5	0.0	99.9	0.1	0.0	99.9	0.1
7	Refuse	1,963	25,393	13.0	1.5	98.2	0.3	6.2	93.1	0.7
8a	Urban buses	1,843	27,359	14.9	2.2	96.7	1.1	7.4	90.4	2.2
8b	Express buses	1,007	31,036	30.8	37.7	57.1	5.2	66.0	29.7	4.3
9a	Freeway work	496	12,146	24.5	58.2	31.5	10.3	75.3	18.1	6.6
9b	Sweeping	757	10,944	14.5	62.1	34.6	3.3	72.6	25.3	2.1
9c	Municipal work	333	9,216	27.8	19.9	78.8	1.3	33.7	65.1	1.2
9d	Towing	1,593	59,135	37.2	49.2	45.0	5.8	67.2	29.1	3.7
10	Utility repair	496	11,186	22.6	13.2	84.0	2.8	28.1	68.7	3.2

Note: F = Freeway; NF = Non-Freeway; R = Ramp

Table 5-3 presents the percentages of time and distance spent in each of the four vehicle operating modes (brake, idle, coast, and cruise/accelerate) that are defined in Table 4-1.

Table 5-3. Vehicle operating mode fraction

No.	Vocation	% Time In				% Distance In			
		Brake	Idle	Coast	Cruise	Brake	Idle	Coast	Cruise
1a	Line haul - out of state	1.8	16.0	5.4	76.8	0.9	0.0	2.5	96.6
1b	Line haul - in state	3.4	28.3	6.1	62.2	2.3	0.1	4.1	93.5
2a	Drayage - No. Cal.	2.9	49.4	11.3	36.4	3.4	0.1	16.5	80.0
2b	Drayage - So. Cal.	4.0	50.9	11.7	33.4	5.0	0.0	19.1	75.9
3b	Agricultural - So. CV	2.1	35.5	5.0	57.4	1.8	0.0	3.4	94.8
4a	Construction	3.5	38.0	9.3	49.2	3.7	0.0	9.8	86.5
4b	Cement mixers	3.4	59.3	3.3	34.0	4.9	0.1	4.4	90.6
5a	Food distribution	3.2	13.2	9.4	74.2	1.5	0.0	6.6	91.9
5b	Beverage distribution	8.5	39.3	13.9	38.3	8.9	0.1	22.1	68.9
5c	Local moving	4.0	33.2	9.2	53.6	3.1	0.0	7.9	89.0
6	Airport shuttle	6.3	50.3	9.6	33.8	7.1	0.1	18.9	73.9
7	Refuse	9.3	44.7	11.2	34.8	8.9	0.2	16.4	74.5
8a	Urban buses	10.3	50.0	8.1	31.6	12.6	0.1	17.5	69.8
8b	Express buses	5.9	43.8	5.4	44.9	5.0	0.0	5.2	89.8
9a	Freeway work	3.6	53.8	5.8	36.8	4.9	0.0	6.3	88.8
9b	Sweeping	3.0	33.1	7.5	56.4	3.7	0.1	8.7	87.5
9c	Municipal work	6.3	26.3	11.7	55.7	5.3	0.1	12.8	81.8
9d	Towing	5.0	37.7	6.6	50.7	4.1	0.0	6.3	89.6

10	Utility repair	5.0	50.9	6.0	38.1	6.2	0.1	9.1	84.6

Based on the statistics presented in Table 5-1 through Table 5-3, some observations are made as discussed below:

- The average speed values are mostly as expected. The average speed for line haul - out of state trucks is the highest at 41.1 mph while the average speed for drayage trucks in Northern California is the lowest at 8.9 mph. The vocations that have a low average speed value tend to spend a significant percentage of time on non-freeway roads, for example, drayage trucks in Southern California, airport shuttles, refuse trucks, and urban buses.

- It is interesting to find that line haul - in state trucks have a much lower average speed value than line haul - out of state trucks (32.4 mph vs. 41.1 mph). When examining the other statistics, it is found that line haul - in state trucks spend much less time on freeways (53.7% vs. 68.2%), and almost double the amount of time in idle mode (28.3% vs. 16.0%) as compared to line haul - out of state trucks.

- The contrasts between urban buses and express buses are as expected. Express buses have twice as high an average speed than urban buses (20.5 mph vs. 10.1 mph) as they spend significantly more time on freeways (25.0% vs. 1.5%). On the other hand, urban buses have a higher percentage of time in brake mode (10.3% vs. 5.9%) as they have to make more stops and experience more congestion.

- It is also interesting to see the contrast between food distribution and beverage distribution trucks. Food distribution trucks have three times higher an average speed (34.6 mph vs. 11.6 mph) as they spend significantly more time on freeways (62.9% vs. 8.3%) and less time idling (13.2% vs. 39.3%) than beverage distribution trucks. This could be partly because the food distribution trucks recruited in this research operate throughout Southern California while the beverage distribution trucks operate solely in the inner Los Angeles metropolitan area where traffic is generally more congested. The vehicle activity patterns of food distribution trucks that operate only within the inner Los Angeles metropolitan area may be similar to the vehicle activity patterns of the beverage distribution trucks in this study.

- Trucks in most of the vocations spend about a third or more of their time in idle mode, irrespective of the percentage of time spent on non-freeway roads. The only exceptions are line haul - out of state trucks, line haul – in state trucks, food distribution trucks, and municipal work trucks. It is surprising for municipal work trucks because they spend 81.1% of their time on non-freeway roads but only 26.3% in idle mode.

- The vocation with the highest percentage of time in idling mode is cement mixers. This is not surprising as these vehicles do their jobs while idling, which often involves the use of PTO. The same is true for utility repair trucks.

- As expected, the average speed values after excluding idle trips and extended idling events are higher across all vocations. The increases are greater for the vocations with a significant amount of idling time such as cement mixers, freeway work trucks, and utility repair trucks.

Table 5-4 presents statistics of instantaneous speed, acceleration, and deceleration while Table 5-5 presents statistics of instantaneous tractive power and kinetic energy. Note the followings:

- For all the vocations, the maximum acceleration values are 5.0 mph/s or close to that value while the maximum deceleration values are 5.0 mph/s. This is because these are the thresholds we used during the data processing to correct any unrealistic acceleration and deceleration values. These thresholds were chosen based on the distributions of acceleration and deceleration data collected.

- Refuse trucks and urban buses have the highest mean acceleration and deceleration values. This is expected as they frequently have to decelerate to come to a full stop and accelerate from a full stop. These maneuvers at very low speeds generally involve a higher level of acceleration and deceleration. In contrast, both line haul - out of state trucks and line haul - in state trucks have the lowest mean acceleration and deceleration values as they spend most of their time cruising at highway speeds, involving only mild acceleration and deceleration.

- Drayage trucks, beverage distribution trucks, airport shuttles, refuse trucks, urban buses, and sweeping trucks have lower mean STP values than other vocations, indicating that their operations do not demand as high power from the engines.

Table 5-4. Instantaneous speed, acceleration, and deceleration statistics

No.	Vocation	Speed (mph)			Acceleration (mph/s)			Deceleration (mph/s)		
		Max	Mean	S.D.	Max	Mean	S.D.	Max	Mean	S.D.
1a	Line haul - out of state	72.7	41.1	25.4	5.0	0.3	0.4	5.0	0.3	0.4
1b	Line haul - in state	75.0	32.4	26.7	4.9	0.3	0.5	5.0	0.4	0.6
2a	Drayage - No. Cal.	66.2	8.9	15.6	5.0	0.6	0.6	5.0	0.5	0.7
2b	Drayage - So. Cal.	67.2	10.5	16.2	4.9	0.7	0.7	5.0	0.7	0.8
3b	Agricultural - So. CV	75.0	30.0	27.6	4.9	0.5	0.5	5.0	0.5	0.6
4a	Construction	75.0	21.5	24.4	5.0	0.5	0.6	5.0	0.5	0.7
4b	Cement mixers	73.5	14.1	22.2	5.0	0.6	0.6	5.0	0.6	0.9
5a	Food distribution	70.9	34.6	21.8	5.0	0.4	0.5	5.0	0.4	0.6
5b	Beverage distribution	67.2	11.6	14.3	5.0	0.9	0.8	5.0	0.9	1.0
5c	Local moving	73.2	23.7	24.3	4.9	0.5	0.5	5.0	0.5	0.7

6	Airport shuttle	61.4	11.1	14.8	5.0	0.8	0.8	5.0	0.8	0.9
7	Refuse	64.0	11.0	16.0	5.0	0.9	0.9	5.0	1.0	1.1
8a	Urban buses	67.8	10.1	13.3	4.9	1.0	0.9	5.0	1.1	1.1
8b	Express buses	75.0	20.5	25.2	4.8	0.7	0.8	5.0	0.8	1.0
9a	Freeway work	75.0	12.8	20.7	4.9	0.6	0.7	5.0	0.7	0.8
9b	Sweeping	75.0	10.5	13.4	5.0	0.4	0.6	5.0	0.4	0.6
9c	Municipal work	74.2	24.9	21.2	4.8	0.5	0.6	5.0	0.5	0.8
9d	Towing	75.0	26.2	25.8	5.0	0.6	0.7	5.0	0.7	0.9
10	Utility repair	66.2	12.7	17.9	5.0	0.7	0.6	5.0	0.8	0.9

Table 5-5. Instantaneous tractive power and kinetic energy statistics

No.	Vocation	Scaled Tractive Power (kW/t)				Kinetic Energy (kJ)			
		Max	Min	Mean	S.D.	Max	Min	Mean	S.D.
1a	Line haul -out of state	90.6	-90.3	5.2	6.4	13,549	0	7,048	3,655
1b	Line haul - in state	94.1	-81.6	4.0	6.8	14,435	0	5,088	4,234
2a	Drayage - No. Cal.	64.4	-53.9	0.8	3.8	11,232	0	1,560	2,680
2b	Drayage - So. Cal.	79.1	-78.6	0.9	4.5	11,595	0	1,973	2,498
3b	Agricultural - So. CV	79.4	-92.3	3.7	7.8	14,435	0	6,657	3,619
4a	Construction	94.3	-93.1	2.4	6.9	14,435	0	4,295	3,953
4b	Cement mixers	45.7	-36.7	1.6	4.0	7,231	0	2,181	2,040
5a	Food distribution	78.5	-85.7	3.7	6.1	12,906	0	4,977	3,007
5b	Beverage distribution	65.3	-69.0	0.9	5.4	11,574	0	1,376	1,885
5c	Local moving	60.4	-73.0	2.6	5.9	13,761	0	4,397	3,788
6	Airport shuttle	37.5	-41.8	0.9	3.2	5,911	0	1,049	1,000
7	Refuse	62.1	-75.3	0.9	5.9	10,520	0	1,631	2,391
8a	Urban buses	39.5	-45.5	0.7	3.6	7,213	0	756	964
8b	Express buses	67.7	-52.7	2.5	5.5	8,814	0	2,920	2,734
9a	Freeway work	48.2	-39.6	1.4	3.7	7,537	0	1,693	1,974
9b	Sweeping	52.2	-43.4	0.8	2.0	7,537	0	563	829
9c	Municipal work	71.4	-70.1	2.5	6.9	14,128	0	3,030	3,028
9d	Towing	102.3	-91.3	3.1	7.9	14,435	0	5,508	3,790
10	Utility repair	33.4	-35.7	1.2	3.2	5,867	0	1,281	1,369

Table 5-6 presents statistics related to trip (or engine) starts, idle trips, and extended idling events. The idle time per day statistic includes idle time during both idle trips and extended idling events. Note that these statistics are based on data from weekdays only. That is, we counted only trip starts, idle trips, and extended idling events that occurred on weekdays. Also, note that operating days here are referred to weekdays that have any vehicle activity data, and thus, the number of operating days is always fewer than or equal to the number of days. Key observations from this table are discussed below:

- Drayage trucks in Northern California have a distinctively high number of starts or trips per day (27.1). However, many of which are idle trips (16.3). Note that the statistics for this vocation were based on data from only one vehicle (see Table 3-2). It is unknown whether the high numbers of starts per day and idle trips per day reflect the typical operation of drayage trucks in Northern California or are due to the behavior of this specific driver.

- Freeway work trucks and sweeping trucks have a distinctively low number of starts per day (2.2 for both). However, when examining the number of starts on a per operating day basis, freeway work trucks and sweeping trucks (4.6 and 4.3, respectively) have higher numbers of starts than cement mixers (3.8) and refuse trucks (4.2). The differences in the number of starts between per day and per operating day could be due to a number of reasons such as working a specific schedule during weekdays, not being used every weekday, being taken out of service for a period of time during the data collection period, or a combination of these. However, the actual reasons are unknown and will require further investigation beyond the scope of this research.
- Out-of-state and in-state line haul trucks have 14.6 and 12.7 starts per day, respectively, which are higher than one would normally expect. Further investigation into potential reasons for such a high number of starts per day for these trucks should be conducted.

- The idle time per day statistics are a function of the number of idle trips and extended events per day and the duration of those idle trips and extended events. For example, drayage trucks in Northern California have the highest value of idle time per day, due in major part to having the highest number of idle trips per day and the third highest number of extended idling events per day.

Table 5-6. Trip start and idle statistics

No.	Vocation	No. of Days *	No. of Operating Days *	No. of Starts per Day*	No. of Starts per Operating Day*	No. of Cold Starts per Day*	No. of Cold Starts per Operating Day*	No. of Idle Trips per Day*	No. of EI per Day*	Idle Time per Day* (min)
1a	Line haul - out of state	224	202	14.6	16.2	0.4	0.4	9.9	3.6	24.9
1b	Line haul - in state	75	74	12.7	12.9	0.2	0.2	2.8	5.7	35.5
2a	Drayage - No. Cal.	39	38	27.1	27.8	1.0	1.0	16.3	5.2	121.9
2b	Drayage - So. Cal.	652	258	7.6	19.3	0.2	0.6	4.4	2.4	14.3
3b	Agricultural - So. CV	313	286	4.4	4.8	0.6	0.7	2.9	2.1	8.2
4a	Construction	215	156	5.6	7.7	0.6	0.9	2.0	2.5	13.1
4b	Cement mixers	71	56	3.0	3.8	0.7	0.9	1.0	1.8	30.9
5a	Food distribution	253	239	12.8	13.5	0.5	0.5	5.8	0.7	4.2
5b	Beverage distribution	318	235	10.4	14.1	0.3	0.4	4.4	1.4	4.2
5c	Local moving	81	65	4.5	5.6	0.6	0.8	2.3	1.7	37.1
6	Airport shuttle	514	486	8.4	8.9	0.4	0.4	2.8	6.2	28.4
7	Refuse	435	398	3.8	4.2	0.9	1.0	1.4	2.0	8.4
8a	Urban buses	363	256	4.2	5.9	0.2	0.3	2.6	3.1	30.2
8b	Express buses	169	157	8.0	8.7	0.2	0.2	4.0	4.2	32.2
9a	Freeway work	489	237	2.2	4.6	0.5	1.0	0.9	0.9	9.4
9b	Sweeping	573	294	2.2	4.3	0.5	1.0	1.2	0.8	6.2
9c	Municipal work	89	64	4.7	6.5	0.7	1.0	1.2	1.4	8.9
9d	Towing	423	358	5.0	5.9	0.5	0.6	1.6	2.4	12.1
10	Utility repair	357	304	10.9	12.8	0.7	0.8	6.3	2.6	11.5

*Note: EI = Extended idling events; *Weekday only*

Table 5-7 presents trip time, trip distance, and trip speed statistics. Table 5-8 presents the same statistics but with the exclusion of idle trips and extended idling events from the calculation. Recall that trip here is referred to a vehicle activity from an engine-on event to the following engine-off event, which is different from trip in the transportation context that is a travel from an origin to a destination. In the context of this research, a trip can consist of multiple stops at various locations as long as the engine is not turned off at those stops.

Table 5-7. Trip time, distance, and speed statistics

No.	Vocation	Trip Time (min)			Trip Distance (mi)			Trip Speed (mph)		
		Max	Mean	S.D.	Max	Mean	S.D.	Max	Mean	S.D.
1a	Line haul - out of state	397	32	71	264	22	59	60.1	9.6	16.2
1b	Line haul - in state	669	72	103	454	39	71	62.3	18.4	17.7
2a	Drayage - No. Cal.	70	10	12	11	1	1	29.9	3.9	4.4
2b	Drayage - So. Cal.	336	19	30	146	3	9	53.3	6.8	7.7
3b	Agricultural - So. CV	625	45	92	331	22	60	66.7	9.2	14.8
4a	Construction	458	48	56	165	17	26	60.0	14.8	14.1
4b	Cement mixers	673	114	158	185	27	38	46.0	10.3	10.7
5a	Food distribution	166	24	35	123	14	24	55.2	14.3	16.2
5b	Beverage distribution	99	11	12	32	2	3	44.8	7.4	6.2
5c	Local moving	229	28	37	141	11	22	53.6	11.9	13.9
6	Airport shuttle	491	59	61	88	11	12	29.3	8.1	5.8
7	Refuse	533	83	119	172	15	24	36.4	9.0	8.2
8a	Urban buses	979	102	182	196	17	37	28.1	4.4	5.6
8b	Express buses	638	63	80	178	22	32	62.7	13.7	14.6
9a	Freeway work	481	45	69	114	10	16	58.1	12.0	13.0
9b	Sweeping	471	48	76	83	8	14	38.3	6.8	7.8
9c	Municipal work	610	54	73	273	22	33	40.9	16.4	12.3
9d	Towing	908	58	79	755	26	45	61.5	17.8	14.9
10	Utility repair	292	12	17	45	3	5	44.2	6.9	9.0

Table 5-8. Trip time, distance, and speed statistics excluding idle trips and extended idling events

No.	Vocation	Trip Time (min)			Trip Distance (mi)			Trip Speed (mph)		
		Max	Mean	S.D.	Max	Mean	S.D.	Max	Mean	S.D.
1a	Line haul - out of state	374	82	100	264	67	88	60.1	27.2	21.3
1b	Line haul - in state	651	82	103	454	50	77	62.3	25.1	17.8
2a	Drayage - No. Cal.	59	14	11	11	2	2	29.9	7.8	4.9
2b	Drayage - So. Cal.	231	23	24	146	8	12	53.3	15.4	8.3
3b	Agricultural - So. CV	506	91	108	331	66	90	66.7	29.7	19.4
4a	Construction	266	53	43	165	27	29	60.0	25.7	13.1
4b	Cement mixers	414	97	101	185	41	41	51.0	24.1	12.5
5a	Food distribution	159	41	39	123	25	28	55.2	24.5	16.3
5b	Beverage distribution	83	14	12	32	3	4	44.9	12.1	5.6
5c	Local moving	214	40	38	141	22	27	55.5	25.7	13.5
6	Airport shuttle	345	62	44	87	16	11	31.2	15.5	2.9
7	Refuse	493	110	117	172	24	27	36.4	15.1	7.3
8a	Urban buses	807	191	188	196	47	47	35.3	13.9	5.0

8b	Express buses	384	86	62	178	44	32	62.7	30.2	10.5
9a	Freeway work	407	41	40	114	18	18	58.1	25.5	12.1
9b	Sweeping	340	71	63	82	17	15	38.3	15.2	7.9
9c	Municipal work	541	65	69	273	30	35	43.5	23.3	10.1
9d	Towing	804	60	64	755	37	50	63.3	31.5	11.2
10	Utility repair	88	16	15	45	6	7	44.2	15.3	9.7

Note that the mean trip speed in Table 5-7 and Table 5-8 has a different meaning from the average speed in Table 5-1 and Table 5-2. The mean trip speed here is the arithmetic mean of the individual trip speed values, which is similar to the average speed in EMFAC. It represents the average speed of a typical trip made by the vehicles in a particular vocation. For example, a vehicle making two trips having the trip speeds of 10 mph and 30 mph will have the mean trip speed of 20 mph. On the other hand, the average speed in Table 5-1 is the arithmetic mean of all the instantaneous speed values from all the trips. It represents the speed at which the vehicles in a particular vocation typically operate at any point in time.

Based on the statistics in Table 5-7 and Table 5-8, the following observations are made:

- As expected, the mean trip distance values in Table 5-8 are higher than those in Table 5-7. Since idle trips and extended idling events usually cover no or very little distance, excluding them increases the mean trip distance values. As a result, the mean trip speed values in Table 5-8 are also higher than those in Table 5-7.

- Drayage trucks in Northern California, beverage distribution trucks and utility repair trucks have very low mean trip distance values in both tables. This may be due to the size of the service area that they cover as indicated by having very low maximum trip distance values. The trip patterns of these trucks seem to different from those of drayage trucks in Southern California which have a comparable mean trip distance value but a much higher maximum trip distance value.

- Cement mixers, refuse trucks, and urban buses have the highest mean trip time values in both tables despite having to make multiple stops to pick up trash (in the case of refuse trucks) and to pick up or drop off passengers (in the case of urban buses). This reflects the typical operation of these vehicles that they usually do not turn off the engine at those stops.

- The maximum trip time values for urban buses and towing trucks in both tables are distinctively high (more than 13 hours). Upon verification of the data, these trips seem to be real. The urban bus operated from around 5 a.m. until around 9 p.m. on that day, running multiple routes in the area multiple times without turning the engine off. The towing truck took on a long tow from the Inland Empire to the East Bay and back without turning the engine off.

In addition to the descriptive statistics of vehicle activity presented and discussed above, we also generated different kinds of vehicle activity distributions for each vocation, including: 1) start temporal distribution, 2) idle temporal distribution, 3) hourly soak period distribution, 4) VMT by speed distribution. The description of these distributions is given in Section 4.3. The vehicle activity distribution results for each of the 19 vocations are presented in Appendix E and summarized below.

In general, the distributions of vehicle activity by hour of day imply two broad groups of operation: 1) part-day operation, and 2) full-day operation. Vocation types that have part-day operation include out-of-state line haul trucks, drayage trucks in Northern California, construction trucks, cement mixers, food distribution trucks, beverage distribution trucks, local moving trucks, refuse trucks, urban buses, express buses, freeway work trucks, sweeping trucks, and municipal work trucks. Vocation types that have full-day operation include in-state line haul trucks, drayage trucks in Southern California, agricultural trucks, airport shuttles, towing trucks, and utility repair trucks

The peak operation period varies greatly among the different vocations. For instance, line haul - out of state trucks are busiest during 6-9 AM while freeway work trucks are busiest during 9 AM - 12 PM. Some vocations have multiple peaks such as local moving trucks that have double peaks (6-7 AM and 12-1 PM). The VMT by speed distributions of the different vocations show a variety of patterns from a single peak (e.g., construction trucks) to multiple peaks (e.g., line haul - out of state trucks) to a wide spread distribution (e.g., drayage - Southern California trucks).

Figure 5-1 shows VMT distribution of drayage trucks in Northern California by speed bins and by hour of day. The distribution indicates part-day operation where the trucks operated between 7 AM and 5 PM where most of the activity occurred in the late morning and early afternoon hours. Due to the nature of stop-and-go driving of these trucks, they drove the most miles in the speed range of 5-15 mph. This translates to a significant amount of time spent in this speed range. As another example, Figure 5-2 shows VMT distribution of line haul – in state trucks by speed bins and by hour of day. The distribution indicates full-day operation where there was vehicle activity throughout the day albeit more in the afternoon and evening. Unsurprisingly, most of the miles for these trucks were driven at highway speeds in the range of 55-65 mph. [Note that the speed limit for trucks in California is 55 mph.]

VMT distributions of heavy-duty diesel vehicles in different vocations have an implication on the diurnal profile of their NO_x emission, which is important for understanding the formation of ozone in many regions in California. A high fraction of VMT in certain hours of day typically implies a high amount of NO_x emission from heavy-duty diesel vehicles in those hours. Since these vehicles account for a large fraction of the NO_x emission inventory in California, the temporal distribution of NO_x emission from these vehicles could have a significant impact on the diurnal profile of ozone in the atmosphere.

In terms of engine soak time, the soak time distribution for most vocations is primarily dominated by short soak events of less than 5 minutes. The exceptions are beverage distribution trucks and local moving trucks. Figure 5-3 shows soak time distribution of municipal work trucks by soak period and by hour of day. It reflects a regular activity pattern of these trucks where they were operated between 6 AM and 4 PM. The red cell in the column "9999" indicates that 10.1% of the soak events were longer than 720 minutes or 12 hours, and that they were followed by an engine start in the hour of 06:00:00-06:59:59 of the next day. These soak events were a typical overnight soak between completing the work for the day and starting the work the next day. Besides these overnight soak events, the remaining soak events were mostly shorter than 5 minutes that occurred throughout the working hours. Figure 5-4 shows soak time distribution of beverage distribution trucks that is more sporadic. The overnight soak is not as dominant and the most common soak periods are 10-20 minutes followed by 60-120 minutes.

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
			8.18	18.37	15.97	10.03	9.91	13.33	11.63	5.38	1.73	1.62	2.32	0.73	0.80	0	0	0	0	0	*100*
Hour																					
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.09		0.03	0.03	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	0.01		0.01	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	9.32		1.40	2.26	1.36	0.73	0.94	1.26	0.98	0.34	0.04	0	0	0	0	0	0	0	0	0	
8	8.36		0.76	2.02	1.87	0.94	0.69	0.91	0.80	0.32	0.05	0	0	0	0	0	0	0	0	0	
9	12.12		0.80	1.94	1.76	1.05	1.20	1.57	1.39	0.68	0.25	0.35	0.97	0.15	0.00	0	0	0	0	0	
10	12.22		0.76	1.93	1.76	1.04	1.22	1.46	1.27	0.91	0.49	0.32	0.48	0.14	0.45	0	0	0	0	0	
11	10.19		0.89	1.93	1.69	1.12	1.10	1.60	1.20	0.59	0.08	0	0	0	0	0	0	0	0	0	
12	5.52		0.49	0.98	0.84	0.68	0.69	0.91	0.71	0.21	0.03	0	0	0	0	0	0	0	0	0	
13	8.96		0.90	1.82	1.59	0.94	0.73	0.92	0.93	0.38	0.17	0.25	0.23	0.10	0	0	0	0	0	0	
14	11.79		0.77	1.96	1.67	1.09	1.13	1.64	1.74	0.67	0.30	0.47	0.32	0.05	0	0	0	0	0	0	
15	11.02		0.70	1.86	1.65	1.08	0.94	1.57	1.40	0.49	0.13	0.22	0.33	0.29	0.35	0	0	0	0	0	
16	8.99		0.54	1.40	1.53	1.17	1.10	1.26	1.01	0.75	0.20	0.02	0	0	0	0	0	0	0	0	
17	1.38		0.11	0.23	0.23	0.17	0.18	0.22	0.21	0.04	0.00	0	0	0	0	0	0	0	0	0	
18	0.03		0.02	0.01	0.00	0.00	0.00	0.01	0	0	0	0	0	0	0	0	0	0	0	0	
19	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure 5-1. VMT distributions for Group 2a (Drayage – Northern California)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
			0.42	0.92	1.15	1.28	1.55	1.95	2.30	2.88	3.37	4.96	10.85	34.32	26.01	7.60	0.44	0	0	0	*100*
Hour																					
0	3.25		0.01	0.02	0.03	0.03	0.04	0.05	0.06	0.08	0.10	0.10	0.28	0.95	1.09	0.36	0.03	0	0	0	
1	3.05		0.01	0.03	0.03	0.03	0.04	0.04	0.06	0.07	0.08	0.09	0.23	0.77	1.11	0.41	0.03	0	0	0	
2	3.13		0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.08	0.09	0.29	0.80	1.06	0.54	0.05	0	0	0	
3	2.88		0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.12	0.46	1.22	0.83	0.04	0	0	0	
4	2.98		0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.05	0.08	0.20	0.78	1.18	0.53	0.02	0	0	0	
5	3.70		0.02	0.04	0.04	0.05	0.06	0.09	0.10	0.10	0.12	0.17	0.37	1.18	0.95	0.40	0.01	0	0	0	
6	4.53		0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.16	0.19	0.29	0.60	1.40	1.05	0.33	0.01	0	0	0	
7	4.16		0.02	0.05	0.07	0.09	0.11	0.13	0.14	0.17	0.19	0.25	0.49	1.44	0.93	0.10	0.00	0	0	0	
8	3.72		0.02	0.05	0.06	0.08	0.09	0.10	0.09	0.13	0.14	0.24	0.48	1.57	0.55	0.11	0.01	0	0	0	
9	4.36		0.02	0.03	0.04	0.05	0.06	0.07	0.10	0.10	0.15	0.29	0.76	1.97	0.69	0.04	0.00	0	0	0	
10	4.32		0.02	0.03	0.04	0.05	0.07	0.09	0.10	0.16	0.16	0.25	0.57	2.02	0.71	0.04	0.00	0	0	0	
11	4.48		0.02	0.04	0.05	0.05	0.06	0.08	0.09	0.11	0.16	0.30	0.70	1.96	0.80	0.05	0.00	0	0	0	
12	4.60		0.02	0.04	0.04	0.04	0.05	0.07	0.09	0.12	0.15	0.26	0.66	2.20	0.77	0.09	0.00	0	0	0	
13	4.93		0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.13	0.21	0.58	2.38	0.95	0.14	0.02	0	0	0	
14	4.36		0.02	0.05	0.05	0.06	0.08	0.10	0.10	0.12	0.14	0.21	0.42	2.09	0.73	0.20	0.00	0	0	0	
15	4.87		0.02	0.06	0.07	0.09	0.10	0.11	0.13	0.16	0.18	0.28	0.55	1.78	1.24	0.09	0.00	0	0	0	
16	4.86		0.02	0.06	0.09	0.10	0.11	0.14	0.16	0.19	0.19	0.27	0.63	1.68	1.17	0.06	0.00	0	0	0	
17	3.89		0.03	0.09	0.10	0.10	0.12	0.14	0.18	0.21	0.21	0.26	0.37	1.03	0.96	0.08	0.01	0	0	0	
18	4.84		0.02	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.20	0.25	0.42	1.32	1.64	0.23	0.02	0	0	0	
19	4.87		0.02	0.04	0.05	0.05	0.07	0.08	0.10	0.16	0.17	0.24	0.46	1.42	1.58	0.39	0.03	0	0	0	
20	5.22		0.01	0.03	0.03	0.04	0.05	0.06	0.08	0.13	0.18	0.28	0.70	1.84	1.40	0.36	0.01	0	0	0	
21	4.69		0.02	0.04	0.04	0.05	0.06	0.08	0.09	0.12	0.16	0.22	0.44	1.38	1.35	0.59	0.03	0	0	0	
22	4.47		0.02	0.04	0.04	0.04	0.04	0.05	0.07	0.08	0.11	0.15	0.31	1.05	1.57	0.85	0.05	0	0	0	
23	3.84		0.02	0.03	0.04	0.04	0.04	0.07	0.07	0.07	0.10	0.13	0.21	0.85	1.32	0.79	0.06	0	0	0	
Sum	*100*																				*100*

Figure 5-2. VMT distributions for Group 1b (Line haul – in state)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
			25.30	11.81	15.66	10.36	7.47	3.86	2.89	5.06	0.96	0.48	0.72	0	0	0	0	0	0	0	15.42	*100*
Hour																					
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.96		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.96	
6	13.01		2.41	0	0.24	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.12	
7	11.33		1.69	2.41	1.93	0.96	0.72	0.48	0.48	0	0	0	0	0	0	0	0	0	0	0	2.65	
8	8.19		1.93	1.20	0.96	0.24	0.96	0.48	0.72	1.20	0	0	0	0	0	0	0	0	0	0	0.48	
9	13.98		3.61	2.41	2.41	2.65	1.20	0.24	0.24	0.48	0.24	0	0	0	0	0	0	0	0	0	0.48	
10	6.02		1.93	0.96	0.96	0.48	0.24	0.24	0	0.96	0	0	0	0	0	0	0	0	0	0	0.24	
11	8.67		3.37	0.48	1.93	1.20	0.96	0.48	0	0.24	0	0	0	0	0	0	0	0	0	0	0	
12	9.88		1.69	0.72	1.93	1.45	1.45	0.24	0.96	0.72	0	0.24	0	0	0	0	0	0	0	0	0.48	
13	6.27		2.65	0.48	1.45	0.24	0.24	0.24	0	0.24	0.24	0.24	0.24	0	0	0	0	0	0	0	0	
14	9.88		2.17	1.69	1.45	0.96	1.20	0.96	0.48	0.24	0.48	0	0.24	0	0	0	0	0	0	0	0	
15	9.40		2.89	1.20	1.45	1.69	0.48	0.48	0	0.96	0	0	0.24	0	0	0	0	0	0	0	0	
16	2.41		0.96	0.24	0.96	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure 5-3. Soak time distributions for Group 9c (Municipal work)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
			12.11	10.21	16.97	11.75	9.45	7.01	5.13	13.62	2.99	1.48	0.85	0.79	0.82	0.66	0.94	0.88	0.82	0.66	2.87	*100*
Hour																						
0	0.97		0.03	0.03	0.15	0	0.12	0.06	0	0	0	0	0	0	0.06	0	0.18	0.06	0.03	0.03	0.21	
1	1.27		0.06	0.06	0.06	0.03	0.09	0	0.12	0.39	0.03	0	0	0	0	0.03	0.12	0.03	0.06	0	0.18	
2	0.76		0	0	0.03	0.06	0.09	0.03	0.06	0.09	0	0	0.03	0	0.03	0	0	0.03	0.09	0.09	0.12	
3	1.75		0.09	0	0.12	0.09	0.15	0.09	0.09	0.33	0.09	0.18	0.03	0	0.03	0	0	0.09	0.06	0.06	0.24	
4	2.87		0.30	0.36	0.54	0.30	0.18	0.09	0.06	0.15	0.24	0.09	0.09	0.03	0.06	0.15	0	0	0	0.09	0.12	
5	2.93		0.33	0.21	0.27	0.12	0.18	0.27	0.24	0.51	0.12	0.03	0.06	0.06	0	0.09	0.09	0.03	0.03	0.09	0.18	
6	8.91		2.08	1.06	0.94	0.30	0.27	0.24	0.24	0.60	0.39	0.18	0.09	0.15	0.09	0.12	0.36	0.45	0.42	0.24	0.66	
7	5.83		1.03	0.57	1.09	0.66	0.36	0.36	0.27	0.63	0.15	0	0	0	0	0.03	0.03	0.06	0.12	0.03	0.42	
8	7.43		0.69	0.72	1.63	0.91	0.82	0.69	0.42	1.33	0.15	0	0	0	0	0	0	0	0	0	0.06	
9	8.70		1.06	0.82	1.63	1.48	0.82	0.60	0.39	1.51	0.21	0.06	0	0	0	0	0.03	0	0	0	0.09	
10	8.91		0.91	0.66	1.81	1.45	1.09	0.79	0.42	1.36	0.24	0.09	0	0	0	0	0	0	0	0	0.09	
11	9.21		0.91	0.97	2.30	1.42	1.00	1.00	0.36	0.91	0.21	0.03	0	0	0	0	0	0	0	0	0.12	
12	8.43		0.97	0.88	1.66	1.36	1.09	0.57	0.54	1.18	0.15	0	0	0	0	0	0	0	0	0	0.03	
13	6.89		0.51	0.79	1.39	0.97	0.88	0.48	0.63	1.06	0.15	0	0	0	0.03	0	0	0	0	0	0	
14	7.04		0.72	0.82	1.12	1.24	0.72	0.66	0.33	1.24	0.15	0	0	0	0	0	0	0	0	0	0.03	
15	4.83		0.57	0.66	0.66	0.42	0.76	0.42	0.33	0.79	0.09	0.09	0	0	0	0	0	0	0	0	0.03	
16	4.68		0.82	0.79	0.88	0.45	0.33	0.15	0.18	0.72	0.09	0.15	0.03	0.03	0.03	0	0	0	0	0	0.03	
17	2.90		0.76	0.48	0.42	0.24	0.15	0.12	0.15	0.21	0.18	0.06	0.06	0.06	0	0	0	0	0	0	0	
18	1.30		0.18	0.33	0.09	0.09	0.06	0.03	0.09	0.09	0.09	0.09	0.06	0	0.06	0	0	0	0	0	0.03	
19	0.91		0.03	0	0.06	0	0.03	0.09	0.06	0.12	0.15	0.12	0.06	0.03	0.06	0	0.03	0	0	0	0.06	
20	1.09		0	0	0.03	0.03	0.09	0.09	0.06	0.12	0.03	0.18	0.15	0.15	0.12	0.03	0	0	0	0	0	
21	1.21		0.06	0	0.03	0.09	0.09	0.09	0.03	0.18	0.03	0.09	0.15	0.12	0.18	0.03	0	0	0	0	0.03	
22	0.45		0	0	0.03	0	0	0.03	0.03	0.06	0.03	0.03	0.03	0.06	0.06	0.03	0.03	0	0	0	0.03	
23	0.76		0	0	0.03	0.03	0.09	0.03	0	0.03	0	0	0	0.09	0	0.15	0.06	0.12	0	0.03	0.09	
Sum	*100*																					*100*

Figure 5-4. Soak time distributions for Group 5b (Beverage distribution)

5.2. SCR Temperature Results

One of the primary objectives of this research is to identify the fraction of vehicle operation that SCR effectiveness may be compromised. Figure 5-5 through Figure 5-21 present the distributions of SCR temperature for the different vocations based on data from the entire data collection period. Note that there are two vocations that do not have SCR temperature data, which are explained below:

- The Drayage - Southern California vocation includes five vehicles. As shown in Appendix C, one of them has a 2008 engine model year and does not have SCR. The other four have a 2012 model year MACK MP8-415C engine and do have SCR. However, it was discovered after the data collection had been completed that MACK is one of a few engine manufacturers that use J1962 connector and J1979 messages on ISO 15765-4 CAN protocol for mandatory ECU information broadcasting instead of the more widely-used J1939 connector and J1939 messages on J1939 CAN protocol. Since, the data loggers used in this project do not support the ISO 15765-4 CAN protocol, data of certain ECU parameters including SCR temperature were not logged.

- Due to the difficulty recruiting express buses in Northern California, in consultation with CARB we collected data from express buses in Southern California instead. These buses have CNG engine and do not have SCR.

The frequency distributions for line haul trucks in Figure 5-5 and Figure 5-6 are similar. They have two peaks. One is around 260-280 °C, which is probably when driving on highways. The other one is around 100 °C, which is probably when idling. The line haul – out of state trucks use Cummins engine of model years 2012-2014 with 450 rated horsepower. The line haul – in state trucks use 2015 Detroit Diesel engine with 500-505 rated horsepower. The ability of line haul – in state trucks to maintain a higher SCR temperature while idling could be due to having a newer engine model year with more mature SCR technology or due to having different SCR temperature management strategies as employed by the different engine manufacturers.

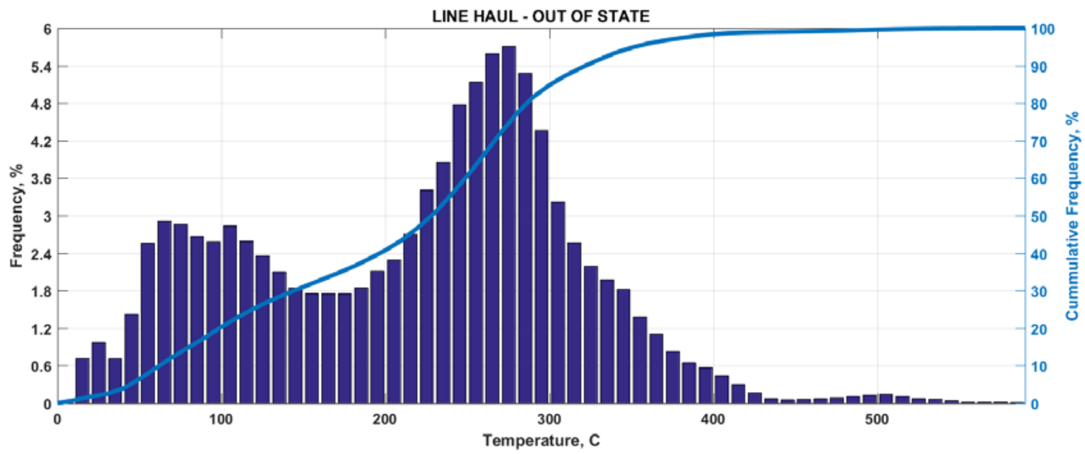


Figure 5-5. SCR temperature distributions for Group 1a (Line haul – out of state)

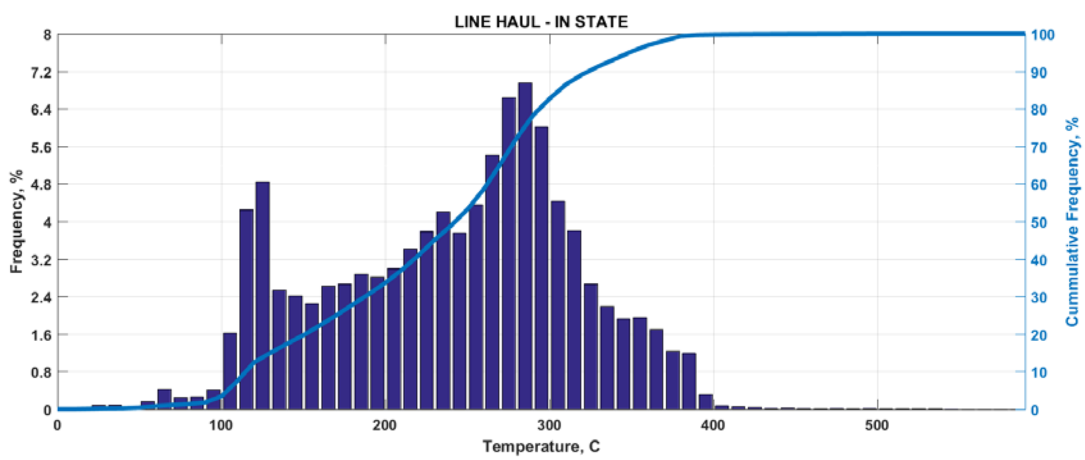


Figure 5-6. SCR temperature distributions for Group 1b (Line haul – in state)

Figure 5-7 shows SCR temperature distributions for Group 2a (Drayage – Northern California). This group consists of only one truck, which come from the same fleet as the trucks in Group 1a. This truck has a 2012 Cummins engine with 450 rated horsepower, which is the same as one of the trucks in Group 1a. Compared to Figure 5-5, the SCR temperature distributions in Figure 5-7 are significantly different where the frequency distribution peaks at around 100-110 °C and skews right. This is a strong evidence of how the differences in vehicle activity patterns affect the SCR temperatures of the vehicles, and likely their real-world NO_x emissions.

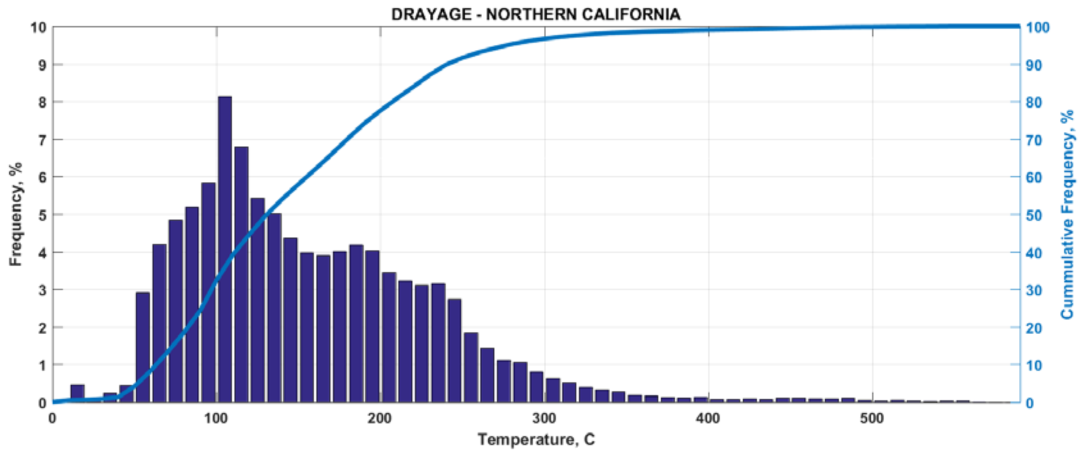


Figure 5-7. SCR temperature distributions for Group 2a (Drayage – Northern California)

The SCR temperatures of agricultural trucks in Figure 5-8 are surprisingly low despite these trucks having similar operating patterns to line haul – in state trucks. One potential reason is that the engine size may be too large for the type of load and weight that they carry. Another potential reason may have to do with the specific engines and SCR systems used in these trucks as there is a distinct peak in the frequency distribution of SCR temperature at 100-110 °C even when cruising at highway speeds.

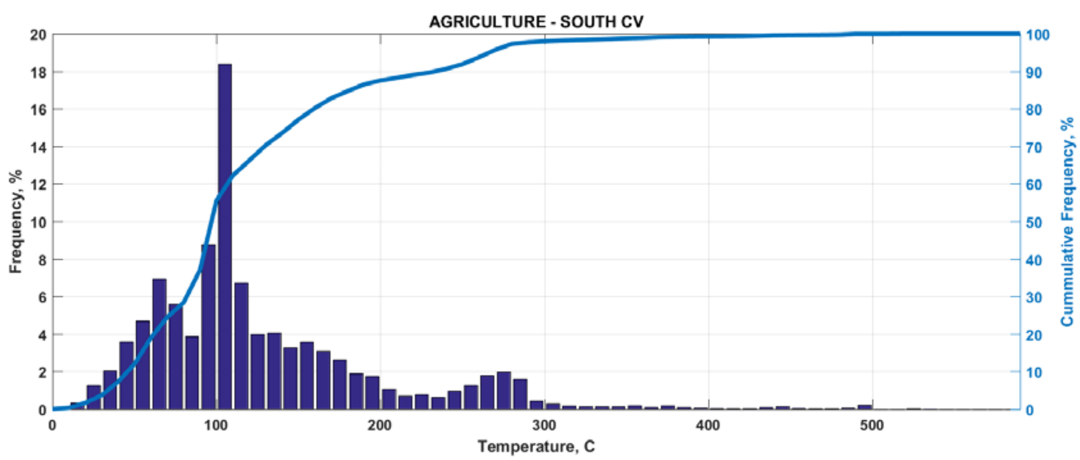


Figure 5-8. SCR temperature distributions for Group 3b (Agricultural – South Central Valley)

The SCR temperature frequency distributions in Figure 5-9 (for construction trucks) and Figure 5-10 (for cement mixers) are similar to each other. They have the shape of

Gaussian distribution with a single peak at around 190-210 °C. Both skew a bit towards the right and look unique as compared to the frequency distributions of the other vocations.

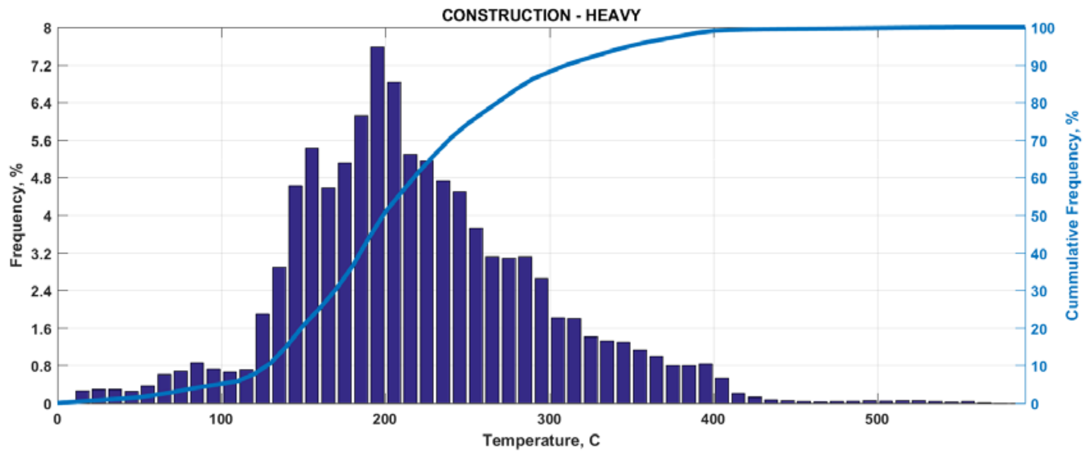


Figure 5-9. SCR temperature distributions for Group 4a (Construction)

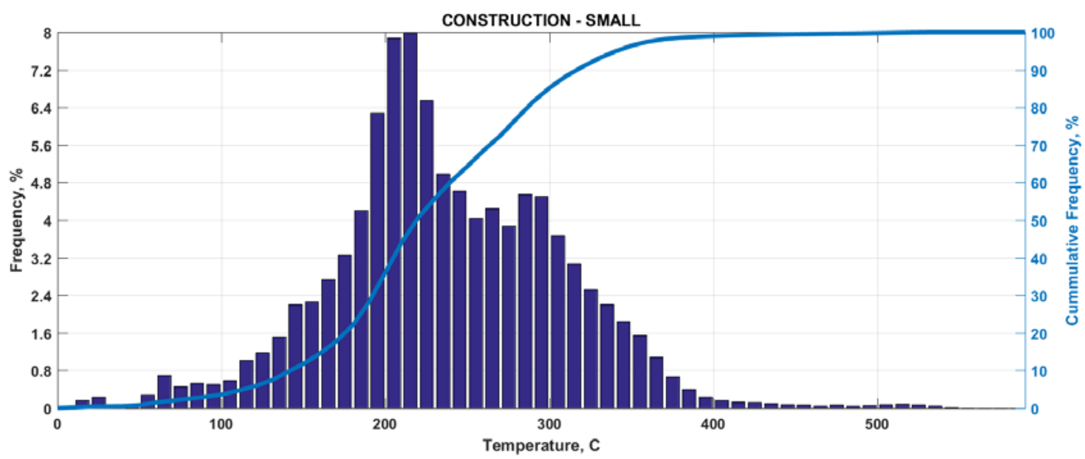


Figure 5-10. SCR temperature distributions for Group 4b (Cement mixers)

The SCR temperature frequency distributions in Figure 5-11 (for food distribution trucks) and Figure 5-12 (for beverage distribution trucks) are similar to each other. They have the shape of the Gaussian distribution with a major peak at around 220-250 °C and a minor peak at around 40-80 °C. Both skew a bit towards the left. One notable difference between them is that the distribution for food distribution trucks has more frequency at the temperature higher than 250 °C. This may be due to the food distribution trucks having a significantly higher fraction of time driving at freeway speeds.

The SCR temperature frequency distribution in Figure 5-13 (for local moving truck) also has a major peak at around 220-250 °C. However, a minor peak at around 40-80 °C is so substantial that the distribution looks like a bi-modal Gaussian distribution. This minor peak may be associated with vehicle activity after cold starts.

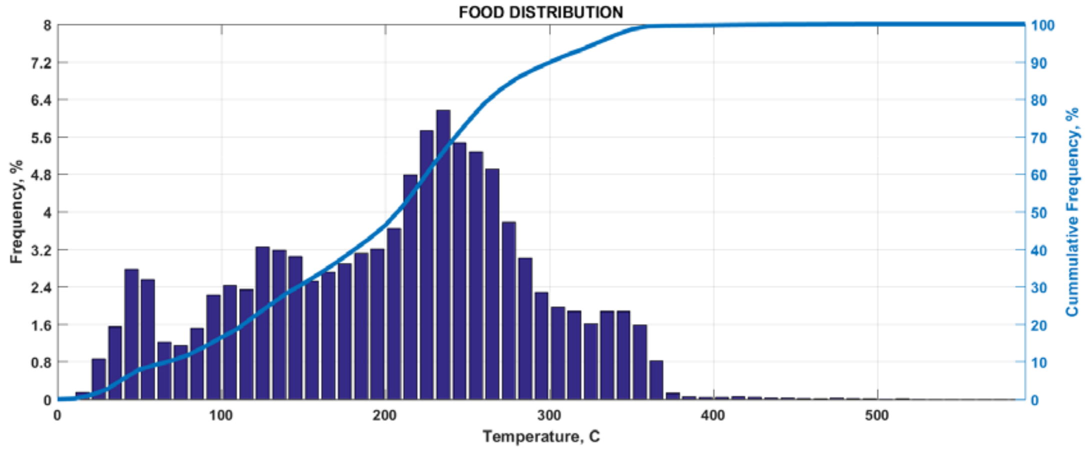


Figure 5-11. SCR temperature distributions for Group 5a (Food distribution)

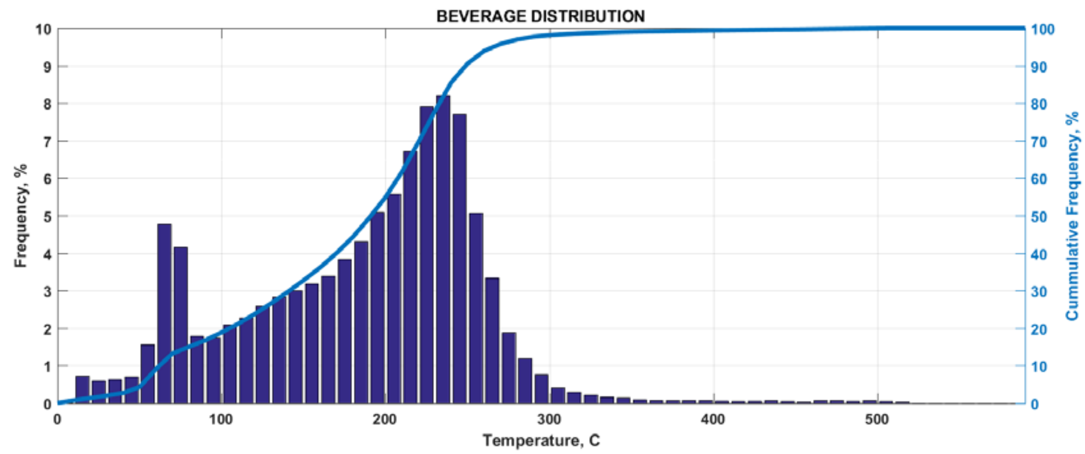


Figure 5-12. SCR temperature distributions for Group 5b (Beverage distribution)

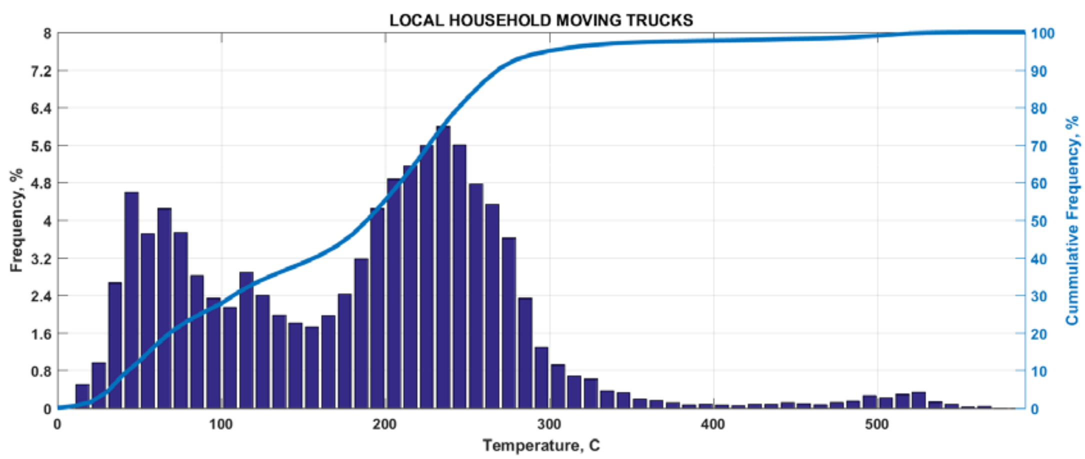


Figure 5-13. SCR temperature distributions for Group 5c (Local moving)

The SCR temperature frequency distributions for airport shuttles and refuse trucks buses are given in Figure 5-14 and Figure 5-15, respectively. They both peak at around 230-250 °C. The distribution for refuse trucks has a noticeable fraction above 400 °C, which should be further examined to see what operating conditions contributed to these high SCR temperatures.

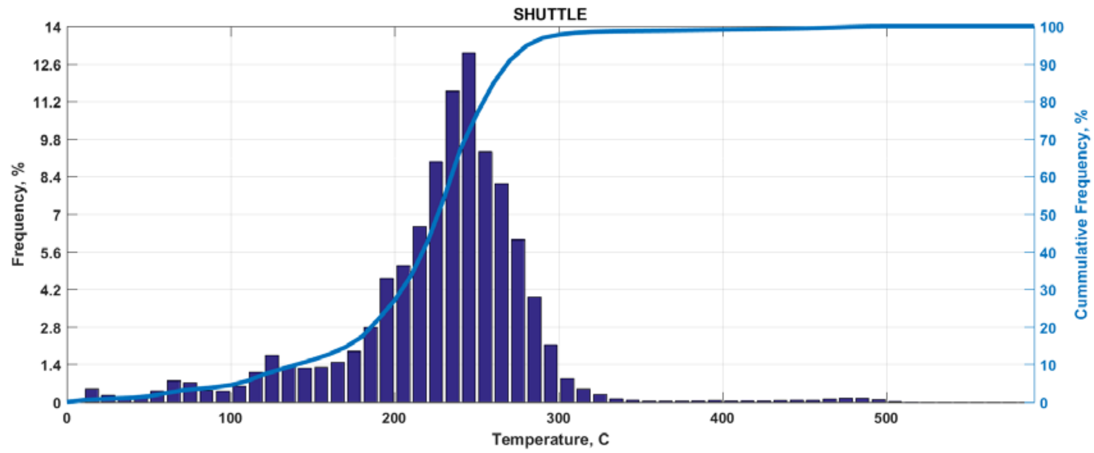


Figure 5-14. SCR temperature distributions for Group 6 (Airport shuttle)

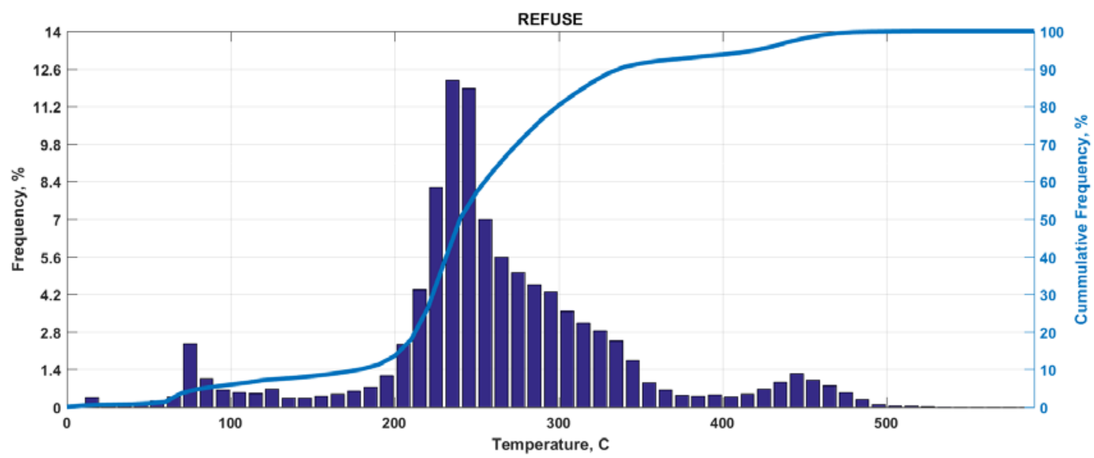


Figure 5-15. SCR temperature distributions for Group 7 (Refuse)

Figure 5-16 shows the SCR temperature frequency distribution for urban buses, which have diesel hybrid electric powertrain. It resembles a bi-modal Gaussian distribution where the major peak is around 270-290 °C and the minor peak is around 60-100 °C. The SCR temperature frequency distribution for urban buses looks similar to the one for out-of-state line haul trucks, indicating that the SCR system in this diesel hybrid electric powertrain operates comparably with SCR systems in conventional diesel engines.

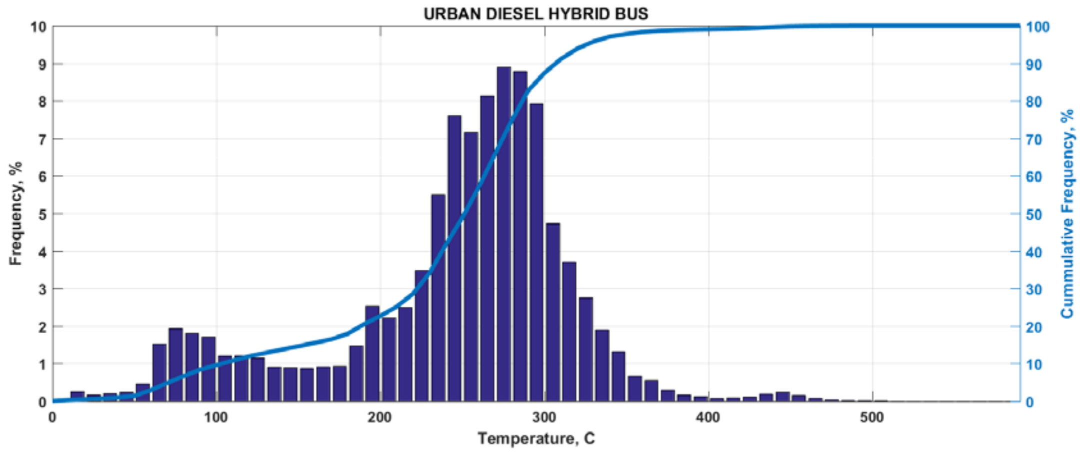


Figure 5-16. SCR temperature distributions for Group 8a (Urban buses)

Figure 5-17 and Figure 5-18 show that sweeping trucks were able to maintain higher SCR temperatures than freeway work trucks despite having similar engine size and vehicle activity characteristics. The sweeping trucks use Cummins ISB6.7 engine with 280 rated horsepower while the freeway work trucks use the same engine with 260 rated horsepower. Both also have a similar GVWR—27,000 lbs for sweeping trucks and 26,000 lbs for freeway trucks. According to Table 5-2 through Table 5-7, both types of trucks have comparable vehicle activity patterns although freeway work trucks spent a higher fraction of time idling (54% vs. 33%). Perhaps, this partly contributes to the freeway work trucks having relatively lower SCR temperatures. Another potential reason is that the sweeping trucks have PTO load on the engine while the freeway work trucks do not.

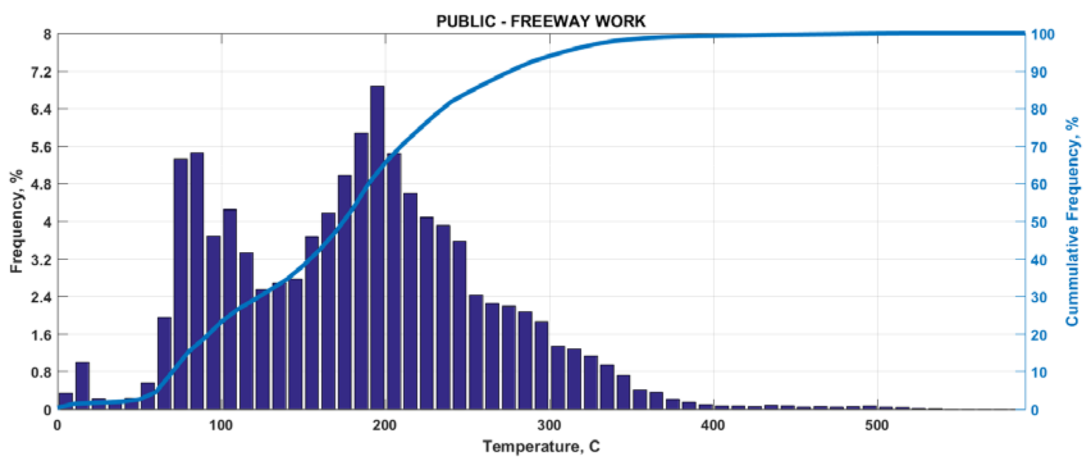


Figure 5-17. SCR temperature distributions for Group 9a (Freeway work)

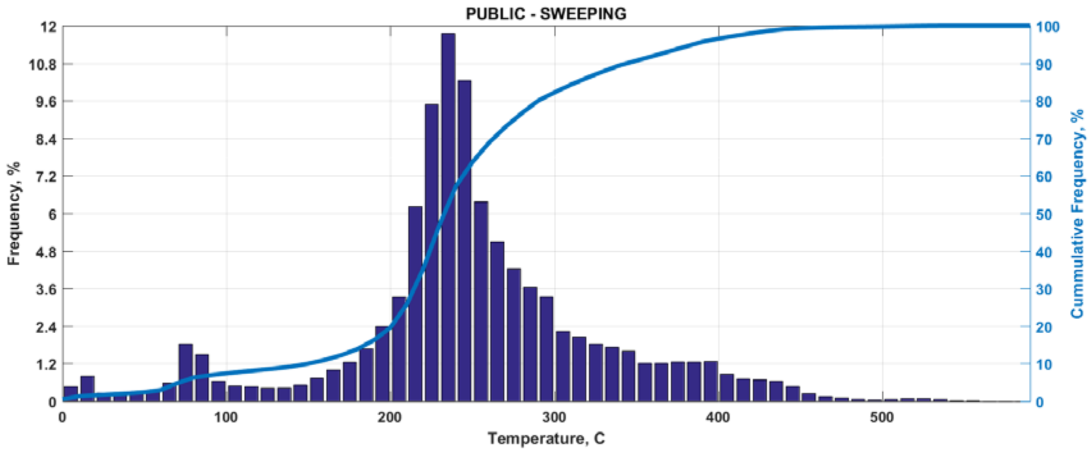


Figure 5-18. SCR temperature distributions for Group 9b (Sweeping)

The SCR temperature frequency distributions in Figure 5-19 (for municipal work trucks) and Figure 5-20 (for towing trucks) are similar to each other with the peak at around 250-280 °C. They have the shape of Gaussian distribution, similar to the SCR temperature frequency distributions of many other vocation types. In contrast, the SCR temperature frequency distribution in Figure 5-21 (for utility repair trucks) has a unique shape. In fact, it deviates the most from Gaussian distribution than the SCR temperature frequency distributions of any other vocation types.

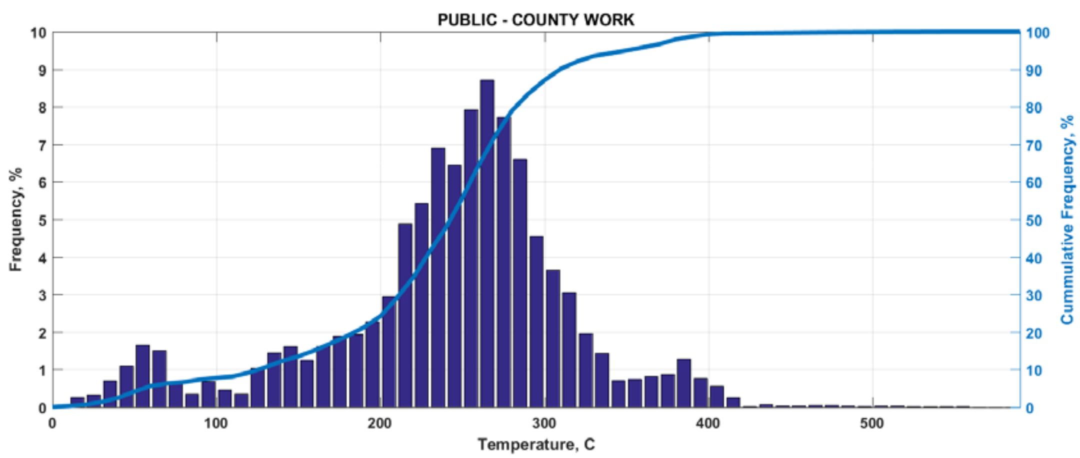


Figure 5-19. SCR temperature distributions for Group 9c (Municipal work)

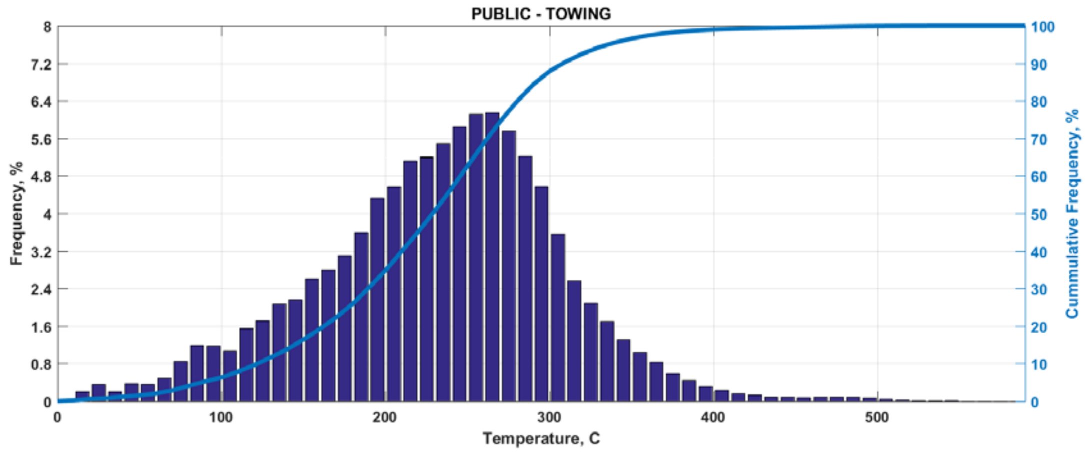


Figure 5-20. SCR temperature distributions for Group 9d (Towing)

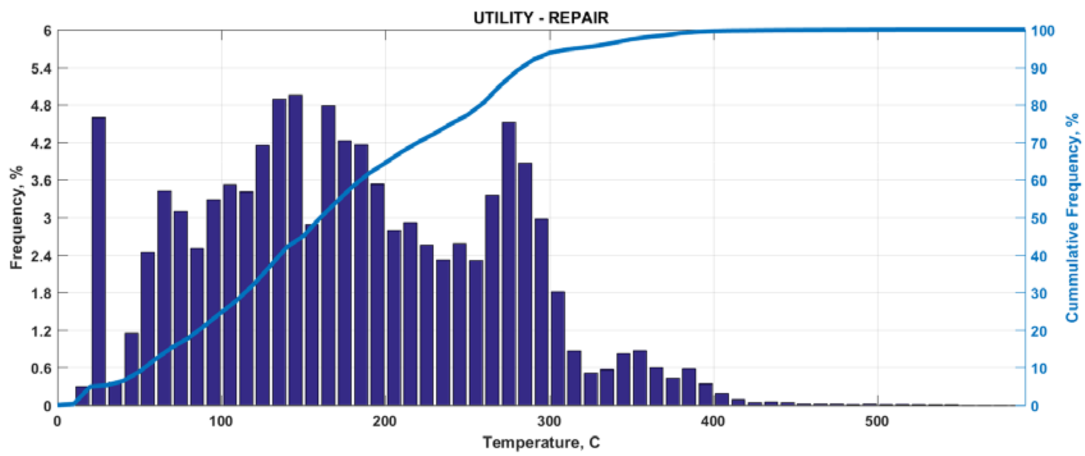


Figure 5-21. SCR temperature distributions for Group 10 (Utility repair)

Table 5-9 presents the information about the fraction of vehicle operating time that the SCR temperature was below certain thresholds. The selected thresholds are from 50 °C to 450 °C with a 50 °C increment. Taking line haul – out of state trucks as an example, Table 5-9 shows that on average their SCR temperatures were lower than 200 °C for 38.5% of the total operating time.

Table 5-9. Percentage of vehicle operating time with SCR temperature below certain thresholds

No.	Vocation	Fraction with SCR Temperature (°C) Lower Than								
		50	100	150	200	250	300	350	400	450
1a	Line haul - out of state	3.9	17.5	29.2	38.5	55.5	81.6	93.4	98.0	99.0
1b	Line haul - in state	0.2	1.7	17.4	30.7	48.9	78.2	93.3	99.7	99.9
2a	Drayage - No. Cal.	1.2	24.2	54.0	74.1	89.8	96.0	98.2	98.9	99.3
2b	Drayage - So. Cal.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3b	Agricultural - So. CV	7.3	37.1	73.5	86.5	90.6	97.7	98.6	99.2	99.6
4a	Construction	1.2	4.4	15.2	44.1	70.6	86.3	94.0	98.5	99.5
4b	Cement mixers	0.5	3.0	9.5	28.3	60.3	81.5	94.9	98.8	99.4
5a	Food distribution	5.3	14.0	28.3	42.8	68.6	87.8	97.1	99.7	99.9
5b	Beverage distribution	2.7	16.7	29.5	49.3	85.5	97.7	98.9	99.3	99.6
5c	Local moving	8.8	25.7	36.9	50.5	77.7	94.1	97.1	97.7	98.1
6	Airport shuttle	1.1	3.9	9.9	22.0	67.3	96.9	98.7	99.0	99.3
7	Refuse	0.7	5.4	7.8	11.2	50.2	76.7	90.5	93.4	97.1
8a	Urban buses	0.9	8.4	13.7	20.5	41.8	82.7	97.1	99.0	99.7
8b	Express buses	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9a	Freeway work	2.0	19.0	34.5	60.1	81.8	92.6	98.0	99.2	99.6
9b	Sweeping	2.0	6.9	9.2	16.3	57.3	80.0	89.5	95.7	99.1
9c	Municipal work	2.5	7.3	12.3	21.3	47.9	83.4	94.2	98.7	99.7
9d	Towing	1.2	5.2	13.8	30.2	56.5	84.3	95.5	98.8	99.5
10	Utility repair	6.4	21.2	42.1	61.8	74.9	92.0	96.6	99.4	99.9

According to Table 5-9, it was found that on average the vehicle samples in this study operated with SCR temperature lower than 250 °C for 42-91% of the time, depending on their vocation. And they operated with SCR temperature lower than 200 °C for 11-87% of the time, depending on their vocation. These portions of vehicle operation with low SCR temperature have a significant implication on the vehicles' real-world NO_x emission.

To estimate the potential impact of real-world SCR temperature of these vehicles on their real-world NO_x emission, we first determined the fraction of vehicle operating time that the SCR temperature was within nine different bins as shown in Table 5-10. For each vocation, the sum of the fraction values across the nine bins equals 100. Then, we assumed a % NO_x reduction value for each of the nine SCR temperature bins based on the NO_x reduction curve in Figure 1-1. The assumed % NO_x reduction values are given in the last row of Table 5-10. Finally, we calculated the weighted average % NO_x reduction for each vocation using the fraction of SCR temperature in the different bins as the weighting factor. The results are presented in the last column of Table 5-10.

Table 5-10. Percentage of vehicle operating time with SCR temperature in certain bins

No.	Vocation	Fraction with SCR Temperature (°C) Between									% NO_x Reduc-tion*
		0-50	51-100	101-150	151-200	201-250	251-300	301-350	351-400	401+	
1a	Line haul - out of state	3.9	13.6	11.8	9.2	17.1	26.1	11.8	4.6	2.1	52.7
1b	Line haul - in state	0.2	1.5	15.7	13.2	18.2	29.4	15.0	6.4	0.3	60.5
2a	Drayage - No. Cal.	1.2	23.0	29.7	20.1	15.7	6.3	2.1	0.7	1.1	25.0
2b	Drayage - So. Cal.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3b	Agricultural - So. CV	7.3	29.9	36.4	13.0	4.1	7.1	0.8	0.7	0.8	15.8
4a	Construction	1.2	3.3	10.8	28.8	26.5	15.7	7.7	4.6	1.5	50.0
4b	Cement mixers	0.5	2.5	6.5	18.8	32.1	21.2	13.4	3.9	1.2	59.7
5a	Food distribution	5.3	8.7	14.3	14.5	25.8	19.3	9.2	2.6	0.3	47.6
5b	Beverage distribution	2.7	14.1	12.8	19.8	36.1	12.3	1.2	0.4	0.7	39.8
5c	Local moving	8.8	16.9	11.2	13.6	27.3	16.4	2.9	0.6	2.3	39.8
6	Airport shuttle	1.1	2.8	6.0	12.1	45.2	29.6	1.9	0.3	1.0	58.6
7	Refuse	0.7	4.7	2.4	3.4	39.0	26.5	13.8	2.9	6.6	68.9
8a	Urban buses	0.9	7.4	5.4	6.7	21.3	40.9	14.4	1.8	1.1	65.7
8b	Express buses	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9a	Freeway work	2.0	17.0	15.6	25.6	21.6	10.8	5.4	1.2	0.8	36.3
9b	Sweeping	2.0	4.9	2.3	7.0	41.1	22.7	9.5	6.2	4.3	64.8
9c	Municipal work	2.5	4.9	4.9	9.0	26.6	35.5	10.8	4.5	1.3	64.3
9d	Towing	1.2	4.1	8.6	16.5	26.3	27.8	11.2	3.2	1.2	58.7
10	Utility repair	6.4	14.8	20.9	19.6	13.2	17.1	4.6	2.8	0.6	35.9
Assumed % NO_x reduction		*0*	*0*	*5*	*25*	*60*	*85*	*93*	*97*	*97*	

**Total estimated % NO_x reduction*

According to the results in Table 5-10, the weighted average % NO_x reduction ranges from 15.8% for agricultural trucks to 68.9% for refuse trucks. The top three vocations with the highest % NO_x reduction are refuse trucks, urban buses, and sweeping trucks. The bottom three vocations with the lowest % NO_x reduction are agricultural trucks, drayage trucks in Northern California, and utility repair trucks. These results indicate that real-world NO_x emissions from heavy-duty diesel vehicles equipped with SCR may be higher than the levels expected from the engine certification standards.

5.3. Vocation-Specific Drive Cycles

This section presents the vocation-specific drive cycles and their statistics that result from the drive cycle development discussed in Section 4.4. Table 5-11 and Table 5-12 provide the statistics of the data population that was used to develop drive cycles. Then, Table 5-13 and Table 5-14 provide the statistics of the resulting drive cycles. Lastly, for each vocation the plot of the drive cycle and the plot of its OMD in comparison with the OMD of the data population are given in Appendix F.

Table 5-11 shows the number of snippets that resulted from splitting vehicle activity strings and that were used to generate candidate cycles. The statistics shown in this table as well as in Table 5-12 are for these snippets, which do not include any idle trips or extended idling events. Therefore, the percentage of time spent in idle mode shown in Table 5-11 is much lower than that shown in Table 5-3. Also, the mean speed shown in Table 5-12 is higher than that shown in Table 5-4 for the same reason.

The time statistic given in Table 5-13 is essentially the length of the drive cycle. The values range from 1,292 to 1,774 seconds or around 20 to 30 minutes, which are in line with the drive cycles widely used in the current practice. For example, the length of the UDDS cycle is 1,063 seconds while the length of the HHDDT Cruise cycle is 2,083 seconds. Based on the experience of the research team in conducting emission testing with chassis dynamometer, this range of the cycle length provides a good balance between sensitivity and cost. A drive cycle that is too short makes it more difficult to measure low levels of emissions for some pollutants that are close to the measurement limits. A short drive cycle also may not generate enough PM mass to adequately measure PM mass emission. On the other hand, a drive cycle that is too long increases the testing cost unnecessarily. A good drive cycle does not need to be very long provided that its characteristics match those of the data population.

As discussed in Section 4.4, we used OMD as the cycle selection criterion and MSE as the performance measure. A drive cycle with low MSE of OMD would have a similar total emission per unit of time to that generated by the entire data population as calculated by MOVES. Table 5-13 shows the MSE of OMD value for the final drive cycle in each vocation. The values for 16 vocations are 0.10 or lower while the values for Group 1a and Group 5c are 0.19 and 0.28, respectively. The plots in Appendix F for these vocations indicate a very good match between the OMD of the drive cycle and the OMD of the data population.

The largest MSE of OMD in Table 5-13 is 2.72 for Group 2a. As shown in Appendix F, for this group the final cycle does not contain high power activities in OpMode bin 33 and higher as in the OMD of its data population. This is because those high power activities are contained exclusively in snippets longer than 1,800 seconds, which is the maximum target length used in the drive cycle development. Thus, these snippets were never considered for inclusion in any of the candidate cycles. A potential solution to this issue is to increase the maximum target length but up to a reasonable threshold.

Another potential solution is to cut those long snippets into shorter ones at non-idling speeds. In this case, additional consideration is required when joining snippets at a non-idling speed to ensure that the resulting acceleration or deceleration is realistic.

Table 5-11. General statistics of data population used for developing drive cycles

No.	Vocation	No. of Snippets	Time (sec)	Dist. (mi)	% Time in			
					Brake	Idle	Coast	Cruise
1a	Line haul - out of state	7,373	5,288,670	71,668	1.3	4.9	5.9	87.9
1b	Line haul - in state	9,617	3,555,115	41,453	3.1	9.2	8.4	79.3
2a	Drayage - No. Cal.	2,330	279,985	1,266	3.5	24.8	18.2	53.6
2b	Drayage - So. Cal.	21,993	3,152,680	17,032	5.0	22.8	19.4	52.8
3b	Agricultural - So. CV	2,326	1,444,393	18,389	2.0	8.5	6.0	83.4
4a	Construction	6,933	2,084,234	18,464	3.9	13.3	14.9	67.8
4b	Cement mixers	3,531	655,492	5,125	5.8	22.1	7.9	64.2
5a	Food distribution	15,126	5,165,227	51,909	2.6	9.7	11.3	76.4
5b	Beverage distribution	15,668	1,623,641	6,587	8.2	27.6	17.9	46.4
5c	Local moving	1,910	519,571	4,809	4.2	11.5	13.0	71.3
6	Airport shuttle	100,192	14,567,407	62,539	6.8	32.2	15.4	45.7
7	Refuse	138,158	5,690,461	16,490	8.4	38.6	13.9	39.1
8a	Urban buses	66,243	6,615,865	27,085	12.2	27.8	13.2	46.8
8b	Express buses	19,073	3,637,644	30,688	6.8	17.6	9.3	66.4
9a	Freeway work	12,375	1,754,238	11,937	5.1	21.3	10.1	63.6
9b	Sweeping	10,767	2,686,923	13,399	3.0	13.7	9.0	74.4
9c	Municipal work	4,228	1,127,266	9,190	5.6	14.5	15.4	64.5
9d	Towing	19,661	5,408,360	55,014	5.7	13.4	10.7	70.2
10	Utility repair	10,095	1,717,643	10,902	7.2	18.5	12.5	61.8

Table 5-12. Instantaneous speed, acceleration, and deceleration statistics of data population

No.	Vocation	Speed (mph)			Acceleration (mph/s)			Deceleration (mph/s)		
		Max	Mean	S.D.	Max	Mean	S.D.	Max	Mean	S.D.
1a	Line haul - out of state	75.0	48.8	20.1	5.0	0.4	0.5	5.0	0.4	0.5
1b	Line haul - in state	75.0	42.0	22.9	5.0	0.5	0.6	5.0	0.5	0.7
2a	Drayage - No. Cal.	66.2	16.3	18.7	5.0	0.7	0.7	5.0	0.7	0.8
2b	Drayage - So. Cal.	67.2	19.4	18.5	5.0	0.8	0.8	5.0	0.8	0.8
3b	Agricultural - So. CV	70.0	45.8	22.6	5.0	0.4	0.5	5.0	0.5	0.6
4a	Construction	75.0	31.9	23.6	5.0	0.7	0.7	5.0	0.7	0.8
4b	Cement mixers	75.0	28.1	24.1	5.0	0.7	0.7	5.0	0.8	1.0
5a	Food distribution	73.6	36.2	20.9	5.0	0.5	0.5	5.0	0.5	0.7
5b	Beverage distribution	75.0	14.6	14.9	5.0	0.9	0.9	5.0	1.0	1.0
5c	Local moving	73.2	33.3	22.8	5.0	0.5	0.6	5.0	0.6	0.7
6	Airport shuttle	67.2	15.5	15.3	5.0	0.9	0.8	5.0	1.0	0.9
7	Refuse	62.9	10.4	14.5	5.0	1.1	1.0	5.0	1.1	1.1
8a	Urban buses	67.8	14.7	13.7	5.0	1.1	1.0	5.0	1.2	1.1
8b	Express buses	75.0	30.4	25.3	5.0	0.7	0.7	5.0	0.8	0.9
9a	Freeway work	75.0	24.5	23.4	5.0	0.7	0.8	5.0	0.8	0.9
9b	Sweeping	73.7	18.0	19.3	5.0	0.5	0.6	5.0	0.5	0.7
9c	Municipal work	74.2	29.3	20.1	5.0	0.6	0.7	5.0	0.7	0.9
9d	Towing	88.2	36.6	23.3	5.0	0.7	0.8	5.0	0.8	0.9
10	Utility repair	68.2	22.8	18.9	5.0	0.8	0.7	5.0	0.9	0.9

Table 5-13. General statistics of drive cycles

No.	Vocation	Time (sec)	Dist. (mi)	Avg. Speed (mph)	% Time in				MSE of OMD
					Brake	Idle	Coast	Cruise	
1a	Line haul - out of state	1,560	21.1	48.6	2.3	4.7	5.5	87.4	0.19
1b	Line haul - in state	1,629	18.5	40.9	3.3	8.7	8.4	79.6	0.10
2a	Drayage - No. Cal.	1,292	4.3	11.9	4.9	25.9	20.3	49.0	2.72
2b	Drayage - So. Cal.	1,756	9.4	19.3	4.6	23.2	19.9	52.3	0.05
3b	Agricultural - So. CV	1,475	18.4	44.8	2.6	8.8	6.0	82.6	0.09
4a	Construction	1,719	15.4	32.3	4.2	12.7	14.8	68.3	0.09
4b	Cement mixers	1,483	11.6	28.1	5.8	22.3	8.1	63.9	0.06
5a	Food distribution	1,774	17.8	36.0	3.0	9.6	10.7	76.7	0.08
5b	Beverage distribution	1,418	5.6	14.2	8.3	27.6	18.1	46.0	0.07
5c	Local moving	1,690	15.3	32.6	4.4	11.9	12.5	71.1	0.28
6	Airport shuttle	1,785	7.4	15.0	6.9	32.3	15.8	45.0	0.04
7	Refuse	1,665	5.1	11.1	7.4	38.3	13.8	40.5	0.09
8a	Urban buses	1,726	7.1	14.9	12.3	27.8	12.1	47.8	0.08
8b	Express buses	1,738	14.6	30.2	6.9	17.9	9.7	65.5	0.04
9a	Freeway work	1,598	10.9	24.5	5.3	21.5	9.6	63.6	0.04
9b	Sweeping	1,668	8.4	18.2	3.1	13.9	9.4	73.6	0.03
9c	Municipal work	1,713	13.6	28.6	6.1	14.6	15.1	64.2	0.07
9d	Towing	1,647	16.9	36.8	5.6	13.2	10.9	70.3	0.05
10	Utility repair	1,734	11.3	23.4	7.2	18.6	12.3	62.0	0.03

Table 5-14. Instantaneous speed, acceleration, and deceleration statistics of drive cycles

No.	Vocation	Speed (mph)			Acceleration (mph/s)			Deceleration (mph/s)		
		Max	Mean	S.D.	Max	Mean	S.D.	Max	Mean	S.D.
1a	Line haul - out of state	64.6	48.6	20.7	3.7	0.4	0.5	4.3	0.4	0.5
1b	Line haul - in state	69.8	40.9	22.5	4.7	0.5	0.6	5.0	0.6	0.9
2a	Drayage - No. Cal.	42.1	11.9	11.6	4.1	0.8	0.7	5.0	0.9	1.0
2b	Drayage - So. Cal.	55.4	19.3	18.0	4.7	0.7	0.7	5.0	0.8	0.9
3b	Agricultural - So. CV	62.2	44.8	22.1	3.4	0.5	0.5	4.4	0.5	0.7
4a	Construction	67.5	32.3	23.7	3.9	0.6	0.7	4.0	0.7	0.7
4b	Cement mixers	64.4	28.1	23.8	4.5	0.8	0.8	4.3	0.8	0.9
5a	Food distribution	63.4	36.0	20.9	3.2	0.5	0.5	4.5	0.5	0.6
5b	Beverage distribution	52.4	14.2	13.9	4.9	0.9	0.8	3.8	1.0	0.9
5c	Local moving	66.6	32.6	22.9	3.8	0.5	0.6	4.8	0.7	0.8
6	Airport shuttle	43.4	15.0	14.0	4.6	1.0	0.8	4.2	1.0	0.9
7	Refuse	57.3	11.1	13.6	4.7	0.9	0.8	5.0	1.1	1.1
8a	Urban buses	59.1	14.9	13.8	4.6	1.0	0.9	5.0	1.2	1.0
8b	Express buses	70.2	30.2	25.1	4.8	0.7	0.7	5.0	0.8	0.8
9a	Freeway work	71.8	24.5	24.3	4.9	0.7	0.8	5.0	0.7	0.9
9b	Sweeping	62.4	18.2	18.4	4.4	0.5	0.6	5.0	0.5	0.8
9c	Municipal work	59.3	28.6	20.2	4.6	0.6	0.7	5.0	0.7	0.9
9d	Towing	67.9	36.8	22.9	4.4	0.8	0.8	5.0	0.8	0.9
10	Utility repair	58.5	23.4	19.1	3.4	0.8	0.7	5.0	0.9	0.9

The drive cycles for the different vocations may be grouped based on their characteristics into four groups as discussed below.

1. ***Mostly highway cruising*:** An example is shown in Figure 5-22 for line haul - out of state trucks. As the name indicates, the drive cycles in this group spend most of the time cruising at highway speeds. A small portion of the drive cycles is at lower speeds, presumably when the vehicles travel between a highway and an origin or destination. Other vocations whose drive cycles fall in this group include line haul - in state, and agricultural

2. ***Mixed driving*:** An example is shown in Figure 5-23 for cement mixers. For this group, the drive cycles consist of a mix of freeway and non-freeway driving in urban areas. The freeway driving makes up of one or more short segments (representing a situation where the vehicle gets on a freeway, cruises over a short distance, and then gets off the freeway) in relative to the first group. There is a larger portion of non-freeway driving than in the first group as many short trips from one location to another can be made without getting on freeway. Vocations whose drive cycles fall in this group also include construction, food distribution, local moving, express buses, freeway work, municipal work, and towing.

3. ***Mostly transient*:** An example is given in Figure 5-24 for urban buses. As the name indicates, the drive cycles in this group spend most of the time in transient mode mostly on non-freeway roads. Vocations whose drive cycles fall in this group also include drayage, beverage distribution, airport shuttle, and utility - repair.

4. ***Mostly creeping*:** An example is given in Figure 5-25 for sweeping trucks. The drive cycles in this group spend most of the time creeping at low speeds while the vehicles are performing their job. There are other parts of the drive cycles involving higher speeds of driving, presumably when the vehicles travel to and from the job site. In addition to sweeping trucks, this group also includes refuse trucks.

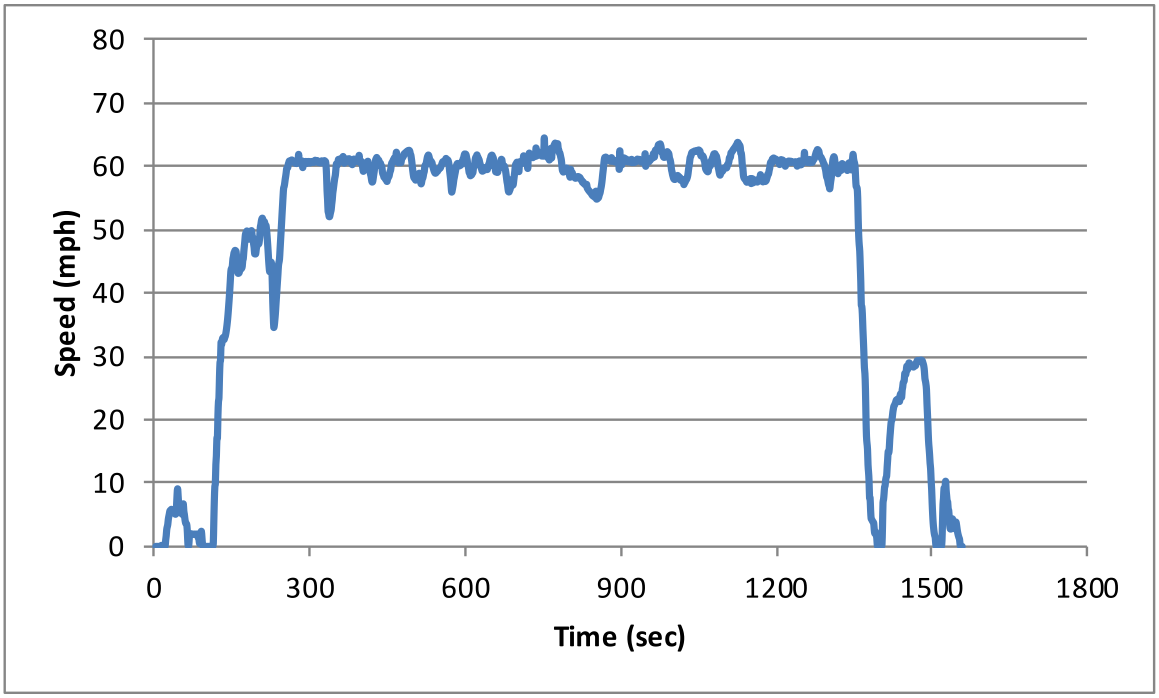


Figure 5-22. Drive cycle for Group 1a (Line haul – out of state)

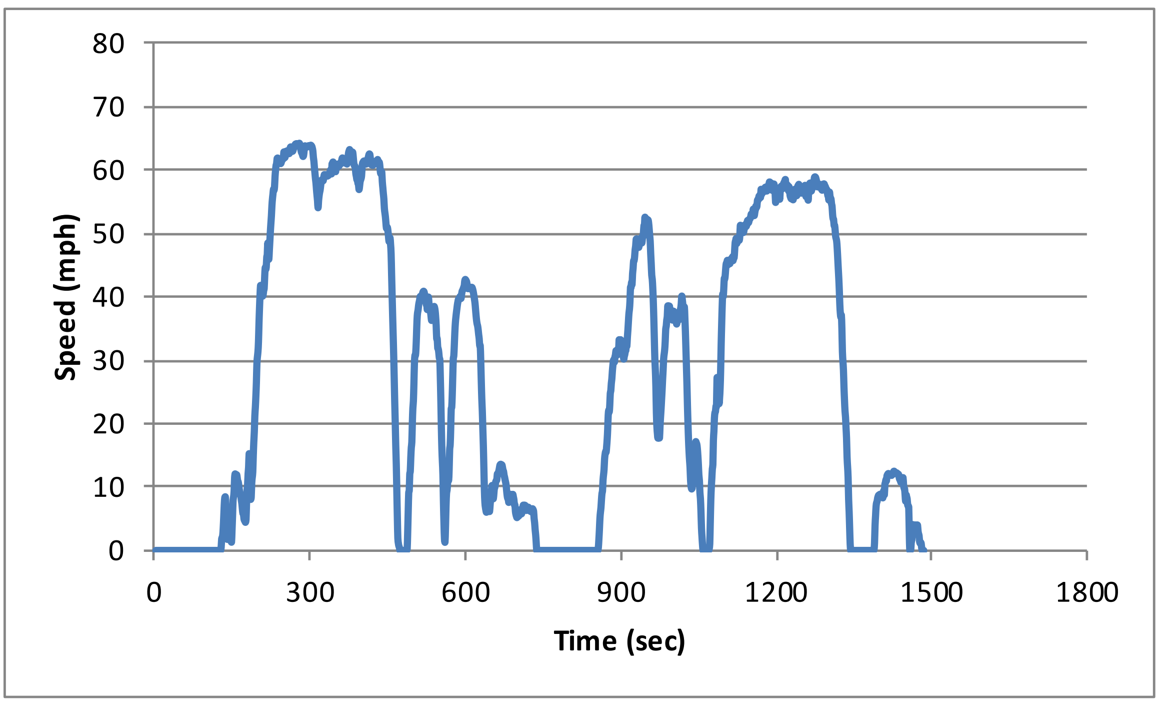


Figure 5-23. Drive cycle for Group 4b (Cement mixers)

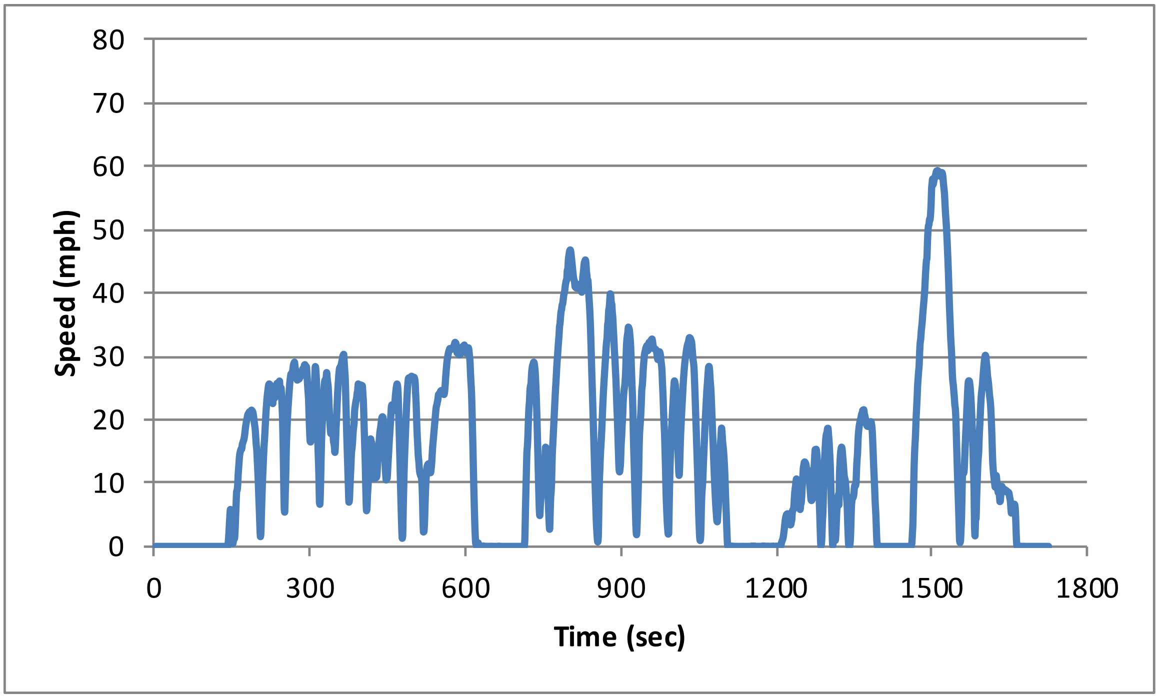


Figure 5-24. Drive cycle for Group 8a (Urban buses)

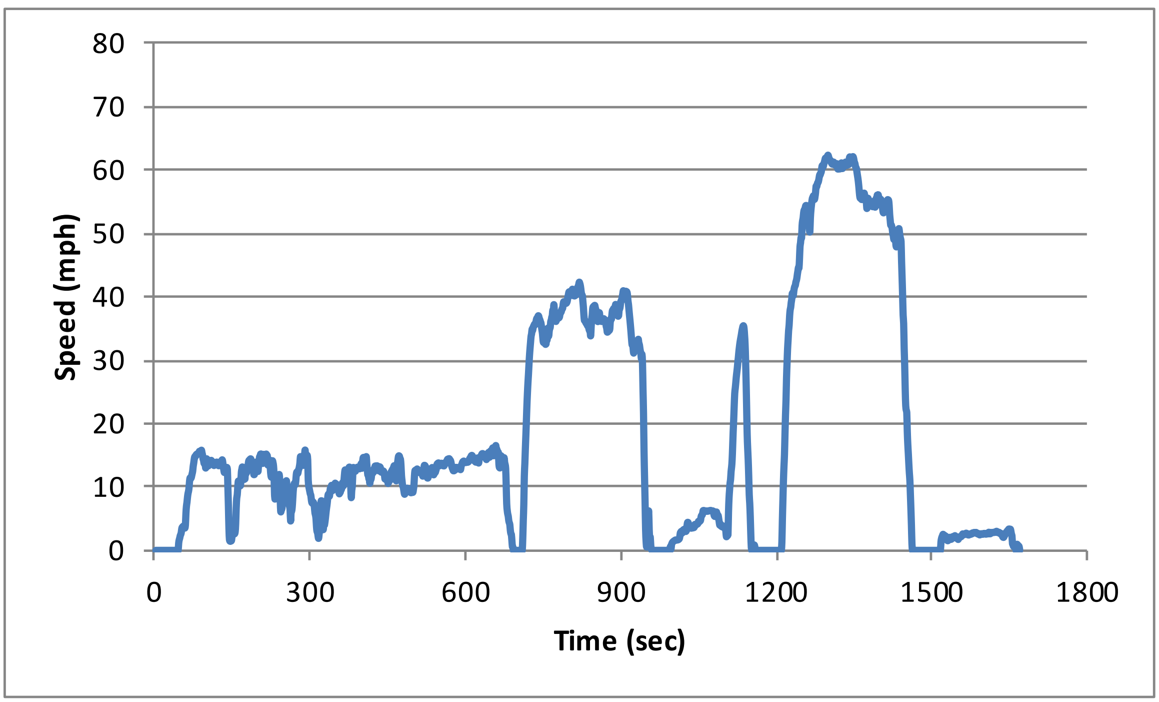


Figure 5-25. Drive cycle for Group 9b (Sweeping)

6. Conclusions

6.1. Concluding Remarks

An accurate characterization of vehicle activity is crucial to the construction of regional emissions inventory of on-road mobile sources. However, it is a challenging task given the limited availability of vehicle activity data at a large scale. Compared to light-duty vehicles, the availability of vehicle activity data for heavy-duty vehicles are even more limited. In addition, heavy-duty vehicles are comprised of a variety of vocations, each of which may have different operational requirements resulting in different vehicle activity patterns. Therefore, it is important to understand the extent of those differences so that appropriate emission control and mitigation strategies can be developed.

Vehicle activity patterns have significant implication for heavy-duty vehicles that employ SCR to meet the new 2010 NO_x emission standards. Typically, SCR needs to be at least 200 °C before significant NO_x reduction is achieved, but there are times when this temperature requirement may not be met such as right after engine start and during low engine loads. Thus, understanding the heavy-duty diesel vehicle activity profiles are critical to the quantification of real-world NO_x emissions from vehicles meeting the new 2010 NO_x emission standards and to the construction of NO_x emission inventories for these vehicles.

There have been improvements in data collection tools over the past decade. GPS receivers have continued to be smaller and more accurate. ECU data loggers have become cheaper and can now be integrated with GPS and wireless communication modems. This has resulted in the powerful data logging tool used in this research that can simultaneously collect data about vehicle position, speed, as well as engine parameters, and then transmit the data to a data server remotely in real time. This allows more data to be collected at a lower cost. The availability of ECU data in the collected vehicle activity data also allows for more accurate analysis of vehicle activity patterns. For example, in this research engine speed data was used to differentiate engine-on events from key-on events, which makes the resulting engine start and engine soak period statistics more accurate.

In this research, vehicle and engine activity data were collected from 90 heavy-duty vehicles that make up 19 different groups defined by a combination of vocational use, GVWR, and geographic region. Almost all of the vehicles are of model year 2010 or newer and are equipped with SCR technology. Due to the large amount of data items that were collected from both GPS and ECU, the size of the data for each group ranges from 0.7 to 12.1 GB. These data went through several steps of data processing and quality assurance to identify road type, filter and correct erroneous data, and protect fleet confidentiality. The processed data were then used to analyze a number of vehicle activity statistics related to engine start, engine soak, idle activity, SCR temperature, etc.

The vehicle activity analysis results reveal several findings about how the vehicle samples in each vocation operated during the data collection period. Some of the findings are as expected while some others are not intuitive or even surprising. Key findings include:

- The average speed values for the different vocations are mostly as expected. The average speed for line haul - out of state trucks is the highest at 41.1 mph while the average speed for drayage trucks in Northern California is the lowest at 8.9 mph. The vocations that have a low average speed value tend to spend a significant portion of time on non-freeway roads, for example, drayage trucks in Southern California, airport shuttles, refuse trucks, and urban buses.

- Line haul - in state trucks are found to have a much lower average speed value than line haul - out of state trucks (32.4 mph vs. 41.1 mph) as they spend much less time on freeways (53.7% vs. 68.2%), and almost double the amount of time idling (28.3% vs. 16.0%).

- The contrasts between urban buses and express buses are as expected. Express buses have twice as high an average speed than urban buses (20.5 mph vs. 10.1 mph)as they spend much more time on freeways (25.0% vs. 1.5%). On the other hand, urban buses have a higher percentage of time in brake mode (10.3% vs. 5.9%) as they have to make more stops and experience more congestion.

- It is also interesting to see the contrast between food distribution and beverage distribution trucks. Food distribution trucks have three times higher average speed (34.6 mph vs. 11.6 mph) as they spend significantly more time on freeways (62.9% vs. 8.3%) and less time idling (13.2% vs. 39.3%) than beverage distribution trucks. This could be partly because the food distribution trucks recruited in this research operate throughout Southern California while the beverage distribution trucks operate solely in the inner Los Angeles metropolitan area where traffic is generally more congested.

- Vehicles in most of the vocations spend about a third or more of their time in idle mode, irrespective of the percentage of time spent on non-freeway roads. The only exceptions are line haul - out of state trucks, line haul - in state trucks, food distribution trucks, and municipal work trucks. This is surprising for municipal work trucks because they spend 81.1% of their time on non-freeway roads but only 26.3% in idle mode. It would be interesting to examine whether the fleet implements any idle reduction technology or policy.

- The vocation with the highest percentage of time in idling mode is cement mixers. This is not surprising as these vehicles do their jobs while idling, which often involves the use of PTO. The same is true for utility repair trucks.

- As expected, the average speed values after excluding idle trips and extended idling events are higher across all vocations. The increases are greater for the vocations with a significant amount of idling time such as cement mixers, freeway work trucks, and utility repair trucks.

Key findings from the SCR temperature analysis include:

- The frequency distributions of SCR temperature for both out-of-state and in-state line haul trucks have two peaks. One of the peaks is around 260-280 °C, which is probably when driving on highways. The other one is around 100 °C, which is probably when idling.

- The Drayage - Northern California group consists of only one truck, which comes from the same fleet as the out-of-state line-haul trucks. This truck has the same engine make/model/year as one of the out-of-state line-haul trucks, but has a significantly different frequency distribution of SCR temperature where the distribution peaks at around 100-110 °C. This is a strong evidence of how the differences in vehicle activity patterns affect the SCR temperatures of the vehicles, and likely their real-world NO_x emissions.

- The SCR temperatures of agricultural trucks are found to be surprisingly low despite these trucks having similar operating patterns to line haul - in state trucks. One potential reason is that the engine size may be too large for the type of load and weight that they carry. Another potential reason may have to do with the specific engines and SCR systems used in these trucks as there is a distinct peak in the frequency distribution of SCR temperature at 100-110 °C.

- The SCR temperature frequency distribution for construction trucks and the one for cement mixers are similar to each other. They have the shape of Gaussian distribution with a single peak at around 190-210 °C. Both frequency distributions look unique as compared to the frequency distributions of the other vocation types.

- The SCR temperature frequency distribution for food distribution trucks and the one for beverage distribution trucks are similar to each other. They have the shape of Gaussian distribution with a major peak at around 220-250 °C and a minor peak at around 40-80 °C. One notable difference between them is that the distribution for food distribution trucks has more frequency at the temperature higher than 250 °C. This may be due to the food distribution trucks having a significantly higher fraction of time driving at freeway speeds.

- The SCR temperature frequency distribution for local moving trucks also has a major peak at around 220-250 °C. However, a minor peak at around 40-80 °C is so substantial that the distribution looks like a bi-modal Gaussian distribution.

- Sweeping trucks are able to maintain higher SCR temperatures than freeway work trucks despite having similar engine size and vehicle activity characteristics. This may be because freeway work trucks spend a higher fraction of idle time (54% vs. 33%) than sweeping trucks.
- Overall, it is found that on average the vehicles in this study operate with SCR temperature lower than 250 °C for 42-91% of the time and lower than 200 °C for 11-87% of the time, depending on their vocation. These portions of vehicle operation with low SCR temperature have a significant implication on the vehicles' real-world NO_x emission. By assuming a generic NO_x reduction curve as a function of SCR temperature for all the vehicles, the weighted average %reduction in engine-out NO_x emission ranges from 16% for agricultural trucks to 69% for refuse trucks. This would have a significant impact on the NO_x emission inventory of heavy-duty diesel vehicles in California.

The processed data were also used to develop a representative drive cycle for each of the 19 vocations. These vocation-specific drive cycles can be used for emission testing of a variety of heavy-duty vehicles in California. Since these drive cycles reflect real-world operating characteristics of the vehicles based on their vocational uses, they would better capture real-world emissions of heavy-duty vehicles in the different vocations than the one-size-fits-all approach based on the existing emission certification test cycle.

In addition to the key findings summarized above, this research has resulted in additional valuable products that can be used for CARB air quality planning and heavy-duty emissions reduction planning purposes. The research team has developed a database containing vehicle and engine activity data at the time resolution of 1 Hz. This database includes a large number of ECU and GPS data fields that can be analyzed to improve our understanding of real-world, in-use performance of vehicle, engine, and emission control system. The processing and quality assurance of ECU data is being conducted by Eastern Research Group with support from the U.S. EPA through the CRADA with UCR. The research team has also developed data processing and analysis scripts that can be used in similar efforts in the future. Lastly, the experiences gained during the conduct of this research, from recruiting truck fleets to protecting fleet confidentiality to handling and processing Big Data of vehicle activity, can serve as best practices for conducting large-scale vehicle activity studies in the future.

6.2. Recommendations for Future Research

While these results provide a significant insight into vehicle activity patterns of heavy-duty vehicles of a variety of vocations, it should be noted that the data were collected from a limited number of vehicles (no more than 8 vehicles in a vocation) from a very limited number of fleets (no more than 3 fleets in a vocation). Therefore, care should be taken when interpreting the results presented in this report as they may not be generalized to the entire heavy-duty vehicle population of that particular vocation in the state. For example, the drayage – Northern California and local moving groups each has only one vehicle sample. The activity patterns of these vehicle samples may not be representative of those of the vehicle population in their respective groups.

While this research is focused on vocational use as the primary factor of variability in heavy-duty vehicle activity patterns, there are other factors that could also contribute to such variability, some of which were also evident in the results presented in this report. These factors include, but not limited to:

- ***Geographic area:*** Activity patterns of heavy-duty vehicles could be highly influenced by where they are operated, for instance, in rural vs. urban area and in Northern California vs. Southern California vs. Central Valley. Part of the reason is that the level of traffic congestion in different areas is different. Vehicles operating in more congested areas would experience more stop-and-go driving. Also, land use patterns in different areas are different. Vehicles serving sprawling areas would have to travel more miles at higher speeds as compared to those serving compact urban areas. As an example, food distribution trucks in this research operates throughout Southern California and are found to have a higher average speed and a longer average trip distance than beverage distribution trucks that operates solely in the inner Los Angeles metropolitan area.

- ***Business practice:*** Activity patterns of heavy-duty vehicles could also be much dictated by business practice. For example, drayage trucks in Southern California in this research show a lot of activities during nighttime as there is a congestion pricing program at the Ports of Los Angeles and Long Beach that incentivizes these trucks to pick up and drop off containers during off-peak hours. In another example, beverage distribution trucks and utility repair trucks in this research have much shorter trip distance than trucks in the other vocations, which may be due to the size of the service areas that they cover. Also, some fleets may implement sustainability programs or technologies internally to reduce fuel consumption and emission from their vehicles such as speed limiter, idling reduction technology or policy, and driver training, all of which would impact the vehicle activity patterns. As an example, municipal work trucks spend 81.1% of their time on non-freeway roads but only 26.3% in idle mode, which may be attributable to idle reduction technology or policy.

To help better understand vehicle activity patterns of heavy-duty vehicles in California, additional research can be conducted as follows:

- Analyze the variability of vehicle activity patterns at the vehicle level. If the variability is high, then collect additional data from more number of vehicles in a particular vocation. As part of this analysis, revisit the grouping of the vehicles. Some groups may be further split while some groups may be consolidated. For example, statistical tests can be conducted to examine whether vehicle activity patterns of cement mixers are statistically different from those of construction trucks.

- Interview, by phone or email, fleet owners/managers of the fleets that participate in this research to relate the results and findings in this research to their fleet operation. For example, whether the time gaps where there is no vehicle activity are part of the normal business practices (e.g., regular maintenance) or unusual circumstances (e.g., vehicle breakdown).
- Associate idle trips and extended idling events with land use to understand whether these idle activities mainly occur at the home base or somewhere else. As part of this analysis, revisit the definition of extended idling events to better capture idle activities that should be subject to idle reduction regulations.

- Examine the relationships between SCR temperature and other ECU parameters such as percent engine load, torque, engine speed, and PTO. This will improve the understanding of factors contributing to low SCR temperatures.

- Develop SCR temperature models that estimate SCR temperature as a function of a variety of factors including vehicle activity (engine starts, engine soak period, speed profile, etc.), engine size, loaded weight, among others. The models can be used to adjust NO_x emission factors based on estimated SCR temperatures. This will improve the NO_x emission inventory of heavy-duty diesel vehicles equipped with SCR.

- Expand the data collection effort to include additional vocations of heavy-duty vehicles, medium-duty vehicles, and other diesel engines such as off-road equipment and marine vessels.

Appendix A:

List of ECU Parameters Requested

PGN (Dec)	PGN (Hex)	SPN	SPN Name
61443	F003	91	Accelerator Pedal Position 1
61443	F003	92	Engine Percent Load At Current Speed
61444	F004	513	Actual Engine - Percent Torque
61444	F004	190	Engine Speed
61445	F005	524	Transmission Selected Gear
61445	F005	526	Transmission Actual Gear Ratio
61445	F005	523	Transmission Current Gear
61450	F00A	2659	Engine Exhaust Gas Recirculation 1 Mass Flow Rate
61450	F00A	132	Engine Intake Air Mass Flow Rate
61450	F00A	5257	Engine Exhaust Gas Recirculation 2 Mass Flow Rate
61452	F00C	3030	Transmission Torque Converter Ratio
61454	F00E	3216	Aftertreatment 1 Selective Catalytic Reduction Intake Nox
61454	F00E	3220	Aftertreatment 1 Selective Catalytic Reduction Intake NOx Reading Stable
61454	F00E	3224	Aftertreatment 1 Selective Catalytic Reduction Intake NOx Sensor Preliminary FMI
61455	F00F	3226	Aftertreatment 1 Outlet Nox
61455	F00F	3230	Aftertreatment 1 Outlet NOx Reading Stable
61455	F00F	3234	Aftertreatment 1 Outlet NOx Sensor Preliminary FMI
61475	F023	4332	Aftertreatment 1 SCR System State
61477	F025	4377	Aftertreatment 1 Outlet NH3
61491	F033	5848	Aftertreatment 1 SCR Intermediate NH3
61491	F033	5850	Aftertreatment 1 SCR Intermediate NH3 Reading Stable
61497	F039	6392	Engine Desired Air Fuel Ratio
64585	FC49	6935	Aftertreatment 1 SCR System Total Cleaning Time
64585	FC49	6936	Aftertreatment 1 SCR System Total Number of System Cleaning Events
64585	FC49	6937	Aftertreatment 1 SCR System Total Number of System Cleaning Inhibit Requests
64585	FC49	6938	Aftertreatment 1 SCR System Total Number of System Cleaning Manual Requests
64585	FC49	6939	Aftertreatment 1 SCR System Average Time Between System Cleaning Events
64585	FC49	6940	Aftertreatment 1 SCR System Average Distance Between System Cleaning Events
64598	FC56	6819	Aftertreatment SCR Malfunction Time
64657	FC91	6579	Engine Exhaust NOx
64697	FCB9	5978	Aftertreatment 1 Diesel Particulate Filter Time to Next Active Regeneration
64697	FCB9	6941	Aftertreatment 1 SCR System Time Since Last System Cleaning Event
64709	FCC5	5862	Aftertreatment 1 SCR Intermediate Temperature
64709	FCC5	5863	Aftertreatment 1 SCR Intermediate Temperature Preliminary FMI
64713	FCC9	5785	Engine Fuel Valve 1 Temperature
64713	FCC9	5786	Engine Fuel Valve 2 Temperature
64735	FCDF	5578	Engine Fuel Delivery Absolute Pressure
64736	FCE0	5503	Aftertreatment 1 Fuel Mass Rate
64739	FCE3	5541	Engine Turbocharger 1 Turbine Outlet Pressure
64739	FCE3	5544	Engine Turbocharger 2 Turbine Outlet Pressure
64740	FCE4	5540	Engine Fuel Temperature (High Resolution)
64748	FCEC	5459	Aftertreatment 1 NOx Adsorber Regeneration Status
64752	FCF0	5417	Engine Fuel Filter (Suction Side) Intake Absolute Pressure
64828	FD3C	4374	Aftertreatment 1 Diesel Exhaust Fluid Pump Motor Speed

PGN (Dec)	PGN (Hex)	SPN	SPN Name
64828	FD3C	5435	Aftertreatment 1 Diesel Exhaust Fluid Pump State
64830	FD3E	4360	Aftertreatment 1 SCR Inlet Temperature
64830	FD3E	4363	Aftertreatment 1 SCR Outlet Temperature
64831	FD3F	4358	Aftertreatment 1 SCR Differential Pressure
64870	FD66	5020	Engine Exhaust Gas Recirculation 1 Mixer Intake Temperature
64878	FD6E	3826	Aftertreatment 1 Diesel Exhaust Fluid Average Consumption
64878	FD6E	3828	Aftertreatment 1 SCR Commanded Diesel Exhaust Fluid Consumption
64878	FD6E	5463	Aftertreatment SCR Operator Inducement Active Traveled Distance
64879	FD6F	4750	Engine Exhaust Gas Recirculation 1 Cooler Intake Temperature
64879	FD6F	4751	Engine Exhaust Gas Recirculation 1 Cooler Intake Absolute Pressure
64891	FD7B	3721	Aftertreatment 1 Diesel Particulate Filter Time Since Last Active Regeneration
64891	FD7B	5466	Aftertreatment 1 Diesel Particulate Filter Soot Load Regeneration Threshold
64892	FD7C	3699	Aftertreatment Diesel Particulate Filter Passive Regeneration Status
64892	FD7C	3700	Aftertreatment Diesel Particulate Filter Active Regeneration Status
64892	FD7C	3701	Aftertreatment Diesel Particulate Filter Status
64897	FD81	3672	Engine Exhaust Gas Recirculation 1 Cooler Bypass Actuator Postion
64920	FD98	3522	Aftertreatment 1 Total Fuel Used
64920	FD98	3523	Aftertreatment 1 Total Regeneration Time
64920	FD98	3524	Aftertreatment 1 Total Disabled Time
64920	FD98	3525	Aftertreatment 1 Total Number of Active Regenerations
64920	FD98	3725	Aftertreatment 1 Diesel Particulate Filter Total Passive Regeneration Time
64929	FDA1	3480	Aftertreatment 1 Fuel Pressure 1
64929	FDA1	3481	Aftertreatment 1 Fuel Rate
64931	FDA3	3675	Engine Turbocharger Compressor Bypass Actuator 1 Position
64932	FDA4	3941	Engagement Status - PTO Engine Flywheel
64932	FDA4	3944	Engagement Status - PTO Engine Accessory Drive 1
64932	FDA4	3947	Engagement Status - PTO Engine Accessory Drive 2
64932	FDA4	3948	At least one PTO engaged
64946	FDB2	3250	Aftertreatment 1 Diesel Particulate Filter Intermediate Temperature
64946	FDB2	3251	Aftertreatment 1 Diesel Particulate Filter Differential Pressure
64947	FDB3	3246	Aftertreatment 1 Diesel Particulate Filter Outlet Temperature
64948	FDB4	3241	Aftertreatment 1 Exhaust Temperature 1
64948	FDB4	3242	Aftertreatment 1 Diesel Particulate Filter Intake Temperature
64976	FDD0	3562	Engine Intake Manifold #2 Pressure
64976	FDD0	3563	Engine Intake Manifold #1 Absolute Pressure
64981	FDD5	2791	Engine Exhaust Gas Recirculation 1 Valve 1 Control 1
65110	FE56	1761	Aftertreatment 1 Diesel Exhaust Fluid Tank Level
65110	FE56	3031	Aftertreatment 1 Diesel Exhaust Fluid Tank Temperature
65110	FE56	5245	Aftertreatment Selective Catalytic Reduction Operator Inducement Active
65153	FE81	1440	Engine Fuel Flow Rate 1
65153	FE81	1442	Engine Fuel Valve 1 Position
65174	FE96	1188	Engine Turbocharger Wastegate Actuator 1 Position

PGN (Dec)	PGN (Hex)	SPN	SPN Name
65188	FEA4	411	Engine Exhaust Gas Recirculation 1 Differential Pressure
65190	FEA6	1127	Engine Turbocharger 1 Boost Pressure
65203	FEB3	1028	Total Engine PTO Governor Fuel Used
65203	FEB3	1029	Trip Average Fuel Rate
65208	FEB8	1007	Trip Drive Fuel Used (Gaseous)
65208	FEB8	1008	Trip PTO Governor Moving Fuel Used (Gaseous)
65208	FEB8	1009	Trip PTO Governor Non-moving Fuel Used (Gaseous)
65208	FEB8	1010	Trip Vehicle Idle Fuel Used (Gaseous)
65209	FEB9	1001	Trip Drive Fuel Used
65209	FEB9	1002	Trip PTO Governor Moving Fuel Used
65209	FEB9	1003	Trip PTO Governor Non-moving Fuel Used
65209	FEB9	1004	Trip Vehicle Idle Fuel Used
65213	FEBD	977	Fan Drive State
65213	FEBD	975	Estimated Percent Fan Speed
65217	FEC1	917	Total Vehicle Distance (High Resolution)
65217	FEC1	918	Trip Distance (High Resolution)
65226	FECA	987	DM1 - Flash Engine Amber Warning Lamp (AWL)
65226	FECA	624	DM1 - Flash Engine Protect Lamp
65226	FECA	623	DM1 - Flash Engine Red Stop Lamp (RSL)
65226	FECA	1213	DM1 - Protect Lamp
65226	FECA	3041	DM1 - Amber Warning Lamp
65226	FECA	3040	DM1 - Red Stop Lamp
65226	FECA	3039	DM1 - Malfunction Indicator Lamp
65226	FECA	3038	DM1 - Failure Mode Identifier
65226	FECA	1214	DM1 - Ocurrence Count
65226	FECA	1215	DM1 - SPN Conversion Method
65226	FECA	1216	DM1 - Suspect Parameter Number
65226	FECA	1706	DM1 - Flash Malfunction Indicator Lamp
65236	FED4	987	DM12 - Protect Lamp
65236	FED4	624	DM12 - Amber Warning Lamp
65236	FED4	623	DM12 - Red Stop Lamp
65236	FED4	1213	DM12 - Malfunction Indicator Lamp
65236	FED4	3041	DM12 - Flash Protect Lamp
65236	FED4	3040	DM12 - Flash Amber Warning Lamp (AWL)
65236	FED4	3039	DM12 - Flash Red Stop Lamp (RSL)
65236	FED4	3038	DM12 - Flash Malfunction Indicator Lamp
65236	FED4	1214	DM12 - Suspect Parameter Number
65236	FED4	1215	DM12 - Failure Mode Identifier
65236	FED4	1216	DM12- Ocurrence Count
65236	FED4	1706	DM12 - SPN Conversion Method
65244	FEDC	236	Engine Total Idle Fuel Used
65244	FEDC	235	Engine Total Idle Hours
65245	FEDD	103	Engine Turbocharger 1 Speed
65247	FEDF	514	Nominal Friction - Percent Torque
65247	FEDF	515	Engine's Desired Operating Speed
65247	FEDF	519	Engine's Desired Operating Speed Asymmetry Adjustment
65247	FEDF	2978	Estimated Engine Parasitic Losses - Percent Torque
65247	FEDF	3236	Aftertreatment 1 Exhaust Gas Mass Flow Rate
65248	FEE0	244	Trip Distance
65248	FEE0	245	Total Vehicle Distance
65251	FEE3	188	Engine Speed At Idle, Point 1
65251	FEE3	539	Engine Percent Torque At Idle, Point 1

PGN (Dec)	PGN (Hex)	SPN	SPN Name
65251	FEE3	528	Engine Speed At Point 2
65251	FEE3	540	Engine Percent Torque At Point 2
65251	FEE3	529	Engine Speed At Point 3
65251	FEE3	541	Engine Percent Torque At Point 3
65251	FEE3	530	Engine Speed At Point 4
65251	FEE3	542	Engine Percent Torque At Point 4
65251	FEE3	531	Engine Speed At Point 5
65251	FEE3	543	Engine Percent Torque At Point 5
65251	FEE3	532	Engine Speed At High Idle, Point 6
65251	FEE3	544	Engine Reference Torque
65251	FEE3	533	Engine Maximum Momentary Override Speed, Point 7
65251	FEE3	535	Engine Requested Speed Control Range Lower Limit
65251	FEE3	536	Engine Requested Speed Control Range Upper Limit
65251	FEE3	537	Engine Requested Torque Control Range Lower Limit
65251	FEE3	538	Engine Requested Torque Control Range Upper Limit
65251	FEE3	1712	Engine Requested Speed Control Range Upper Limit (Extended Range)
65251	FEE3	1794	Engine Moment of Inertia
65251	FEE3	1846	Engine Default Torque Limit
65253	FEE5	247	Engine Total Hours of Operation
65255	FEE7	246	Total Vehicle Hours
65257	FEE9	182	Engine Trip Fuel
65257	FEE9	250	Engine Total Fuel Used
65262	FEEE	110	Engine Coolant Temperature
65262	FEEE	174	Engine Fuel Temperature 1
65262	FEEE	175	Engine Oil Temperature 1
65265	FEF1	84	Wheel-Based Vehicle Speed
65266	FEF2	183	Engine Fuel Rate
65266	FEF2	184	Engine Instantaneous Fuel Economy
65266	FEF2	51	Engine Throttle Valve 1 Position 1
65269	FEF5	108	Barometric Pressure
65269	FEF5	105	Engine Intake Air Temperature
65270	FEF6	105	Engine Intake Manifold 1 Temperature
65270	FEF6	106	Engine Intake Air Pressure
65270	FEF6	173	Engine Exhaust Temperature

Appendix B:

Data Logger Installation Procedure and Form

HEM J1939 Data Logger Installation Procedure v01

Date created: 01/13/2015: Daniel Sandez

Required Items

- J1939 mini logger
- MicroSD card
- Computer with DawnEdit2 software and Microsoft Excel or similar spreadsheet software.
- USB Memory Card Reader or MicroSD to SD adapter if computer already has an SD card reader.

Preparing for Data Logging

There are two versions of the HEM J1939 Mini Logger. The older version is defined by a 5-digit serial number, while the newer version has a 4-digit serial number. The new version of the logger contains an internal battery, which when discharged will cause problems when attempting to log data. **PLEASE SEE APPENDIX A FOR MORE INFORMATION ON USING THE NEW LOGGERS.**

The HEM logger can be operated in either free record mode, or selective record mode. The mode is determined through a file (config.txt) created with the DawnEdit2 software.

Free Record Mode

Free record mode collects all data it sees on the CAN bus. For this project we will not be using this mode.

Selective Record Mode

Selective record mode only records data specified in the config.txt file. To operate the logger in this mode, follow these steps.

1. A “config.txt” file should have been provided to you by UCR. Navigate to the folder where it is saved and proceed to step 2.

2. Remove the MicroSD card from logger and connect it to the computer.

3. On a separate window, navigate to the root folder of the MicroSD card (this will be a drive letter followed by a slash, e.g. “E:\”).

4. Copy the config.txt file you want to use and paste it in the root folder of the logger’s Micro SD card.

5. Close the MicroSD card folder and eject MicroSD card from computer and plug into logger.

6. Proceed to Data Logging section.

Data Logging

Now that the logger is loaded with the config.txt file, follow these steps to connect the logger to the vehicle and start the recording of data.

1. Locate the J1939 9-pin Deutsch connector in the vehicle. For most commercial heavy-duty vehicles, it is located underneath the dashboard. Some engines may have two different connectors (grey or black 9-pin and grey 6-pin). The HEM logger only plugs in into the 9-pin connector.

2. With the engine off, and ignition switch off, plug in the logger. The logger only goes in one way. Once the logger is fully inserted, make sure to rotate the ring clockwise until it locks into place.

3. Turn engine on and observe logger's LED. After a few seconds, the LED should start blinking green. The logger will continue logging data as long as the engine is on.

NOTE: IF LED IS NOT FLASHING GREEN, THEN THE LOGGER IS NOT LOGGING DATA. REPEAT ALL PREVIOUS STEPS WITH DIFFERENT LOGGER. IF RESULT IS THE SAME, DO NOT LEAVE A LOGGER ON THE VEHICLE.

4. If possible, have a qualified driver take the vehicle out for a short drive. Instruct the driver to leave the engine on upon parking after the test drive. If the vehicle can't be taken out for the drive, let the logger record about 5 minutes of data with engine idling, then proceed to step 6.

5. Once the driver steps off the vehicle (engine should still be on), or after 5 minutes of idling, check the logger's LED to make sure it is still blinking green. If not, there is a problem.

6. **Removing logger (VERY IMPORTANT):** The logger continuously writes to the file so you do not want to remove the logger while the engine and/or ignition switch is on as you may damage the data file or the logger.
    1. First turn off the engine, and make sure ignition switch is in "Off" position.
    2. Once engine is off, wait for the red and blue lights to stop flashing (red means writing, blue means closing file).
    3. Once the LED turns off completely, remove logger.
    4. Proceed to Data Extraction section.

Data Extraction

1. Remove the MicroSD card from the logger and plug it into computer with access to the DawnEdit2 software.

2. In DawnEdit2, open the project's database ("J1939_CARB v##.xml") by clicking on "File > Open Database", and navigating to the folder where it is saved. The database

file should have been provided to you by UCR.

3. In DawnEdit2, click on the heading “Logger” and select “Convert Mini Logger Data File to CSV…” from the drop-down menu. Choose the directory containing the .IOS file corresponding to the file that you have just recorded, and choose where you would like the .CSV file to be saved (**See Figure 1 for example setup screen**).

4. Click “Convert” in the bottom right-hand corner of the prompt (See Figure B-1). The window should indicate how many files were converted in the bottom, left-hand side.

5. Open the .CSV file with Microsoft Excel to verify data.

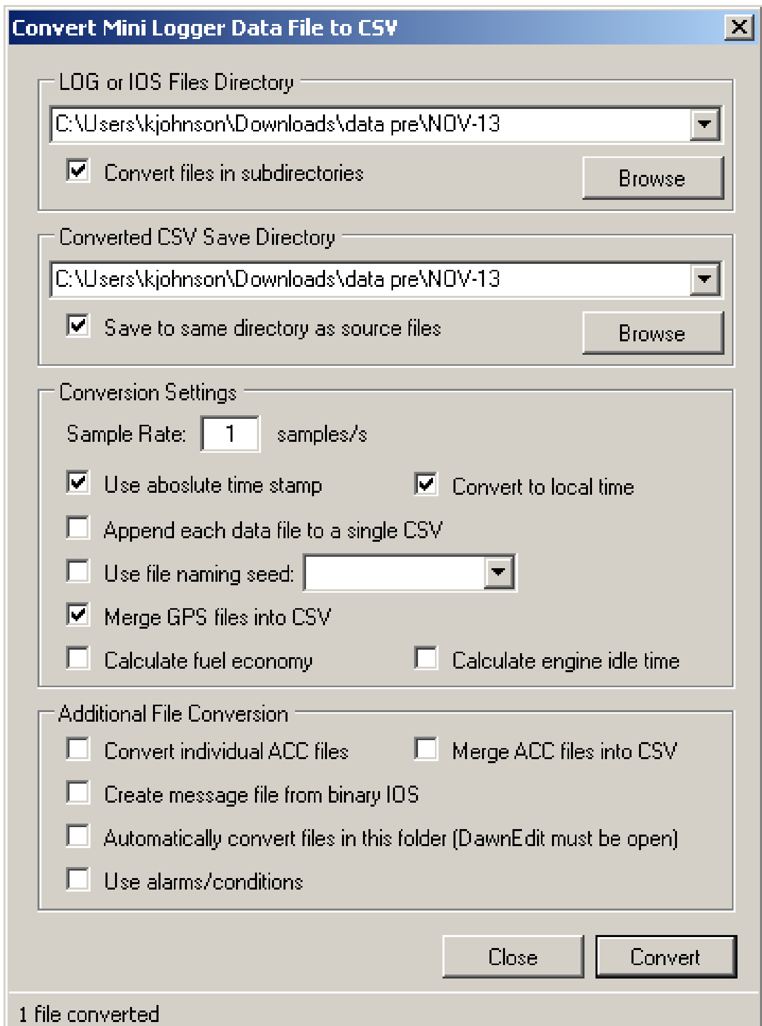


Figure B-1. Convert mini logger files to CVS window

Using the New Version of J1939 Loggers

The new version of HEM Data's J1939 logger (four-digit serial number) includes an internal battery which is intended to maintain the real-time clock of the device between uses. When fully charged it will last from a couple weeks to a month.

Unfortunately, there is a bug in the firmware that causes the logger to misbehave when attempting to log data with a fully discharged battery. When you attempt to log data with a logger in this state, it will simply blink red even after turning the ignition off. Analyzing the contents of the MicroSD card will reveal corrupted folders.

To avoid this issue, the internal battery of the logger can be pre-charged by plugging in the logger to a computer or USB wall charger using a Mini-USB cable. The Mini-USB port on the logger is right next to the MicroSD card slot. The LED on the logger will blink blue when the battery is charging. **Ideally, you want to pre-charge the logger for at least one hour, and do it preferably on the day of installation or the previous day at the earliest.**

If the red blinking LED problem arises in the field, leaving the logger plugged in for about 10 minutes with the engine on, then unplugging it and plugging it back in with the engine still on, should make it work again. Unfortunately, the MicroSD card will be corrupted, and reformatting it is necessary once the logger is operating properly to avoid potential data issues.

To reformat the MicroSD card, connect it to the computer, then in the "My Computer" window, right click on the folder for the SD card and select "Format". Choose FAT32 as the file system, default allocation size for "Allocation Unit Size", and make sure the "Quick Format" option is ticked.

Vehicle and Data Logger Installation Form

Center for Environmental Research & Technology, UCR

Name of the Fleet Owner:____________________Phone Number/Email:__________________

Address: ____

Name of Driver: _____________phone:______________Mileage Odometer:______________

Trailer Types: ☐ Goods delivery ☐ Services Construction ☐ Agriculture ☐ Other

Data Logger ID:________________Date of Installation Start:_____________Stop:__________

Comment: ____

Getting Information by Researcher ☐

Vehicle Manufacturer:__________________VIN #:(17 DIGIT):_______________________

Vehicle Model Year:_______Hybrid Technology: ☐ Y ☐ N GVWR:_______# Gears:_____

Transmission Manufacturer:_________________Model: ____________Ratio:____________

Fleet Tractor #:___________License Plate # :________________Total Number of Axles:_____

Getting Information from Picture of door sticker, glove compartment and License Plate ☐

Engine Manufacturer:___________________________Model:_____________Year:________

Engine Family #:_______________________________Engine Serial#:___________________

Engine Displacement:______# of Cylinders:____________Configuration:_________________

Engine Rebuilt: ☐ Y ☐ N If Yes, Year of Rebuild:__________Primary Fuel Type:_________

#of Fuel Tanks:________________Capacity:_________________Idle Speed:_______________

Max. Engine Power:_______hp @______RPM Max. Engine Torque:_____ftlbs @______RPM

After-treatment Configuration: ☐ DPF ☐ SCR ☐ ☐

After-treatment information should be checked from On-Road New Vehicle & Engine Certification Program
http://www.arb.ca.gov/msprog/onroad/cert/cert.php#6

Getting Information from Picture of Engine ☐
Picture Folder on server ☐
Downloading the EO ☐

Appendix C:

Vehicle and Engine Information

Table C-1. Engine information

Veh ID	Engine Manufacturer	Engine Model	Engine Family	Engine Serial Number	Engine Model Year	Rated Power (HP)	Rated Speed (rpm)
			Line haul - out of state				
18	Cummins	ISX15 450	CCEXH0912XAP		2012	450	1800
19	Cummins	ISX15 450	DCEXH0912XAT		2013	450	1800
20	Cummins	ISX15 450	ECEXH0912XAT		2014	450	1800
			Line haul - in state				
114	Detroit Diesel	DD15AT	FDDXH14.8EAD		2015	505	1800
116	Detroit Diesel	DD13	FDDXH12.8FED		2015	500	1800
117	Detroit Diesel	DD13	FDDXH12.8FED		2015	500	1800
			Drayage - No. Cal.				
99	Cummins	ISX15 450	CCEXH0912XAP	79583862	2012	450	1800
			Drayage - So. Cal.				
73	MACK	MP8-415C	CVPTH12.8S01	1007362	2012	415	1500
75	MACK	MP8-415C	CVPTH12.8S01	1016600	2012	415	1500
76	MACK	MP8-415C	CVPTH12.8S01	1017135	2012	415	1500
78	MACK	MP8-415C	CVPTH12.8S01	1019156	2012	415	1500
79	Detroit Diesel	Series 60	8DDXH14.0ELC	06R1021755	2008		
			Agricultural - So. CV				
85	Paccar	MX	APCRH12.9M01 BPCRH12.9M01		2010/11		
86	Paccar	MX	APCRH12.9M01 BPCRH12.9M01		2010/11		
87	Paccar	MX	CPCRH12.9M01	Y012086	2013	455	1900
88	Paccar	MX-13	DPCRH12.9M01	Y037590	2014	455	1700
89	Mercedez-Benz (Detroit Diesel)	OM 460 LA CID 781	8DDXH12.8DJC		2009	450	1900
90	Mercedez-Benz (Detroit Diesel)	OM 460 LA CID 781	8DDXH12.8DJC		2009	450	1900
91	Paccar	MX-13	DPCRH12.9M01	Y038547	2014	455	1700
92	Paccar	MX-13	DPCRH12.9M01	Y039302	2014	455	1700
			Construction				
1	Cummins	ISB6.7 240			Unknown	240	2300
55	Paccar	ISL 300	ECEXH0540LAV		Unknown		
56	Paccar	ISL 300	ECEXH0540LAV		Unknown		
80	Paccar	ISX15 485	BCEXH0912XAQ	79512219	2011	485	1800
81	Paccar	ISX15 550	FCEXH0912XAU	79852598	2015	550	2000
82	Paccar	ISX15 550	FCEXH0912XAU	79852599	2015	550	2000
			Cement mixers				
83	Cummins	ISL9 350	DCEXH0540LAV	73568362	Unknown	350	2200
84	Cummins	ISL9 350	DCEXH0540LAV	73613598	Unknown	350	2200
111	Paccar	ISL9 370	FCEXH0540LAV		2013	370	1900
112	Paccar	ISL9 370	FCEXH0540LAV	73823467	2013	370	1900
113	Paccar	ISL9 370	FCEXH0540LAV	73833556	2013	370	1900

Table C-1. Engine information (continued)

Veh ID	Engine Manufacturer	Engine Model	Engine Family	Engine Serial Number	Engine Model Year	Rated Power (HP)	Rated Speed (rpm)
Food distribution							
50	Detroit Diesel	DD13	DDDXH12.8FED	47192750197632	2013	500	1800
51	Detroit Diesel	DD13	DDDXH12.8FED	47192750197637	2013	500	1800
52	Detroit Diesel	DD13	DDDXH12.8FED	47192750197419	2013	500	1800
53	Detroit Diesel	DD13	DDDXH12.8FED	47192750197635	2013	500	1800
54	Detroit Diesel	DD13	DDDXH12.8FED	47192750197460	2013	500	1800
Beverage distribution							
9	Paccar	PX-9			2003		
10	Cummins	ISX11.9 370	BCEXH0729XAB		2011	370	2100
13	Paccar	PX-9			2013		
14	Paccar	PX-8			2012		
16	Paccar	PX-9			2013		
17	Paccar	PX-8			2012		
Local moving							
49	Navistar	A410	DNVXH07570SB	126HM2Y4300244	2013	410	1700
Airport shuttle							
57	Cummins	ISL			2012		
58	Cummins	ISL			2012		
59	Cummins	ISL			2012		
60	Cummins	ISL			2012		
61	Cummins	ISL			2012		
Refuse							
24	Cummins	ISL		73411471	2010	380	2100
25	Cummins	ISL		73236156	2010	345	2100
26	Unknown	Unknown			Unknown		
102	Cummins	ISL		73118726	Unknown		
103	Cummins	ISL		73411470	2010	380	2100
104	Cummins	ISL9		73623319	2013	345	2100
Urban buses							
68	Unknown	Unknown		73471643	Unknown		
69	Unknown	Unknown			Unknown		
70	Unknown	Unknown			Unknown		
108	Unknown	Unknown			Unknown		
109	Unknown	Unknown			Unknown		
110	Unknown	Unknown			Unknown		
Express buses							
93	Cummins	ISL G280	DCEXH0540LBG	73622386	2013	280	2200
94	Cummins	ISL G280	DCEXH0540LBG	73621068	2013	280	2200
95	Cummins	ISL G280	DCEXH0540LBG	73621526	2013	280	2200
96	Cummins	ISL G280	DCEXH0540LBG	73622493	2013	280	2200
97	Cummins	ISL G280	DCEXH0540LBG	73754071	2013	280	2200

Table C-1. Engine information (continued)

Veh ID	Engine Manufacturer	Engine Model	Engine Family	Engine Serial Number	Engine Model Year	Rated Power (HP)	Rated Speed (rpm)
			Freeway work				
3	Cummins	ISB6.7 260	CCEXH0408BAH		2012	260	2400
4	Cummins	ISB6.7 260	CCEXH0408BAH		2012	260	2400
37	Cummins	ISB6.7 260	CCEXH0408BAH	73409465	2012	260	2400
38	Cummins	ISB6.7 260	CCEXH0408BAH	73409450	2012	260	2400
62	Cummins	ISB6.7 260	CCEXH0408BAH	73428308	2012	260	2400
			Sweeping				
40	Cummins	ISB6.7 280	CCEXH0408BAH		2012	280	2400
41	Cummins	ISB6.7 280	CCEXH0408BAH	73471266	2012	280	2400
42	Cummins	ISB6.7 280	DCEXH0408BAP	73569694	2013	280	2400
43	Cummins	ISB6.7 280	CCEXH0408BAH	73491289	2012	280	2400
44	Cummins	ISB6.7 280	CCEXH0408BAH	73471269	2012	280	2300
			Municipal work				
5	Detroit Diesel	DD13 12.8	ADDXH12.8FED		2010	500	1800
6	Cummins	ISB6.7 240	ACEXH0408BAH		2010	240	2300
7	Cummins	ISB6.7 240	ACEXH0408BAH		2010	240	2300
			Towing				
45	Cummins	ISX15 550	CCEXH0912XAR	79610425	2012	550	1800
46	Cummins	ISX15 525	ECEXH0912XAU	79738668	2014	525	2000
47	Cummins	ISX15 550	ECEXH0912XAU	79740508	2014	550	2000
48	PACCAR	PX-8			Unknown		
105	Cummins	ISB6.7 260	ECEXH0408BAP	73691584	2014	260	2400
106	Cummins	ISB6.7 280	DCEXH0408BAP	73537569	2013	280	2400
107	Cummins	ISB6.7 281	ECEXH0408BAP	73751040	2014	280	2400
			Utility repair				
63	Detroit Diesel	DD13	CDDHX12.8FED	47191350148273	2012	500	1800
64	Detroit Diesel	DD13	CDDHX12.8FED	47191350148269	2012	500	1800
65	Detroit Diesel	DD13	CDDHX12.8FED	47191350148281	2012	500	1800
66	Detroit Diesel	DD13	CDDHX12.8FED	47192750195823	2012	500	1800
67	Detroit Diesel	DD13	CDDHX12.8FED	47192750196165	2012	500	1800

Table C-2. Vehicle and aftertreatment information

Veh ID	Weight (lbs)	Vehicle Manufacturer	Vehicle Model	Vehicle Model Year	Emissions control (EC) equipment
Line haul - out of state					
18	53,200	KENWORTH		2012	EGR, PTOX, SCRC
19	53,200	KENWORTH	T660	2013	EGR, PTOX, SCRC
20	53,200	KENWORTH		2014	EGR, PTOX, SCRC
Line haul - in state					
114	53,220	Freightliner	PX125064S T	2015	TC, CAC, EGR, DDI, ECM, DOC, PTOX, SCR, AMOX
116	52,000	Freightliner	PX125064S T	2015	TC, CAC, EGR, DDI, ECM, DOC, PTOX, SCR, AMOX
117	52,000	Freightliner	PX125064S T	2015	TC, CAC, EGR, DDI, ECM, DOC, PTOX, SCR, AMOX
Drayage - No. Cal.					
99	53,200	KENWORTH	T660	2012	EGR, PTOX, SCRC
Drayage - So. Cal.					
73	52,000	MACK	CXU613	2012	
75	52,000	MACK	CXU613	2012	TC, CAC, EGR, DDI, ECM, DOC, PTOX, SCR, AMOX
76	52,000	MACK	CXU613	2012	TC, CAC, EGR, DDI, ECM, DOC, PTOX, SCR, AMOX
78	52,000	MACK	CXU613	2013	TC, CAC, EGR, DDI, ECM, DOC, PTOX, SCR, AMOX
79	Unknown	MACK	Freightliner	2008	Unknown
Agricultural - So. CV					
85	Unknown	Peterbilt	384	2012	Unknown
86	Unknown	Peterbilt	384	2012	Unknown
87	Unknown	Peterbilt	388	2013	Unknown
88	Unknown	Peterbilt	388	2014	Unknown
89	Unknown	Freightliner		2009	Unknown
90	Unknown	Freightliner		2009	Unknown
91	Unknown	Kenworth	T680	2014	Unknown
92	Unknown	Kenworth	T680	2014	Unknown
Construction					
1	33,000	FORD	F750 4X2	2012	Unknown
55	54,600	Peterbilt		Unknown	Unknown
56	54,600	Peterbilt		Unknown	Unknown
80	52,000	Peterbilt		2011	EGR, PTOX, SCRC
81	53,200	Peterbilt	PB367	2015	EGR, PTOX, SCRC
82	53,200	Peterbilt	PB367	2015	EGR, PTOX, SCRC
Cement mixers					
83	Unknown	Freightliner	108SD	2014	Unknown
84	Unknown	Freightliner	108SD	2014	Unknown
111	60,000	Kenworth	W900	2015	EGR, PTOX, SCRC
112	60,000	Kenworth	W900	2015	EGR, PTOX, SCRC
113	60,000	Kenworth	W900	2015	EGR, PTOX, SCRC

Table C-2. Vehicle and aftertreatment information (continued)

Veh ID	Weight (lbs)	Vehicle Manufacturer	Vehicle Model	Vehicle Model Year	Emissions control (EC) equipment
			Food distribution		
50	52,000	Freightliner		2013	DDI, TC, CAC, ECM, EGR, OC, PTOX, SCR-U, AMOX
51	52,000	Freightliner		2013	DDI, TC, CAC, ECM, EGR, OC, PTOX, SCR-U, AMOX
52	52,000	Freightliner		2013	DDI, TC, CAC, ECM, EGR, OC, PTOX, SCR-U, AMOX
53	52,000	Freightliner		2013	DDI, TC, CAC, ECM, EGR, OC, PTOX, SCR-U, AMOX
54	52,000	Freightliner		2013	DDI, TC, CAC, ECM, EGR, OC, PTOX, SCR-U, AMOX
			Beverage distribution		
9	33,000	Peterbilt	PB337	2013	Unknown
10	52,000	Peterbilt		2011	EGR, PTOX, SCRC
13	33,000	Peterbilt	PB337	2013	Unknown
14	33,000	Peterbilt	PB337	2012	Unknown
16	33,000	Peterbilt	PB337	2013	Unknown
17	33,000	Peterbilt	PB337	2012	Unknown
			Local moving		
49	Unknown	Navistar	International	2013	Unknown
			Airport shuttle		
57	17,963	Gillig	G27D102N4	2012	Unknown
58	17,963	Gillig	G27D102N4	2012	Unknown
59	17,963	Gillig	G27D102N4	2012	Unknown
60	17,963	Gillig	G27D102N4	2012	Unknown
61	17,963	Gillig	G27D102N4	2012	Unknown
			Refuse		
24	66,000	AUTOCAR		2012	Unknown
25	Unknown	AUTOCAR		2011	Unknown
26	58,180	KENWORTH	T4	2013	Unknown
102	Unknown			Unknown	Unknown
103	Unknown			Unknown	Unknown
104	Unknown			Unknown	Unknown
			Urban buses		
68	39,600	Gillig	G30D102N4	2013	Unknown
69	57,541	Nova Bus		2014	Unknown
70	57,541	Nova Bus		2014	Unknown
108	39,600	Gillig	G30D102N4	2013	Unknown
109	39,600	Gillig	G30D102N4	2012	Unknown
110	39,600	Gillig	G30D102N4	2013	Unknown
			Express buses		
93	Unknown	Gillig LLC	G27D102N4	2014	Unknown
94	Unknown	Gillig LLC	G27D102N5	2015	Unknown
95	Unknown	Gillig LLC	G27D102N6	2016	Unknown
96	Unknown	Gillig LLC	G27D102N7	2017	Unknown
97	Unknown	Gillig LLC	G27D102N8	2018	Unknown

Table C-2. Vehicle and aftertreatment information (continued)

Veh ID	Weight (lbs)	Vehicle Manufacturer	Vehicle Model	Vehicle Model Year	Emissions control (EC) equipment
Freeway work					
3	26,000	Ford	F650 4X2	2014	EGR, PTOX, SCRC
4	26,000	Ford	F650 4X2	2013	EGR, PTOX, SCRC
37	26,000	Ford	F650 4X2	2012	EGR, PTOX, SCRC
38	26,000	Ford	F650 4X2	2012	EGR, PTOX, SCRC
62	26,000	Ford	F650 4X2	2012	EGR, PTOX, SCRC
Sweeping					
40	27,000	Global	M4	2013	EGR, PTOX, SCRC
41	27,000	Global	M4	2013	EGR, PTOX, SCRC
42	27,000	Global	M4	2013	EGR, PTOX, SCRC
43	27,000	Global	M4	2013	EGR, PTOX, SCRC
44	27,000	Global	M4	2013	EGR, PTOX, SCRC
Municipal work					
5	54,600	Freightliner	MM1120645	2010	Unknown
6	33,000	Freightliner	MM106042S	2010	EGR, PTOX SCRC
7	33,000	Freightliner	MM106042S	2010	EGR, PTOX SCRC
Towing					
45	64,600	Peterbilt		2012	EGR, PTOX, SCRC
46	52,000	Peterbilt		2014	EGR, PTOX, SCRC
47	76,000	Peterbilt		2014	EGR, PTOX, SCRC
48	33,000	Peterbilt	PB337	2011	Unknown
105	33,000	Freightliner	FDTN2VOCV04C	2014	EGR, PTOX, SCRC
106	26,000	Ford	F650 4X2	2013	EGR, PTOX, SCRC
107	26,000	Ford	F650 4X3	2014	EGR, PTOX, SCRC
Utility repair					
63	66,000	Freightliner	DDTN2VOCV05C	2013	LRRS
64	66,000	Freightliner	DDTN2VOCV05C	2012	LRRS
65	66,000	Freightliner	DDTN2VOCV05C	2012	LRRS
66	66,000	Freightliner	DDTN2VOCV05C	2013	LRRS
67	66,000	Freightliner	DDTN2VOCV05C	2013	LRRS

Appendix D:

Drive Cycle Development Method Comparison

UCR | College of Engineering- Center for Environmental Research & Technology

Driving Cycle Development Methods

- Segmentation method (e.g., micro-trip)
  - Connecting vehicle activity snippets to create a pool of candidate driving cycles, and then select one that is most representative.
- Probabilistic method (e.g., Markov chain)
  - Define states of vehicle activity and develop a transition matrix for these states based on the entire data population. Then, use the transition matrix to generate driving cycles.
    - Driving states can be defined in various ways such as velocity/acceleration pairs or driving modes (acceleration, deceleration, cruise, etc.)

1

UCR | College of Engineering- Center for Environmental Research & Technology

Considerations in Cycle Development

- Splitting activity data
  - At idle (e.g., at first or last second of idle, in middle of idle period)
  - At specified interval (e.g., 10 seconds, 20 seconds)
  - When driving condition changes (e.g., road type, level of congestion, driving mode)
- Connecting snippets
  - Thresholds for difference in speed, acceleration, and/or power
  - Methods for speed transition (e.g., linear interpolation, polynomial smoothing filter, binomial smoothing filter)
- Selecting representative cycle
  - Criteria (e.g., percent idle, mean speed, max acceleration, joint speed-acceleration distribution, operating mode distribution)
  - Performance measures (e.g., sum absolute error, mean squared error, Kolmogorov-Smirnov stat)

2

UCR | College of Engineering- Center for Environmental Research & Technology

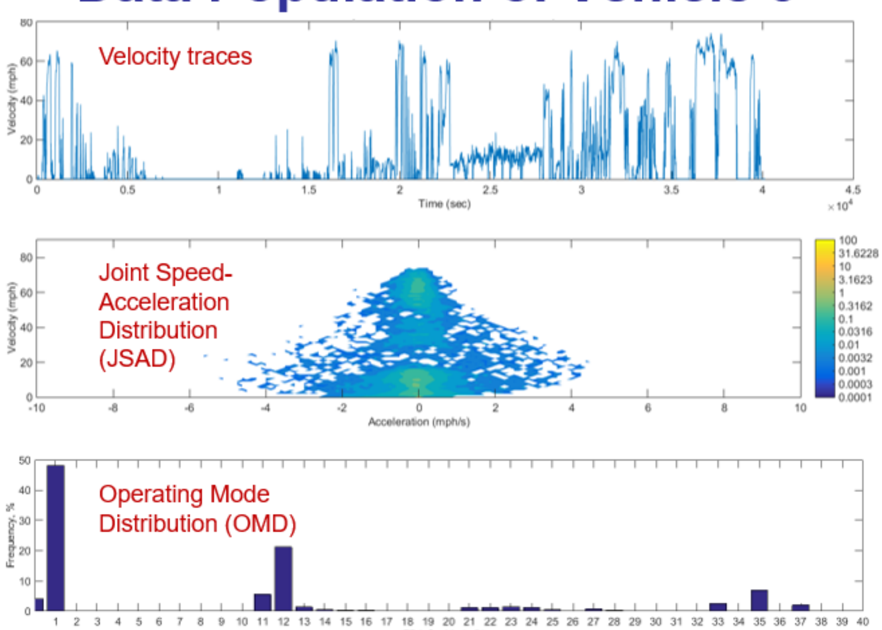
Comparative Evaluation

- Develop driving cycles based on data for one truck
  - Vehicle 3: Caltrans' freeway service truck
- Segmentation method → 6 variations
  - 3 ways of splitting activity data
    - Mid idle period
    - 20-second interval
    - 10-second interval
  - 2 cycle selection criteria
    - Mean squared error (MSE) of joint speed-acceleration distribution (JSAD)
    - Mean squared error (MSE) of operating mode distribution (OMD)
- Probabilistic method → NREL's Drive-Cycle Rapid Investigation, Visualization, and Evaluation (DRIVE) tool

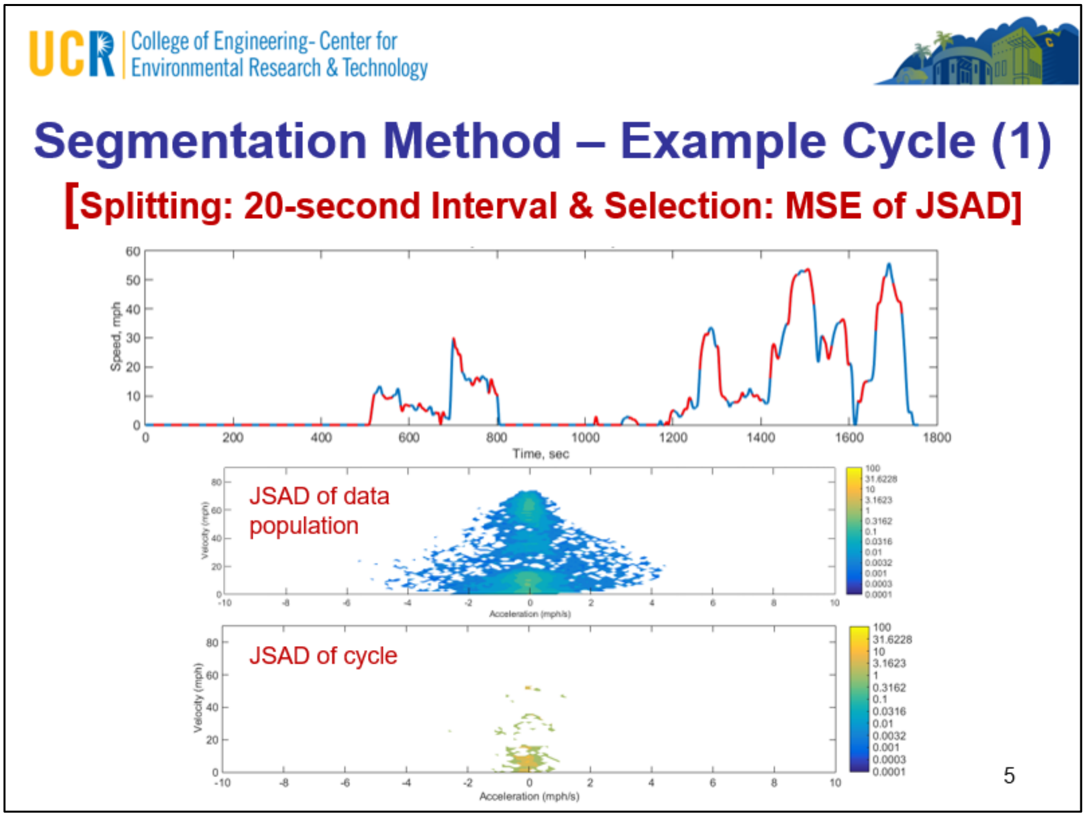
3

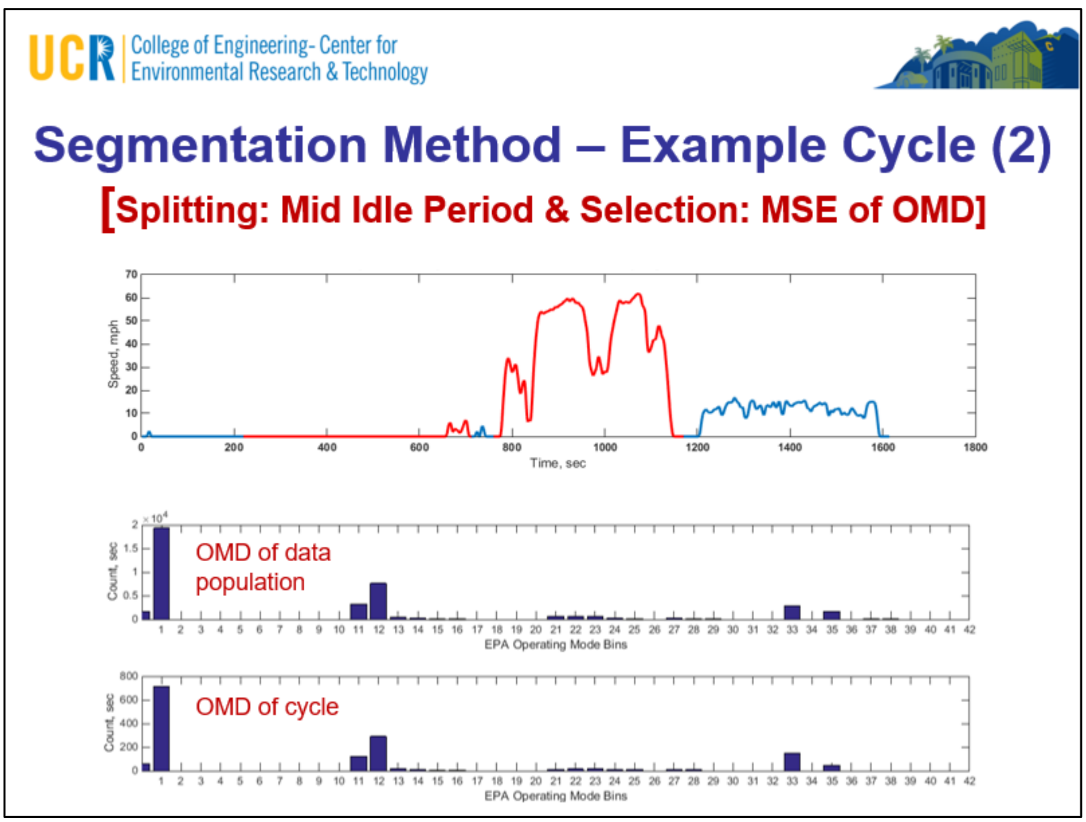
UCR | College of Engineering- Center for Environmental Research & Technology

Data Population of Vehicle 3



4

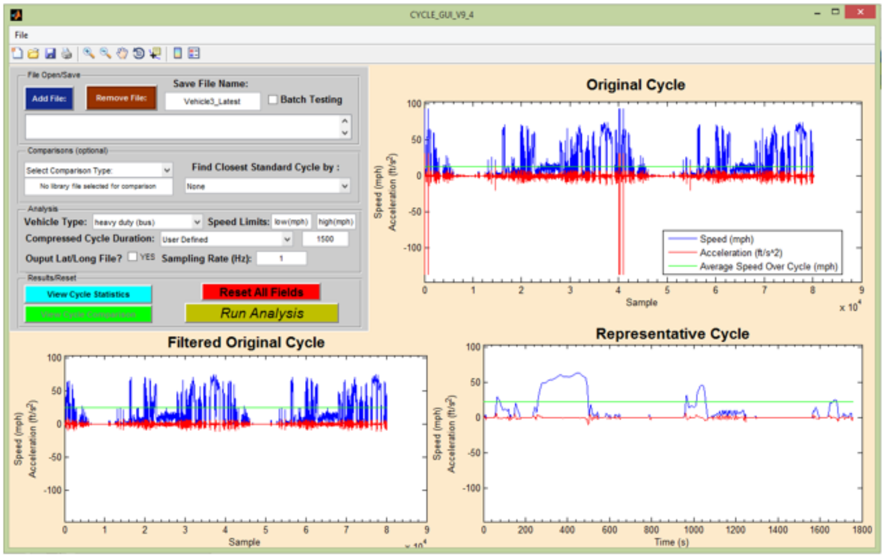

UCR | College of Engineering- Center for Environmental Research & Technology
Segmentation Method – Example Cycle (1)
[Splitting: 20-second Interval & Selection: MSE of JSAD]
Speed, mph
Time, sec
JSAD of data population
Velocity (mph)
Acceleration (mph/s)
JSAD of cycle
5


UCR | College of Engineering- Center for Environmental Research & Technology
Segmentation Method – Example Cycle (2)
[Splitting: Mid Idle Period & Selection: MSE of OMD]
Speed, mph
Time, sec
OMD of data population
Count, sec
EPA Operating Mode Bins
OMD of cycle

UCR | College of Engineering- Center for Environmental Research & Technology

Probabilistic Method – Example Cycle

[Generated using DRIVE tool]



7

UCR | College of Engineering- Center for Environmental Research & Technology

Statistics of Cycles

Cycle	Duration (sec)	Distance (miles)	Idle Time (%)	Stops/ Mile	Max Speed (mph)	Avg Speed (mph)	Stdev Speed	Max Accel (mph/s)	Avg Pos Accel (mph/s)	Stdev Pos Accel	Max STP (kw/ton)	Avg STP (kw/ton)	Stdev STP	MSE JSAD	MSE OMD
Vehicle 3 Data Population	40,156	144.6	48.0	1.5	74.4	13.0	20.4	6.3	0.6	0.8	14.8	1.4	3.0	0	0
Split at Idle (MSE of JSAD)	1,426	3.7	48.9	2.4	60.9	9.4	13.6	4.4	1.0	1.0	9.9	0.8	2.1	4.69E-04	5.37E+00
Split at Idle (MSE of OMD)	1,614	5.8	48.3	1.2	61.7	12.8	18.6	4.1	0.5	0.7	10.4	1.3	2.6	5.75E-04	1.50E-01
Split at 20 sec (MSE of JSAD)	1,758	4.5	49.0	1.5	55.8	9.3	14.1	4.3	0.5	0.7	9.9	0.8	1.7	4.23E-04	2.19E+00
Split at 20 sec (MSE of OMD)	1,348	4.7	47.7	2.4	59.6	12.5	18.5	3.3	0.6	0.7	9.4	1.2	2.4	1.14E-03	2.17E-01
Split at 10 sec (MSE of JSAD)	1,363	2.8	48.7	3.2	42.5	7.4	10.6	3.4	0.6	0.7	6.3	0.5	1.2	4.83E-04	4.60E+00
Split at 10 sec (MSE of OMD)	1,205	4.5	47.9	1.1	63.3	13.4	20.5	4.8	0.4	0.7	9.9	1.4	2.7	7.19E-04	3.94E-01
DRIVE	1,761	5.8	48.2	2.4	63.6	11.8	19.2	4.5	0.8	0.9	9.7	1.2	2.6	5.33E-04	1.39E+00

Notes: STP = Scaled tractive power; MSE = Mean squared error; JSAD = Joint speed-acceleration distribution; OMD = Operating mode distribution

8

UCR | College of Engineering- Center for Environmental Research & Technology

Emissions of Cycles

Cycle	CO_2 (g/mi)	NO_x (g/mi)	PM (g/mi)	% Error CO_2 (g/mi)	% Error NO_x (g/mi)	% Error PM (g/mi)	Avg CO_2 (g/s)	Avg NO_x (g/s)	Avg PM (g/s)	% Error Avg CO_2 (g/s)	% Error Avg NO_x (g/s)	% Error Avg PM (g/s)
Vehicle 3 Data Population	1,920	8.8	2.95E-02	0	0	0	6.9	0.032	1.06E-04	0	0	0
Split at Idle (MSE of JSAD)	2,576	11.7	4.33E-02	34.1	32.9	46.8	6.7	0.030	1.12E-04	-3.4	-4.3	5.7
Split at Idle (MSE of OMD)	1,920	8.8	3.02E-02	0.0	-0.6	2.4	6.9	0.031	1.08E-04	-0.9	-1.5	1.4
Split at 20 sec (MSE of JSAD)	2,312	11.2	3.91E-02	20.4	26.4	32.5	6.0	0.029	1.01E-04	-13.7	-9.4	-5.0
Split at 20 sec (MSE of OMD)	1,853	8.8	2.96E-02	-3.5	-0.2	0.3	6.4	0.031	1.03E-04	-6.8	-3.6	-3.1
Split at 10 sec (MSE of JSAD)	2,650	13.2	4.54E-02	38.0	49.9	53.9	5.5	0.027	9.36E-05	-21.0	-14.2	-11.9
Split at 10 sec (MSE of OMD)	1,811	8.5	2.80E-02	-5.7	-4.0	-5.1	6.8	0.032	1.05E-04	-2.2	-0.4	-1.6
DRIVE	1,979	9.3	3.16E-02	3.1	5.1	7.1	6.5	0.030	1.03E-04	-6.4	-4.6	-2.7

Notes: STP = Scaled tractive power; MSE = Mean squared error; JSAD = Joint speed-acceleration distribution; OMD = Operating mode distribution

9

UCR | College of Engineering- Center for Environmental Research & Technology

Drivability on Chassis Dyno

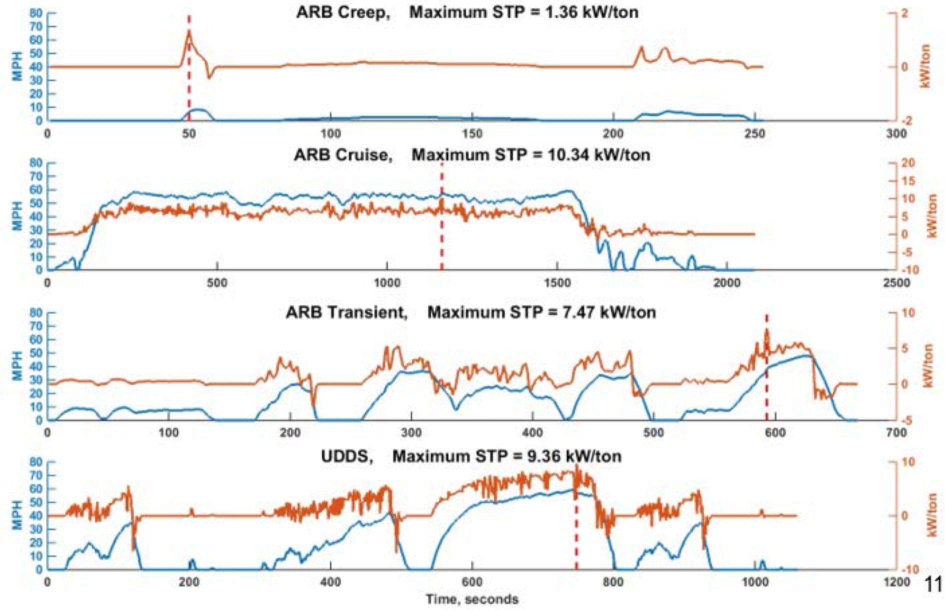
- Dependent on the specification of the chassis dyno
- Description of UCR's chassis dyno

  MAE's advanced Heavy-Duty AC Motor Chassis Dynamometers allow the testing of a variety of heavy vehicles under loaded and transient in-use conditions with corresponding emissions measurements. The dynamometer as configured in this instance for Riverside is capable of meeting the inertia simulation range requirements of 10,000 to 80,000 lb for each of the cycles listed below. This includes acceleration rates up-to 6 mph/sec, as found in the UDDS Section D Drive Schedule and deceleration rates of up to 7 mph/sec as required for the WHM Refuse Drive Schedule. The dynamometer can also provide a load in excess of 600 HP @ 70 mph. The dynamometer also has the ability to continuously handle 200 Hp @ 15 mph for applications such as yard tractors.
- Use maximum scaled tractive power (STP) of standard heavy-duty cycles as threshold
  - STP is a similar metric to vehicle specific power (VSP) but is specific to heavy-duty vehicles.

10

UCR | College of Engineering- Center for Environmental Research & Technology

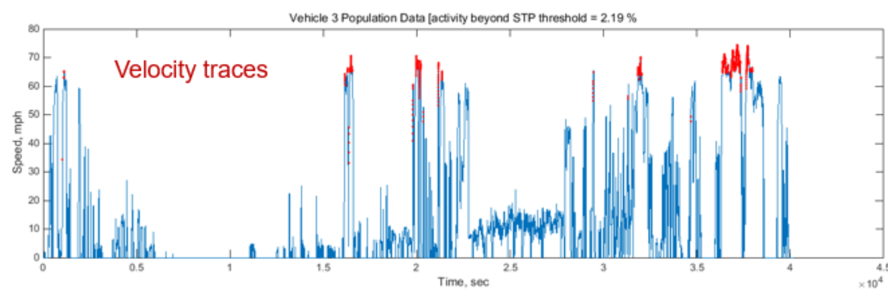
STP of Standard HDD Cycles

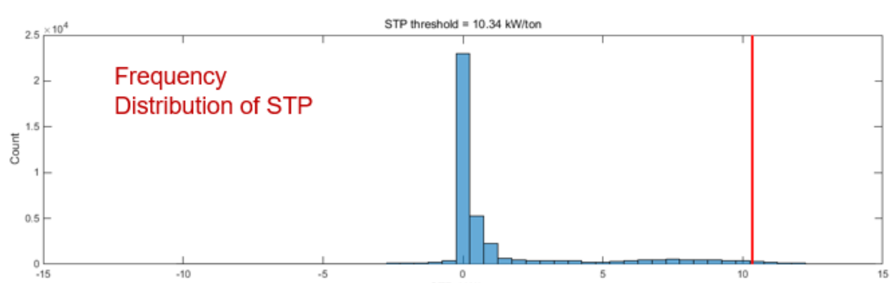


11

UCR | College of Engineering- Center for Environmental Research & Technology

Data Exceeding STP Threshold



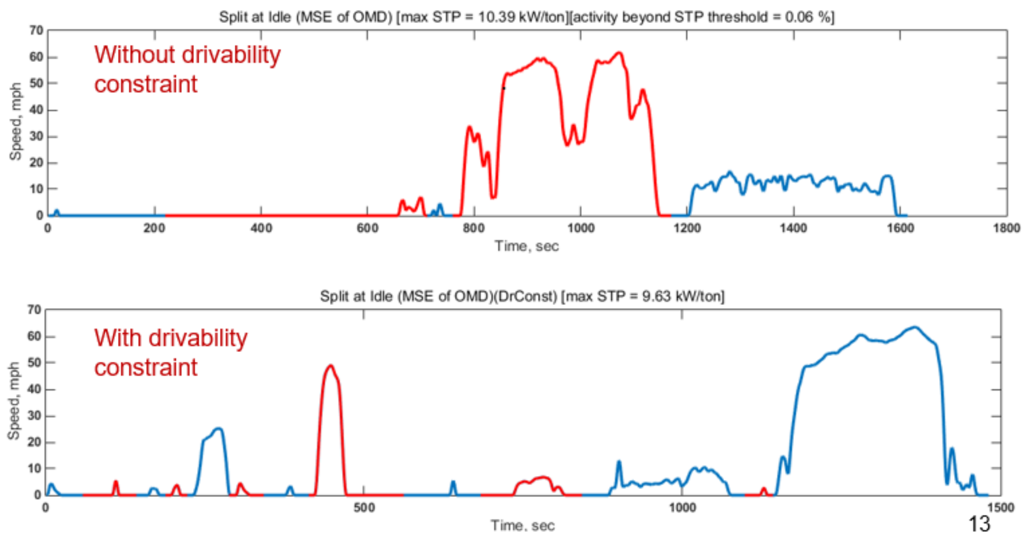


12

UCR | College of Engineering- Center for Environmental Research & Technology

Cycles without & with Drivability Constraint

[Splitting: Mid Idle Interval & Selection: MSE of OMD]



13

UCR | College of Engineering- Center for Environmental Research & Technology

Statistics of Cycles with Constraint

Cycle	Duration (sec)	Distance (miles)	Idle Time (%)	Stops/ Mile	Max Speed (mph)	Avg Speed (mph)	Stdev Speed	Max Accel (mph/s)	Avg Pos Accel (mph/s)	Stdev Pos Accel	Max STP (kw/ton)	Avg STP (kw/ton)	Stdev STP	MSE JSAD	MSE OMD
Vehicle 3 Data Population	40,156	144.6	48.0	1.5	74.4	13.0	20.4	6.3	0.6	0.8	14.8	1.4	3.0	0.00	0.00
Split at Idle (MSE of JSAD)	1,652	3.1	48.7	2.6	42.2	6.6	9.1	3.2	0.6	0.7	7.6	0.4	1.1	4.81E-04	5.73E+00
Split at Idle (MSE of OMD)	1,481	5.0	47.2	2.6	63.6	12.2	20.5	4.4	0.5	0.8	9.6	1.4	2.8	1.99E-03	4.30E-01
Split at 20 sec (MSE of JSAD)	2,059	6.1	49.2	1.7	63.4	10.6	15.8	3.9	0.7	0.8	9.7	1.0	2.2	4.08E-04	1.14E+00
Split at 20 sec (MSE of OMD)	1,282	4.2	48.4	1.9	61.0	11.7	18.6	4.7	0.6	0.8	9.6	1.2	2.5	7.19E-04	1.90E-01
Split at 10 sec (MSE of JSAD)	1,673	4.5	49.3	1.3	53.7	9.7	14.7	4.0	0.5	0.6	8.2	0.8	1.8	4.66E-04	3.55E+00
Split at 10 sec (MSE of OMD)	1,639	5.5	46.4	2.0	61.4	12.1	18.6	4.6	0.6	0.8	9.2	1.2	2.5	1.21E-03	2.33E-01
Split at Idle (MSE of OMD) w/o constraint	1,614	5.8	48.3	1.2	61.7	12.8	18.6	4.1	0.5	0.7	10.4	1.3	2.6	5.75E-04	1.50E-01

Notes: STP = Scaled tractive power; MSE = Mean squared error; JSAD = Joint speed-acceleration distribution; OMD = Operating mode distribution

14

UCR | College of Engineering- Center for Environmental Research & Technology

Emissions of Cycles with Constraint

Cycle	CO2 (g/mi)	NOx (g/mi)	PM (g/mi)	% Error CO2 (g/mi)	% Error NOx (g/mi)	% Error PM (g/mi)	Avg CO2 (g/s)	Avg NOx (g/s)	Avg PM (g/s)	% Error Avg CO2 (g/s)	% Error Avg NOx (g/s)	% Error Avg PM (g/s)
Vehicle 3 Data Population	1,920	8.8	2.95E-02	0	0	0	6.9	0.032	1.06E-04	0	0	0
Split at Idle (MSE of JSAD)	2,811	14.3	4.87E-02	46.4	61.8	65.1	5.2	0.026	8.99E-05	-25.0	-17.1	-15.4
Split at Idle (MSE of OMD)	1,950	9.2	3.09E-02	1.6	4.4	4.7	6.6	0.031	1.05E-04	-4.2	-1.5	-1.2
Split at 20 sec (MSE of JSAD)	2,191	10.2	3.60E-02	14.1	15.5	22.0	6.5	0.030	1.06E-04	-6.6	-5.4	-0.1
Split at 20 sec (MSE of OMD)	2,086	9.7	3.29E-02	8.6	10.2	11.5	6.8	0.032	1.07E-04	-1.7	-0.2	1.0
Split at 10 sec (MSE of JSAD)	2,235	10.8	3.76E-02	16.4	22.3	27.5	6.0	0.029	1.02E-04	-12.7	-8.2	-4.4
Split at 10 sec (MSE of OMD)	1,962	9.3	3.14E-02	2.2	5.4	6.4	6.6	0.031	1.06E-04	-4.6	-1.6	-0.7
Split at Idle (MSE of OMD) w/o constraint	1,920	8.8	3.02E-02	0.0	-0.6	2.4	6.9	0.031	1.08E-04	-0.9	-1.5	1.4

Notes: STP = Scaled tractive power; MSE = Mean squared error; JSAD = Joint speed-acceleration distribution; OMD = Operating mode distribution

15

UCR | College of Engineering- Center for Environmental Research & Technology

Summary of Findings

- Splitting vehicle activity at idle has the following advantages:
  - Acceleration and deceleration profiles are realistic.
  - No need for synthetic data point(s) to smooth speed transition.
- Operating mode distribution represents emission characteristics better than joint speed-acceleration distribution.
- Cycle statistics of one method are not necessarily better than those of the other method.
  - Depending on what statistics are compared.
- Inclusion of the drivability constraint does not significantly impact the representativeness of the generated cycles.

16

Appendix E:

Vocation-Specific Vehicle Activity Patterns

Line Haul – Out of State

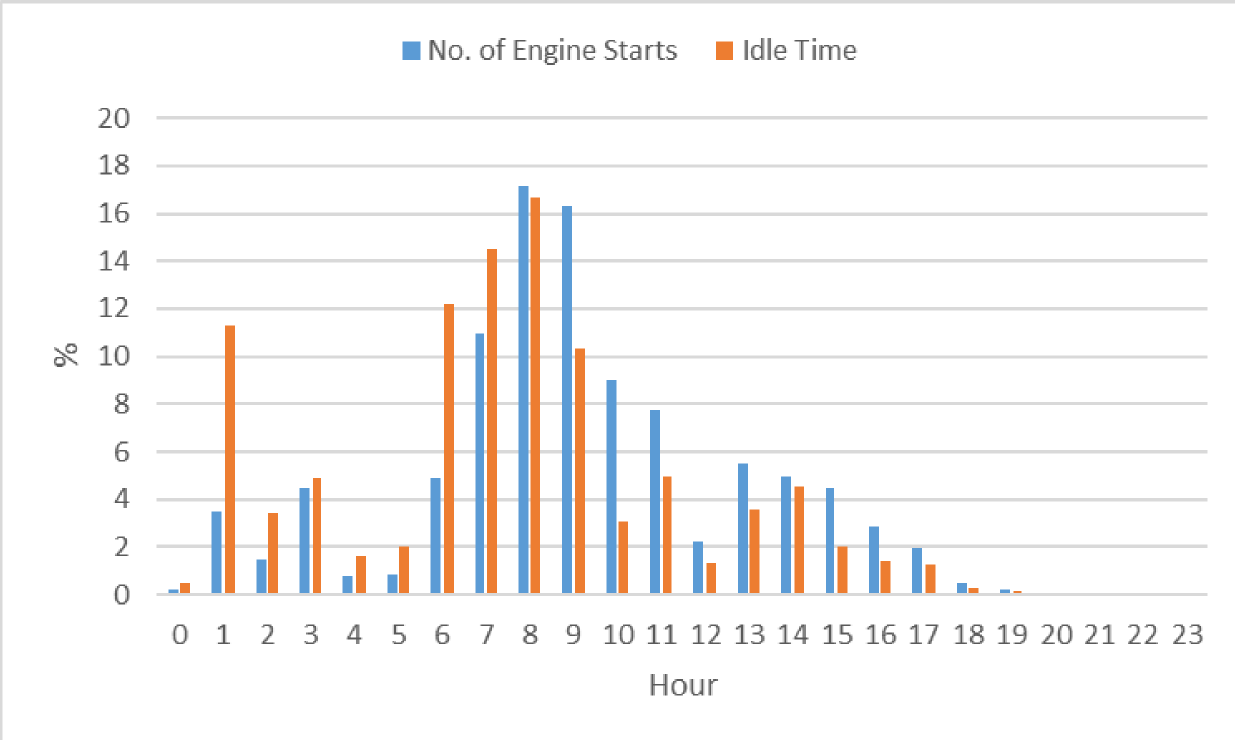


Figure E-1. Start and idle temporal distributions for Group 1a (Line haul – out of state)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		50.00	19.12	11.13	4.15	2.56	1.80	1.19	2.77	0.61	0.21	0.21	0.03	0.03	0.24	0.15	1.13	1.04	1.01	2.62	*100*
Hour																					
0	0.21	0	0	0.03	0	0	0	0	0	0	0	0	0	0.03	0	0	0.09	0	0.03	0.03	
1	3.48	0.43	0.27	0.06	0	0	0	0	0.03	0	0	0	0	0	0.09	0.12	0.43	0.58	0.52	0.95	
2	1.43	0.49	0.34	0.12	0	0	0	0	0	0	0	0	0	0	0.03	0.03	0.12	0.09	0.06	0.15	
3	4.48	2.04	0.55	0.12	0.03	0	0	0	0	0	0	0	0	0	0.03	0	0.46	0.27	0.34	0.64	
4	0.76	0.24	0.18	0.12	0	0	0	0	0.03	0	0	0	0	0	0	0	0.03	0.06	0.03	0.06	
5	0.82	0.27	0.15	0.18	0.06	0.03	0.06	0	0	0	0	0	0	0	0	0	0	0	0.03	0.03	
6	4.88	2.35	1.04	0.46	0.61	0.18	0.06	0.06	0.03	0	0	0	0	0	0	0	0	0	0	0.09	
7	10.91	5.82	1.77	1.13	0.64	0.76	0.52	0.15	0.09	0	0.03	0	0	0	0	0	0	0	0	0	
8	17.16	11.71	3.14	1.07	0.55	0.18	0.27	0.03	0.06	0.03	0.03	0	0	0	0.03	0	0	0	0	0.06	
9	16.28	10.18	3.05	1.80	0.52	0.30	0.06	0.06	0.09	0	0	0.03	0.03	0	0	0	0	0	0	0.15	
10	8.96	4.30	1.49	1.07	0.55	0.46	0.24	0.37	0.43	0	0	0	0	0	0	0	0	0	0	0.06	
11	7.71	4.27	1.40	0.91	0.27	0.15	0.09	0.06	0.40	0.06	0	0	0	0	0	0	0	0	0	0.09	
12	2.23	1.10	0.40	0.37	0.03	0.03	0	0.12	0.15	0	0	0	0	0	0.03	0	0	0	0	0	
13	5.49	1.77	1.40	1.01	0.18	0.06	0.03	0.06	0.70	0.09	0.09	0.06	0	0	0	0	0	0	0	0.03	
14	4.97	1.92	1.07	1.07	0.27	0.18	0.06	0	0.06	0.12	0.03	0.03	0	0	0	0	0	0	0	0.15	
15	4.45	1.43	1.19	0.79	0.18	0.06	0.24	0.15	0.27	0.06	0	0	0	0	0	0	0	0	0	0.06	
16	2.90	0.95	0.67	0.49	0.18	0.15	0.03	0.03	0.21	0.12	0	0.03	0	0	0.03	0	0	0	0	0	
17	1.98	0.55	0.70	0.21	0.03	0	0.12	0.06	0.18	0.03	0	0.03	0	0	0	0	0	0	0	0.06	
18	0.49	0.09	0.21	0.09	0.03	0	0	0.03	0	0.03	0	0	0	0	0	0	0	0	0	0	
19	0.18	0.09	0.03	0.03	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0	
20	0.09	0	0.03	0	0	0	0	0	0	0.06	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	
23	0.09	0	0.03	0	0	0	0	0	0	0	0.03	0.03	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-2. Soak time distributions for Group 1a (Line haul – out of state)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		0.33	0.64	0.82	0.86	0.81	0.77	1.31	1.27	1.99	3.21	7.64	27.20	52.59	0.55	0.00	0	0	0	*100*
Hour																				
0	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.08	0.03	0.00	0	0	0	0	
1	1.38	0.01	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.02	0.04	0.08	0.26	0.79	0.00	0	0	0	0	
2	6.94	0.01	0.01	0.02	0.02	0.03	0.04	0.11	0.07	0.13	0.30	0.81	2.16	3.21	0.01	0.00	0	0	0	
3	9.12	0.01	0.01	0.02	0.02	0.03	0.04	0.07	0.05	0.10	0.28	0.88	3.18	4.39	0.05	0	0	0	0	
4	13.09	0.00	0.01	0.01	0.01	0.01	0.02	0.08	0.05	0.11	0.26	0.65	3.38	8.41	0.08	0.00	0	0	0	
5	11.81	0.01	0.01	0.02	0.02	0.03	0.03	0.05	0.06	0.15	0.32	0.95	3.35	6.73	0.09	0	0	0	0	
6	6.63	0.03	0.03	0.04	0.05	0.07	0.07	0.08	0.08	0.11	0.16	0.42	1.41	4.07	0.01	0.00	0	0	0	
7	3.40	0.05	0.10	0.16	0.20	0.19	0.15	0.13	0.10	0.12	0.15	0.25	0.65	1.13	0.01	0	0	0	0	
8	2.19	0.06	0.11	0.17	0.14	0.12	0.10	0.10	0.09	0.07	0.07	0.13	0.48	0.55	0.01	0	0	0	0	
9	3.08	0.04	0.08	0.11	0.09	0.05	0.06	0.06	0.05	0.06	0.07	0.21	0.87	1.33	0.00	0	0	0	0	
10	5.38	0.02	0.04	0.06	0.05	0.03	0.04	0.05	0.07	0.08	0.12	0.30	1.66	2.85	0.01	0	0	0	0	
11	7.72	0.02	0.05	0.06	0.04	0.04	0.04	0.10	0.11	0.16	0.24	0.56	2.31	3.97	0.01	0.00	0	0	0	
12	8.94	0.01	0.02	0.02	0.02	0.03	0.03	0.12	0.14	0.25	0.34	0.73	2.49	4.72	0.03	0	0	0	0	
13	7.59	0.02	0.03	0.04	0.04	0.04	0.03	0.11	0.13	0.24	0.32	0.66	2.06	3.81	0.06	0.00	0	0	0	
14	5.60	0.02	0.03	0.03	0.04	0.04	0.03	0.09	0.10	0.18	0.25	0.46	1.41	2.86	0.06	0.00	0	0	0	
15	3.58	0.01	0.02	0.02	0.03	0.03	0.03	0.06	0.07	0.12	0.14	0.28	0.77	1.94	0.05	0.00	0	0	0	
16	2.04	0.01	0.02	0.02	0.02	0.02	0.02	0.04	0.05	0.07	0.10	0.17	0.43	1.01	0.04	0	0	0	0	
17	1.00	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.03	0.03	0.08	0.16	0.56	0.04	0	0	0	0	
18	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.11	0.00	0	0	0	0	
19	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0	0	0	0	
20	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0	0	0	0	0	
23	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-3. VMT distributions for Group 1a (Line haul – out of state)

Line Haul – In State

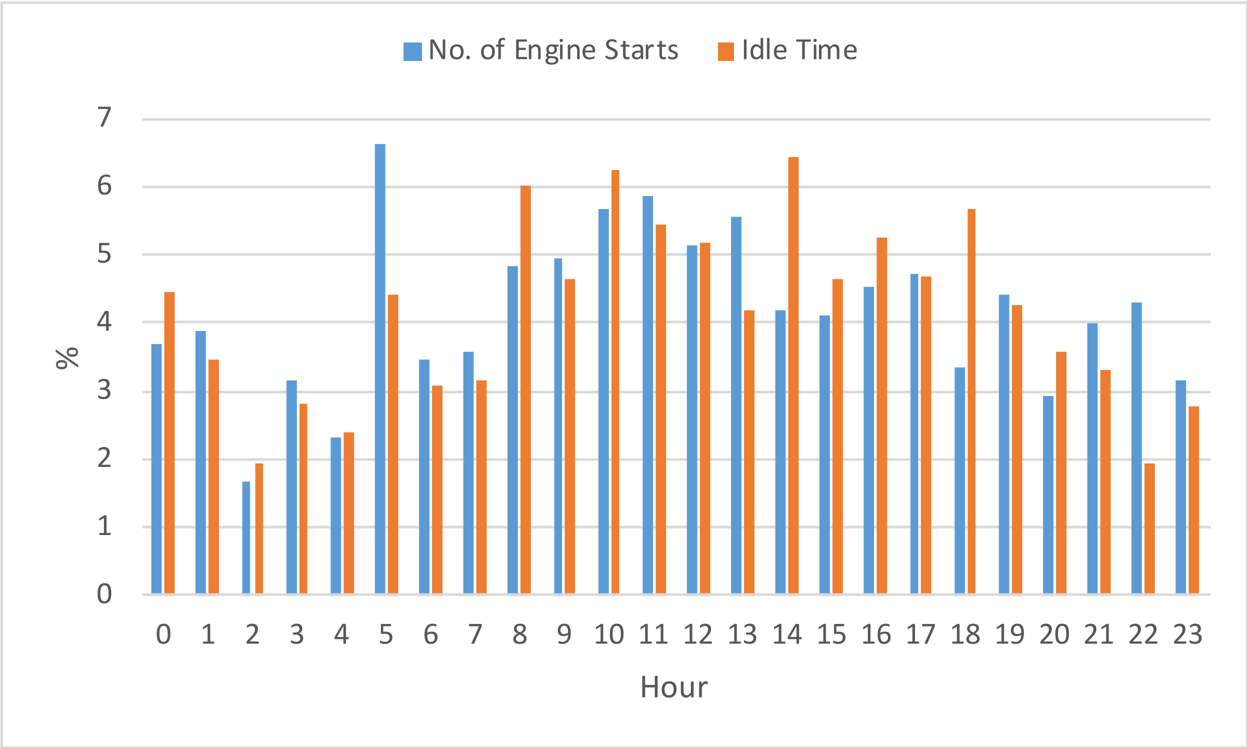


Figure E-4. Start and idle temporal distributions for Group 1b (Line haul – in state)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
			45.96	20.04	14.90	4.83	2.73	1.47	1.36	3.57	1.36	0.31	0.10	0.10	0	0.10	0.42	0.42	0.52	0.42	1.36	*100*
Hour																						
0	3.67		2.20	0.73	0.42	0	0.10	0.10	0	0.10	0	0	0	0	0	0	0	0	0	0	0	
1	3.88		1.57	1.26	0.52	0.21	0.21	0	0	0	0.10	0	0	0	0	0	0	0	0	0	0	
2	1.68		0.42	0.31	0.31	0.31	0.21	0.10	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	3.15		0.94	0.31	1.05	0.31	0.10	0	0.10	0.21	0	0	0	0	0	0.10	0	0	0	0	0	
4	2.31		0.42	0.52	0.21	0.21	0	0.10	0	0.10	0.21	0	0	0	0	0	0.10	0.10	0	0	0.31	
5	6.61		2.73	1.05	0.42	0.10	0.10	0.10	0.10	0.52	0.42	0	0.10	0.10	0	0	0	0.10	0.21	0.21	0.31	
6	3.46		1.57	0.31	0.84	0.31	0.10	0	0	0.31	0	0	0	0	0	0	0	0	0	0	0	
7	3.57		1.68	0.63	0.63	0.10	0	0.10	0.10	0.10	0	0	0	0	0	0	0	0	0.10	0	0.10	
8	4.83		2.31	0.42	1.05	0.31	0	0	0.10	0.21	0	0.10	0	0	0	0	0.10	0.21	0	0	0	
9	4.93		2.31	0.84	0.52	0.21	0.31	0.10	0.42	0	0.21	0	0	0	0	0	0	0	0	0	0	
10	5.67		2.62	0.94	0.63	0.21	0.21	0.21	0	0.42	0	0	0	0	0	0	0.10	0	0.10	0.10	0.10	
11	5.88		3.15	0.94	1.05	0	0.21	0.10	0.10	0.10	0.10	0	0	0	0	0	0	0	0	0.10	0	
12	5.14		2.62	0.63	0.84	0.31	0	0.21	0.10	0.21	0	0	0	0	0	0	0	0	0	0	0.21	
13	5.56		1.99	2.10	0.63	0.10	0.10	0	0	0.31	0	0	0	0	0	0	0	0	0	0	0.31	
14	4.20		1.57	0.73	1.15	0.21	0.31	0.10	0	0.10	0	0	0	0	0	0	0	0	0	0	0	
15	4.09		1.15	1.05	0.73	0.42	0.21	0	0	0.10	0.21	0.21	0	0	0	0	0	0	0	0	0	
16	4.51		2.31	1.15	0.52	0	0	0.10	0.10	0.10	0.10	0	0	0	0	0	0	0	0.10	0	0	
17	4.72		1.99	1.36	0.63	0.52	0	0	0	0.21	0	0	0	0	0	0	0	0	0	0	0	
18	3.36		2.10	0.52	0.52	0	0.10	0	0	0.10	0	0	0	0	0	0	0	0	0	0	0	
19	4.41		2.41	0.94	0.52	0.21	0.10	0	0.10	0.10	0	0	0	0	0	0	0	0	0	0	0	
20	2.94		1.47	0.63	0.31	0.21	0	0.10	0	0.10	0	0	0	0	0	0	0.10	0	0	0	0	
21	3.99		2.31	0.84	0.42	0.21	0.10	0	0	0.10	0	0	0	0	0	0	0	0	0	0	0	
22	4.30		2.52	0.94	0.63	0	0.21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	3.15		1.57	0.84	0.31	0.31	0	0	0.10	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																					*100*

Figure E-5. Soak time distributions for Group 1b (Line haul – in state)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
			0.42	0.92	1.15	1.28	1.55	1.95	2.30	2.88	3.37	4.96	10.85	34.32	26.01	7.60	0.44	0	0	0	*100*
Hour																					
0	3.25		0.01	0.02	0.03	0.03	0.04	0.05	0.06	0.08	0.10	0.10	0.28	0.95	1.09	0.36	0.03	0	0	0	
1	3.05		0.01	0.03	0.03	0.03	0.04	0.04	0.06	0.07	0.08	0.09	0.23	0.77	1.11	0.41	0.03	0	0	0	
2	3.13		0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.08	0.09	0.29	0.80	1.06	0.54	0.05	0	0	0	
3	2.88		0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.12	0.46	1.22	0.83	0.04	0	0	0	
4	2.98		0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.05	0.08	0.20	0.78	1.18	0.53	0.02	0	0	0	
5	3.70		0.02	0.04	0.04	0.05	0.06	0.09	0.10	0.10	0.12	0.17	0.37	1.18	0.95	0.40	0.01	0	0	0	
6	4.53		0.01	0.03	0.05	0.07	0.09	0.11	0.13	0.16	0.19	0.29	0.60	1.40	1.05	0.33	0.01	0	0	0	
7	4.16		0.02	0.05	0.07	0.09	0.11	0.13	0.14	0.17	0.19	0.25	0.49	1.44	0.93	0.10	0.00	0	0	0	
8	3.72		0.02	0.05	0.06	0.08	0.09	0.10	0.09	0.13	0.14	0.24	0.48	1.57	0.55	0.11	0.01	0	0	0	
9	4.36		0.02	0.03	0.04	0.05	0.06	0.07	0.10	0.10	0.15	0.29	0.76	1.97	0.69	0.04	0.00	0	0	0	
10	4.32		0.02	0.03	0.04	0.05	0.07	0.09	0.10	0.16	0.16	0.25	0.57	2.02	0.71	0.04	0.00	0	0	0	
11	4.48		0.02	0.04	0.05	0.05	0.06	0.08	0.09	0.11	0.16	0.30	0.70	1.96	0.80	0.05	0.00	0	0	0	
12	4.60		0.02	0.04	0.04	0.04	0.05	0.07	0.09	0.12	0.15	0.26	0.66	2.20	0.77	0.09	0.00	0	0	0	
13	4.93		0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.13	0.21	0.58	2.38	0.95	0.14	0.02	0	0	0	
14	4.36		0.02	0.05	0.05	0.06	0.08	0.10	0.10	0.12	0.14	0.21	0.42	2.09	0.73	0.20	0.00	0	0	0	
15	4.87		0.02	0.06	0.07	0.09	0.10	0.11	0.13	0.16	0.18	0.28	0.55	1.78	1.24	0.09	0.00	0	0	0	
16	4.86		0.02	0.06	0.09	0.10	0.11	0.14	0.16	0.19	0.19	0.27	0.63	1.68	1.17	0.06	0.00	0	0	0	
17	3.89		0.03	0.09	0.10	0.10	0.12	0.14	0.18	0.21	0.21	0.26	0.37	1.03	0.96	0.08	0.01	0	0	0	
18	4.84		0.02	0.05	0.07	0.09	0.11	0.13	0.15	0.17	0.20	0.25	0.42	1.32	1.64	0.23	0.02	0	0	0	
19	4.87		0.02	0.04	0.05	0.05	0.07	0.08	0.10	0.16	0.17	0.24	0.46	1.42	1.58	0.39	0.03	0	0	0	
20	5.22		0.01	0.03	0.03	0.04	0.05	0.06	0.08	0.13	0.18	0.28	0.70	1.84	1.40	0.36	0.01	0	0	0	
21	4.69		0.02	0.04	0.04	0.05	0.06	0.08	0.09	0.12	0.16	0.22	0.44	1.38	1.35	0.59	0.03	0	0	0	
22	4.47		0.02	0.04	0.04	0.04	0.04	0.05	0.07	0.08	0.11	0.15	0.31	1.05	1.57	0.85	0.05	0	0	0	
23	3.84		0.02	0.03	0.04	0.04	0.04	0.07	0.07	0.07	0.10	0.13	0.21	0.85	1.32	0.79	0.06	0	0	0	
Sum	*100*																				*100*

Figure E-6. VMT distributions for Group 1b (Line haul – in state)

Drayage – Northern California

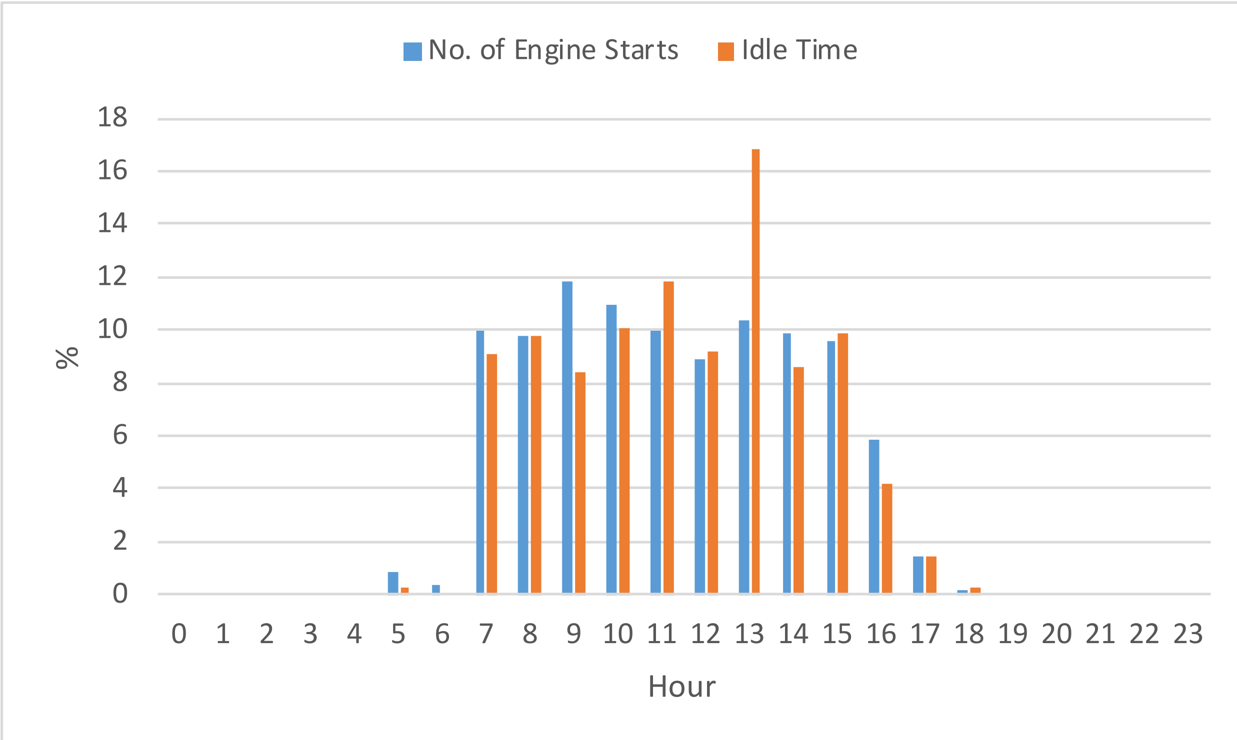


Figure E-7. Start and idle temporal distributions for Group 2a (Drayage – Northern California)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		61.15	17.96	8.70	4.06	2.27	0.38	0.47	1.04	0.19	0	0	0	0	0	0.09	0	0.09	0.09	3.50	*100*
Hour																					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.85	0.19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.57	
6	0.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.38	
7	10.02	5.86	0.95	0.38	0	0	0	0.09	0.57	0.09	0	0	0	0	0	0	0	0	0	2.08	
8	9.74	5.95	1.89	0.95	0.76	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	
9	11.81	7.56	2.65	0.85	0.38	0.28	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	
10	10.96	6.52	2.36	1.42	0.28	0.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	
11	10.02	6.24	1.98	1.04	0.28	0.19	0	0.09	0.09	0	0	0	0	0	0	0	0	0	0	0.09	
12	8.88	4.91	1.23	0.85	0.85	0.57	0.28	0.19	0	0	0	0	0	0	0	0	0	0	0	0	
13	10.40	6.05	2.17	1.23	0.47	0.09	0	0.09	0.09	0.09	0	0	0	0	0	0	0	0	0	0.09	
14	9.92	7.47	1.51	0.57	0.28	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	9.55	5.29	1.89	0.85	0.66	0.47	0.09	0	0.09	0	0	0	0	0	0	0.09	0	0	0	0.09	
16	5.86	4.25	0.95	0.38	0.09	0.09	0	0	0	0	0	0	0	0	0	0	0	0.09	0	0	
17	1.42	0.76	0.28	0.19	0	0.09	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	
18	0.19	0.09	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-8. Soak time distributions for Group 2a (Drayage – Northern California)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		8.18	18.37	15.97	10.03	9.91	13.33	11.63	5.38	1.73	1.62	2.32	0.73	0.80	0	0	0	0	0	*100*
Hour																				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.09	0.03	0.03	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	0.01	0.01	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	9.32	1.40	2.26	1.36	0.73	0.94	1.26	0.98	0.34	0.04	0	0	0	0	0	0	0	0	0	
8	8.36	0.76	2.02	1.87	0.94	0.69	0.91	0.80	0.32	0.05	0	0	0	0	0	0	0	0	0	
9	12.12	0.80	1.94	1.76	1.05	1.20	1.57	1.39	0.68	0.25	0.35	0.97	0.15	0.00	0	0	0	0	0	
10	12.22	0.76	1.93	1.76	1.04	1.22	1.46	1.27	0.91	0.49	0.32	0.48	0.14	0.45	0	0	0	0	0	
11	10.19	0.89	1.93	1.69	1.12	1.10	1.60	1.20	0.59	0.08	0	0	0	0	0	0	0	0	0	
12	5.52	0.49	0.98	0.84	0.68	0.69	0.91	0.71	0.21	0.03	0	0	0	0	0	0	0	0	0	
13	8.96	0.90	1.82	1.59	0.94	0.73	0.92	0.93	0.38	0.17	0.25	0.23	0.10	0	0	0	0	0	0	
14	11.79	0.77	1.96	1.67	1.09	1.13	1.64	1.74	0.67	0.30	0.47	0.32	0.05	0	0	0	0	0	0	
15	11.02	0.70	1.86	1.65	1.08	0.94	1.57	1.40	0.49	0.13	0.22	0.33	0.29	0.35	0	0	0	0	0	
16	8.99	0.54	1.40	1.53	1.17	1.10	1.26	1.01	0.75	0.20	0.02	0	0	0	0	0	0	0	0	
17	1.38	0.11	0.23	0.23	0.17	0.18	0.22	0.21	0.04	0.00	0	0	0	0	0	0	0	0	0	
18	0.03	0.02	0.01	0.00	0.00	0.00	0.01	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-9. VMT distributions for Group 2a (Drayage – Northern California)

Drayage – Southern California

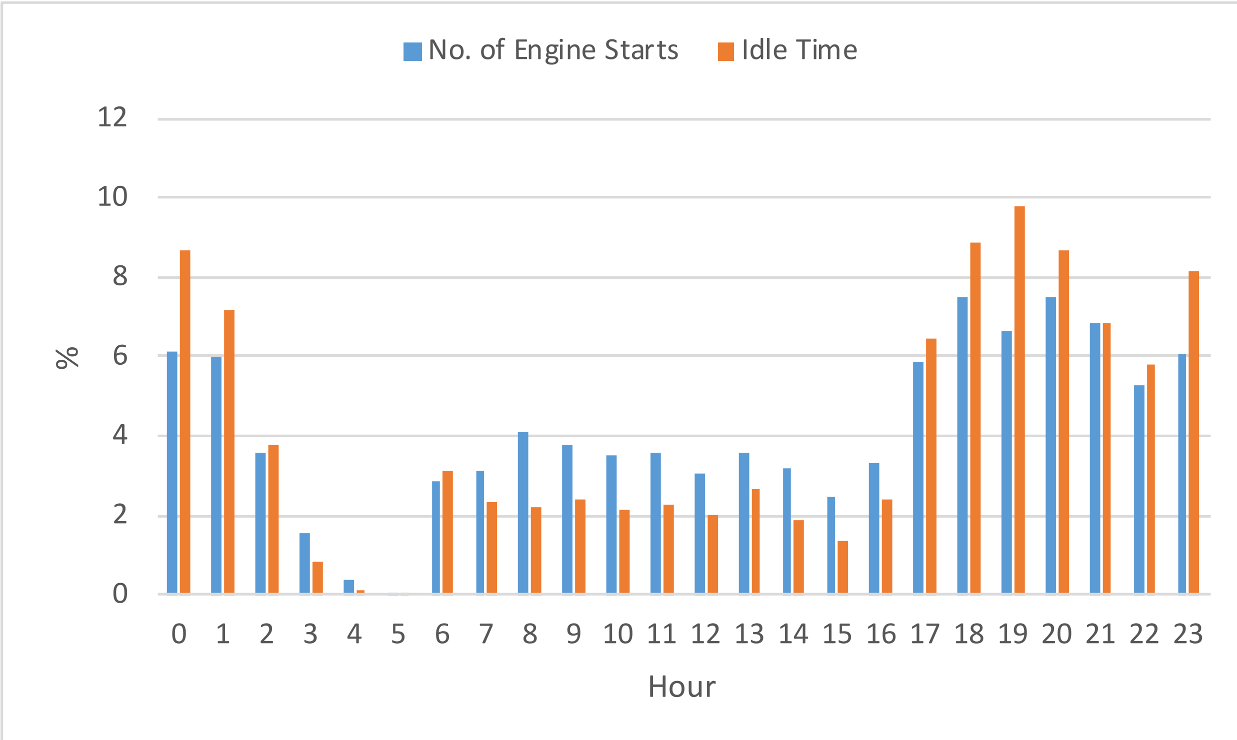


Figure E-10. Start and idle temporal distributions for Group 2b (Drayage – Southern California)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		60.99	14.25	9.71	3.37	2.37	1.36	0.62	1.87	0.58	0.44	0.42	0.18	0.22	0.08	0.04	0.06	0.08	0.16	3.19	*100*
Hour																					
0	6.16	4.33	0.70	0.52	0.22	0.16	0.08	0	0.12	0.02	0	0	0	0	0	0	0	0	0	0	
1	6.02	4.17	0.62	0.68	0.20	0.22	0.02	0.04	0.04	0.02	0	0	0	0	0	0	0	0	0	0	
2	3.55	2.45	0.32	0.38	0.14	0.14	0.08	0	0.02	0	0	0	0	0	0	0	0	0	0	0.02	
3	1.53	0.56	0.08	0.28	0.06	0.12	0.12	0.08	0.22	0	0	0	0	0	0	0	0	0	0	0	
4	0.40	0.08	0.10	0.04	0	0.06	0.02	0	0.08	0	0	0	0.02	0	0	0	0	0	0	0	
5	0.04	0	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0.02	0	0	
6	2.87	1.00	0.28	0.14	0.04	0	0	0	0.02	0.18	0.24	0.16	0.08	0.04	0	0	0	0	0.02	0.66	
7	3.11	2.29	0.52	0.20	0.02	0	0	0	0	0	0.04	0.02	0	0	0	0	0	0	0	0.02	
8	4.11	2.83	0.58	0.42	0.08	0.02	0.02	0	0.02	0.02	0	0	0	0	0	0	0	0	0	0.12	
9	3.77	2.29	0.40	0.52	0.08	0.12	0.06	0.02	0.04	0	0	0.02	0.02	0.08	0.02	0.02	0	0	0.02	0.06	
10	3.51	2.11	0.68	0.32	0.10	0.06	0.08	0	0.06	0	0	0	0	0.04	0	0	0	0	0	0.06	
11	3.59	2.59	0.52	0.34	0.04	0	0.04	0.02	0	0.02	0	0	0	0	0	0	0.02	0	0	0	
12	3.05	1.71	0.50	0.36	0.20	0.04	0	0.04	0.06	0.04	0.02	0	0	0	0	0	0	0.04	0	0.04	
13	3.61	1.91	0.34	0.48	0.16	0.20	0.04	0.10	0.12	0	0.02	0.04	0	0	0	0.02	0.04	0	0.02	0.12	
14	3.19	1.97	0.28	0.32	0.10	0.24	0.08	0.04	0.04	0	0	0.04	0.02	0	0.02	0	0	0	0.02	0.02	
15	2.45	1.49	0.34	0.20	0.04	0.08	0.10	0.12	0.06	0	0	0	0	0	0	0	0	0	0	0.02	
16	3.29	1.26	0.38	0.22	0.18	0.10	0.06	0	0.04	0	0.04	0.04	0	0.06	0.02	0	0	0.02	0.02	0.84	
17	5.86	2.99	0.60	0.36	0.16	0.06	0.06	0.04	0.16	0.14	0.06	0.06	0.02	0	0.02	0	0	0	0.06	1.06	
18	7.53	5.32	1.12	0.54	0.20	0.06	0	0	0.14	0.04	0	0.02	0.02	0	0	0	0	0	0	0.06	
19	6.66	4.01	1.49	0.72	0.26	0.04	0.10	0	0	0	0	0	0	0	0	0	0	0	0	0.04	
20	7.51	4.54	1.49	0.88	0.36	0.14	0.04	0	0.02	0	0	0.02	0	0	0	0	0	0	0	0.02	
21	6.84	4.74	1.08	0.62	0.20	0.06	0.08	0.04	0	0	0	0	0	0	0	0	0	0	0	0.02	
22	5.26	3.13	1.02	0.50	0.24	0.14	0.06	0.04	0.10	0.02	0	0	0	0	0	0	0	0	0	0	
23	6.08	3.23	0.78	0.64	0.28	0.30	0.22	0.04	0.50	0.08	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-11. Soak time distributions for Group 2b (Drayage – Southern California)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		2.40	6.60	7.12	6.17	5.89	6.84	8.57	10.62	11.46	12.35	11.46	7.57	2.89	0.06	0	0	0	0	*100*
Hour																				
0	6.53	0.18	0.50	0.52	0.43	0.39	0.42	0.49	0.66	0.74	0.73	0.75	0.50	0.22	0.00	0	0	0	0	
1	6.21	0.17	0.51	0.55	0.46	0.41	0.43	0.49	0.58	0.72	0.77	0.64	0.38	0.11	0.00	0	0	0	0	
2	6.18	0.12	0.34	0.42	0.39	0.41	0.52	0.62	0.78	0.90	0.81	0.53	0.29	0.05	0	0	0	0	0	
3	2.41	0.03	0.09	0.13	0.11	0.13	0.17	0.24	0.37	0.45	0.34	0.20	0.12	0.03	0	0	0	0	0	
4	0.40	0.00	0.01	0.02	0.02	0.02	0.05	0.03	0.05	0.08	0.08	0.03	0.01	0.00	0	0	0	0	0	
5	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	2.77	0.05	0.15	0.12	0.12	0.17	0.24	0.33	0.39	0.44	0.35	0.27	0.12	0.03	0	0	0	0	0	
7	4.19	0.09	0.25	0.26	0.27	0.32	0.38	0.55	0.68	0.55	0.41	0.25	0.17	0.03	0	0	0	0	0	
8	3.62	0.08	0.23	0.33	0.28	0.23	0.23	0.31	0.33	0.33	0.39	0.48	0.33	0.06	0	0	0	0	0	
9	3.42	0.07	0.21	0.24	0.22	0.20	0.24	0.30	0.38	0.37	0.39	0.31	0.29	0.21	0.00	0	0	0	0	
10	4.31	0.07	0.20	0.22	0.20	0.21	0.23	0.30	0.42	0.41	0.57	0.72	0.45	0.30	0.01	0	0	0	0	
11	3.30	0.07	0.18	0.20	0.19	0.20	0.28	0.35	0.34	0.30	0.36	0.40	0.32	0.10	0.00	0	0	0	0	
12	3.26	0.05	0.14	0.16	0.16	0.20	0.26	0.32	0.34	0.31	0.42	0.33	0.37	0.21	0.00	0	0	0	0	
13	2.97	0.06	0.17	0.21	0.19	0.20	0.24	0.26	0.27	0.25	0.33	0.39	0.31	0.08	0	0	0	0	0	
14	2.99	0.06	0.18	0.21	0.18	0.18	0.21	0.22	0.26	0.28	0.28	0.39	0.32	0.20	0.02	0	0	0	0	
15	3.28	0.05	0.18	0.24	0.23	0.23	0.24	0.34	0.41	0.41	0.47	0.36	0.12	0.00	0	0	0	0	0	
16	1.80	0.04	0.13	0.14	0.15	0.15	0.18	0.20	0.26	0.23	0.18	0.10	0.03	0.00	0	0	0	0	0	
17	3.50	0.12	0.30	0.25	0.22	0.25	0.31	0.38	0.47	0.45	0.37	0.26	0.10	0.02	0.00	0	0	0	0	
18	6.15	0.20	0.52	0.55	0.46	0.43	0.53	0.67	0.77	0.72	0.55	0.46	0.25	0.03	0	0	0	0	0	
19	5.55	0.21	0.49	0.52	0.42	0.33	0.34	0.45	0.57	0.71	0.75	0.53	0.20	0.02	0	0	0	0	0	
20	6.10	0.21	0.52	0.50	0.39	0.30	0.32	0.36	0.53	0.83	0.95	0.80	0.35	0.04	0	0	0	0	0	
21	8.36	0.20	0.50	0.54	0.47	0.41	0.46	0.59	0.71	0.83	1.30	1.50	0.68	0.17	0.00	0	0	0	0	
22	6.46	0.13	0.36	0.34	0.29	0.28	0.32	0.44	0.62	0.73	0.82	0.87	0.94	0.32	0.00	0	0	0	0	
23	6.24	0.15	0.44	0.43	0.34	0.26	0.25	0.35	0.40	0.42	0.72	0.88	0.92	0.65	0.02	0	0	0	0	
Sum	*100*																			*100*

Figure E-12. VMT distributions for Group 2b (Drayage – Southern California)

Agricultural – South Central Valley

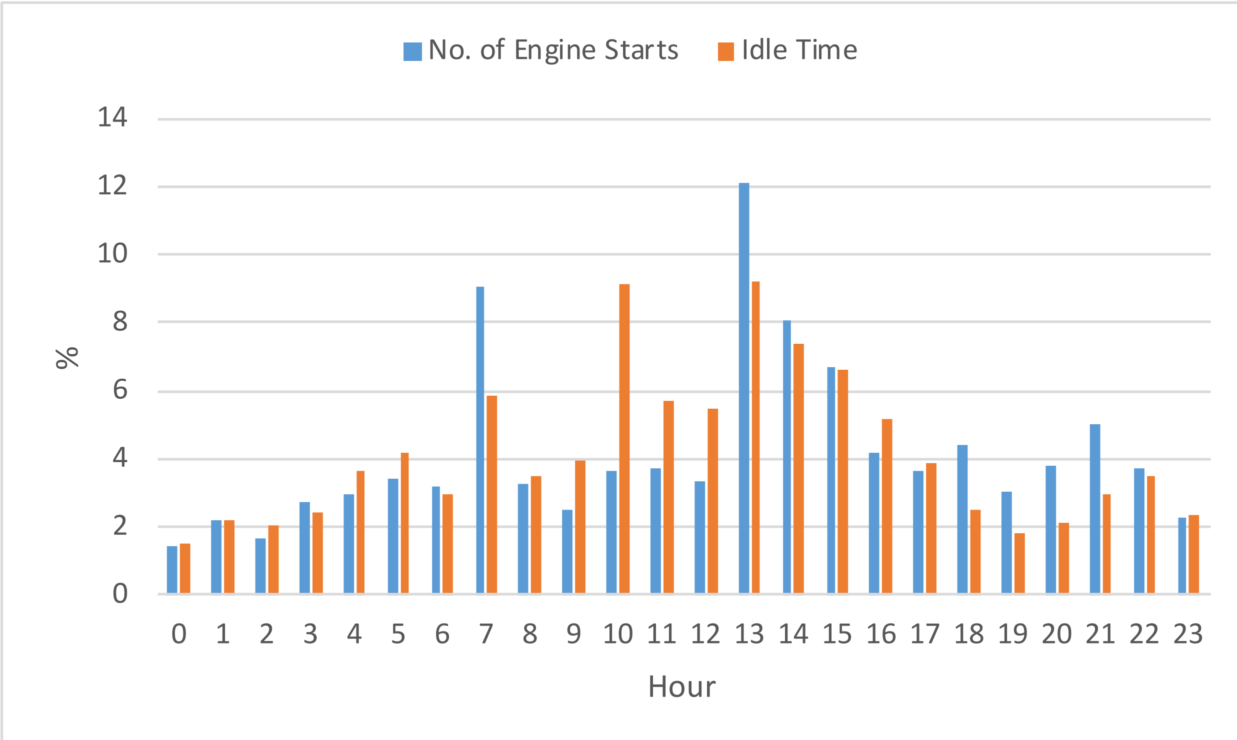


Figure E-13. Start and idle temporal distributions for Group 3b (Agricultural – South Central Valley)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	Sum
			24.96	8.22	8.81	5.60	3.49	2.62	1.97	6.33	3.13	3.06	1.75	2.26	3.28	3.35	2.47	2.11	1.46	1.16	13.97	*100*
Hour																						
0	1.46		0.36	0.15	0	0.29	0	0	0.07	0.15	0	0	0	0	0	0.15	0	0.15	0.07	0	0.07	
1	2.18		0.36	0	0.29	0.15	0	0.07	0	0.07	0.15	0.15	0	0	0	0.15	0.07	0.07	0.15	0	0.51	
2	1.67		0.36	0.22	0.07	0	0.22	0	0	0.07	0	0	0.07	0.07	0	0.07	0.07	0.07	0	0.07	0.29	
3	2.69		0.36	0.29	0.22	0.15	0.07	0	0	0	0.15	0.07	0.07	0	0.22	0.15	0	0.15	0.07	0.07	0.66	
4	2.98		0.80	0.22	0.15	0.15	0.07	0.07	0.07	0	0.07	0	0.07	0	0	0.29	0.15	0.07	0.22	0.07	0.51	
5	3.42		0.95	0.22	0.07	0.36	0.15	0.07	0	0.36	0.07	0	0.07	0	0	0.07	0.15	0.07	0.15	0.15	0.51	
6	3.20		1.09	0	0.44	0.07	0.29	0.07	0.07	0.51	0	0.07	0.07	0	0	0	0.07	0.22	0.07	0	0.15	
7	9.02		2.26	0.22	1.09	0.15	0.07	0.22	0.07	0.22	0.07	0	0	0	0.15	0.44	0.58	0.66	0.36	0.29	2.18	
8	3.28		0.73	0.22	0.22	0.29	0.07	0.15	0.07	0.29	0.07	0.15	0	0	0	0.07	0.07	0.15	0.07	0.07	0.58	
9	2.47		0.44	0.22	0.36	0.15	0.15	0.15	0.15	0.22	0	0	0	0.07	0.07	0	0	0	0	0.07	0.44	
10	3.64		1.60	0.36	0.15	0.07	0.07	0.15	0	0.29	0.15	0.15	0.07	0.15	0	0	0.07	0	0	0	0.36	
11	3.71		1.53	0.36	0.36	0.29	0.07	0	0.07	0.36	0	0.22	0.07	0	0	0	0	0	0	0	0.36	
12	3.35		1.38	0.29	0.44	0.07	0.22	0.07	0.15	0.07	0.15	0.07	0.07	0	0	0.07	0.07	0	0	0	0.22	
13	12.08		2.91	2.84	0.51	0.51	0	0	0	0.22	0.15	0.07	0.15	1.02	1.09	0	0	0	0	0	2.62	
14	8.08		1.82	0.36	1.16	0.44	0.51	0.44	0.44	0.51	0.15	0.15	0.07	0.15	0.44	0.07	0.15	0.07	0.07	0	1.09	
15	6.70		2.18	0.51	0.73	0.29	0.36	0.29	0.22	0.58	0.15	0.15	0.07	0	0.22	0	0	0	0	0.07	0.87	
16	4.15		1.02	0.29	0.51	0.07	0.36	0.07	0.07	0.29	0.22	0.22	0.15	0	0.07	0.07	0.07	0	0.07	0.07	0.51	
17	3.64		1.02	0.07	0.36	0.22	0.07	0.15	0.07	0.44	0.36	0.58	0.07	0.15	0	0	0	0	0	0.07	0	
18	4.44		0.87	0.36	0.29	0.36	0.15	0.15	0.07	0.44	0.22	0.36	0.15	0.07	0.07	0.07	0.15	0	0.07	0	0.58	
19	3.06		0.73	0.22	0.15	0.29	0.22	0.07	0.15	0.29	0.07	0.07	0.07	0.22	0.07	0.15	0	0	0	0.07	0.22	
20	3.78		1.02	0.29	0.07	0.15	0.15	0.15	0.07	0.29	0.15	0.15	0.07	0.22	0.44	0.15	0	0.07	0.07	0.07	0.22	
21	5.02		0.36	0.22	0.66	0.44	0.07	0.15	0	0.29	0.51	0.22	0.15	0.07	0.29	1.02	0.15	0	0	0	0.44	
22	3.71		0.22	0.15	0.51	0.58	0.07	0.15	0.07	0.07	0.15	0.22	0.15	0.07	0.15	0.29	0.58	0	0	0	0.29	
23	2.26		0.58	0.15	0	0.07	0.07	0	0.07	0.29	0.15	0	0.07	0	0	0.07	0.07	0.36	0	0	0.29	
Sum	*100*																					*100*

Figure E-14. Soak time distributions for Group 3b (Agricultural – South Central Valley)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	Sum
			0.30	1.09	1.13	0.87	0.88	1.12	1.54	1.77	2.23	2.86	8.29	43.27	34.44	0.21	0.00	0	0	0	*100*
Hour																					
0	1.43		0.01	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.13	0.97	0.10	0.00	0	0	0	0	
1	2.51		0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.03	0.04	0.04	0.16	1.75	0.39	0	0	0	0	0	
2	3.88		0.00	0.02	0.02	0.01	0.01	0.02	0.04	0.07	0.06	0.08	0.33	1.96	1.25	0.00	0	0	0	0	
3	5.23		0.01	0.02	0.02	0.02	0.02	0.03	0.05	0.07	0.12	0.19	0.56	2.48	1.61	0.01	0.00	0	0	0	
4	4.83		0.01	0.04	0.04	0.03	0.02	0.05	0.06	0.06	0.10	0.16	0.47	2.88	0.87	0.05	0	0	0	0	
5	4.64		0.01	0.04	0.05	0.03	0.02	0.03	0.06	0.07	0.09	0.14	0.36	2.45	1.28	0.01	0.00	0	0	0	
6	5.73		0.01	0.05	0.06	0.04	0.05	0.07	0.11	0.13	0.15	0.19	0.45	2.76	1.64	0.01	0.00	0	0	0	
7	6.51		0.02	0.07	0.09	0.09	0.08	0.10	0.14	0.11	0.13	0.16	0.60	3.34	1.58	0.02	0.00	0	0	0	
8	10.23		0.02	0.08	0.10	0.08	0.08	0.09	0.13	0.13	0.17	0.23	0.67	2.72	5.71	0.02	0	0	0	0	
9	10.29		0.01	0.05	0.06	0.05	0.05	0.07	0.10	0.16	0.18	0.19	0.63	3.18	5.54	0.00	0	0	0	0	
10	5.73		0.02	0.09	0.08	0.06	0.08	0.09	0.09	0.11	0.14	0.17	0.58	2.47	1.75	0.00	0	0	0	0	
11	8.42		0.02	0.06	0.07	0.06	0.07	0.09	0.11	0.13	0.17	0.19	0.50	3.01	3.90	0.06	0.00	0	0	0	
12	7.72		0.01	0.06	0.06	0.05	0.05	0.07	0.09	0.11	0.13	0.17	0.44	2.17	4.31	0.01	0.00	0	0	0	
13	5.24		0.02	0.12	0.15	0.07	0.06	0.07	0.09	0.11	0.14	0.16	0.44	1.92	1.87	0.01	0	0	0	0	
14	3.29		0.02	0.07	0.07	0.05	0.04	0.05	0.06	0.08	0.09	0.13	0.35	1.43	0.83	0.00	0	0	0	0	
15	2.67		0.02	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.08	0.12	0.27	1.28	0.51	0.00	0	0	0	0	
16	2.23		0.02	0.06	0.05	0.05	0.06	0.06	0.08	0.08	0.10	0.10	0.22	0.96	0.38	0.00	0	0	0	0	
17	2.45		0.01	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.06	0.08	0.20	1.37	0.48	0.00	0	0	0	0	
18	1.75		0.01	0.04	0.03	0.02	0.02	0.02	0.05	0.04	0.05	0.05	0.19	1.08	0.14	0.00	0	0	0	0	
19	1.64		0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.05	0.08	0.07	0.17	1.05	0.10	0	0	0	0	0	
20	1.12		0.01	0.02	0.01	0.00	0.00	0.01	0.02	0.04	0.03	0.02	0.14	0.76	0.05	0	0	0	0	0	
21	0.78		0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.03	0.06	0.13	0.43	0.01	0	0	0	0	0	
22	0.95		0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.21	0.49	0.03	0	0	0	0	0	
23	0.75		0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.10	0.37	0.12	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-15. VMT distributions for Group 3b (Agricultural – South Central Valley)

Construction

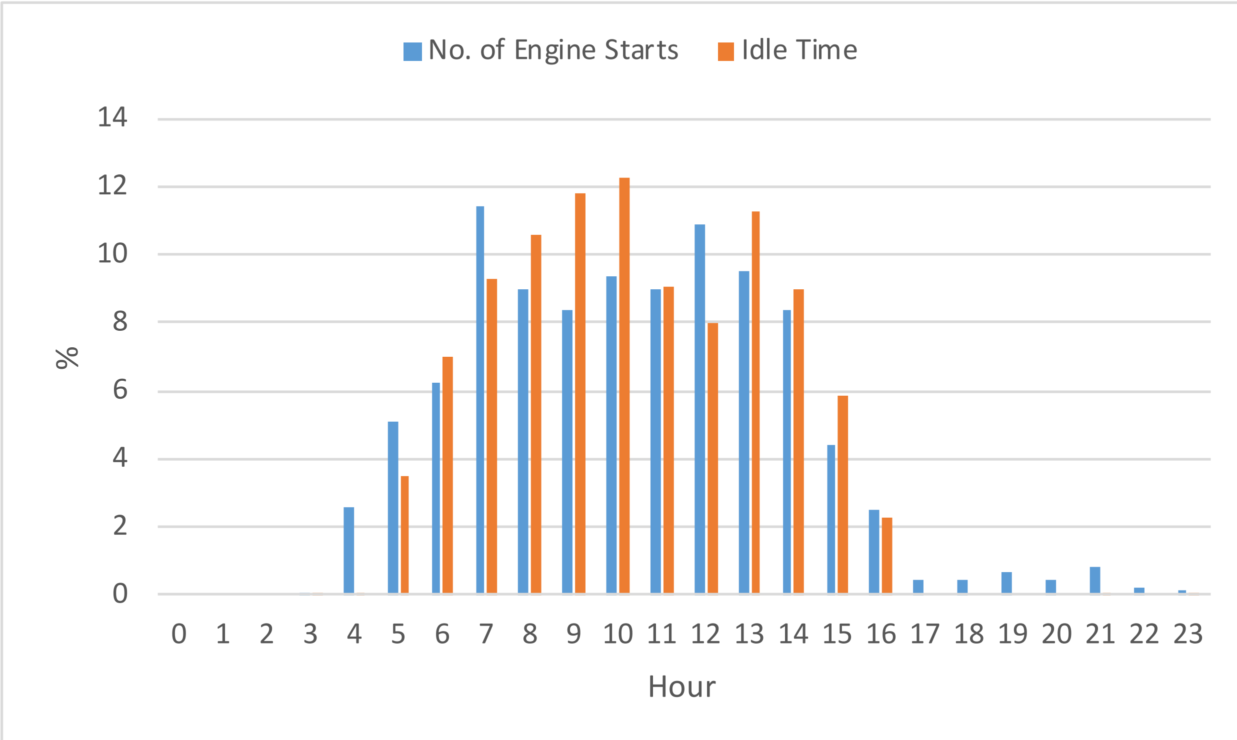


Figure E-16. Start and idle temporal distributions for Group 4a (Construction)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		44.82	12.19	9.02	5.76	3.42	2.67	1.17	4.76	1.34	0.58	0.50	0.17	0.50	0.42	0.42	0.25	0.17	0.58	11.27	*100*
Hour																					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	
4	2.59	0.08	0	0.08	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0.58	1.75	
5	5.09	0.58	0.17	0.25	0.25	0.17	0	0	0.17	0	0	0	0	0	0.17	0.25	0.17	0.17	0	2.75	
6	6.26	1.42	1.25	0.50	0.17	0	0	0	0.42	0	0	0	0	0.08	0	0.08	0.08	0	0	2.25	
7	11.44	4.92	1.59	1.09	0.67	0.33	0.17	0.08	0.08	0	0.08	0	0	0	0	0.08	0	0	0	2.34	
8	9.02	5.59	1.09	0.67	0.83	0.08	0.17	0	0.25	0	0	0	0	0	0	0	0	0	0	0.33	
9	8.35	4.59	1.09	1.00	0	0.50	0.50	0.33	0.08	0.08	0	0	0	0	0	0	0	0	0	0.17	
10	9.35	4.51	1.50	1.17	0.58	0.25	0.42	0.08	0.58	0.17	0	0	0	0	0	0	0	0	0	0.08	
11	9.02	4.92	1.09	0.67	0.75	0.17	0.33	0.17	0.33	0	0.17	0	0	0	0	0	0	0	0	0.42	
12	10.85	5.59	0.92	0.92	0.67	0.83	0.58	0.25	0.75	0.17	0	0	0	0	0	0	0	0	0	0.17	
13	9.52	4.26	1.59	1.09	0.83	0.58	0.17	0	0.75	0.08	0	0	0.08	0	0	0	0	0	0	0.08	
14	8.35	4.51	0.83	0.67	0.42	0.50	0.25	0.08	0.42	0.08	0.17	0	0	0.17	0	0	0	0	0	0.25	
15	4.42	2.25	0.58	0.50	0.25	0	0	0.17	0.08	0.08	0.08	0	0	0.08	0.08	0	0	0	0	0.25	
16	2.50	1.00	0.33	0.25	0.17	0	0.08	0	0.42	0.17	0	0.08	0	0	0	0	0	0	0	0	
17	0.42	0	0	0	0	0	0	0	0.17	0.17	0	0	0	0	0	0	0	0	0	0.08	
18	0.42	0.17	0.08	0.08	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	
19	0.67	0.17	0.08	0	0	0	0	0	0	0.17	0	0.17	0	0	0	0	0	0	0	0.08	
20	0.42	0	0	0	0	0	0	0	0	0.08	0	0.17	0.08	0.08	0	0	0	0	0	0	
21	0.83	0.17	0	0.08	0.08	0	0	0	0.25	0	0	0	0	0	0.08	0	0	0	0	0.17	
22	0.25	0	0	0	0.08	0	0	0	0	0.08	0	0	0	0	0.08	0	0	0	0	0	
23	0.17	0.08	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-17. Soak time distributions for Group 4a (Construction)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		1.13	2.05	1.92	2.23	3.06	3.66	4.57	5.33	6.67	8.12	10.31	31.05	11.10	4.66	4.13	0	0	0	*100*
Hour																				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	3.08	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.03	0.04	0.03	0.16	0.40	1.23	1.05	0	0	0	
5	5.25	0.01	0.03	0.03	0.03	0.05	0.04	0.06	0.09	0.13	0.17	0.17	0.92	0.80	1.22	1.49	0	0	0	
6	10.49	0.08	0.21	0.16	0.13	0.18	0.25	0.35	0.44	0.64	0.74	1.06	4.95	1.26	0.02	0.00	0	0	0	
7	9.11	0.14	0.24	0.24	0.29	0.41	0.50	0.50	0.55	0.73	0.87	1.00	2.82	0.78	0.01	0.00	0	0	0	
8	10.44	0.12	0.23	0.22	0.29	0.35	0.40	0.47	0.57	0.71	0.82	1.12	4.08	1.03	0.03	0.00	0	0	0	
9	9.27	0.11	0.20	0.18	0.21	0.36	0.40	0.50	0.59	0.69	0.79	1.06	3.17	0.98	0.02	0.00	0	0	0	
10	9.27	0.12	0.20	0.18	0.22	0.33	0.39	0.47	0.54	0.67	0.83	1.06	3.21	1.04	0.02	0.00	0	0	0	
11	8.90	0.12	0.20	0.19	0.22	0.30	0.37	0.49	0.59	0.71	0.85	1.14	2.79	0.89	0.04	0.00	0	0	0	
12	8.78	0.12	0.21	0.21	0.23	0.33	0.35	0.46	0.49	0.62	0.76	0.93	3.06	0.97	0.02	0.00	0	0	0	
13	8.24	0.11	0.19	0.20	0.22	0.25	0.33	0.42	0.51	0.58	0.75	1.03	2.78	0.85	0.02	0.00	0	0	0	
14	9.50	0.10	0.16	0.16	0.19	0.27	0.35	0.47	0.54	0.71	0.89	0.99	2.07	1.12	0.89	0.58	0	0	0	
15	7.04	0.06	0.13	0.11	0.13	0.17	0.22	0.30	0.33	0.40	0.54	0.67	1.01	0.95	1.07	0.96	0	0	0	
16	0.60	0.02	0.03	0.02	0.02	0.03	0.04	0.05	0.05	0.04	0.08	0.05	0.04	0.05	0.07	0.02	0	0	0	
17	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	
23	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-18. VMT distributions for Group 4a (Constructio)

Cement Mixers

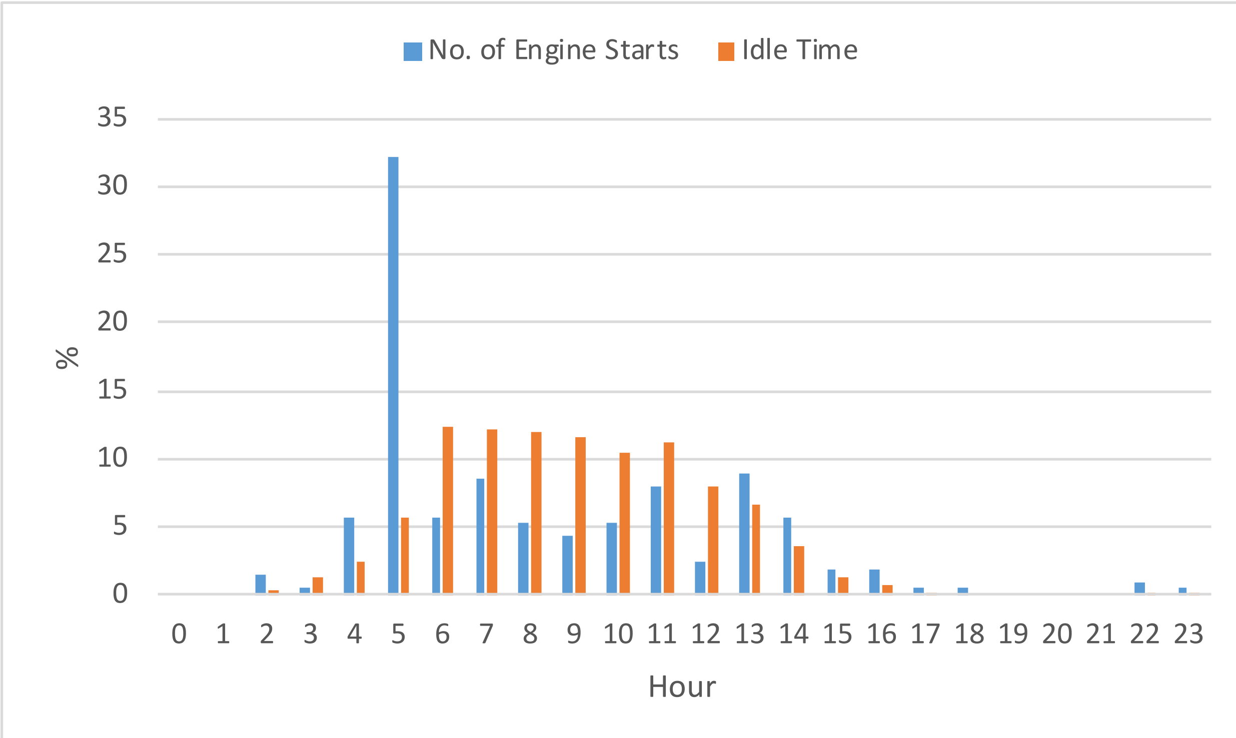


Figure E-19. Start and idle temporal distributions for Group 4b (Cement mixers)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
			41.43	14.29	6.19	2.38	2.86	1.43	0.48	1.43	1.43	0.95	0	0.95	0	0	0	0	1.43	0	24.76	*100*
Hour																						
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	1.43		0	0	0	0	0	0	0	0	0.48	0	0	0	0	0	0	0	0.48	0	0.48	
3	0.48		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.48	0	0	
4	5.71		0.95	0	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.29	
5	31.90		12.38	2.38	1.90	0	0	0	0	0	0	0	0	0	0	0	0	0	0.48	0	14.76	
6	5.71		1.90	0.95	0	0.95	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	1.43	
7	8.57		4.29	1.43	0.48	0.48	0	0.48	0.48	0	0	0	0	0	0	0	0	0	0	0	0.95	
8	5.24		4.29	0	0.48	0	0	0	0	0	0.48	0	0	0	0	0	0	0	0	0	0	
9	4.29		1.43	1.43	0.48	0.48	0	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	5.24		3.81	0.48	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	8.10		3.33	1.90	0.95	0.48	0	0.48	0	0	0.48	0	0	0	0	0	0	0	0	0	0.48	
12	2.38		0.48	0.48	0	0	0.48	0	0	0	0	0	0	0.48	0	0	0	0	0	0	0.48	
13	9.05		4.76	1.90	0.48	0	0.48	0	0	0.95	0	0.48	0	0	0	0	0	0	0	0	0	
14	5.71		2.38	1.90	0	0	1.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	1.90		0.95	0.95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	1.90		0	0	0	0	0	0	0	0	0	0.48	0	0	0	0	0	0	0	0	1.43	
17	0.48		0	0.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0.48		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.48	
19	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.95		0.48	0	0	0	0	0	0	0	0	0	0	0.48	0	0	0	0	0	0	0	
23	0.48		0	0	0	0	0	0	0	0.48	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																					*100*

Figure E-20. Soak time distributions for Group 4b (Cement mixers)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
			1.07	2.43	2.35	2.23	2.54	3.20	4.05	5.30	7.34	6.81	7.95	28.43	25.54	0.72	0.03	0	0	0	*100*
Hour																					
0	0.00		0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0.11		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.06	0	0	0	0	0	0	
3	0.95		0.01	0.01	0.01	0.02	0.04	0.04	0.06	0.07	0.09	0.04	0.06	0.43	0.07	0	0	0	0	0	
4	1.34		0.02	0.04	0.03	0.02	0.03	0.04	0.05	0.08	0.12	0.12	0.12	0.60	0.08	0	0	0	0	0	
5	8.54		0.09	0.11	0.11	0.15	0.18	0.23	0.26	0.36	0.55	0.68	1.00	2.44	2.28	0.09	0.00	0	0	0	
6	8.44		0.11	0.18	0.21	0.21	0.21	0.27	0.30	0.39	0.58	0.64	0.55	1.67	3.06	0.06	0.00	0	0	0	
7	7.86		0.12	0.28	0.26	0.23	0.27	0.34	0.47	0.63	0.82	0.64	0.44	2.06	1.22	0.09	0.00	0	0	0	
8	11.60		0.13	0.28	0.32	0.31	0.37	0.47	0.53	0.61	0.85	0.74	0.92	2.88	2.90	0.27	0.02	0	0	0	
9	10.81		0.10	0.25	0.24	0.21	0.25	0.27	0.39	0.58	0.94	0.81	0.92	3.48	2.35	0.01	0	0	0	0	
10	11.62		0.13	0.24	0.27	0.28	0.30	0.33	0.45	0.59	0.85	0.78	0.86	4.18	2.35	0.02	0	0	0	0	
11	8.69		0.10	0.24	0.22	0.17	0.17	0.24	0.34	0.42	0.50	0.53	0.67	2.88	2.20	0.01	0	0	0	0	
12	10.70		0.10	0.27	0.25	0.24	0.27	0.35	0.43	0.61	0.80	0.67	1.02	2.85	2.80	0.04	0.00	0	0	0	
13	9.47		0.09	0.24	0.22	0.20	0.20	0.27	0.39	0.48	0.63	0.56	0.83	2.73	2.57	0.05	0	0	0	0	
14	6.98		0.06	0.18	0.15	0.15	0.20	0.26	0.27	0.32	0.37	0.35	0.42	1.66	2.55	0.04	0	0	0	0	
15	2.09		0.02	0.07	0.06	0.03	0.05	0.06	0.10	0.14	0.20	0.21	0.09	0.25	0.77	0.04	0.00	0	0	0	
16	0.79		0.01	0.02	0.02	0.00	0.01	0.01	0.01	0.01	0.02	0.03	0.05	0.24	0.34	0.01	0	0	0	0	
17	0.00		0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.00		0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0.01		0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-21. VMT distributions for Group 4b (Cement mixers)

Food Distribution

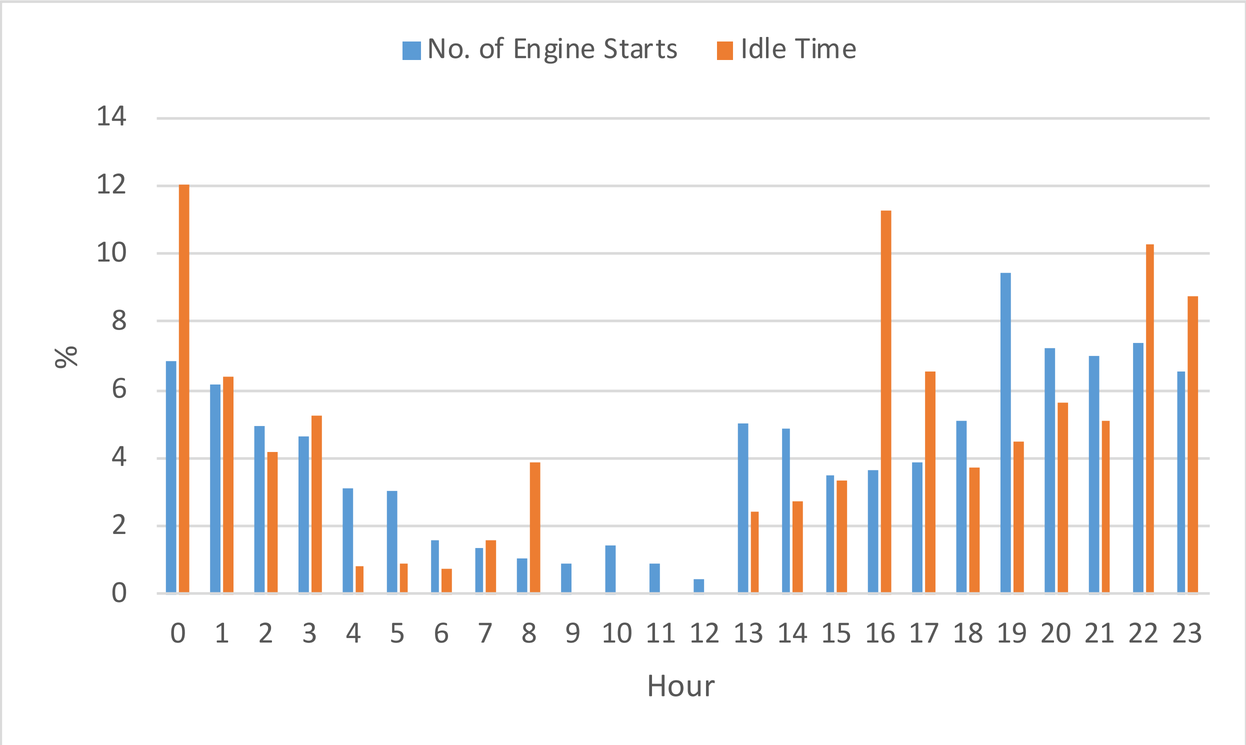


Figure E-22. Start and idle temporal distributions for Group 5a (Food distribution)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	Sum
			34.99	15.19	11.94	5.85	5.54	4.02	2.69	8.38	1.73	0.90	0.65	0.84	0.53	0.65	0.53	0.71	0.46	0.68	3.71	100
Hour																						
0	6.84		2.29	1.14	1.05	0.28	0.34	0.46	0.31	0.68	0.15	0	0.03	0	0.03	0	0	0	0	0	0.06	
1	6.19		2.32	0.90	0.90	0.34	0.22	0.40	0.25	0.80	0.03	0	0	0	0	0	0	0	0	0	0.03	
2	4.92		1.52	0.93	0.59	0.22	0.28	0.28	0.15	0.77	0.09	0.06	0.03	0	0	0	0	0	0	0	0	
3	4.61		1.58	0.99	0.34	0.22	0.22	0.25	0.09	0.84	0.09	0	0	0	0	0	0	0	0	0	0	
4	3.13		1.14	0.65	0.28	0.12	0.12	0.09	0.19	0.40	0.09	0.03	0	0	0	0	0	0	0	0	0	
5	3.06		1.18	0.71	0.34	0	0.06	0.06	0.09	0.28	0.15	0.06	0.06	0.03	0	0	0	0	0.03	0	0	
6	1.58		0.65	0.22	0.12	0.06	0.06	0.03	0	0.22	0.03	0.06	0	0.06	0.06	0	0	0	0	0	0	
7	1.33		0.46	0.25	0.06	0.03	0.03	0.03	0.03	0.15	0.03	0	0.03	0.03	0.09	0.03	0.03	0	0	0	0.03	
8	1.08		0.40	0.12	0.06	0.06	0	0.03	0.06	0	0.03	0.06	0.03	0.12	0.03	0.03	0	0	0	0	0.03	
9	0.87		0.19	0.06	0.12	0.12	0	0	0	0	0	0.06	0.06	0.03	0.03	0.03	0	0	0	0	0.15	
10	1.42		0.53	0.28	0.03	0.06	0.03	0	0.03	0.03	0.06	0.09	0.03	0.09	0	0	0.03	0.03	0	0.06	0.03	
11	0.90		0.28	0.19	0.12	0	0	0	0	0.03	0.06	0	0	0.03	0.06	0.03	0	0.03	0	0.03	0.03	
12	0.46		0.03	0.12	0.03	0	0	0.03	0	0	0	0	0	0	0	0	0.12	0.03	0.03	0	0.06	
13	5.04		1.98	1.21	0.25	0	0.03	0.03	0	0.03	0.12	0.06	0.03	0.06	0.06	0.12	0.06	0.22	0.09	0.12	0.56	
14	4.89		1.92	0.74	0.25	0.06	0	0.03	0.03	0.15	0	0.19	0.06	0.09	0.03	0.15	0.09	0.15	0.12	0.28	0.53	
15	3.47		1.67	0.71	0.34	0.12	0.06	0.03	0.06	0.12	0.03	0	0.09	0.03	0	0.03	0	0.03	0	0.06	0.06	
16	3.68		1.36	0.25	0.53	0.25	0.31	0.15	0.03	0.12	0	0	0.03	0.03	0.03	0.03	0.03	0.06	0.06	0.03	0.37	
17	3.87		0.90	0.50	0.15	0.28	0.37	0.22	0.19	0.59	0.15	0.03	0.09	0	0	0.03	0.03	0	0.03	0	0.31	
18	5.07		1.39	0.56	0.68	0.53	0.43	0.09	0.15	0.71	0.12	0.03	0.03	0.03	0	0	0.03	0.03	0.03	0.03	0.19	
19	9.44		3.59	1.36	1.21	0.46	0.62	0.15	0.09	0.25	0.06	0.06	0.03	0.15	0.09	0.06	0.09	0.12	0.06	0.06	0.90	
20	7.24		2.48	1.02	1.08	1.14	0.50	0.25	0.19	0.34	0.06	0	0	0	0	0.03	0	0	0	0	0.15	
21	7.02		2.35	1.02	1.33	0.50	0.68	0.40	0.22	0.34	0.03	0	0	0.03	0	0	0	0	0	0	0.12	
22	7.36		2.51	0.68	1.02	0.62	0.65	0.59	0.15	0.96	0.12	0.03	0	0	0	0.03	0	0	0	0	0	
23	6.53		2.29	0.59	1.05	0.37	0.53	0.40	0.37	0.56	0.19	0.06	0	0	0	0.03	0	0	0	0	0.09	
Sum	*100*																					*100*

Figure E-23. Soak time distributions for Group 5a (Food distribution)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	Sum
			0.43	1.50	1.53	1.56	1.89	2.18	2.36	2.92	4.51	15.40	42.97	22.09	0.64	0.02	0.00	0	0	0	100
Hour																					
0	8.83		0.03	0.09	0.07	0.07	0.10	0.12	0.18	0.23	0.34	1.75	4.30	1.50	0.05	0.00	0	0	0	0	
1	7.39		0.03	0.08	0.07	0.06	0.08	0.08	0.12	0.13	0.25	1.27	3.34	1.82	0.04	0.00	0	0	0	0	
2	5.37		0.02	0.07	0.06	0.05	0.05	0.06	0.08	0.09	0.16	0.75	2.36	1.51	0.11	0.01	0.00	0	0	0	
3	4.21		0.01	0.06	0.05	0.04	0.04	0.04	0.04	0.05	0.08	0.46	1.81	1.47	0.04	0.00	0.00	0	0	0	
4	3.04		0.01	0.04	0.04	0.02	0.03	0.03	0.03	0.03	0.06	0.44	1.27	1.03	0.01	0.00	0	0	0	0	
5	1.39		0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.04	0.21	0.62	0.38	0.00	0.00	0	0	0	0	
6	0.92		0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.18	0.50	0.13	0.01	0	0	0	0	0	
7	0.30		0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.05	0.11	0.03	0.00	0	0	0	0	0	
8	0.34		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.10	0.10	0.00	0	0	0	0	0	
9	0.35		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.11	0.08	0.00	0	0	0	0	0	
10	0.14		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.03	0.04	0.00	0	0	0	0	0	
11	0.20		0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.09	0.04	0.00	0	0	0	0	0	
12	0.20		0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.08	0.05	0.00	0	0	0	0	0	
13	0.70		0.01	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.13	0.21	0.08	0.01	0	0	0	0	0	
14	2.88		0.01	0.06	0.05	0.05	0.06	0.07	0.07	0.09	0.15	0.74	1.26	0.26	0.01	0.00	0	0	0	0	
15	5.95		0.02	0.08	0.09	0.12	0.16	0.18	0.20	0.22	0.34	0.84	2.07	1.60	0.03	0.00	0	0	0	0	
16	4.24		0.02	0.08	0.11	0.13	0.15	0.18	0.16	0.18	0.21	0.36	1.36	1.27	0.03	0	0	0	0	0	
17	3.53		0.03	0.09	0.12	0.15	0.19	0.19	0.19	0.19	0.21	0.36	1.13	0.64	0.02	0.00	0	0	0	0	
18	5.27		0.04	0.15	0.20	0.23	0.26	0.27	0.24	0.24	0.26	0.61	1.75	0.99	0.02	0.00	0	0	0	0	
19	8.80		0.04	0.15	0.16	0.17	0.21	0.24	0.24	0.31	0.51	1.31	3.47	1.91	0.07	0.00	0	0	0	0	
20	10.11		0.04	0.11	0.11	0.12	0.14	0.17	0.19	0.30	0.59	1.81	4.43	2.05	0.07	0.00	0	0	0	0	
21	8.61		0.03	0.10	0.10	0.11	0.12	0.16	0.18	0.25	0.41	1.04	4.16	1.93	0.04	0.00	0	0	0	0	
22	8.52		0.03	0.11	0.10	0.08	0.11	0.14	0.16	0.26	0.37	1.16	4.40	1.57	0.02	0.00	0	0	0	0	
23	8.69		0.03	0.09	0.07	0.07	0.09	0.11	0.15	0.23	0.40	1.78	3.98	1.63	0.06	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-24. VMT distributions for Group 5a (Food distribution)

Beverage Distribution

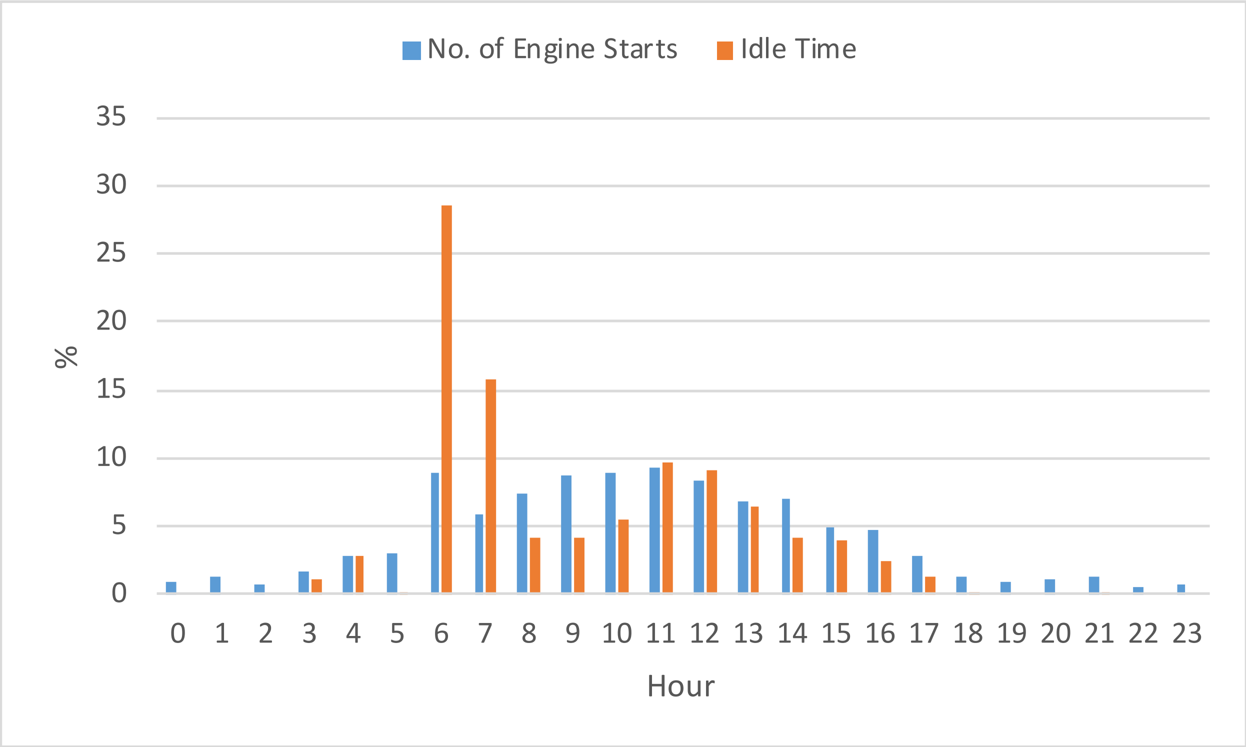


Figure E-25. Start and idle temporal distributions for Group 5b (Beverage distribution)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		12.11	10.21	16.97	11.75	9.45	7.01	5.13	13.62	2.99	1.48	0.85	0.79	0.82	0.66	0.94	0.88	0.82	0.66	2.87	*100*
Hour																					
0	0.97	0.03	0.03	0.15	0	0.12	0.06	0	0	0	0	0	0	0.06	0	0.18	0.06	0.03	0.03	0.21	
1	1.27	0.06	0.06	0.06	0.03	0.09	0	0.12	0.39	0.03	0	0	0	0	0.03	0.12	0.03	0.06	0	0.18	
2	0.76	0	0	0.03	0.06	0.09	0.03	0.06	0.09	0	0	0.03	0	0.03	0	0	0.03	0.09	0.09	0.12	
3	1.75	0.09	0	0.12	0.09	0.15	0.09	0.09	0.33	0.09	0.18	0.03	0	0.03	0	0	0.09	0.06	0.06	0.24	
4	2.87	0.30	0.36	0.54	0.30	0.18	0.09	0.06	0.15	0.24	0.09	0.09	0.03	0.06	0.15	0	0	0	0.09	0.12	
5	2.93	0.33	0.21	0.27	0.12	0.18	0.27	0.24	0.51	0.12	0.03	0.06	0.06	0	0.09	0.09	0.03	0.03	0.09	0.18	
6	8.91	2.08	1.06	0.94	0.30	0.27	0.24	0.24	0.60	0.39	0.18	0.09	0.15	0.09	0.12	0.36	0.45	0.42	0.24	0.66	
7	5.83	1.03	0.57	1.09	0.66	0.36	0.36	0.27	0.63	0.15	0	0	0	0	0.03	0.03	0.06	0.12	0.03	0.42	
8	7.43	0.69	0.72	1.63	0.91	0.82	0.69	0.42	1.33	0.15	0	0	0	0	0	0	0	0	0	0.06	
9	8.70	1.06	0.82	1.63	1.48	0.82	0.60	0.39	1.51	0.21	0.06	0	0	0	0	0.03	0	0	0	0.09	
10	8.91	0.91	0.66	1.81	1.45	1.09	0.79	0.42	1.36	0.24	0.09	0	0	0	0	0	0	0	0	0.09	
11	9.21	0.91	0.97	2.30	1.42	1.00	1.00	0.36	0.91	0.21	0.03	0	0	0	0	0	0	0	0	0.12	
12	8.43	0.97	0.88	1.66	1.36	1.09	0.57	0.54	1.18	0.15	0	0	0	0	0	0	0	0	0	0.03	
13	6.89	0.51	0.79	1.39	0.97	0.88	0.48	0.63	1.06	0.15	0	0	0	0.03	0	0	0	0	0	0	
14	7.04	0.72	0.82	1.12	1.24	0.72	0.66	0.33	1.24	0.15	0	0	0	0	0	0	0	0	0	0.03	
15	4.83	0.57	0.66	0.66	0.42	0.76	0.42	0.33	0.79	0.09	0.09	0	0	0	0	0	0	0	0	0.03	
16	4.68	0.82	0.79	0.88	0.45	0.33	0.15	0.18	0.72	0.09	0.15	0.03	0.03	0.03	0	0	0	0	0	0.03	
17	2.90	0.76	0.48	0.42	0.24	0.15	0.12	0.15	0.21	0.18	0.06	0.06	0.06	0	0	0	0	0	0	0	
18	1.30	0.18	0.33	0.09	0.09	0.06	0.03	0.09	0.09	0.09	0.09	0.06	0	0.06	0	0	0	0	0	0.03	
19	0.91	0.03	0	0.06	0	0.03	0.09	0.06	0.12	0.15	0.12	0.06	0.03	0.06	0	0.03	0	0	0	0.06	
20	1.09	0	0	0.03	0.03	0.09	0.09	0.06	0.12	0.03	0.18	0.15	0.15	0.12	0.03	0	0	0	0	0	
21	1.21	0.06	0	0.03	0.09	0.09	0.09	0.03	0.18	0.03	0.09	0.15	0.12	0.18	0.03	0	0	0	0	0.03	
22	0.45	0	0	0.03	0	0	0.03	0.03	0.06	0.03	0.03	0.03	0.06	0.06	0.03	0.03	0	0	0	0.03	
23	0.76	0	0	0.03	0.03	0.09	0.03	0	0.03	0	0	0	0.09	0	0.15	0.06	0.12	0	0.03	0.09	
Sum	*100*																				*100*

Figure E-26. Soak time distributions for Group 5b (Beverage distribution)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		2.64	5.66	7.75	10.72	14.94	18.43	14.65	7.20	3.19	3.15	4.28	4.77	2.58	0.04	0	0	0	0	*100*
Hour																				
0	0.08	0.01	0.03	0.03	0.01	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0.11	0.02	0.04	0.03	0.02	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0.06	0.01	0.02	0.02	0.01	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0.10	0.02	0.03	0.03	0.01	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0.35	0.04	0.06	0.04	0.03	0.03	0.02	0.01	0.01	0.08	0.04	0	0	0	0	0	0	0	0	
5	5.73	0.06	0.16	0.18	0.26	0.36	0.52	0.75	0.65	0.57	0.69	0.76	0.65	0.12	0.00	0	0	0	0	
6	4.96	0.14	0.33	0.37	0.54	0.65	0.64	0.50	0.32	0.18	0.20	0.30	0.44	0.34	0.01	0	0	0	0	
7	14.18	0.31	0.70	1.09	1.55	2.05	2.26	1.80	1.00	0.53	0.59	0.71	0.85	0.71	0.00	0	0	0	0	
8	7.69	0.24	0.45	0.63	0.89	1.21	1.52	0.99	0.40	0.13	0.18	0.29	0.47	0.29	0.00	0	0	0	0	
9	6.78	0.22	0.43	0.57	0.80	1.17	1.49	1.16	0.43	0.10	0.09	0.15	0.13	0.04	0	0	0	0	0	
10	8.47	0.22	0.45	0.61	0.85	1.27	1.85	1.55	0.69	0.18	0.25	0.24	0.24	0.08	0.00	0	0	0	0	
11	6.92	0.21	0.39	0.55	0.78	1.17	1.52	1.16	0.46	0.11	0.07	0.15	0.18	0.17	0	0	0	0	0	
12	8.40	0.23	0.42	0.59	0.87	1.35	1.84	1.41	0.65	0.17	0.14	0.19	0.32	0.21	0.02	0	0	0	0	
13	8.57	0.19	0.41	0.62	0.89	1.29	1.68	1.44	0.71	0.32	0.16	0.32	0.32	0.21	0	0	0	0	0	
14	9.41	0.19	0.45	0.70	0.97	1.40	1.57	1.25	0.69	0.36	0.38	0.58	0.62	0.25	0.01	0	0	0	0	
15	8.78	0.17	0.46	0.69	1.01	1.42	1.81	1.43	0.67	0.25	0.19	0.28	0.28	0.10	0	0	0	0	0	
16	6.18	0.16	0.43	0.59	0.79	1.02	1.15	0.79	0.34	0.15	0.12	0.28	0.27	0.07	0	0	0	0	0	
17	2.51	0.11	0.24	0.29	0.36	0.44	0.47	0.35	0.16	0.05	0.03	0.01	0.00	0	0	0	0	0	0	
18	0.46	0.03	0.05	0.05	0.05	0.08	0.09	0.07	0.02	0.01	0.01	0.01	0.00	0	0	0	0	0	0	
19	0.07	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	
20	0.07	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	
21	0.05	0.02	0.02	0.01	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	
23	0.05	0.01	0.02	0.02	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-27. VMT distributions for Group 5b (Beverage distribution)

Local Moving

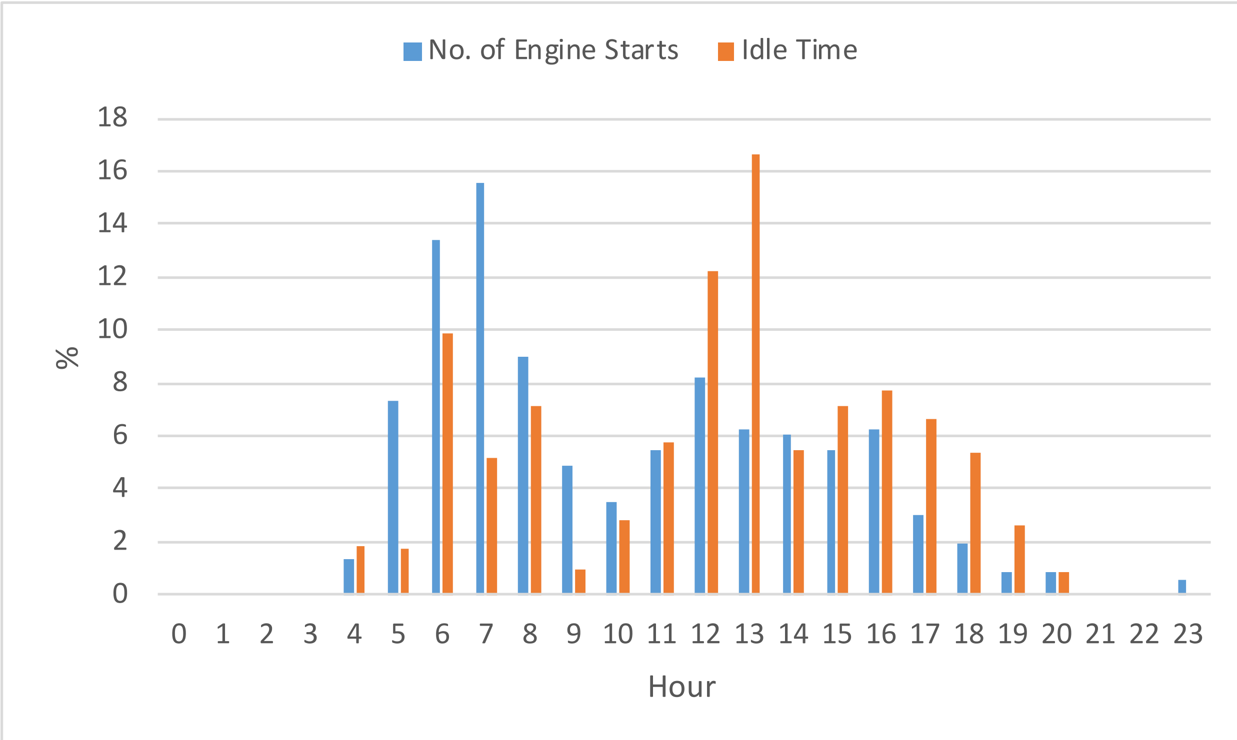


Figure E-28. Start and idle temporal distributions for Group 5c (Local moving)

Soak Period			**5**	**10**	**20**	**30**	**40**	**50**	**60**	**120**	**180**	**240**	**300**	**360**	**420**	**480**	**540**	**600**	**660**	**720**	**9999**	***Sum***
			10.93	11.20	13.39	5.19	2.46	4.37	3.28	10.93	7.10	5.74	3.55	1.64	0.27	1.64	0.82	0.55	0.82	2.19	13.93	*100*
Hour																						
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	1.37		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.27	0.27	0	0.27	0.55	
5	7.38		1.37	1.09	0.55	0	0	0	0	0	0	0	0	0	0	0	0	0	0.27	1.09	3.01	
6	13.39		0.82	0.55	1.37	1.37	0	0.82	0.27	0.27	0	0	0	0	0	0	0	0.27	0	0.82	6.83	
7	15.57		1.37	2.73	3.83	0.27	0.27	0.82	1.09	2.19	0	0	0	0	0	0	0	0	0.55	0	2.46	
8	9.02		2.19	1.37	2.73	0.27	0	0.55	0.27	0.55	0.55	0	0	0	0	0	0	0	0	0	0.55	
9	4.92		0	0.82	0.55	0.27	0.27	0	0.27	2.19	0.55	0	0	0	0	0	0	0	0	0	0	
10	3.55		0	0.27	0.82	0	0	0.27	0	1.37	0.82	0	0	0	0	0	0	0	0	0	0	
11	5.46		0.27	0	0.55	0.55	0	0	0.27	0.27	1.91	1.37	0.27	0	0	0	0	0	0	0	0	
12	8.20		0.82	0.55	0.82	0	0.55	0.82	0	1.09	1.09	1.09	1.09	0	0.27	0	0	0	0	0	0	
13	6.28		1.09	0.55	0	1.09	0.55	0	0.27	0.27	0.55	0.55	0.55	0.55	0	0.27	0	0	0	0	0	
14	6.01		0.27	1.09	1.09	0.55	0.55	0.55	0	0.27	0	0	0.55	0.55	0	0.27	0	0	0	0	0.27	
15	5.46		0.27	0.55	0	0.55	0	0.27	0.27	1.64	0.27	0.82	0	0	0	0.82	0	0	0	0	0	
16	6.28		1.37	1.09	0.82	0	0	0.27	0	0.55	0.55	0.82	0.55	0	0	0.27	0	0	0	0	0	
17	3.01		0.27	0.27	0.27	0	0.27	0	0.55	0.27	0	0.82	0.27	0	0	0	0	0	0	0	0	
18	1.91		0.55	0.27	0	0	0	0	0	0	0.27	0.27	0	0.27	0	0	0	0	0	0	0.27	
19	0.82		0	0	0	0	0	0	0	0	0.55	0	0	0	0	0	0.27	0	0	0	0	
20	0.82		0	0	0	0.27	0	0	0	0	0	0	0.27	0.27	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0.55		0.27	0	0	0	0	0	0	0	0	0	0	0	0	0	0.27	0	0	0	0	
Sum	*100*																					*100*

Figure E-29. Soak time distributions for Group 5c (Local moving)

Speed Bin			**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	***Sum***
			0.84	1.83	2.13	2.61	3.30	4.27	5.32	5.62	5.29	6.24	12.79	25.37	21.95	2.37	0.07	0	0	0	*100*
Hour																					
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0.70		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.05	0.32	0.18	0.00	0	0	0	0	
5	4.19		0.04	0.08	0.08	0.08	0.10	0.14	0.18	0.18	0.21	0.32	0.48	1.17	1.02	0.10	0	0	0	0	
6	9.23		0.10	0.15	0.12	0.12	0.12	0.21	0.32	0.38	0.40	0.31	0.99	2.73	2.80	0.44	0.04	0	0	0	
7	20.70		0.12	0.26	0.33	0.42	0.56	0.84	1.11	1.09	1.02	1.25	3.18	6.12	4.02	0.37	0.01	0	0	0	
8	10.26		0.11	0.27	0.29	0.36	0.42	0.53	0.58	0.69	0.62	0.92	1.54	2.36	1.41	0.17	0	0	0	0	
9	3.52		0.03	0.06	0.10	0.12	0.19	0.24	0.25	0.30	0.32	0.32	0.29	0.40	0.79	0.12	0.00	0	0	0	
10	2.74		0.02	0.05	0.07	0.07	0.10	0.11	0.10	0.10	0.11	0.08	0.18	0.21	1.49	0.06	0.00	0	0	0	
11	2.20		0.02	0.05	0.06	0.06	0.06	0.10	0.11	0.12	0.14	0.15	0.18	0.39	0.72	0.04	0.00	0	0	0	
12	5.00		0.04	0.09	0.13	0.17	0.23	0.25	0.27	0.28	0.29	0.24	0.63	1.00	1.20	0.16	0.00	0	0	0	
13	5.13		0.06	0.11	0.14	0.19	0.24	0.34	0.42	0.42	0.33	0.25	0.45	0.69	1.42	0.08	0	0	0	0	
14	5.52		0.04	0.11	0.11	0.14	0.16	0.20	0.21	0.19	0.24	0.31	0.77	1.40	1.29	0.34	0.00	0	0	0	
15	5.29		0.05	0.13	0.18	0.23	0.28	0.29	0.34	0.34	0.31	0.47	0.76	1.29	0.60	0.02	0	0	0	0	
16	10.86		0.06	0.18	0.22	0.26	0.34	0.42	0.54	0.54	0.44	0.63	1.51	3.80	1.90	0.02	0	0	0	0	
17	8.32		0.05	0.14	0.14	0.20	0.23	0.32	0.47	0.60	0.53	0.64	1.18	2.12	1.54	0.16	0.01	0	0	0	
18	3.67		0.05	0.11	0.09	0.11	0.14	0.15	0.23	0.23	0.21	0.22	0.33	0.78	0.82	0.20	0.00	0	0	0	
19	1.75		0.01	0.02	0.03	0.06	0.08	0.09	0.11	0.07	0.07	0.12	0.22	0.27	0.54	0.06	0	0	0	0	
20	0.52		0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.05	0.02	0.01	0.04	0.14	0.11	0.02	0	0	0	0	
21	0.38		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.18	0.10	0.00	0	0	0	0	
22	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0.00		0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-30. VMT distributions for Group 5c (Local moving)

Airport Shuttle

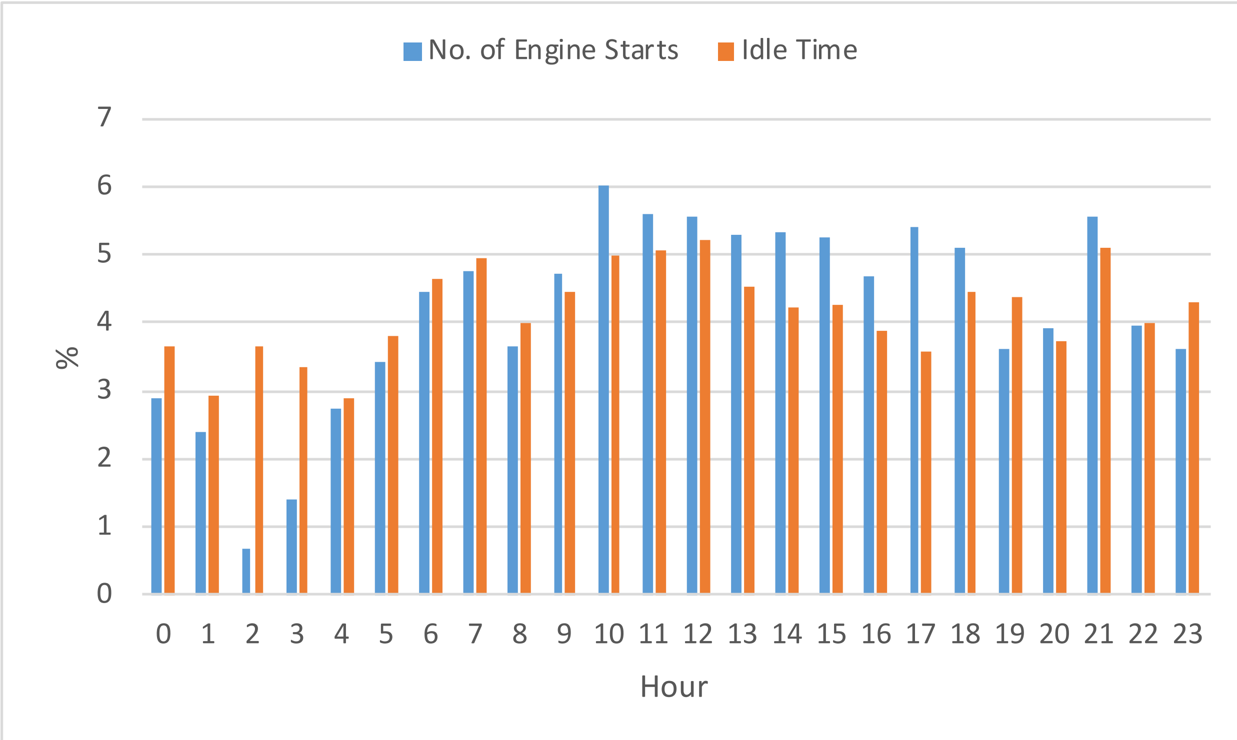


Figure E-31. Start and idle temporal distributions for Group 6 (Airport shuttle)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		36.26	5.15	19.52	4.27	8.45	2.65	1.27	4.06	2.77	2.03	1.68	1.66	1.45	1.15	1.04	0.81	0.88	0.74	4.15	*100*
Hour																					
0	2.88	1.94	0.32	0.37	0.14	0.07	0.02	0	0	0.02	0	0	0	0	0	0	0	0	0	0	
1	2.40	0.85	0.23	0.23	0.16	0.60	0.18	0	0.02	0.02	0	0	0.02	0.02	0	0	0	0	0	0.05	
2	0.67	0.35	0.02	0.09	0	0	0.02	0	0.07	0.02	0	0.02	0	0	0	0	0	0	0.02	0.05	
3	1.41	0.25	0.02	0.07	0	0.05	0.05	0	0.07	0.09	0	0.05	0.07	0.12	0.07	0.09	0.07	0.12	0.07	0.16	
4	2.72	0.72	0.16	0.60	0.14	0.05	0	0	0.07	0.05	0.09	0.09	0.05	0.18	0.14	0.07	0.02	0.02	0.05	0.23	
5	3.42	1.34	0.07	0.18	0.02	0.02	0.02	0	0	0.09	0.09	0.12	0.09	0.25	0.23	0.18	0.07	0.09	0.05	0.48	
6	4.45	0.62	0.32	1.08	0.12	0.16	0.14	0	0.09	0.02	0.09	0.14	0.25	0.14	0.07	0.16	0.12	0.09	0.16	0.67	
7	4.75	0.90	0.18	1.04	0.09	0.12	0.09	0.21	0.46	0.14	0.05	0	0.14	0.21	0.09	0.09	0.14	0.12	0.14	0.55	
8	3.65	0.95	0.14	0.78	0.23	0.07	0.07	0.07	0.23	0.23	0.02	0	0.05	0.07	0.07	0.02	0.12	0.12	0.09	0.32	
9	4.71	0.81	0.53	0.67	0.18	1.13	0.09	0.16	0.25	0.16	0.23	0.02	0	0	0.02	0.02	0	0.09	0.02	0.30	
10	6.02	1.32	0.39	1.48	0.53	0.62	0.16	0.07	0.32	0.12	0.07	0.25	0.09	0	0	0.05	0.02	0.02	0.09	0.42	
11	5.61	1.20	0.62	1.36	0.21	0.53	0.18	0.30	0.32	0.12	0.05	0.09	0.16	0	0	0	0.02	0.05	0.02	0.37	
12	5.56	1.22	0.37	1.18	0.35	0.83	0.23	0.07	0.55	0.21	0.14	0.05	0.05	0.07	0.05	0	0	0.02	0	0.18	
13	5.31	1.25	0.18	1.57	0.32	0.25	0.18	0.09	0.62	0.30	0.23	0.05	0.05	0.02	0.09	0	0	0	0	0.09	
14	5.33	2.22	0.48	1.73	0.12	0.09	0.02	0.12	0.23	0.14	0.02	0.02	0.02	0.05	0	0.05	0	0	0	0.02	
15	5.24	1.85	0.05	1.41	0.07	0.32	0.23	0.07	0.21	0.46	0.16	0.18	0.09	0.05	0.02	0	0.02	0	0	0.05	
16	4.68	2.19	0.14	0.69	0.07	0.55	0.18	0	0.12	0.23	0.28	0.12	0.05	0	0.02	0	0	0	0	0.05	
17	5.40	2.58	0.16	0.99	0.21	0.58	0.07	0	0.12	0.07	0.25	0.07	0.18	0.07	0	0.02	0	0.02	0	0	
18	5.10	2.22	0.09	1.15	0.23	0.74	0.02	0.05	0.07	0.09	0.07	0.21	0.12	0	0	0.02	0	0	0	0.02	
19	3.62	2.40	0.05	0.72	0.23	0.16	0.02	0	0	0.02	0	0	0	0	0	0	0	0.02	0	0	
20	3.90	1.98	0.05	0.81	0.30	0.39	0.16	0	0.02	0.09	0	0	0.02	0.02	0.02	0.02	0	0	0	0	
21	5.56	2.63	0.16	0.23	0.12	0.76	0.16	0.02	0.09	0.05	0.16	0.18	0.12	0.18	0.18	0.18	0.16	0.07	0.02	0.07	
22	3.97	2.28	0.18	0.42	0.12	0.32	0.32	0.05	0.05	0.02	0.02	0.02	0.02	0	0.05	0.05	0.02	0	0	0.02	
23	3.62	2.19	0.21	0.67	0.32	0.02	0	0	0.07	0	0	0	0.02	0	0.02	0	0.02	0.02	0	0.05	
Sum	*100*																				*100*

Figure E-32. Soak time distributions for Group 6 (Airport shuttle)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		1.57	4.86	5.56	6.50	7.98	11.30	20.26	22.81	13.82	4.12	1.14	0.09	0.00	0	0	0	0	0	*100*
Hour																				
0	2.41	0.03	0.11	0.15	0.17	0.26	0.46	0.49	0.40	0.22	0.08	0.04	0.00	0	0	0	0	0	0	
1	1.00	0.01	0.05	0.06	0.06	0.09	0.16	0.17	0.16	0.12	0.07	0.05	0.00	0	0	0	0	0	0	
2	0.67	0.01	0.03	0.04	0.05	0.08	0.13	0.11	0.08	0.07	0.05	0.03	0.00	0	0	0	0	0	0	
3	1.10	0.01	0.05	0.06	0.09	0.14	0.23	0.20	0.15	0.09	0.05	0.03	0.00	0	0	0	0	0	0	
4	2.53	0.03	0.13	0.15	0.18	0.24	0.41	0.54	0.53	0.20	0.07	0.03	0.00	0	0	0	0	0	0	
5	3.83	0.05	0.17	0.20	0.24	0.33	0.48	0.76	0.92	0.45	0.15	0.06	0.01	0	0	0	0	0	0	
6	3.80	0.06	0.18	0.20	0.23	0.28	0.32	0.62	1.04	0.67	0.17	0.04	0.00	0	0	0	0	0	0	
7	4.36	0.07	0.21	0.23	0.27	0.32	0.34	0.67	1.11	0.85	0.22	0.06	0.01	0	0	0	0	0	0	
8	6.95	0.10	0.31	0.36	0.42	0.50	0.57	1.13	1.70	1.33	0.43	0.09	0.01	0.00	0	0	0	0	0	
9	6.08	0.10	0.29	0.33	0.38	0.44	0.50	1.02	1.53	1.09	0.34	0.05	0.00	0	0	0	0	0	0	
10	5.91	0.10	0.28	0.31	0.36	0.44	0.51	0.98	1.49	1.07	0.30	0.06	0.00	0	0	0	0	0	0	
11	6.12	0.11	0.29	0.32	0.38	0.45	0.53	1.09	1.55	1.05	0.29	0.05	0.00	0	0	0	0	0	0	
12	5.68	0.11	0.29	0.31	0.37	0.41	0.55	1.10	1.31	0.87	0.30	0.05	0.00	0	0	0	0	0	0	
13	5.37	0.10	0.27	0.30	0.35	0.39	0.55	1.11	1.22	0.81	0.24	0.03	0.00	0	0	0	0	0	0	
14	5.10	0.09	0.26	0.29	0.33	0.38	0.51	1.09	1.24	0.71	0.15	0.03	0.00	0	0	0	0	0	0	
15	4.95	0.08	0.25	0.28	0.33	0.38	0.56	1.13	1.16	0.64	0.13	0.01	0.00	0	0	0	0	0	0	
16	5.03	0.08	0.24	0.28	0.33	0.39	0.53	1.13	1.22	0.64	0.13	0.05	0.00	0	0	0	0	0	0	
17	5.00	0.08	0.24	0.28	0.33	0.39	0.57	1.15	1.18	0.62	0.14	0.04	0.00	0	0	0	0	0	0	
18	4.90	0.08	0.25	0.28	0.33	0.39	0.58	1.20	1.11	0.49	0.14	0.04	0.00	0	0	0	0	0	0	
19	4.93	0.08	0.24	0.27	0.33	0.40	0.61	1.23	1.04	0.48	0.16	0.09	0.01	0	0	0	0	0	0	
20	4.00	0.06	0.20	0.24	0.28	0.35	0.56	1.01	0.80	0.34	0.11	0.05	0.00	0	0	0	0	0	0	
21	3.35	0.06	0.17	0.20	0.23	0.29	0.48	0.80	0.65	0.32	0.11	0.04	0.00	0	0	0	0	0	0	
22	3.81	0.06	0.19	0.22	0.25	0.35	0.61	0.83	0.69	0.38	0.16	0.06	0.00	0	0	0	0	0	0	
23	3.14	0.04	0.16	0.19	0.21	0.28	0.54	0.68	0.54	0.30	0.12	0.06	0.00	0	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-33. VMT distributions for Group 6 (Airport shuttle)

Refuse

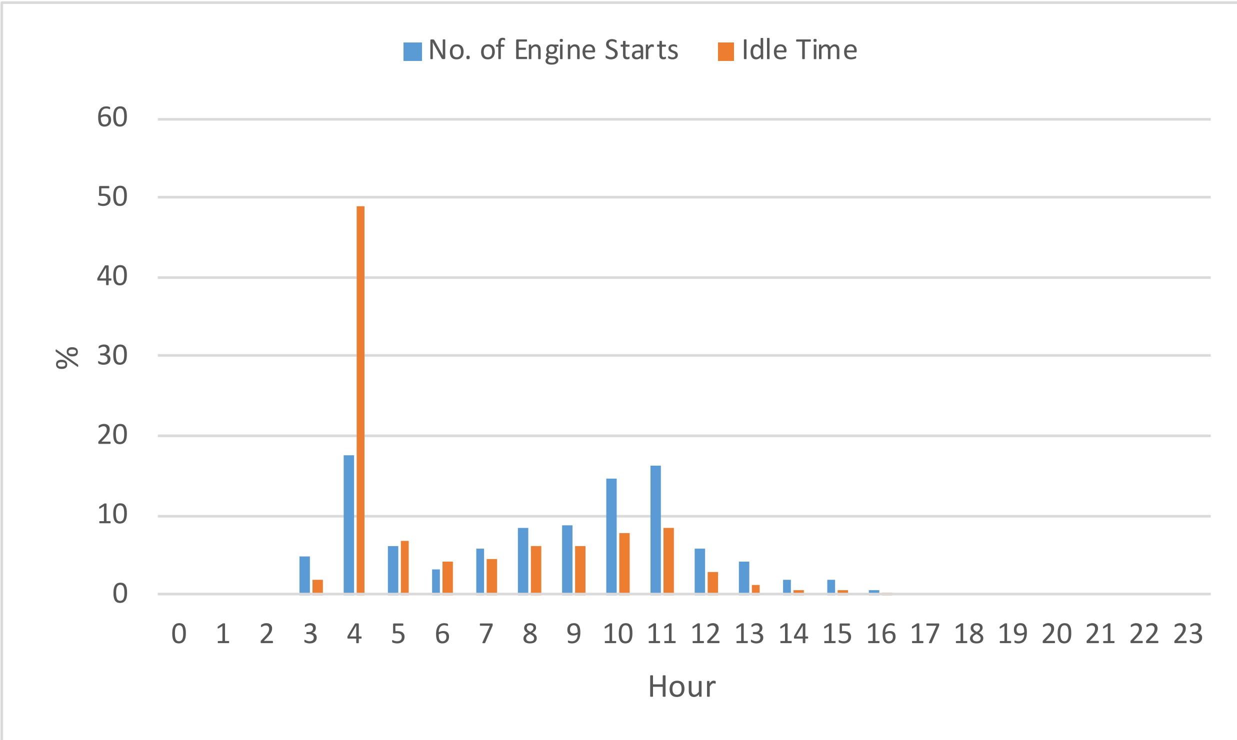


Figure E-34. Start and idle temporal distributions for Group 7 (Refuse)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		33.07	12.68	8.19	7.60	4.01	1.85	1.97	3.89	1.61	0.66	0.36	0.12	0	0.18	0	0	0.06	0.36	23.39	*100*
Hour																					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	4.90	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.30	4.43	
4	17.70	1.50	0.18	0	0	0	0.36	0.78	0.30	0	0	0	0	0	0	0	0	0	0.06	14.53	
5	5.98	1.61	0.72	1.02	1.38	0.18	0	0.18	0.18	0	0	0	0	0	0	0	0	0	0	0.72	
6	3.23	1.02	1.02	0.36	0.06	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0.72	
7	5.74	3.11	0.66	0.42	0.30	0.18	0.12	0	0.12	0.06	0.06	0	0	0	0	0	0	0	0	0.72	
8	8.31	3.95	1.26	0.18	0.78	0.30	0.30	0.12	0.42	0.18	0	0	0	0	0	0	0	0	0	0.84	
9	8.73	3.05	1.56	1.08	0.72	0.78	0.24	0.12	0.42	0.18	0.12	0	0	0	0	0	0	0	0	0.48	
10	14.71	5.32	3.11	2.57	1.44	1.44	0.30	0.18	0.06	0.06	0	0.06	0	0	0	0	0	0	0	0.18	
11	16.33	8.67	2.51	1.44	1.73	0.66	0.12	0.18	0.42	0.18	0.06	0	0	0	0.06	0	0	0	0	0.30	
12	5.68	2.51	0.72	0.48	0.42	0.24	0.24	0.18	0.42	0.24	0.12	0	0	0	0	0	0	0	0	0.12	
13	4.25	0.96	0.42	0.36	0.36	0.06	0.12	0.06	1.08	0.48	0.18	0	0.06	0	0	0	0	0	0	0.12	
14	2.03	0.66	0.12	0.18	0.12	0.06	0.06	0.12	0.24	0.12	0.12	0.12	0	0	0	0	0	0	0	0.12	
15	1.85	0.42	0.24	0.12	0.30	0.06	0	0.06	0.24	0.12	0	0.06	0	0	0.12	0	0	0	0	0.12	
16	0.54	0.18	0.18	0	0	0	0	0	0	0	0	0.12	0.06	0	0	0	0	0	0	0	
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-35. Soak time distributions for Group 7 (Refuse)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		2.74	7.16	7.75	6.39	7.69	8.01	8.68	9.47	10.52	9.83	7.89	11.60	2.25	0	0	0	0	0	*100*
Hour																				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0.02	0.00	0.01	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0.39	0.03	0.09	0.03	0.03	0.03	0.04	0.04	0.03	0.02	0.01	0.00	0.01	0.00	0	0	0	0	0	
5	9.74	0.47	1.19	1.28	0.92	0.97	0.76	0.78	0.75	0.70	0.60	0.46	0.76	0.11	0	0	0	0	0	
6	13.27	0.45	1.19	1.36	0.89	0.89	0.98	0.95	0.88	1.05	1.10	1.02	2.06	0.44	0	0	0	0	0	
7	17.75	0.37	0.99	1.07	0.90	1.09	1.21	1.33	1.56	1.97	2.02	1.78	2.97	0.49	0	0	0	0	0	
8	14.35	0.45	1.16	1.19	0.88	1.01	1.16	1.17	1.24	1.43	1.53	1.26	1.50	0.37	0	0	0	0	0	
9	14.75	0.44	1.16	1.16	0.94	1.13	1.22	1.34	1.43	1.46	1.33	1.03	1.71	0.40	0	0	0	0	0	
10	16.34	0.31	0.83	0.96	0.98	1.30	1.31	1.59	1.94	2.21	1.90	1.30	1.45	0.25	0	0	0	0	0	
11	8.48	0.13	0.35	0.43	0.53	0.80	0.81	0.91	1.06	1.13	0.89	0.70	0.67	0.06	0	0	0	0	0	
12	2.24	0.04	0.11	0.14	0.17	0.23	0.25	0.26	0.28	0.26	0.19	0.12	0.16	0.03	0	0	0	0	0	
13	1.20	0.02	0.05	0.06	0.07	0.10	0.13	0.15	0.15	0.14	0.12	0.09	0.10	0.03	0	0	0	0	0	
14	0.92	0.01	0.03	0.04	0.06	0.09	0.11	0.09	0.09	0.08	0.09	0.08	0.11	0.03	0	0	0	0	0	
15	0.51	0.01	0.02	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.05	0.08	0.03	0	0	0	0	0	
16	0.05	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0	0	0	0	0	0	0	0	
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-36. VMT distributions for Group 7 (Refuse)

Urban Buses

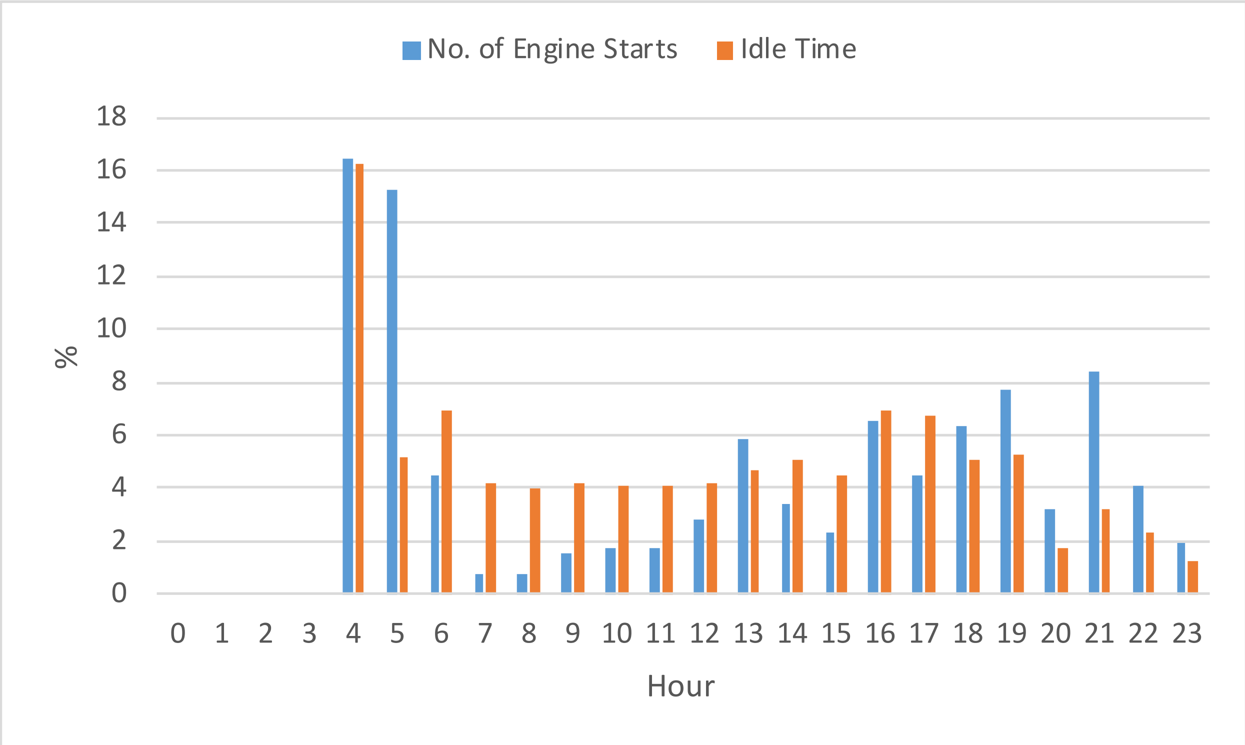


Figure E-37. Start and idle temporal distributions for Group 8a (Urban buses)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
			22.39	4.98	7.77	7.11	7.11	6.05	3.99	11.76	3.19	2.26	3.32	3.46	3.79	1.46	3.12	1.46	1.46	1.00	4.32	*100*
Hour																						
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	16.48		0.20	0.20	0	0	0	0	0	0	0	0	1.66	1.59	2.33	1.00	2.52	1.26	1.46	0.93	3.32	
5	15.28		3.79	0.20	1.40	1.33	2.92	2.33	1.79	1.53	0	0	0	0	0	0	0	0	0	0	0	
6	4.52		1.26	0.07	0.20	0	0	0	0	2.72	0.07	0	0	0	0	0	0	0	0	0	0.20	
7	0.73		0.07	0.07	0.13	0	0.07	0	0	0.07	0.07	0.07	0	0	0	0.07	0	0.07	0	0	0.07	
8	0.73		0.20	0.20	0	0.07	0	0	0	0.13	0.13	0	0	0	0	0	0	0	0	0	0	
9	1.59		0	0	0	0.13	0.13	0.13	0	0.66	0.13	0.07	0.33	0	0	0	0	0	0	0	0	
10	1.79		0.73	0.07	0.13	0.07	0	0	0	0.13	0.27	0.20	0	0.20	0	0	0	0	0	0	0	
11	1.73		0.47	0.27	0.20	0.07	0	0	0.07	0.13	0	0.20	0.13	0	0.07	0.07	0	0	0	0	0.07	
12	2.79		0.80	0.13	0.13	0	0.07	0.07	0	0.20	0.13	0.20	0.60	0.33	0	0	0	0	0	0	0.13	
13	5.85		1.06	0.13	0.86	0.53	0.20	0.07	0	0.20	0.07	0.20	0.13	1.06	0.93	0.07	0.33	0	0	0	0	
14	3.46		0.86	0.27	0.47	0.20	0.27	0.33	0.07	0.27	0	0.07	0.13	0.07	0.33	0	0	0.13	0	0	0	
15	2.33		0.40	0.27	0.33	0.40	0	0	0.07	0.20	0.20	0	0	0	0.07	0.20	0.20	0	0	0	0	
16	6.51		1.73	0.33	0.73	0.80	0.60	0.20	0.13	0.73	0.60	0.13	0.13	0	0	0	0.07	0	0	0.07	0.27	
17	4.45		1.66	0.27	0.60	0.47	0.33	0.20	0.20	0.40	0.07	0	0	0	0	0.07	0	0	0	0	0.20	
18	6.31		2.26	0.80	0.40	1.13	0.66	0.33	0.20	0.33	0.07	0.07	0	0.07	0	0	0	0	0	0	0	
19	7.71		3.39	0.93	0.86	0.66	0.20	0.27	0.40	0.66	0.20	0.07	0	0	0	0	0	0	0	0	0.07	
20	3.26		0.66	0.13	0.33	0.33	0.33	0.60	0.47	0.13	0	0.27	0	0	0	0	0	0	0	0	0	
21	8.44		1.79	0.27	0.60	0.27	0.80	0.86	0.27	2.39	0.73	0.33	0.07	0.07	0	0	0	0	0	0	0	
22	4.12		0.80	0.20	0.27	0.66	0.47	0.40	0.27	0.33	0.13	0.33	0.13	0.07	0.07	0	0	0	0	0	0	
23	1.93		0.27	0.20	0.13	0	0.07	0.27	0.07	0.53	0.33	0.07	0	0	0	0	0	0	0	0	0	
Sum	*100*																					*100*

Figure E-38. Soak time distributions for Group 8a (Urban buses)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
			1.51	4.47	7.42	12.14	18.46	20.70	14.62	7.30	3.67	2.41	2.32	2.69	2.12	0.17	0	0	0	0	*100*
Hour																					
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0.00		0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	3.91		0.03	0.08	0.15	0.26	0.46	0.59	0.48	0.30	0.14	0.14	0.29	0.54	0.43	0.02	0	0	0	0	
6	9.41		0.11	0.36	0.65	1.11	1.69	1.94	1.41	0.77	0.35	0.21	0.21	0.34	0.23	0.01	0	0	0	0	
7	7.96		0.11	0.36	0.61	1.02	1.52	1.64	1.21	0.66	0.30	0.17	0.15	0.12	0.07	0.01	0	0	0	0	
8	5.89		0.08	0.25	0.44	0.70	1.10	1.25	0.97	0.46	0.27	0.16	0.10	0.07	0.04	0.00	0	0	0	0	
9	5.60		0.08	0.23	0.42	0.68	1.08	1.23	0.89	0.43	0.21	0.13	0.10	0.08	0.04	0.00	0	0	0	0	
10	6.05		0.08	0.25	0.44	0.71	1.10	1.33	0.98	0.45	0.24	0.12	0.12	0.15	0.08	0.00	0	0	0	0	
11	6.26		0.09	0.26	0.46	0.74	1.15	1.34	0.95	0.48	0.23	0.16	0.14	0.15	0.11	0.01	0	0	0	0	
12	6.64		0.11	0.31	0.53	0.84	1.25	1.46	0.99	0.47	0.21	0.15	0.13	0.11	0.08	0.00	0	0	0	0	
13	7.10		0.10	0.31	0.53	0.86	1.24	1.39	1.00	0.56	0.30	0.22	0.22	0.22	0.14	0.01	0	0	0	0	
14	8.47		0.15	0.40	0.67	1.07	1.54	1.77	1.27	0.59	0.30	0.21	0.18	0.18	0.14	0.01	0	0	0	0	
15	8.76		0.14	0.41	0.71	1.12	1.64	1.80	1.30	0.64	0.35	0.19	0.17	0.16	0.12	0.01	0	0	0	0	
16	7.14		0.12	0.36	0.57	0.93	1.38	1.50	1.04	0.51	0.27	0.18	0.14	0.10	0.04	0.00	0	0	0	0	
17	6.99		0.11	0.33	0.54	0.89	1.39	1.53	1.00	0.49	0.25	0.16	0.13	0.10	0.06	0.00	0	0	0	0	
18	5.31		0.08	0.26	0.41	0.71	1.15	1.19	0.68	0.28	0.12	0.08	0.09	0.11	0.15	0.02	0	0	0	0	
19	3.13		0.06	0.17	0.21	0.38	0.56	0.49	0.29	0.14	0.06	0.07	0.11	0.19	0.35	0.06	0	0	0	0	
20	0.97		0.01	0.05	0.07	0.10	0.17	0.22	0.11	0.06	0.05	0.03	0.04	0.04	0.03	0.00	0	0	0	0	
21	0.22		0.03	0.05	0.02	0.02	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0	0	0	0	0	
22	0.13		0.01	0.02	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.00	0	0	0	0	0	
23	0.07		0.01	0.02	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-39. VMT distributions for Group 8a (Urban buses)

Express Buses

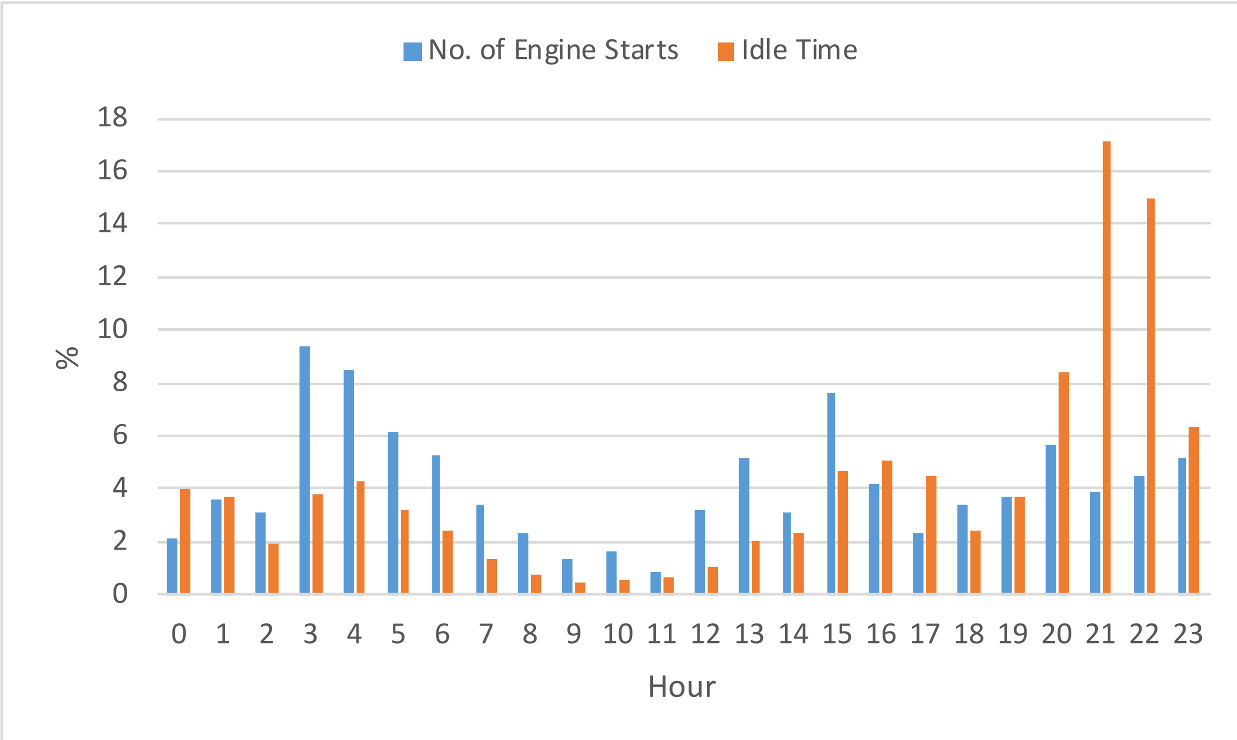


Figure E-40. Start and idle temporal distributions for Group 8b (Express buses)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		22.30	14.20	14.28	7.43	3.75	1.69	1.69	7.06	6.84	4.49	3.38	3.68	3.02	2.58	0.44	0.29	0.29	0.15	2.43	*100*
Hour																					
0	2.13	0.22	0.29	0.07	0.15	0	0.15	0.15	0.44	0.52	0.15	0	0	0	0	0	0	0	0	0	
1	3.61	0.52	0.81	0.15	0	0.07	0.15	0.07	0.37	0.44	0.81	0.07	0	0	0	0	0	0	0	0.15	
2	3.16	0.59	0.37	0	0.15	0.07	0.07	0.07	0.44	0.44	0.37	0.15	0.15	0	0	0	0	0	0.15	0.15	
3	9.42	3.75	0.66	0.59	0.07	0	0	0	0.66	0.66	0.81	0.88	0.74	0.07	0.07	0	0	0	0	0.44	
4	8.54	2.58	0.96	1.10	0.22	0.07	0.15	0.07	0.66	0.66	0.37	0.59	0.44	0.15	0.07	0.07	0	0	0	0.37	
5	6.18	1.18	0.96	2.58	1.10	0.07	0	0	0	0.15	0	0.07	0	0	0	0	0	0	0	0.07	
6	5.30	0.66	0.96	1.69	0.44	0.07	0	0	0.37	0.15	0.15	0.44	0.07	0	0.15	0	0	0	0	0.15	
7	3.38	0.37	0.66	1.32	0.52	0.22	0.15	0	0.07	0	0	0	0	0	0	0	0	0	0	0.07	
8	2.35	0.29	0.07	0.88	0.59	0.15	0	0	0.22	0	0.07	0	0	0	0	0	0	0	0	0.07	
9	1.40	0	0.07	0.15	0.22	0.07	0.15	0.07	0.44	0.07	0	0.07	0	0	0	0	0	0	0	0.07	
10	1.69	0.37	0.15	0.37	0.07	0.07	0.07	0.07	0.07	0.15	0	0.07	0	0.07	0	0	0	0	0	0.15	
11	0.88	0.07	0	0.15	0	0.07	0.07	0	0.07	0.07	0.29	0.07	0	0	0	0	0	0	0	0	
12	3.24	1.69	0.07	0.07	0	0	0.15	0.07	0	0.07	0.07	0.15	0.37	0.22	0.07	0	0	0.07	0	0.15	
13	5.15	1.99	0.22	0.22	0	0	0	0.15	0.22	0.22	0.07	0.15	0.74	0.96	0.15	0	0	0	0	0.07	
14	3.16	0.29	0	0.44	0.37	0.22	0	0	0.15	0.22	0.07	0.15	0.29	0.29	0.52	0.07	0	0	0	0.07	
15	7.58	1.25	1.03	1.18	0.07	0.22	0	0.07	0.15	0.15	0.22	0.07	0.59	0.81	1.18	0.07	0.22	0.07	0	0.22	
16	4.19	0.96	1.03	0.37	0.37	0.22	0	0	0.29	0.07	0	0.29	0.07	0.29	0.22	0	0	0	0	0	
17	2.35	0.81	0.44	0.07	0.07	0	0	0	0	0.22	0	0.07	0.07	0.07	0.15	0.15	0.07	0.15	0	0	
18	3.38	0.37	0.59	0.52	0.74	0.88	0.07	0.07	0	0	0.07	0	0.07	0	0	0	0	0	0	0	
19	3.68	0.15	0.59	1.18	1.25	0.15	0.07	0	0	0.07	0	0.07	0	0	0	0	0	0	0	0.15	
20	5.67	0.52	0.52	0.37	0.29	0.22	0.07	0.22	1.32	1.32	0.66	0	0	0.07	0	0.07	0	0	0	0	
21	3.90	0.88	0.66	0.37	0.44	0.66	0.15	0.15	0.37	0.15	0	0	0.07	0	0	0	0	0	0	0	
22	4.49	1.03	1.40	0.37	0.29	0.07	0.22	0.29	0.52	0.15	0.15	0	0	0	0	0	0	0	0	0	
23	5.15	1.77	1.69	0.07	0	0.15	0	0.15	0.22	0.88	0.15	0	0	0	0	0	0	0	0	0.07	
Sum	*100*																				*100*

Figure E-41. Soak time distributions for Group 8b (Express buses)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		0.69	2.00	2.25	2.89	3.67	4.66	5.18	4.98	4.29	4.57	7.55	12.84	17.75	20.76	5.93	0	0	0	*100*
Hour																				
0	0.08	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0	0	0	
1	0.07	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0	0	0	0	0	0	0	0	
2	0.06	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0	0	0	0	0	0	0	0	
3	4.04	0.02	0.03	0.03	0.03	0.05	0.09	0.10	0.08	0.12	0.22	0.26	0.53	1.05	1.19	0.21	0	0	0	
4	8.94	0.04	0.13	0.14	0.17	0.24	0.31	0.36	0.39	0.32	0.47	0.80	1.35	1.83	2.03	0.35	0	0	0	
5	10.81	0.04	0.14	0.16	0.21	0.26	0.32	0.39	0.40	0.38	0.48	0.83	1.48	1.99	2.77	0.96	0	0	0	
6	9.24	0.06	0.18	0.19	0.24	0.32	0.41	0.57	0.61	0.47	0.42	0.63	1.12	1.53	1.99	0.51	0	0	0	
7	6.73	0.06	0.15	0.16	0.20	0.25	0.31	0.40	0.43	0.37	0.34	0.58	0.93	1.23	1.12	0.20	0	0	0	
8	2.83	0.03	0.07	0.08	0.11	0.14	0.17	0.22	0.21	0.16	0.13	0.27	0.31	0.44	0.44	0.07	0	0	0	
9	2.17	0.02	0.05	0.05	0.06	0.08	0.10	0.13	0.09	0.05	0.07	0.19	0.26	0.40	0.57	0.05	0	0	0	
10	1.01	0.01	0.01	0.02	0.03	0.04	0.05	0.05	0.04	0.01	0.03	0.07	0.15	0.20	0.23	0.07	0	0	0	
11	0.85	0.01	0.02	0.02	0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.16	0.12	0.10	0.13	0.04	0	0	0	
12	0.35	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.03	0.03	0.02	0.01	0.02	0.02	0.03	0.01	0	0	0	
13	1.79	0.02	0.05	0.05	0.06	0.07	0.10	0.09	0.07	0.06	0.07	0.19	0.29	0.25	0.33	0.08	0	0	0	
14	3.45	0.03	0.07	0.08	0.11	0.14	0.19	0.20	0.19	0.17	0.19	0.32	0.43	0.66	0.64	0.05	0	0	0	
15	5.22	0.05	0.14	0.20	0.27	0.34	0.40	0.41	0.35	0.32	0.28	0.32	0.56	0.73	0.67	0.17	0	0	0	
16	7.90	0.06	0.20	0.26	0.35	0.43	0.49	0.51	0.49	0.44	0.36	0.55	0.98	1.14	1.22	0.41	0	0	0	
17	9.22	0.07	0.21	0.25	0.34	0.39	0.51	0.53	0.50	0.44	0.40	0.57	0.99	1.51	1.81	0.72	0	0	0	
18	8.23	0.05	0.16	0.20	0.26	0.34	0.43	0.44	0.45	0.42	0.45	0.62	0.92	1.24	1.65	0.60	0	0	0	
19	7.23	0.03	0.12	0.13	0.18	0.24	0.35	0.33	0.25	0.19	0.25	0.65	1.21	1.46	1.46	0.38	0	0	0	
20	6.53	0.04	0.11	0.11	0.15	0.20	0.27	0.28	0.24	0.20	0.21	0.36	0.74	1.44	1.58	0.60	0	0	0	
21	3.05	0.02	0.04	0.04	0.05	0.06	0.08	0.08	0.07	0.07	0.09	0.18	0.47	0.51	0.86	0.43	0	0	0	
22	0.06	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	
23	0.13	0.01	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0	0	0	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-42. VMT distributions for Group 8b (Express buses)

Freeway Work

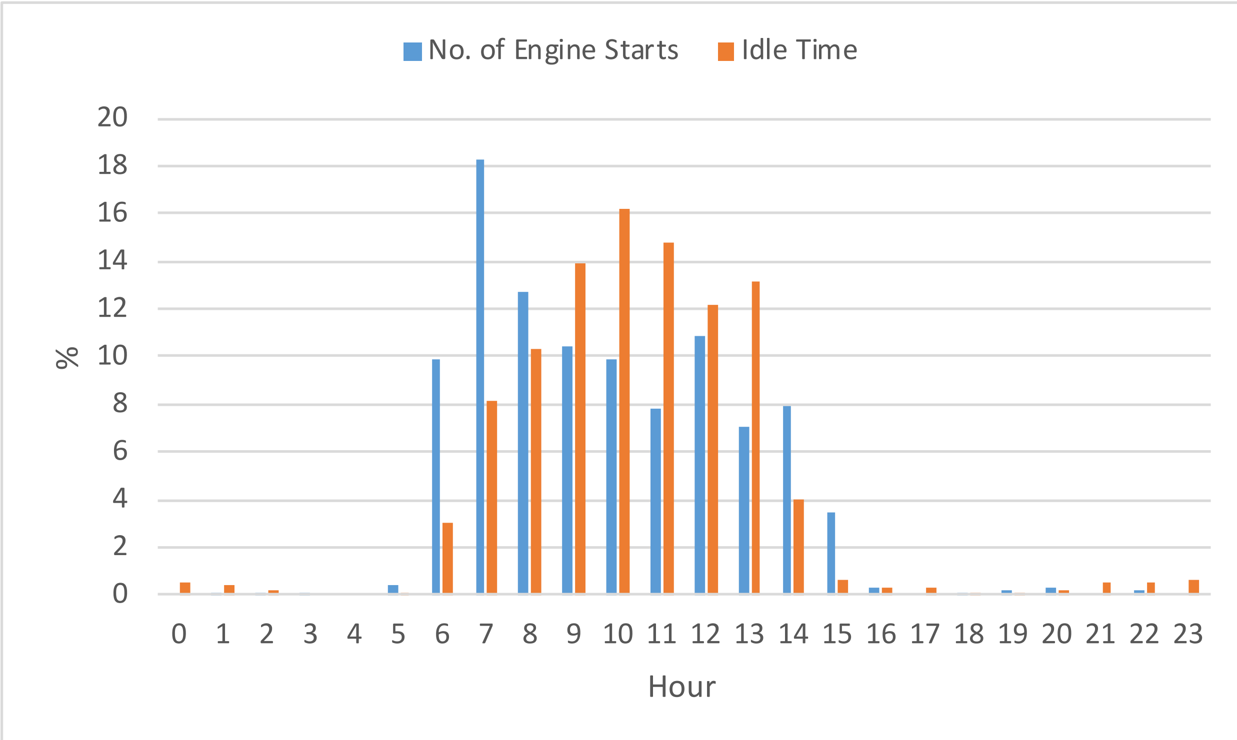


Figure E-43. Start and idle temporal distributions for Group 9a (Freeway work)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
			17.74	13.14	11.76	8.92	5.06	5.88	3.40	7.81	2.39	1.10	0.74	0.28	0.09	0	0	0	0	0	21.69	*100*
Hour																						
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0.09		0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0.09		0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0.09		0	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.37		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.37	
6	9.93		0.92	0.37	0.74	0.09	0	0.09	0.09	0	0	0	0	0	0	0	0	0	0	0	7.63	
7	18.29		3.86	3.13	2.30	1.10	0.37	0.28	0	0	0	0	0	0	0	0	0	0	0	0	7.26	
8	12.68		2.67	1.38	1.84	1.29	0.64	0.46	0.55	0.64	0.18	0	0	0	0	0	0	0	0	0	3.03	
9	10.48		1.93	1.56	1.19	0.74	0.28	1.01	0.74	1.75	0.37	0	0	0.09	0	0	0	0	0	0	0.83	
10	9.83		1.75	1.19	1.38	1.10	0.55	0.55	0.46	1.65	0.55	0	0	0	0	0	0	0	0	0	0.64	
11	7.81		1.38	1.56	0.74	1.19	0.74	0.37	0.37	0.74	0.18	0.28	0.09	0	0	0	0	0	0	0	0.18	
12	10.85		1.01	0.83	0.64	1.56	1.29	1.93	0.64	1.29	0.18	0.09	0.37	0.09	0	0	0	0	0	0	0.92	
13	7.08		1.65	0.92	1.19	0.92	0.18	0.46	0.28	0.46	0.37	0.28	0.18	0	0	0	0	0	0	0	0.18	
14	7.90		1.19	0.92	0.92	0.55	0.83	0.64	0.18	1.01	0.55	0.46	0.09	0.09	0.09	0	0	0	0	0	0.37	
15	3.49		1.19	1.19	0.74	0.18	0	0.09	0	0.09	0	0	0	0	0	0	0	0	0	0	0	
16	0.28		0	0.09	0	0	0	0	0	0.18	0	0	0	0	0	0	0	0	0	0	0	
17	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0.09		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	
19	0.18		0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	
20	0.28		0.09	0	0	0	0.09	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.18		0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	
23	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																					*100*

Figure E-44. Soak time distributions for Group 9a (Freeway work)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
			2.16	2.51	3.28	3.17	3.83	4.26	4.71	5.19	5.66	8.24	14.63	20.18	14.35	6.24	1.60	0	0	0	*100*
Hour																					
0	0.02		0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	
1	0.19		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.06	0.00	0	0	0	0	
2	0.26		0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.03	0.04	0.09	0.03	0.01	0	0	0	
3	0.00		0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.23		0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.03	0.12	0.04	0	0	0	
6	1.14		0.02	0.06	0.03	0.04	0.06	0.07	0.06	0.06	0.04	0.04	0.11	0.20	0.21	0.09	0.04	0	0	0	
7	12.22		0.14	0.33	0.40	0.53	0.67	0.75	0.71	0.64	0.64	1.01	1.88	2.04	1.33	0.84	0.31	0	0	0	
8	16.74		0.14	0.33	0.43	0.54	0.64	0.75	0.86	1.04	1.11	1.59	2.24	3.11	2.73	0.86	0.37	0	0	0	
9	12.63		0.27	0.35	0.51	0.36	0.42	0.49	0.58	0.65	0.68	1.06	1.87	2.67	1.76	0.83	0.12	0	0	0	
10	11.65		0.39	0.29	0.30	0.35	0.44	0.42	0.47	0.55	0.63	0.88	1.77	2.44	1.55	0.87	0.28	0	0	0	
11	10.06		0.35	0.25	0.34	0.30	0.32	0.35	0.43	0.51	0.63	0.90	1.60	2.27	1.35	0.38	0.07	0	0	0	
12	9.04		0.27	0.21	0.39	0.28	0.30	0.31	0.40	0.41	0.41	0.59	1.19	2.00	1.42	0.77	0.10	0	0	0	
13	11.44		0.40	0.25	0.26	0.23	0.30	0.35	0.41	0.47	0.62	1.02	1.96	2.76	1.64	0.60	0.16	0	0	0	
14	10.49		0.14	0.26	0.37	0.35	0.44	0.48	0.50	0.55	0.59	0.78	1.46	2.02	1.81	0.66	0.08	0	0	0	
15	3.23		0.03	0.12	0.21	0.17	0.22	0.26	0.24	0.25	0.26	0.29	0.33	0.35	0.31	0.16	0.01	0	0	0	
16	0.11		0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.00	0	0	0	
17	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0.02		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	
19	0.00		0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0.26		0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.06	0.10	0.02	0.00	0	0	0	0	
21	0.01		0.00	0.00	0.01	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.18		0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.08	0.05	0.00	0.00	0	0	0	0	
23	0.09		0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-45. VMT distributions for Group 9a (Freeway work)

Sweeping

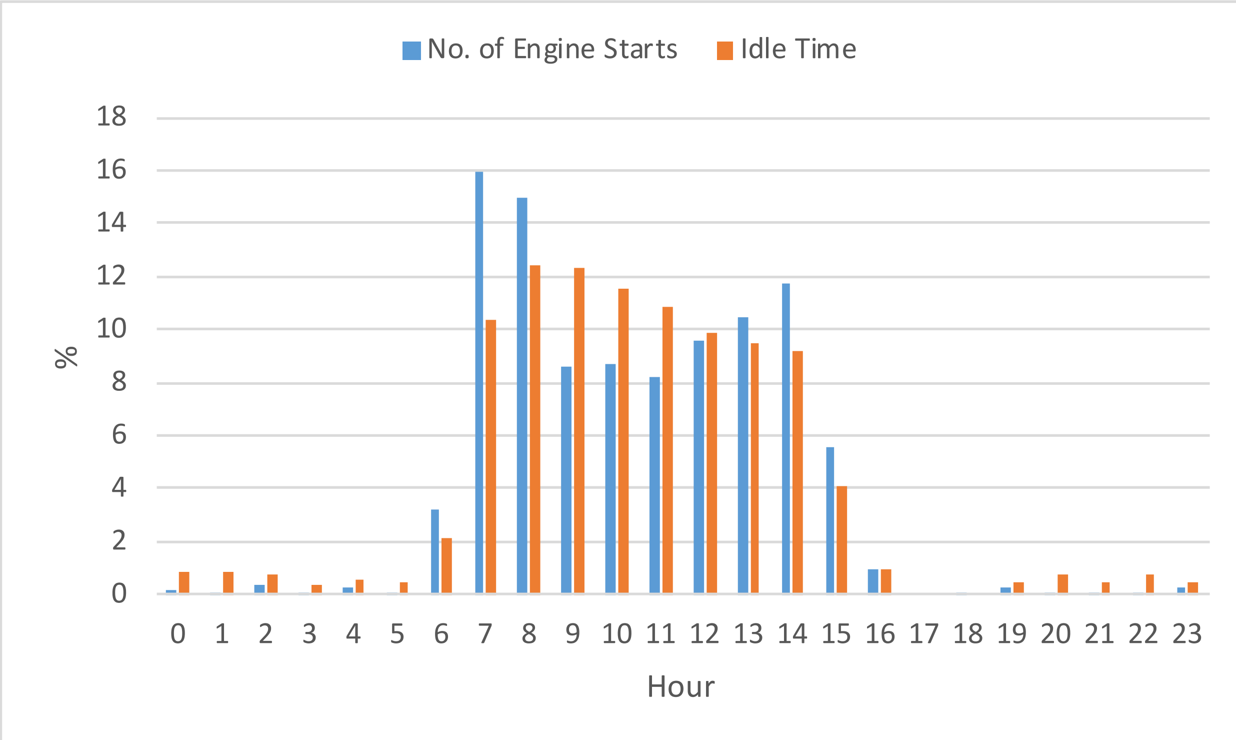


Figure E-46. Start and idle temporal distributions for Group 9b (Sweeping)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		14.53	13.04	16.81	8.64	5.42	3.61	2.20	6.83	2.51	0.94	1.57	0.47	0.31	0.24	0.16	0.24	0.08	0	22.39	*100*
Hour																					
0	0.16	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	
1	0.08	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0.39	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	
3	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	
4	0.31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.31	
5	0.08	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	3.22	0.08	0.39	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	2.51	
7	15.95	2.28	1.34	1.73	0.63	0.31	0.24	0	0.08	0	0	0.08	0	0	0	0	0	0	0	9.27	
8	15.00	1.96	2.91	2.51	1.81	0.31	0.31	0	0.47	0	0	0.08	0.08	0	0	0	0	0	0	4.56	
9	8.64	1.41	1.34	1.49	0.47	0.55	0.63	0.24	0.63	0.31	0	0.08	0	0.08	0	0	0	0	0	1.41	
10	8.72	1.41	1.34	1.73	0.47	0.55	0.24	0.08	0.94	0.71	0.08	0	0	0	0	0	0	0	0	1.18	
11	8.17	0.71	0.47	1.73	1.41	1.34	0.47	0.16	0.63	0.16	0.24	0.24	0.08	0	0	0	0	0	0	0.55	
12	9.58	0.94	0.24	0.94	1.02	0.86	0.79	1.10	2.12	0.31	0.16	0.31	0	0	0	0	0	0	0	0.79	
13	10.45	1.81	1.34	2.04	1.10	0.39	0.16	0.31	1.34	0.71	0.39	0.24	0.08	0.08	0	0	0	0	0	0.47	
14	11.70	2.20	2.99	2.51	1.10	0.79	0.24	0.24	0.39	0.08	0	0.16	0.24	0.08	0.08	0	0	0	0	0.63	
15	5.58	1.34	0.63	1.89	0.47	0.31	0.16	0.08	0.08	0.08	0.08	0.08	0	0.08	0.16	0	0	0	0	0.16	
16	0.94	0.08	0	0.08	0.16	0	0.24	0	0.08	0.08	0	0.08	0	0	0	0	0	0	0	0.16	
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0.08	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	
19	0.31	0	0	0	0	0	0	0	0	0	0	0.24	0	0	0	0	0	0	0	0.08	
20	0.08	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	
21	0.08	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	
23	0.31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0.08	0	0	0.08	
Sum	*100*																				*100*

Figure E-47. Soak time distributions for Group 9b (Sweeping)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		4.66	14.32	8.13	4.29	6.86	10.48	14.07	16.88	13.30	4.98	1.26	0.57	0.14	0.03	0.01	0	0	0	*100*
Hour																				
0	0.62	0.04	0.07	0.08	0.02	0.06	0.14	0.13	0.07	0.01	0	0	0	0	0	0	0	0	0	
1	0.75	0.05	0.08	0.05	0.02	0.05	0.10	0.15	0.15	0.08	0.01	0	0	0	0	0	0	0	0	
2	0.60	0.02	0.03	0.01	0.01	0.03	0.08	0.10	0.07	0.20	0.04	0	0	0	0	0	0	0	0	
3	0.56	0.03	0.02	0.01	0.01	0.05	0.13	0.08	0.05	0.12	0.06	0.01	0	0	0	0	0	0	0	
4	0.39	0.02	0.03	0.01	0.00	0.01	0.04	0.09	0.06	0.07	0.03	0.01	0.01	0	0	0	0	0	0	
5	0.55	0.05	0.05	0.02	0.02	0.01	0.04	0.07	0.11	0.11	0.05	0.00	0.02	0.01	0	0	0	0	0	
6	0.64	0.02	0.03	0.01	0.01	0.02	0.05	0.10	0.13	0.08	0.06	0.08	0.02	0.00	0	0	0	0	0	
7	4.51	0.15	0.31	0.18	0.19	0.38	0.59	0.70	0.83	0.78	0.34	0.05	0.00	0.00	0.00	0	0	0	0	
8	11.66	0.46	1.16	0.45	0.44	1.03	1.46	1.95	2.00	1.89	0.69	0.09	0.03	0.00	0	0	0	0	0	
9	13.55	0.68	1.80	0.87	0.53	0.86	1.49	1.93	2.55	1.79	0.71	0.23	0.09	0.02	0.00	0	0	0	0	
10	12.22	0.66	2.24	1.25	0.56	0.64	0.98	1.59	2.38	1.41	0.40	0.08	0.04	0.00	0.00	0	0	0	0	
11	9.26	0.66	1.80	1.05	0.50	0.54	0.74	1.10	1.39	0.94	0.31	0.14	0.08	0.01	0.00	0	0	0	0	
12	9.57	0.68	2.07	1.06	0.50	0.71	0.88	1.06	1.27	0.77	0.45	0.06	0.04	0.02	0.01	0.00	0	0	0	
13	13.88	0.68	2.82	1.62	0.63	0.96	1.40	1.66	1.84	1.51	0.52	0.17	0.05	0.02	0.00	0.00	0	0	0	
14	13.38	0.29	1.36	1.05	0.47	0.76	1.34	2.08	2.39	2.15	0.98	0.28	0.17	0.06	0.01	0.00	0	0	0	
15	4.99	0.08	0.28	0.19	0.24	0.46	0.74	0.90	1.04	0.81	0.19	0.05	0.02	0	0	0	0	0	0	
16	1.52	0.01	0.03	0.03	0.06	0.14	0.12	0.15	0.33	0.50	0.15	0.00	0.00	0	0	0	0	0	0	
17	0.14	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.04	0.00	0	0	0	0	0	0	0	0	0	
18	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0.23	0.01	0.02	0.01	0.02	0.03	0.04	0.07	0.03	0.00	0	0	0	0	0	0	0	0	0	
20	0.10	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.03	0.04	0	0	0	0	0	0	0	0	0	
21	0.15	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.00	0	0	0	0	0	0	0	0	0	
22	0.19	0.03	0.04	0.05	0.02	0.00	0.01	0.02	0.02	0	0	0	0	0	0	0	0	0	0	
23	0.54	0.03	0.06	0.11	0.02	0.05	0.07	0.10	0.08	0.02	0.00	0	0	0	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-48. VMT distributions for Group 9b (Sweeping)

Municipal Work

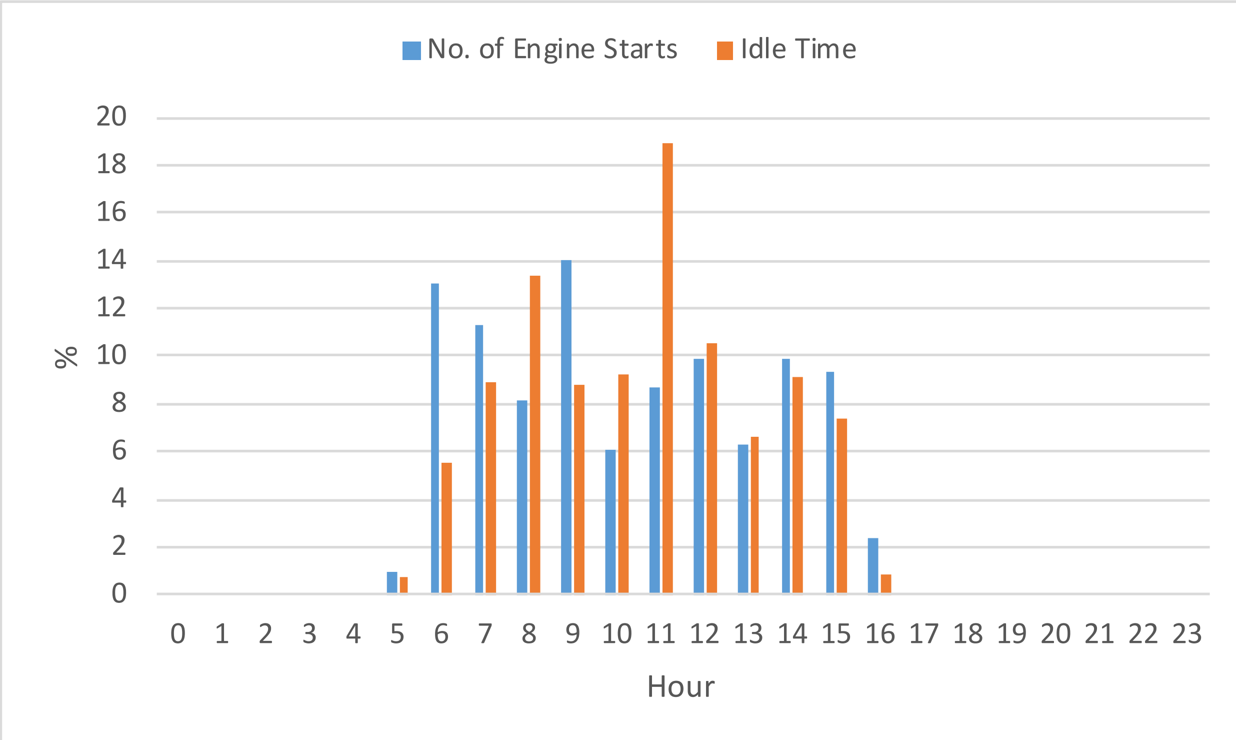


Figure E-49. Start and idle temporal distributions for Group 9c (Municipal work)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
			25.30	11.81	15.66	10.36	7.47	3.86	2.89	5.06	0.96	0.48	0.72	0	0	0	0	0	0	0	15.42	*100*
Hour																						
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.96		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.96	
6	13.01		2.41	0	0.24	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.12	
7	11.33		1.69	2.41	1.93	0.96	0.72	0.48	0.48	0	0	0	0	0	0	0	0	0	0	0	2.65	
8	8.19		1.93	1.20	0.96	0.24	0.96	0.48	0.72	1.20	0	0	0	0	0	0	0	0	0	0	0.48	
9	13.98		3.61	2.41	2.41	2.65	1.20	0.24	0.24	0.48	0.24	0	0	0	0	0	0	0	0	0	0.48	
10	6.02		1.93	0.96	0.96	0.48	0.24	0.24	0	0.96	0	0	0	0	0	0	0	0	0	0	0.24	
11	8.67		3.37	0.48	1.93	1.20	0.96	0.48	0	0.24	0	0	0	0	0	0	0	0	0	0	0	
12	9.88		1.69	0.72	1.93	1.45	1.45	0.24	0.96	0.72	0	0.24	0	0	0	0	0	0	0	0	0.48	
13	6.27		2.65	0.48	1.45	0.24	0.24	0.24	0	0.24	0.24	0.24	0.24	0	0	0	0	0	0	0	0	
14	9.88		2.17	1.69	1.45	0.96	1.20	0.96	0.48	0.24	0.48	0	0.24	0	0	0	0	0	0	0	0	
15	9.40		2.89	1.20	1.45	1.69	0.48	0.48	0	0.96	0	0	0.24	0	0	0	0	0	0	0	0	
16	2.41		0.96	0.24	0.96	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
17	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																					*100*

Figure E-50. Soak time distributions for Group 9c (Municipal work)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
			0.65	1.66	2.35	3.28	4.09	5.87	7.40	9.47	13.14	13.56	16.69	18.36	3.08	0.36	0.02	0	0	0	*100*
Hour																					
0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0.00		0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	6.38		0.04	0.12	0.13	0.17	0.29	0.39	0.50	0.85	1.29	1.09	0.74	0.69	0.07	0.01	0	0	0	0	
7	8.39		0.05	0.15	0.19	0.26	0.35	0.52	0.62	0.90	1.32	1.20	1.13	1.40	0.27	0.02	0.00	0	0	0	
8	10.56		0.09	0.20	0.31	0.43	0.53	0.76	0.92	1.09	1.41	1.44	1.62	1.63	0.11	0.00	0	0	0	0	
9	11.13		0.07	0.19	0.29	0.41	0.45	0.60	0.83	0.96	1.37	1.44	2.35	1.94	0.23	0.03	0.00	0	0	0	
10	14.32		0.08	0.21	0.32	0.44	0.55	0.77	0.87	1.22	1.81	1.97	2.63	3.01	0.38	0.05	0.00	0	0	0	
11	7.38		0.06	0.12	0.19	0.26	0.29	0.43	0.55	0.62	0.81	1.04	1.19	1.47	0.31	0.04	0.00	0	0	0	
12	11.73		0.07	0.19	0.28	0.37	0.44	0.65	0.84	1.08	1.45	1.48	2.14	2.30	0.40	0.03	0	0	0	0	
13	12.44		0.07	0.19	0.29	0.43	0.58	0.81	0.94	1.07	1.40	1.66	1.99	2.49	0.40	0.12	0.01	0	0	0	
14	8.67		0.05	0.13	0.18	0.24	0.28	0.47	0.68	0.79	0.99	1.03	1.57	1.86	0.36	0.02	0.01	0	0	0	
15	8.68		0.05	0.14	0.16	0.26	0.31	0.46	0.62	0.87	1.24	1.12	1.29	1.57	0.55	0.04	0.00	0	0	0	
16	0.31		0.01	0.03	0.01	0.01	0.01	0.02	0.03	0.02	0.05	0.08	0.04	0.00	0	0	0	0	0	0	
17	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sum	*100*																				*100*

Figure E-51. VMT distributions for Group 9c (Municipal work)

Towing

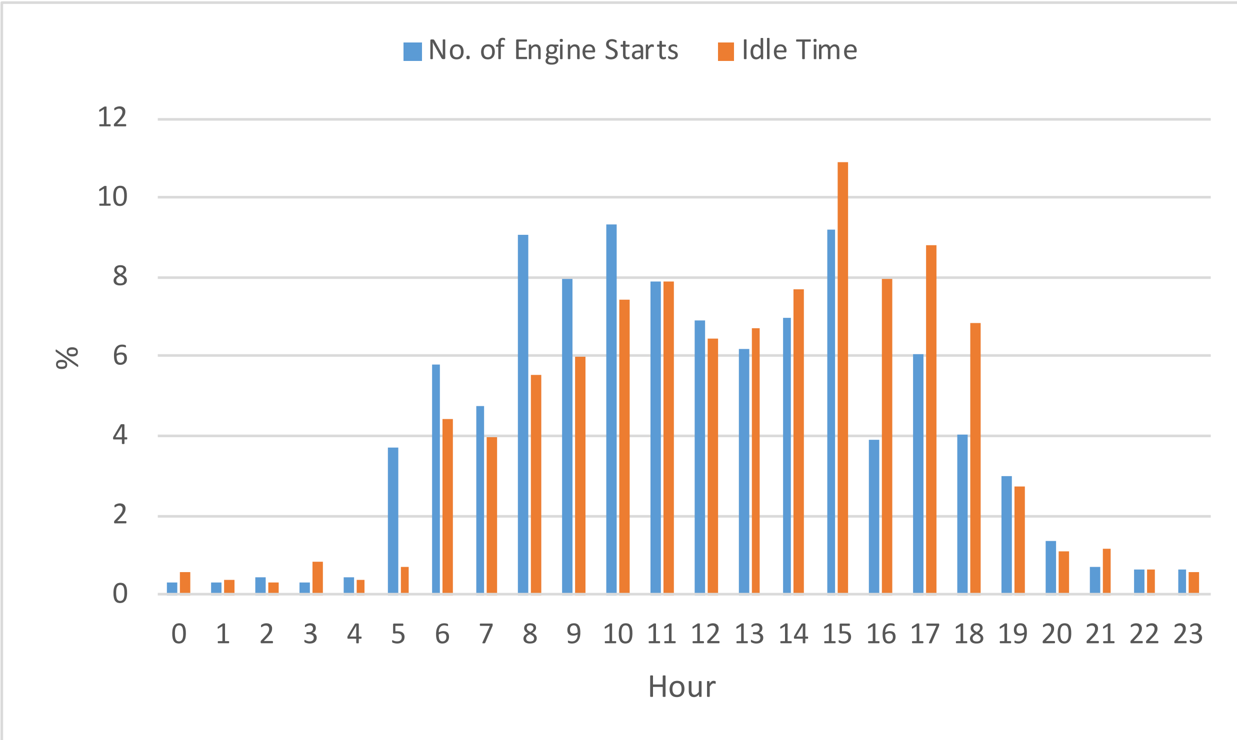


Figure E-52. Start and idle temporal distributions for Group 9d (Towing)

Soak Period			5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	Sum
			20.52	15.53	15.91	6.26	3.67	2.92	2.12	7.72	3.01	1.74	1.74	1.46	0.56	0.28	0.61	0.94	3.62	1.04	10.35	*100*
Hour																						
0	0.33		0.09	0	0.09	0	0.09	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	
1	0.33		0	0.09	0.05	0.05	0	0	0.05	0	0	0	0.05	0	0	0	0	0	0	0	0.05	
2	0.47		0.05	0.05	0	0	0	0	0	0	0	0	0.09	0	0	0.05	0	0.09	0	0.05	0.09	
3	0.28		0	0	0	0	0	0	0	0.05	0	0	0	0.05	0	0	0.09	0	0	0.05	0.05	
4	0.42		0.05	0.05	0.05	0	0	0	0	0	0	0	0	0	0	0.05	0.05	0.05	0.09	0	0.05	
5	3.72		0.38	0.09	0	0	0	0	0.05	0	0.05	0	0	0.05	0	0	0.05	0.09	2.26	0.33	0.38	
6	5.79		1.18	0.94	0.99	0.28	0.05	0	0	0.05	0	0	0.09	0	0	0	0.05	0.05	0.89	0.24	0.99	
7	4.75		0.80	0.38	0.28	0.09	0.14	0.05	0.05	0.28	0	0.05	0	0.05	0	0.05	0.09	0.05	0.09	0.19	2.12	
8	9.08		1.55	1.27	2.96	0.42	0.14	0.09	0.14	0.19	0.09	0	0	0	0.05	0	0.09	0.19	0.05	0.05	1.79	
9	7.95		1.60	1.36	1.65	0.38	0.19	0.09	0.19	0.47	0.09	0.05	0	0	0	0.05	0.05	0.05	0.09	0.09	1.55	
10	9.32		2.26	1.69	1.69	0.80	0.33	0.28	0.05	0.61	0.24	0.05	0	0	0.05	0	0.05	0.09	0	0	1.13	
11	7.91		2.35	0.94	0.85	0.75	0.42	0.38	0.14	0.75	0.33	0.05	0	0	0.14	0.05	0	0.05	0	0	0.71	
12	6.92		1.27	1.22	0.89	0.80	0.24	0.56	0.19	0.80	0.24	0.19	0.19	0	0	0	0.05	0	0	0	0.28	
13	6.21		1.32	0.85	0.80	0.47	0.38	0.24	0.24	0.71	0.33	0.33	0.09	0.09	0.05	0	0	0	0	0	0.33	
14	6.96		1.51	1.36	0.80	0.38	0.38	0.28	0.19	0.71	0.24	0.09	0.47	0.24	0.09	0	0	0.05	0	0	0.19	
15	9.22		1.55	1.36	1.36	0.52	0.56	0.66	0.33	1.08	0.28	0.42	0.38	0.38	0.09	0.05	0	0	0.05	0	0.14	
16	3.91		0.89	0.66	0.71	0.33	0.14	0.05	0.14	0.24	0.14	0.09	0.14	0.05	0	0	0	0	0	0	0.33	
17	6.07		1.04	1.41	0.89	0.47	0.24	0.09	0.09	0.66	0.19	0.14	0.05	0.42	0.05	0	0.05	0.09	0.05	0	0.14	
18	4.05		1.08	0.66	1.13	0.19	0.14	0.09	0.14	0.24	0.14	0.09	0	0	0	0	0	0.05	0.05	0	0.05	
19	2.96		0.89	0.75	0.38	0	0.09	0	0.09	0.38	0.14	0.09	0.05	0.09	0	0	0	0	0	0	0	
20	1.36		0.24	0.28	0.14	0.09	0.09	0	0.05	0.24	0.19	0	0	0	0	0	0	0.05	0	0	0	
21	0.71		0.09	0.09	0.05	0	0	0	0	0.14	0.19	0.05	0.05	0	0	0	0	0	0	0.05	0	
22	0.61		0.24	0	0.05	0	0	0	0	0.09	0.09	0.05	0.05	0.05	0	0	0	0	0	0	0	
23	0.66		0.09	0	0.09	0.24	0.05	0.05	0	0.05	0	0	0.05	0	0.05	0	0	0	0	0	0	
Sum	*100*																					*100*

Figure E-53. Soak time distributions for Group 9d (Towing)

Speed Bin			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	Sum
			0.40	0.94	1.31	1.69	2.27	3.04	3.73	4.44	5.05	6.36	15.37	26.72	20.66	7.10	0.91	0	0	0	*100*
Hour																					
0	0.96		0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.11	0.27	0.39	0.05	0.00	0	0	0	
1	0.90		0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.08	0.23	0.47	0.05	0.00	0	0	0	
2	0.77		0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.05	0.22	0.32	0.04	0.03	0	0	0	
3	0.97		0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.07	0.27	0.34	0.16	0.01	0	0	0	
4	1.15		0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.05	0.08	0.38	0.38	0.13	0.02	0	0	0	
5	1.68		0.00	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.05	0.07	0.15	0.44	0.53	0.26	0.02	0	0	0	
6	5.16		0.01	0.04	0.05	0.05	0.07	0.12	0.14	0.16	0.18	0.28	1.23	1.54	0.90	0.37	0.01	0	0	0	
7	7.37		0.02	0.05	0.07	0.09	0.12	0.17	0.20	0.21	0.24	0.35	1.93	2.50	1.21	0.20	0.02	0	0	0	
8	6.72		0.03	0.06	0.08	0.10	0.14	0.20	0.27	0.27	0.28	0.39	1.52	2.04	1.15	0.17	0.02	0	0	0	
9	7.88		0.03	0.07	0.08	0.11	0.16	0.21	0.28	0.33	0.38	0.48	1.16	2.45	1.67	0.44	0.06	0	0	0	
10	6.71		0.03	0.07	0.09	0.11	0.16	0.21	0.28	0.35	0.37	0.39	0.60	1.57	1.62	0.74	0.11	0	0	0	
11	6.24		0.03	0.06	0.08	0.11	0.15	0.19	0.25	0.31	0.37	0.38	0.70	1.54	1.36	0.59	0.13	0	0	0	
12	5.33		0.03	0.05	0.07	0.10	0.14	0.19	0.21	0.26	0.30	0.32	0.62	1.20	1.10	0.62	0.12	0	0	0	
13	5.97		0.02	0.05	0.07	0.10	0.12	0.17	0.22	0.28	0.33	0.41	0.74	1.54	1.38	0.47	0.05	0	0	0	
14	5.21		0.03	0.06	0.09	0.11	0.15	0.19	0.24	0.28	0.32	0.40	0.65	1.07	1.11	0.47	0.04	0	0	0	
15	4.92		0.03	0.07	0.10	0.13	0.17	0.21	0.26	0.34	0.36	0.41	0.54	0.89	0.88	0.48	0.05	0	0	0	
16	7.74		0.03	0.09	0.15	0.20	0.26	0.32	0.36	0.40	0.45	0.59	1.55	1.98	0.93	0.32	0.09	0	0	0	
17	7.41		0.04	0.11	0.15	0.20	0.25	0.32	0.37	0.38	0.41	0.54	1.22	2.17	1.02	0.20	0.04	0	0	0	
18	7.30		0.02	0.06	0.09	0.12	0.15	0.22	0.27	0.30	0.36	0.50	1.28	2.13	1.26	0.50	0.06	0	0	0	
19	3.23		0.01	0.03	0.05	0.05	0.07	0.10	0.13	0.19	0.23	0.26	0.34	0.60	0.72	0.45	0.01	0	0	0	
20	2.06		0.01	0.01	0.02	0.02	0.03	0.05	0.07	0.10	0.12	0.12	0.26	0.59	0.51	0.14	0.02	0	0	0	
21	1.62		0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.07	0.12	0.20	0.41	0.52	0.10	0.01	0	0	0	
22	1.68		0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.06	0.09	0.12	0.17	0.46	0.50	0.12	0.01	0	0	0	
23	1.01		0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.06	0.05	0.11	0.23	0.38	0.04	0.00	0	0	0	
Sum	*100*																				*100*

Figure E-54. VMT distributions for Group 9d (Towing)

Utility Repair

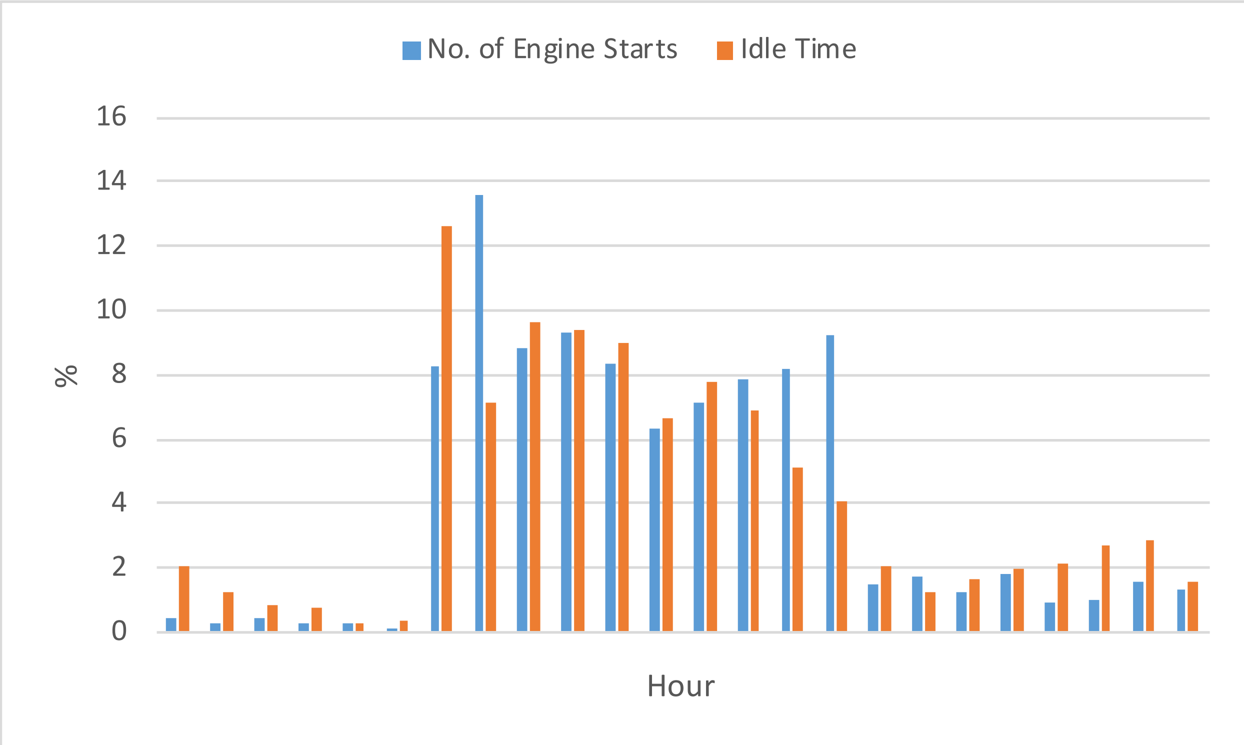


Figure E-55. Start and idle temporal distributions for Group 10 (Utility repair)

Soak Period		5	10	20	30	40	50	60	120	180	240	300	360	420	480	540	600	660	720	9999	*Sum*
		25.08	15.56	17.69	8.95	4.77	4.62	2.69	7.85	2.67	1.15	0.69	0.44	0.46	0.36	0.18	0.08	0.23	0.10	6.44	*100*
Hour																					
0	0.44	0.08	0.08	0.08	0.03	0.05	0.05	0	0.03	0	0	0	0	0	0	0.03	0	0	0	0.03	
1	0.26	0.03	0.05	0.08	0	0	0.03	0	0.05	0.03	0	0	0	0	0	0	0	0	0	0	
2	0.41	0.03	0.08	0.08	0.03	0	0	0.05	0.10	0.03	0	0	0	0	0	0	0	0.03	0	0	
3	0.31	0.10	0.03	0.05	0.03	0	0	0.03	0.03	0	0	0.03	0	0	0	0	0	0	0.03	0	
4	0.26	0.05	0	0.05	0.05	0	0	0	0.05	0.05	0	0	0	0	0	0	0	0	0	0	
5	0.15	0.03	0.03	0	0	0	0	0.03	0.03	0	0	0	0	0	0	0	0	0	0	0.05	
6	8.28	1.49	0.95	0.49	0.13	0	0	0.03	0.03	0	0	0	0.03	0.26	0.18	0.05	0.03	0.13	0.08	4.44	
7	13.59	3.41	2.62	3.49	1.67	0.64	0.31	0.03	0.10	0.03	0	0	0	0	0.10	0	0.03	0.03	0	1.15	
8	8.85	2.31	1.44	2.03	1.18	0.69	0.51	0.21	0.33	0	0	0	0	0	0	0	0	0	0	0.15	
9	9.33	2.79	1.79	1.64	1.10	0.49	0.33	0.21	0.82	0.10	0.03	0	0	0	0	0	0	0	0	0.03	
10	8.31	2.38	1.08	1.56	0.82	0.54	0.36	0.23	0.77	0.46	0.05	0	0	0	0	0	0	0	0	0.05	
11	6.36	1.26	0.92	1.10	0.38	0.46	0.54	0.26	0.79	0.33	0.18	0.05	0	0	0	0.03	0	0	0	0.05	
12	7.10	1.72	0.95	0.92	0.28	0.38	0.44	0.49	1.26	0.18	0.26	0.08	0.05	0	0	0	0	0	0	0.10	
13	7.90	1.85	1.15	1.56	0.74	0.38	0.54	0.18	0.85	0.36	0.15	0.08	0.05	0	0	0	0	0	0	0	
14	8.18	1.62	1.15	1.38	0.92	0.44	0.59	0.28	0.90	0.31	0.15	0.18	0.13	0.05	0.03	0	0	0	0	0.05	
15	9.21	2.59	1.92	1.92	0.79	0.31	0.36	0.18	0.46	0.18	0.10	0.15	0.05	0.03	0.03	0.05	0	0	0	0.08	
16	1.46	0.41	0.21	0.10	0.15	0.13	0.03	0.13	0.15	0.05	0	0.03	0	0	0	0	0	0	0	0.08	
17	1.77	0.72	0.28	0.21	0.08	0.05	0.08	0.03	0.26	0	0.05	0	0	0	0	0	0	0	0	0.03	
18	1.28	0.38	0.15	0.08	0.10	0.05	0.08	0.08	0.18	0.13	0.03	0	0	0	0	0.03	0	0	0	0	
19	1.79	0.72	0.13	0.18	0.13	0.05	0.05	0.03	0.13	0.15	0.08	0.03	0	0	0	0	0	0.05	0	0.08	
20	0.92	0.18	0.10	0.03	0.13	0.03	0.13	0.13	0.10	0	0.03	0.03	0.03	0	0	0	0	0	0	0.03	
21	1.00	0.26	0.13	0.21	0	0.03	0.05	0.03	0.03	0.10	0.03	0	0.10	0.05	0	0	0	0	0	0	
22	1.54	0.41	0.21	0.31	0.10	0	0.08	0.03	0.18	0.08	0.03	0	0	0.08	0	0	0.03	0	0	0.03	
23	1.31	0.28	0.13	0.15	0.10	0.05	0.08	0.08	0.23	0.10	0	0.05	0	0	0.03	0	0	0	0	0.03	
Sum	*100*																				*100*

Figure E-56. Soak time distributions for Group 10 (Utility repair)

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		1.27	4.69	5.25	4.65	5.67	7.52	9.21	11.69	12.23	11.45	15.90	10.40	0.08	0.00	0	0	0	0	*100*
Hour																				
0	0.38	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.04	0.04	0.10	0.07	0.00	0	0	0	0	0	
1	0.98	0.00	0.02	0.02	0.02	0.02	0.04	0.06	0.13	0.20	0.13	0.17	0.16	0.00	0	0	0	0	0	
2	0.91	0.00	0.02	0.02	0.02	0.03	0.05	0.05	0.11	0.13	0.16	0.23	0.09	0	0	0	0	0	0	
3	0.58	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.05	0.06	0.08	0.13	0.15	0.00	0	0	0	0	0	
4	0.39	0.00	0.01	0.01	0.02	0.02	0.03	0.06	0.09	0.05	0.02	0.06	0.02	0	0	0	0	0	0	
5	0.57	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.05	0.07	0.11	0.20	0.00	0	0	0	0	0	
6	1.33	0.05	0.33	0.17	0.04	0.05	0.06	0.08	0.11	0.13	0.12	0.16	0.04	0	0	0	0	0	0	
7	15.45	0.22	1.01	0.78	0.68	0.97	1.35	1.74	2.10	2.32	1.95	1.78	0.55	0.00	0	0	0	0	0	
8	13.81	0.17	0.51	0.67	0.77	0.97	1.28	1.56	2.00	2.10	1.49	1.64	0.64	0.00	0	0	0	0	0	
9	5.99	0.09	0.25	0.28	0.25	0.28	0.38	0.51	0.72	0.73	0.64	1.10	0.75	0.00	0	0	0	0	0	
10	6.23	0.08	0.23	0.30	0.29	0.35	0.46	0.54	0.64	0.64	0.69	1.08	0.93	0.01	0	0	0	0	0	
11	5.71	0.07	0.23	0.30	0.33	0.35	0.43	0.46	0.57	0.60	0.61	0.97	0.79	0.00	0	0	0	0	0	
12	6.70	0.09	0.26	0.37	0.41	0.41	0.45	0.53	0.60	0.62	0.68	1.36	0.91	0.01	0	0	0	0	0	
13	8.59	0.09	0.32	0.51	0.45	0.48	0.63	0.70	0.82	0.86	0.92	1.65	1.15	0.00	0	0	0	0	0	
14	12.12	0.11	0.41	0.58	0.53	0.64	0.84	1.03	1.22	1.26	1.26	2.37	1.83	0.01	0	0	0	0	0	
15	12.70	0.14	0.71	0.75	0.46	0.61	0.87	1.11	1.48	1.63	1.87	1.79	1.26	0.02	0	0	0	0	0	
16	1.46	0.03	0.08	0.10	0.10	0.11	0.13	0.15	0.19	0.18	0.16	0.14	0.10	0	0	0	0	0	0	
17	0.70	0.02	0.05	0.06	0.05	0.07	0.09	0.09	0.11	0.07	0.03	0.03	0.03	0	0	0	0	0	0	
18	1.14	0.01	0.04	0.07	0.07	0.08	0.10	0.12	0.16	0.10	0.06	0.15	0.17	0.00	0	0	0	0	0	
19	0.95	0.02	0.05	0.05	0.04	0.05	0.05	0.08	0.11	0.10	0.07	0.14	0.18	0.01	0.00	0	0	0	0	
20	0.84	0.01	0.03	0.04	0.03	0.05	0.09	0.08	0.09	0.09	0.08	0.13	0.13	0.00	0	0	0	0	0	
21	0.95	0.01	0.04	0.04	0.03	0.05	0.07	0.10	0.15	0.13	0.13	0.16	0.03	0	0	0	0	0	0	
22	0.70	0.01	0.02	0.03	0.02	0.02	0.03	0.05	0.07	0.09	0.07	0.22	0.08	0	0	0	0	0	0	
23	0.81	0.01	0.05	0.04	0.02	0.02	0.03	0.03	0.06	0.04	0.10	0.24	0.15	0.01	0	0	0	0	0	
Sum	*100*																			*100*

Figure E-57. VMT distributions for Group 10 (Utility repair)

Appendix F:

Vocation-Specific Drive Cycles

Line Haul – Out of State

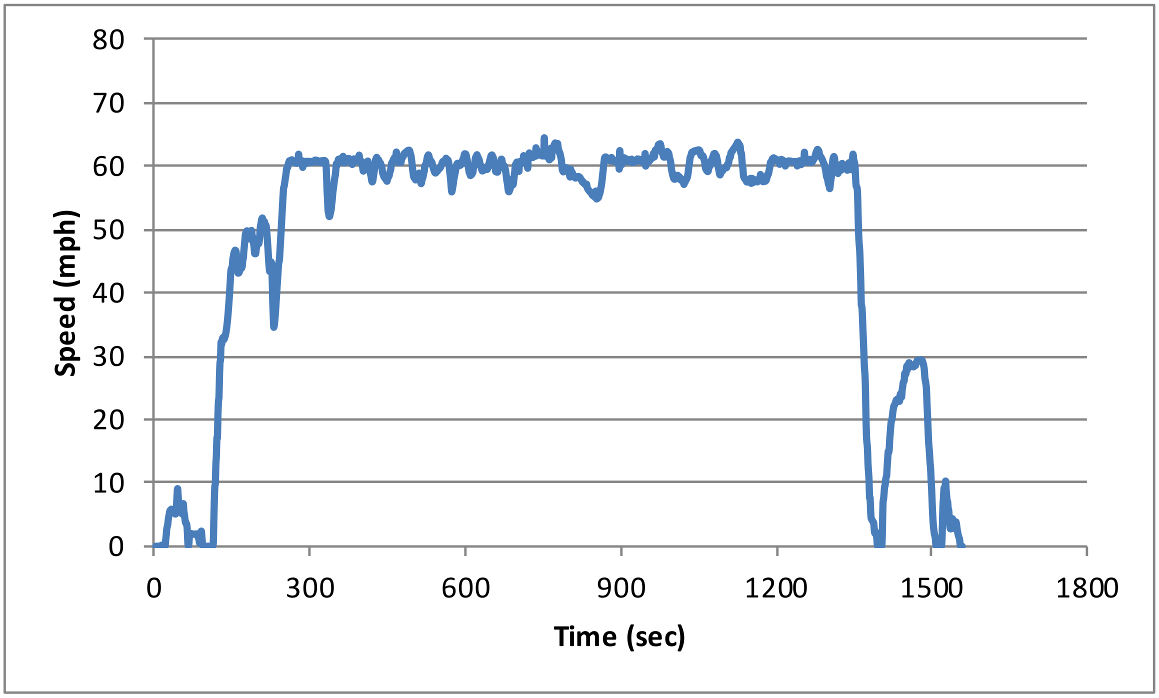


Figure F-1. Drive cycle for Group 1a (Line haul – out of state)

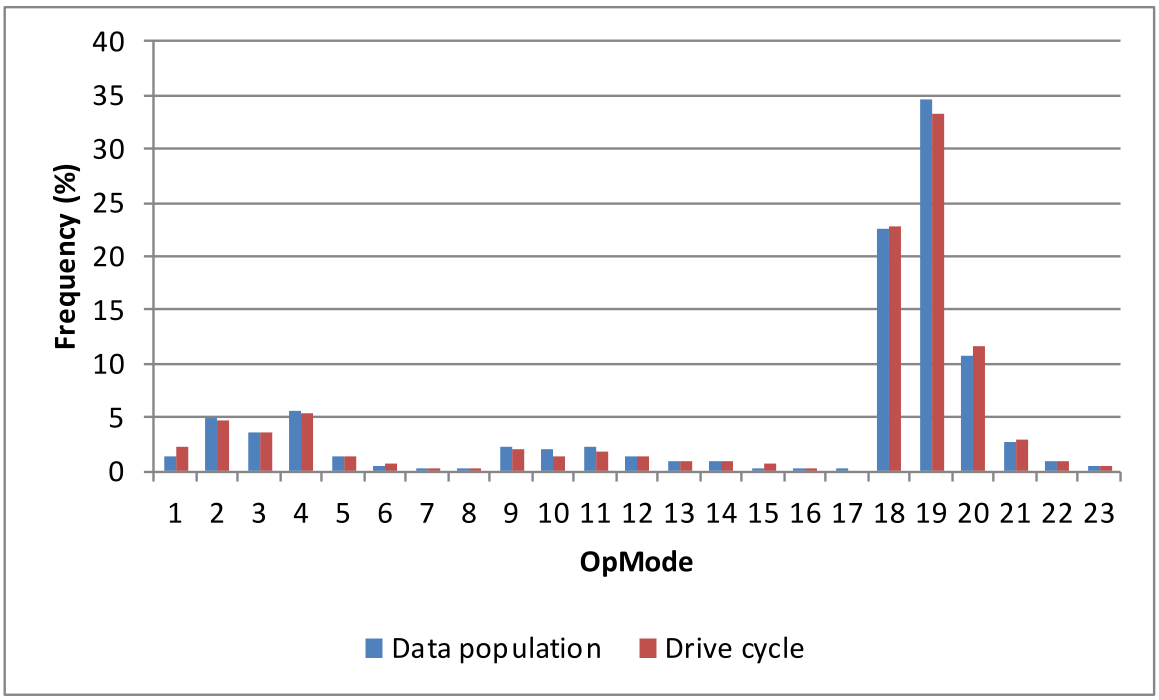


Figure F-2. Comparison of operating mode distribution for Group 1a (Line haul – out of state)

Line Haul – In State

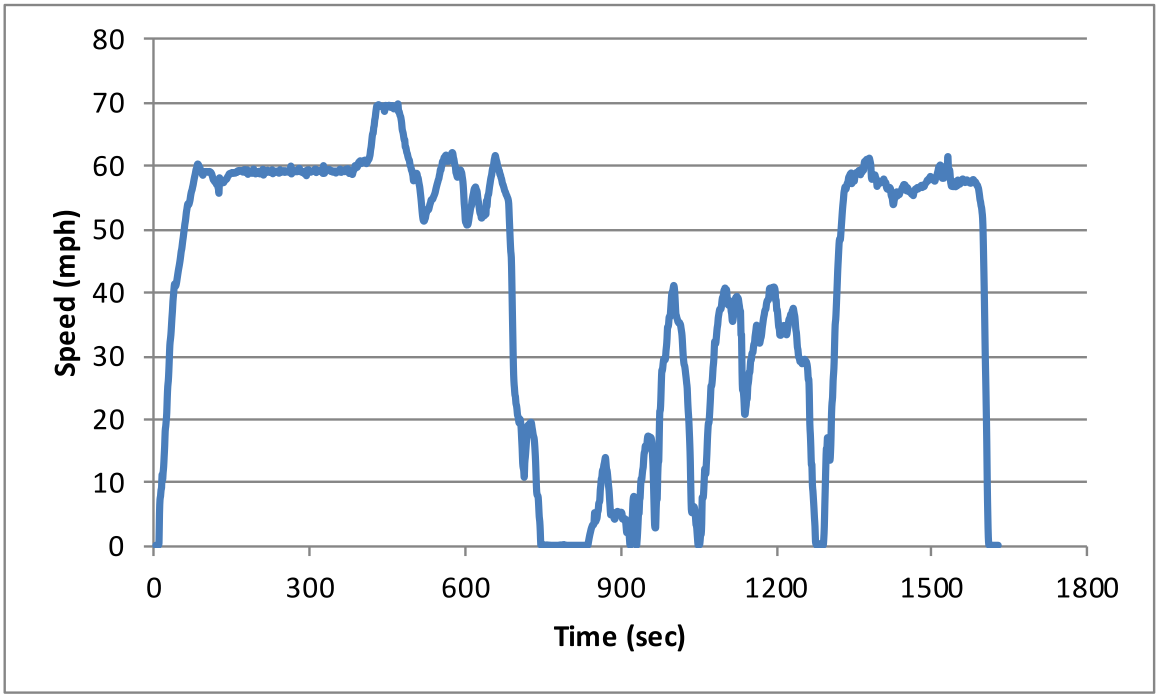


Figure F-3. Drive cycle for Group 1b (Line haul – in state)

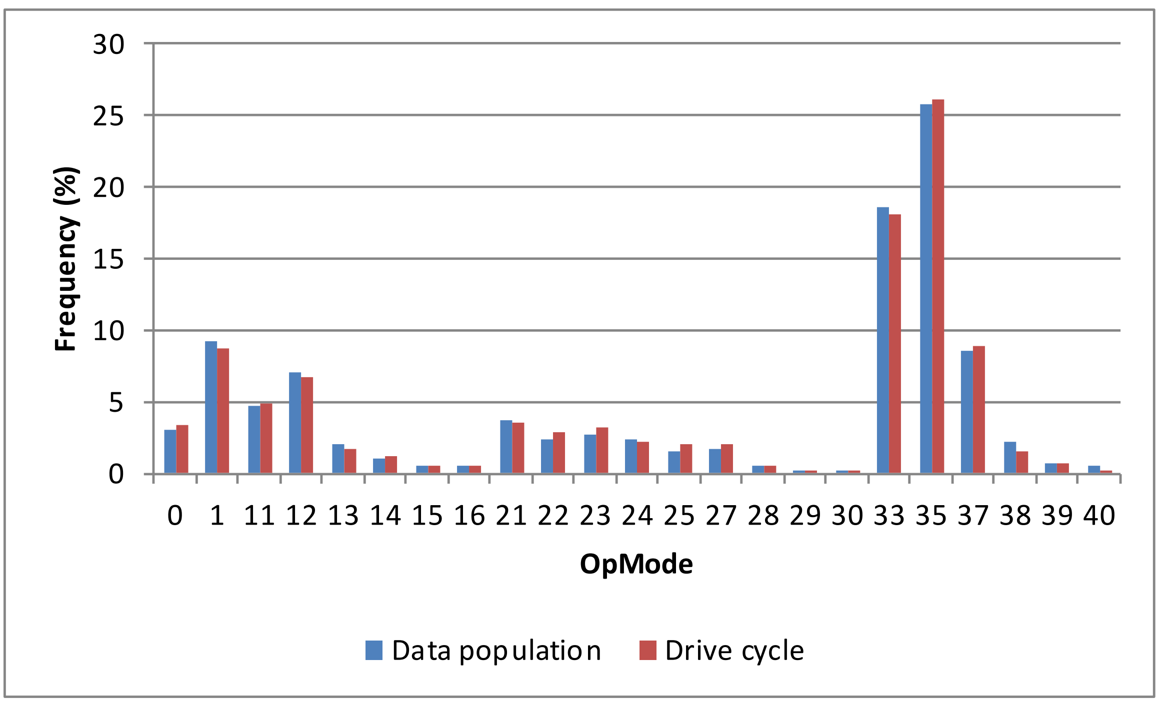


Figure F-4. Comparison of operating mode distribution for Group 1b (Line haul – in state)

Drayage – Northern California

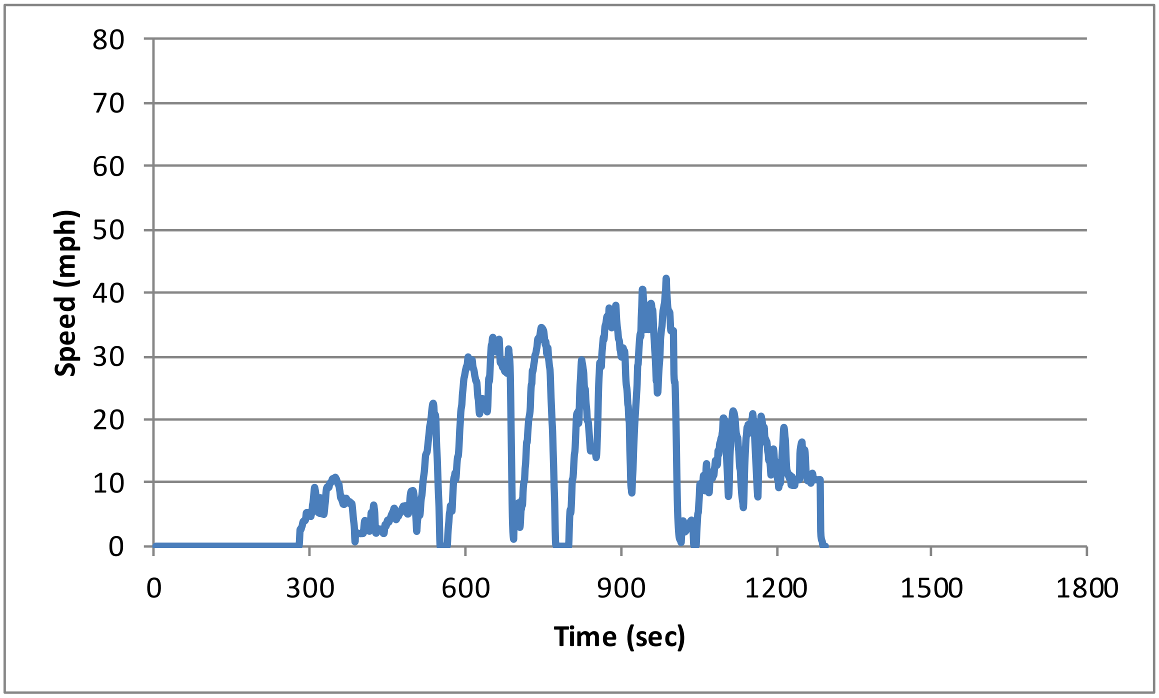


Figure F-5. Drive cycle for Group 2a (Drayage – Northern California)

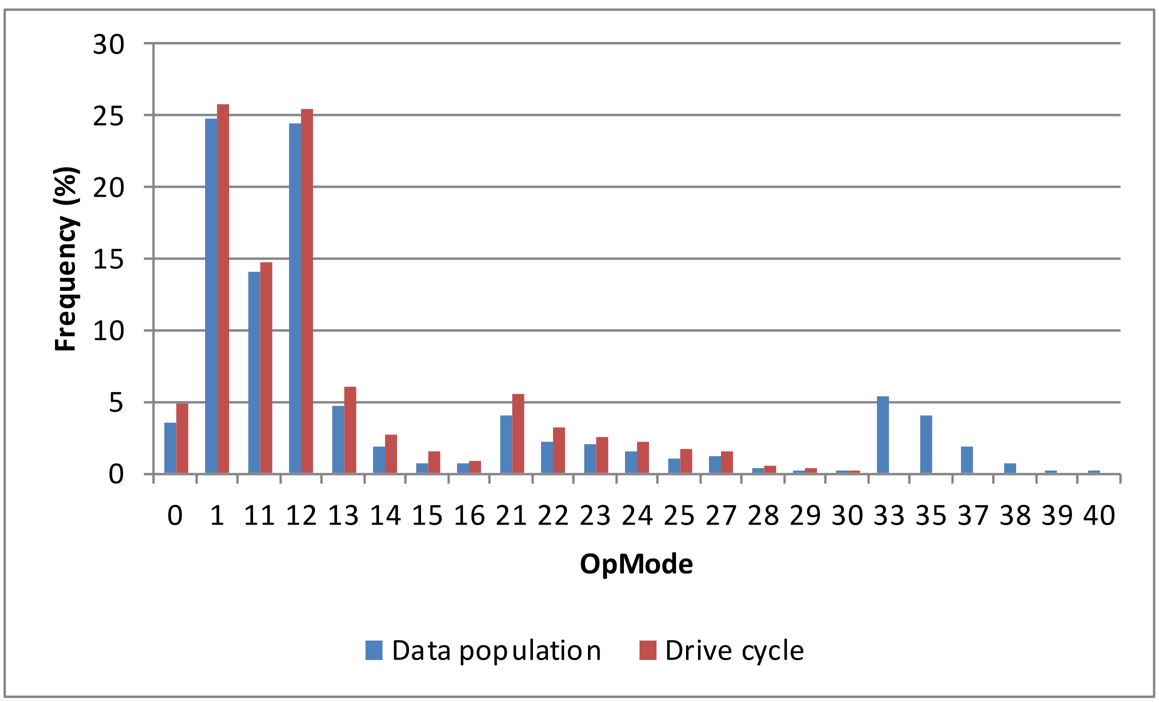


Figure F-6. Comparison of operating mode distribution for Group 2a (Drayage – Northern California)

Drayage – Southern California

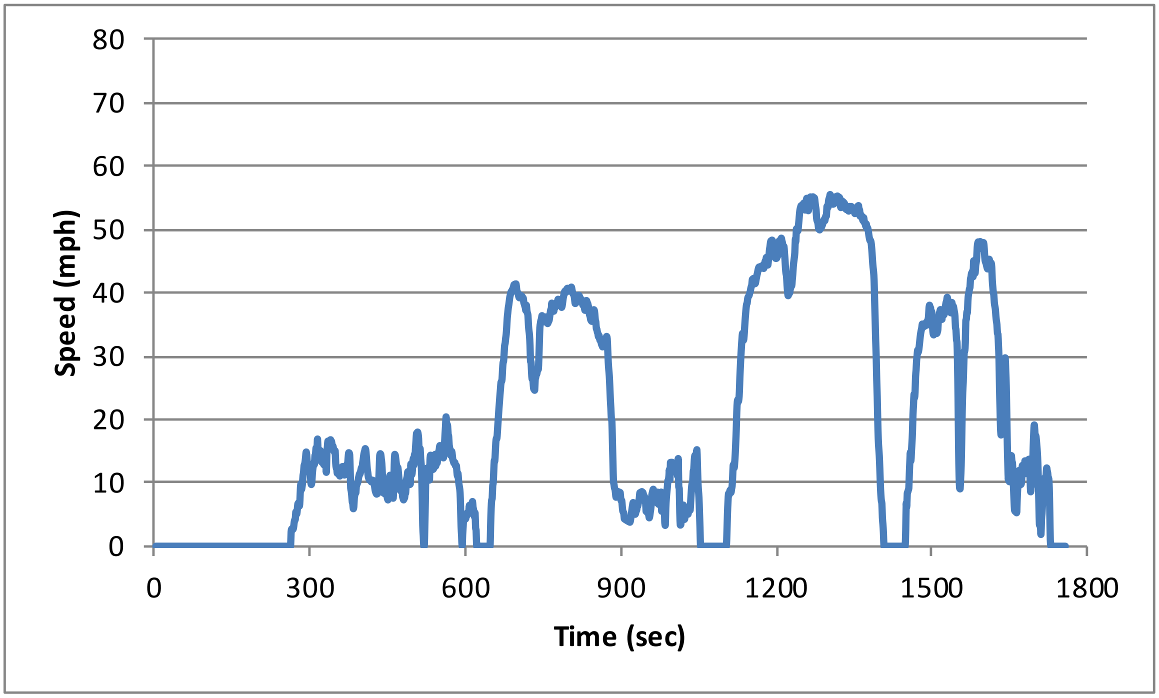


Figure F-7. Drive cycle for Group 2b (Drayage – Southern California)

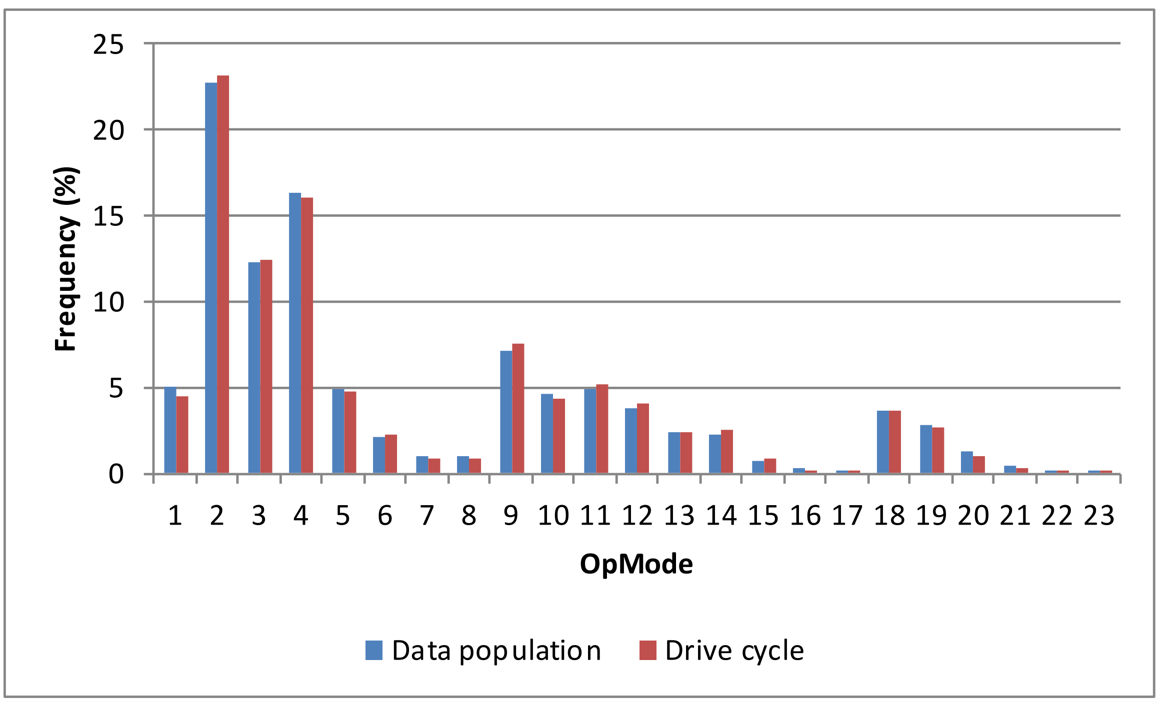


Figure F-8. Comparison of operating mode distribution for Group 2b (Drayage – Southern California)

Agricultural – South Central Valley

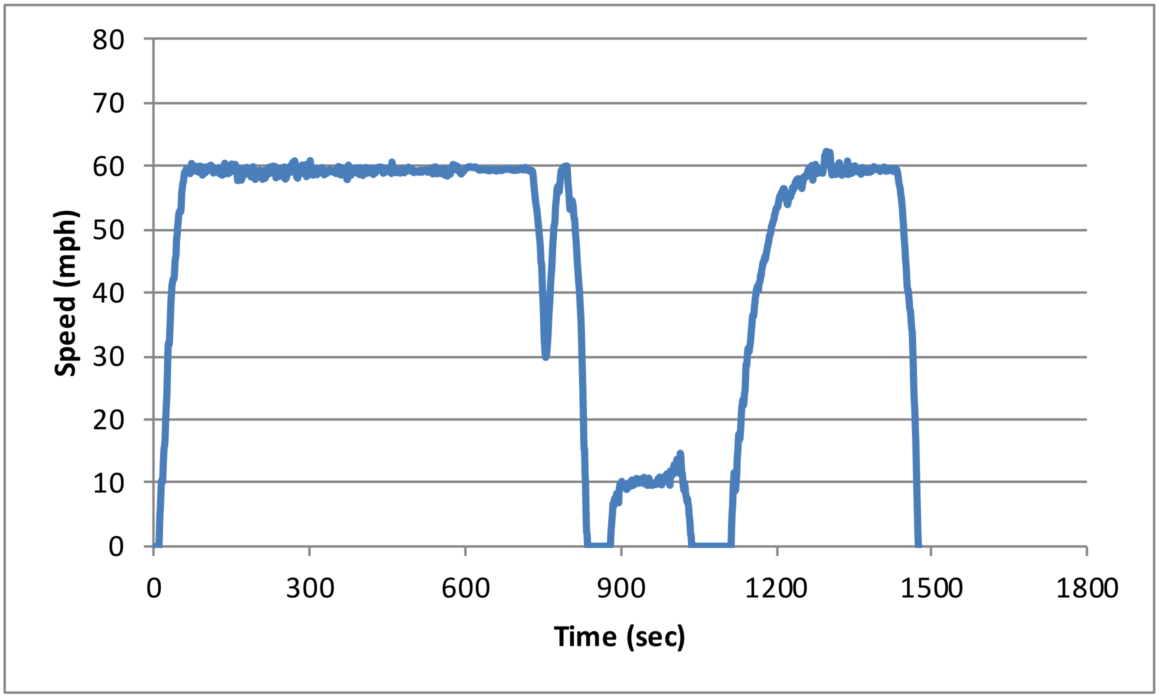


Figure F-9. Drive cycle for Group 3b (Agricultural – South Central Valley)

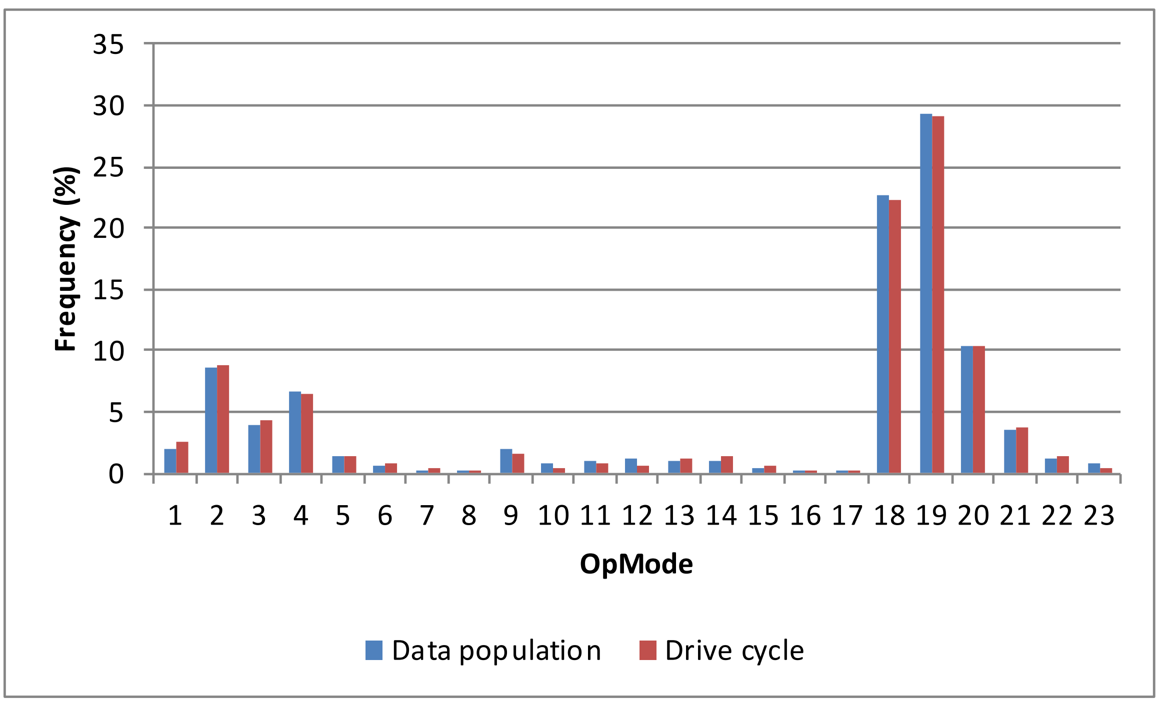


Figure F-10. Comparison of operating mode distribution for Group 3b (Agricultural – South CV)

Construction

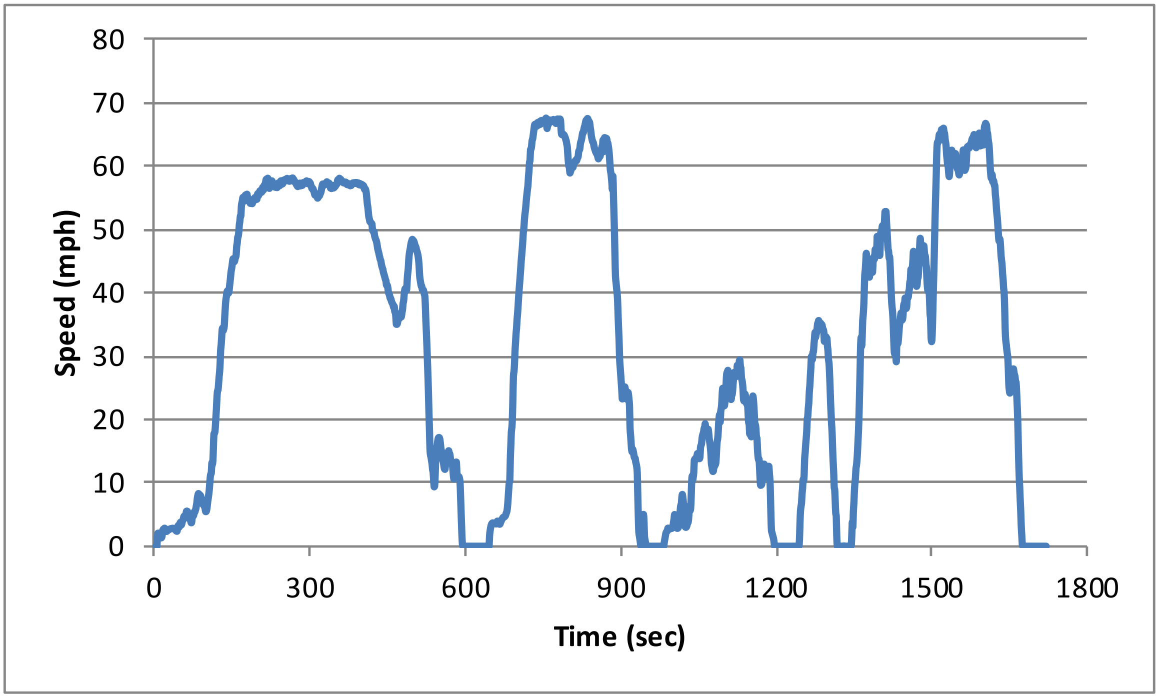


Figure F-11. Drive cycle for Group 4a (Construction)

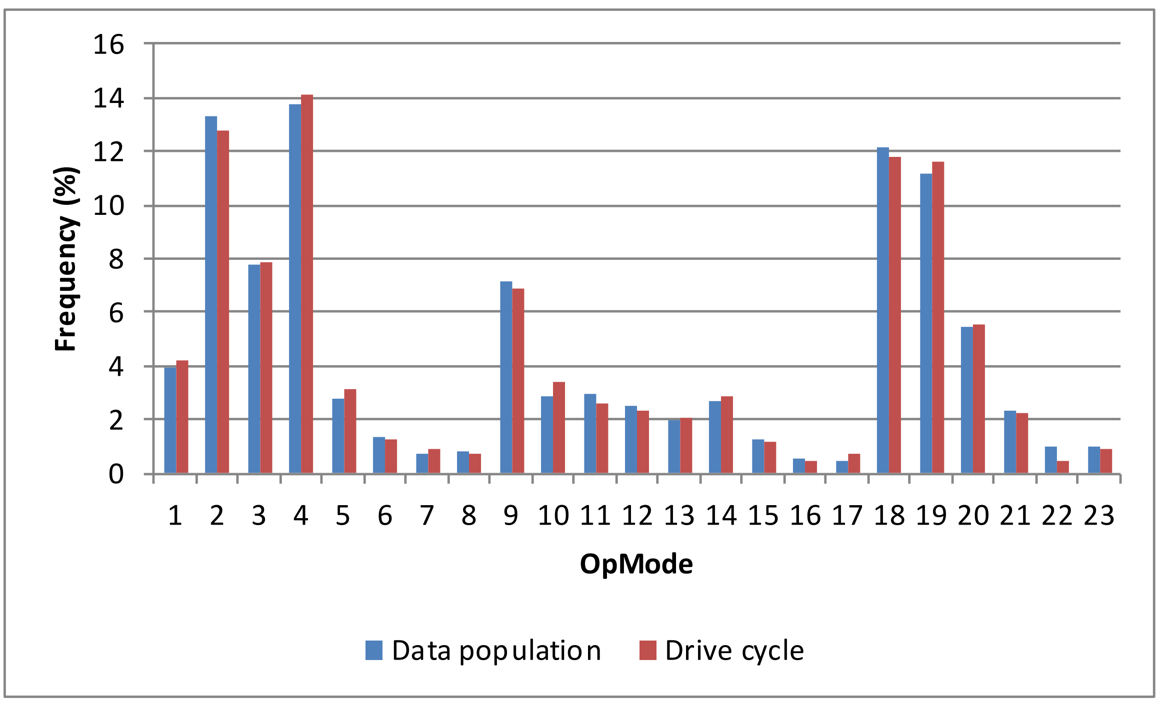


Figure F-12. Comparison of operating mode distribution for Group 4a (Construction)

Cement Mixers

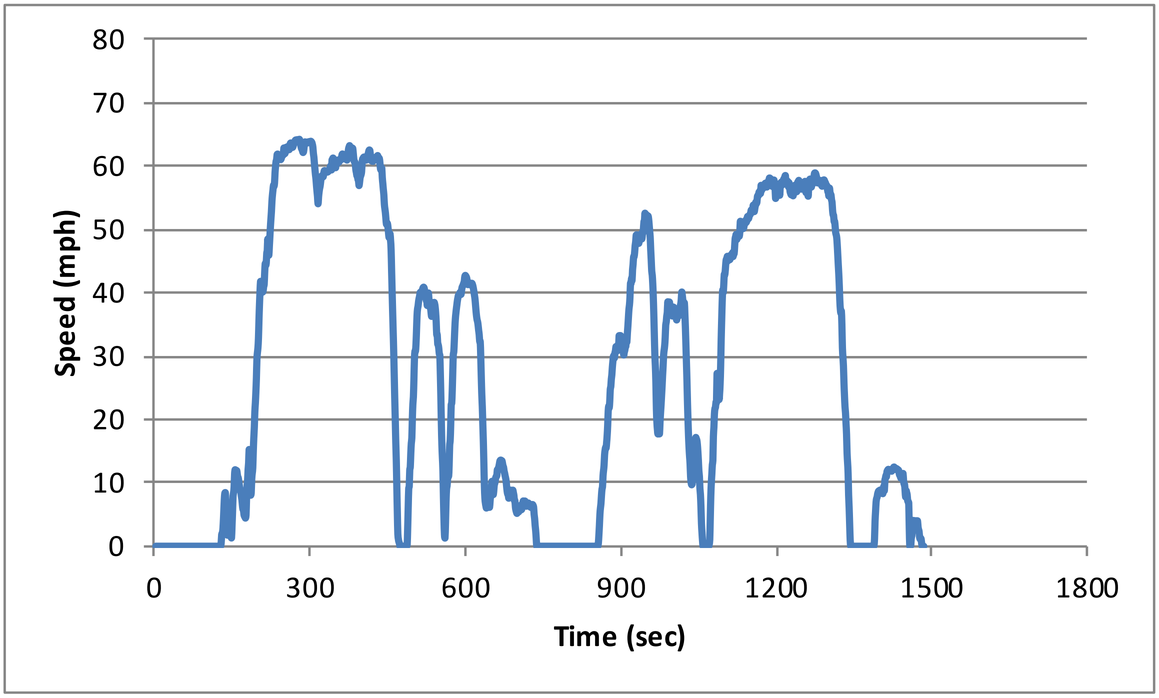


Figure F-13. Drive cycle for Group 4b (Cement mixers)

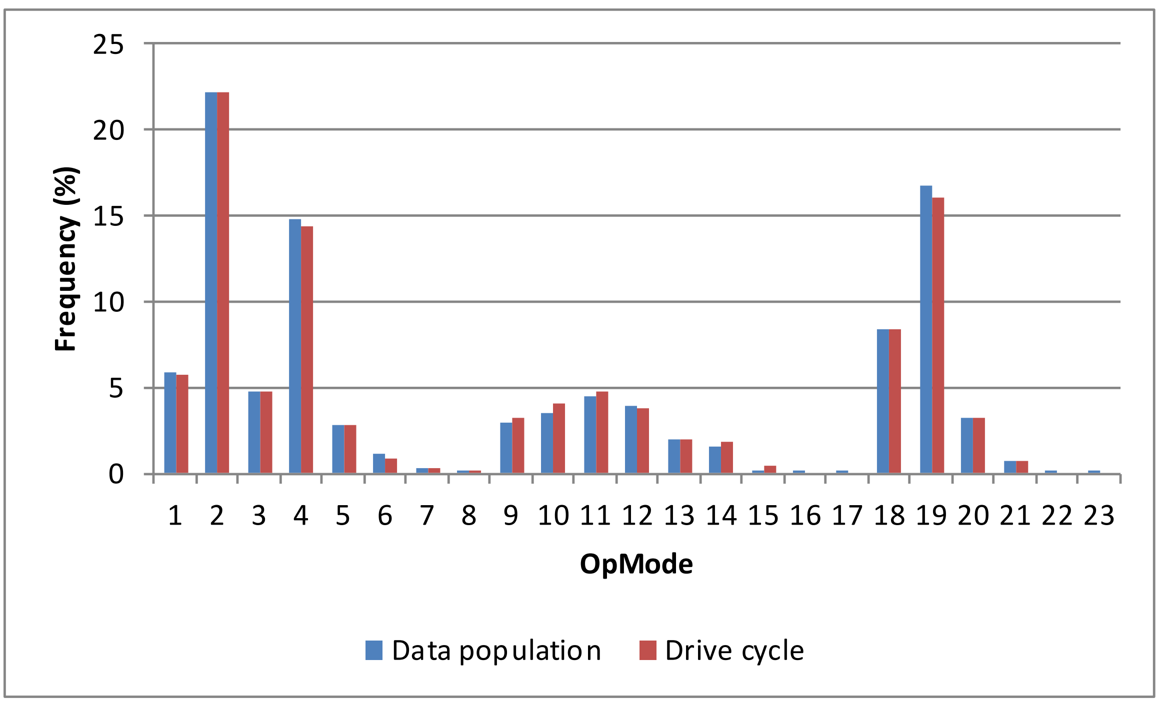


Figure F-14. Comparison of operating mode distribution for Group 4b (Cement mixers)

Food Distribution

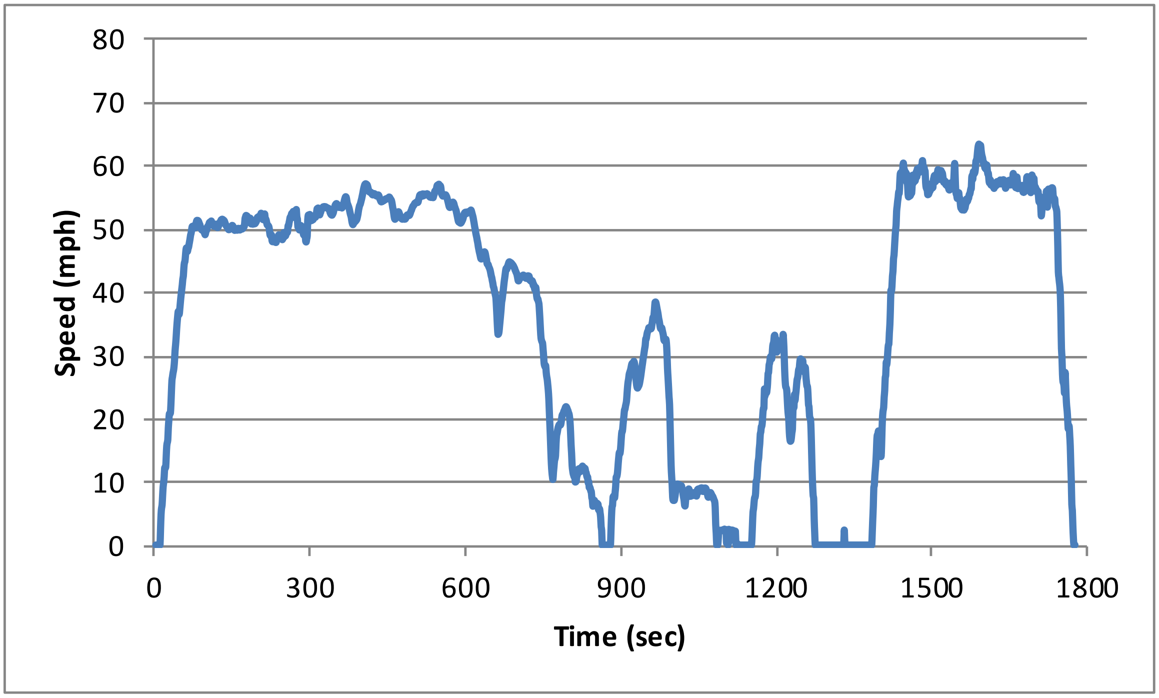


Figure F-15. Drive cycle for Group 5a (Food distribution)

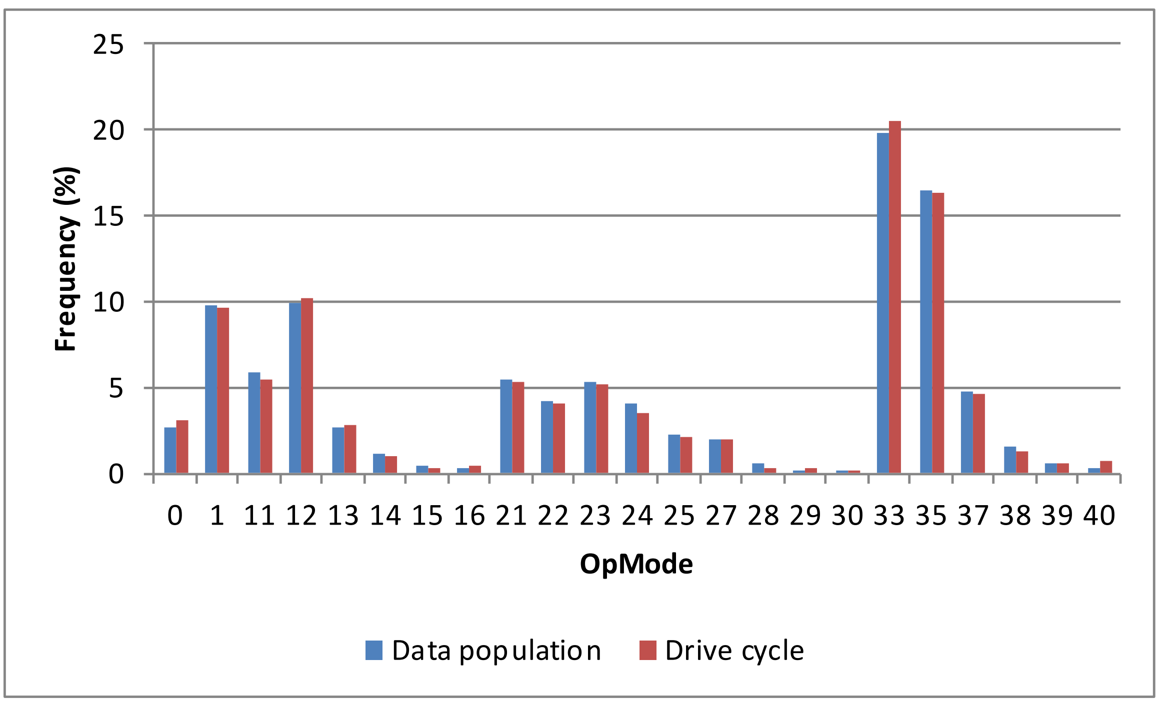


Figure F-16. Comparison of operating mode distribution for Group 5a (Food distribution)

Beverage Distribution

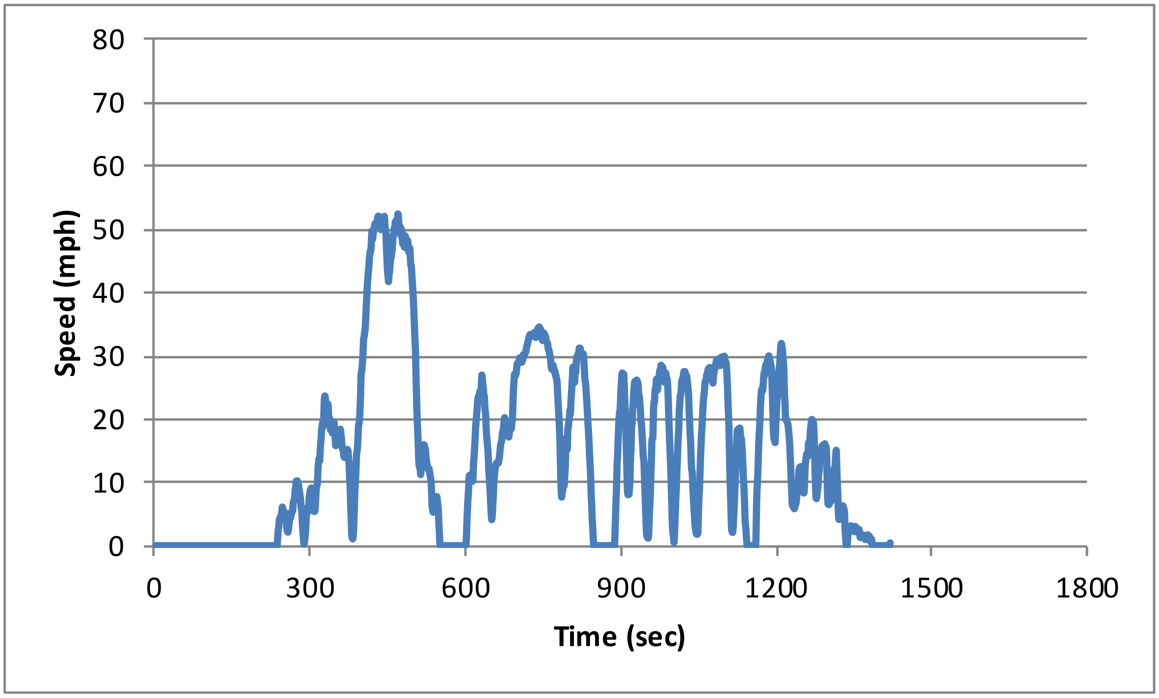


Figure F-17. Drive cycle for Group 5b (Beverage distribution)

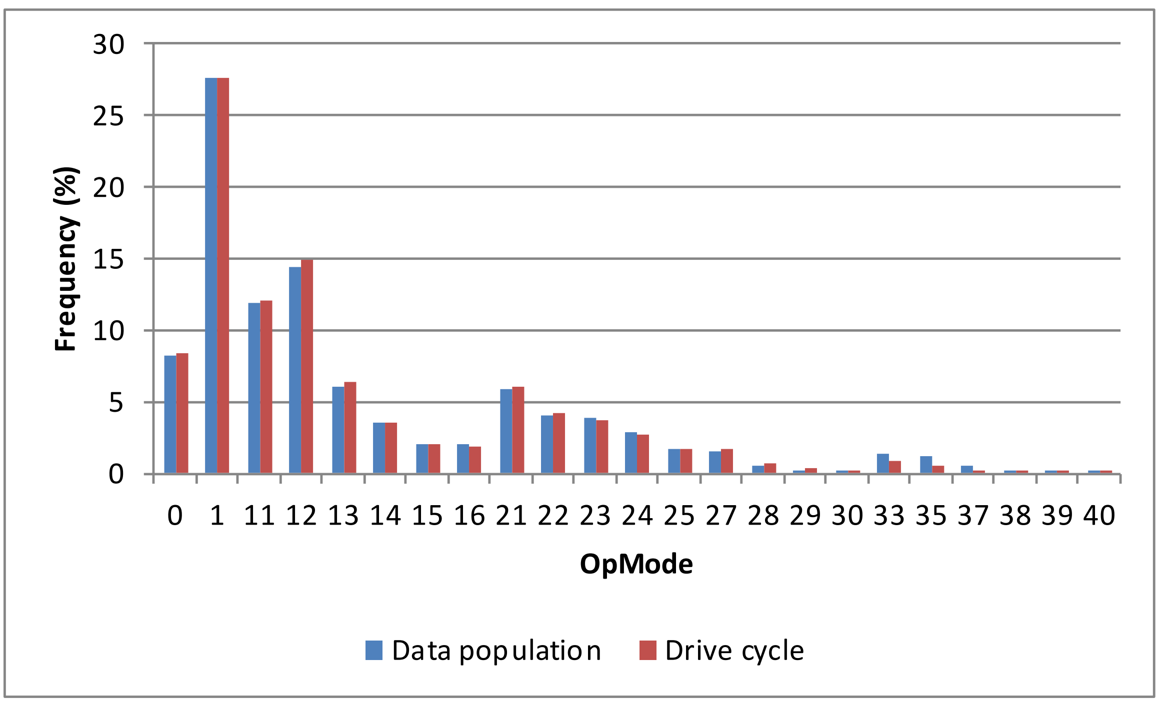


Figure F-18. Comparison of operating mode distribution for Group 5b (Beverage distribution)

Local Moving

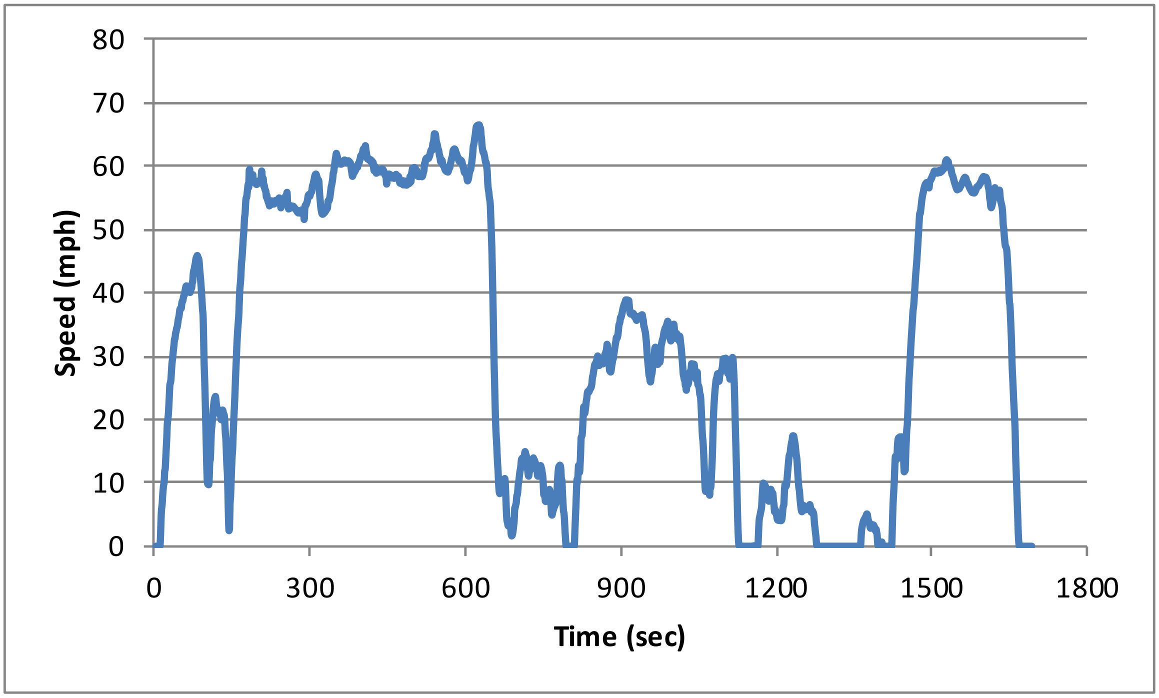


Figure F-19. Drive cycle for Group 5c (Local moving)

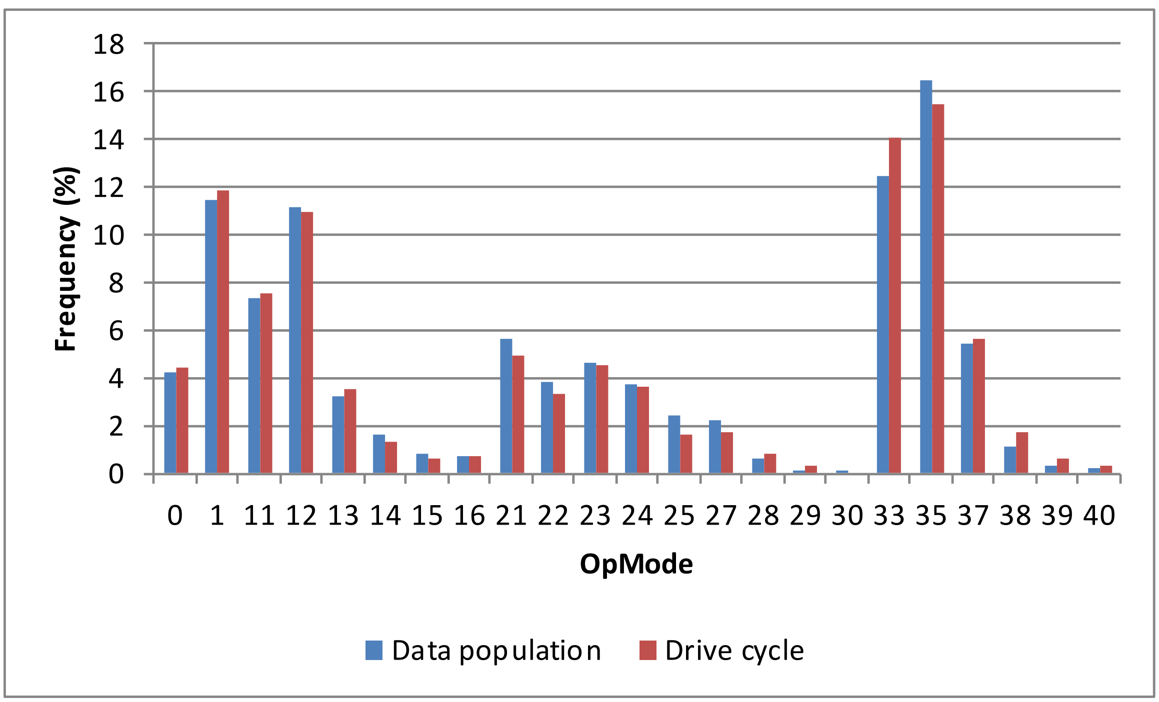


Figure F-20. Comparison of operating mode distribution for Group 5c (Local moving)

Airport Shuttle

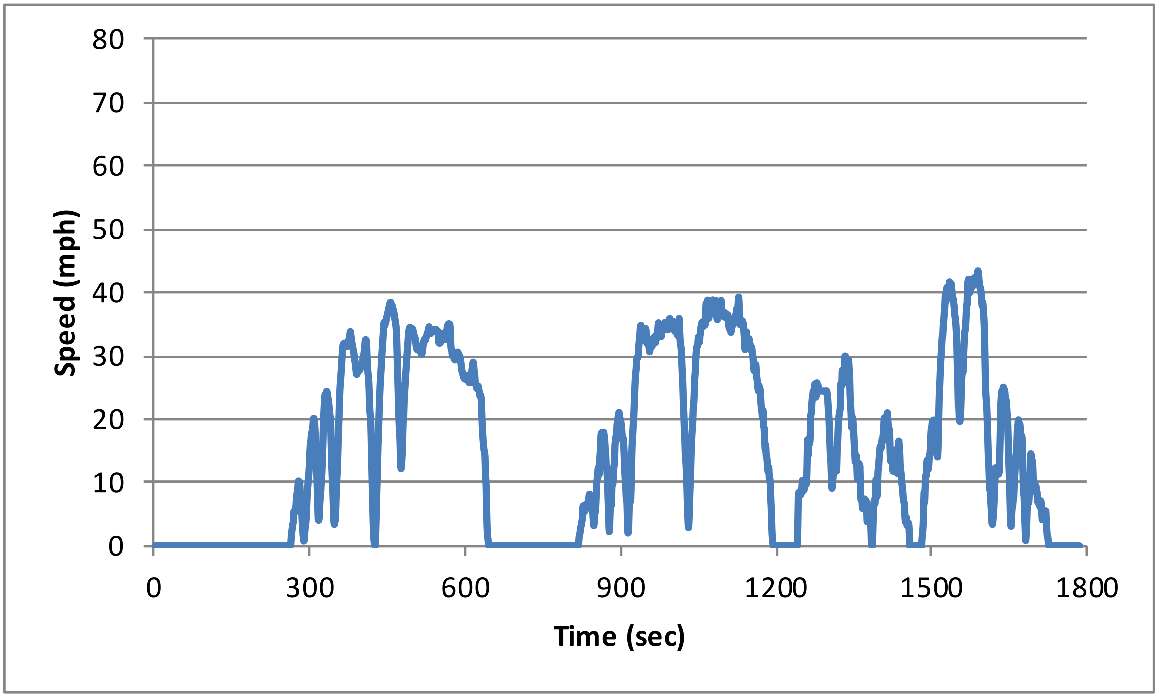


Figure F-21. Drive cycle for Group 6 (Airport shuttle)

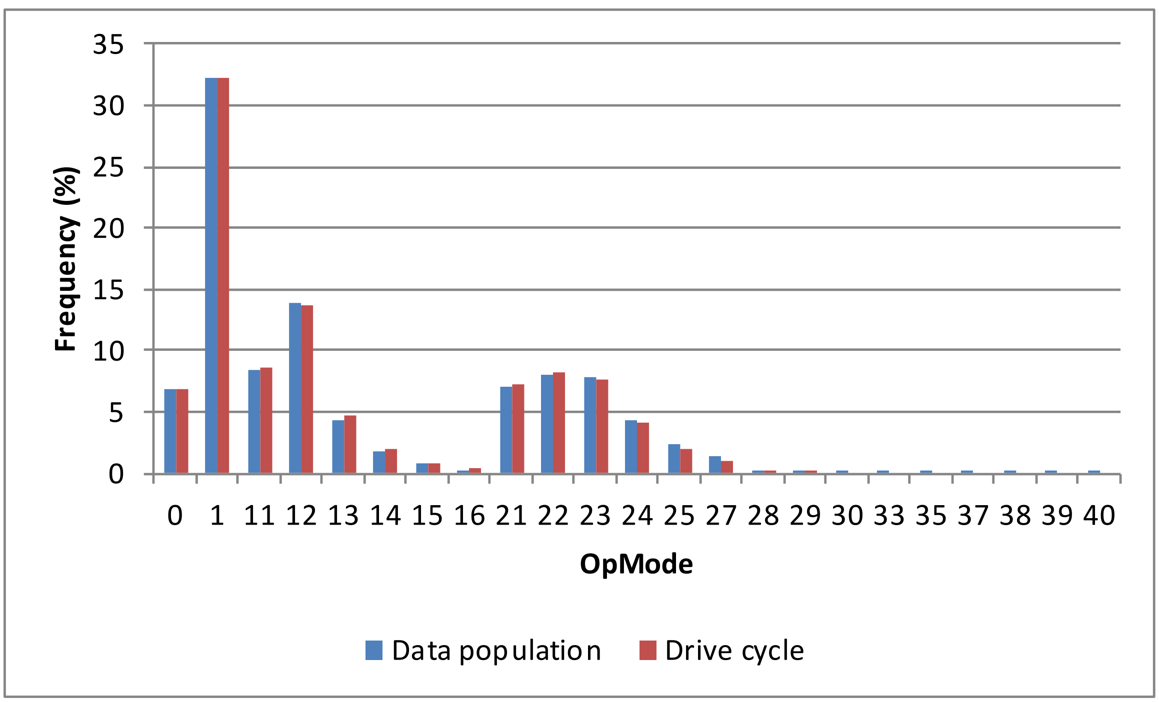


Figure F-22. Comparison of operating mode distribution for Group 6 (Airport shuttle)

Refuse

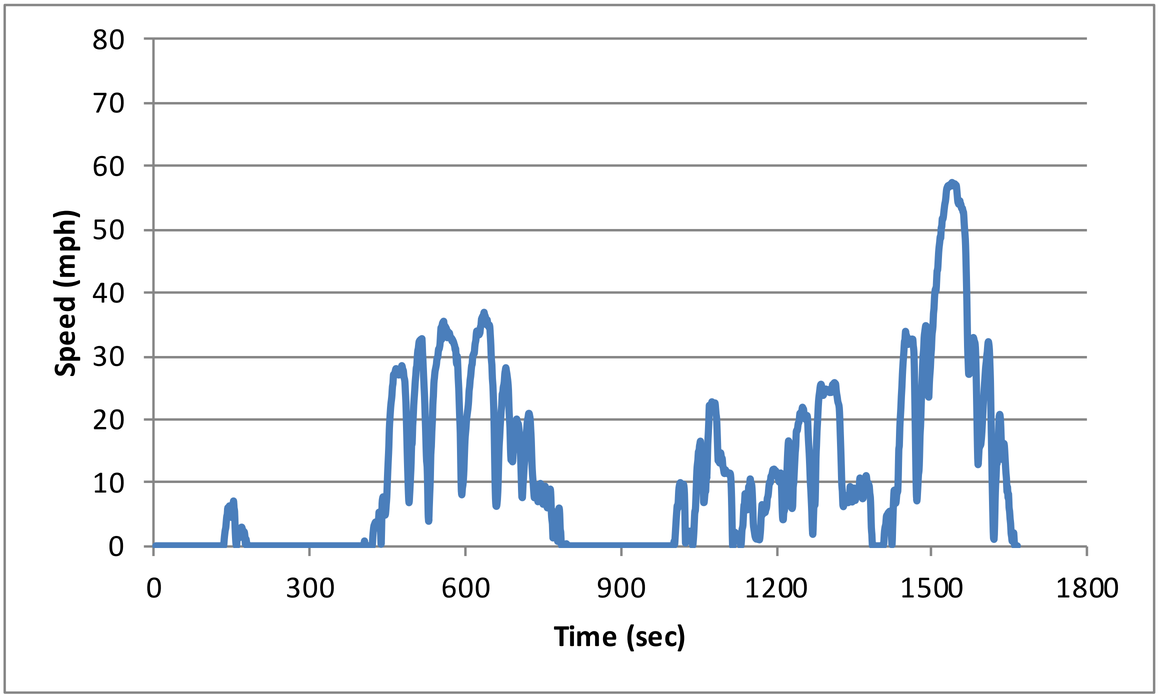


Figure F-23. Drive cycle for Group 7 (Refuse)

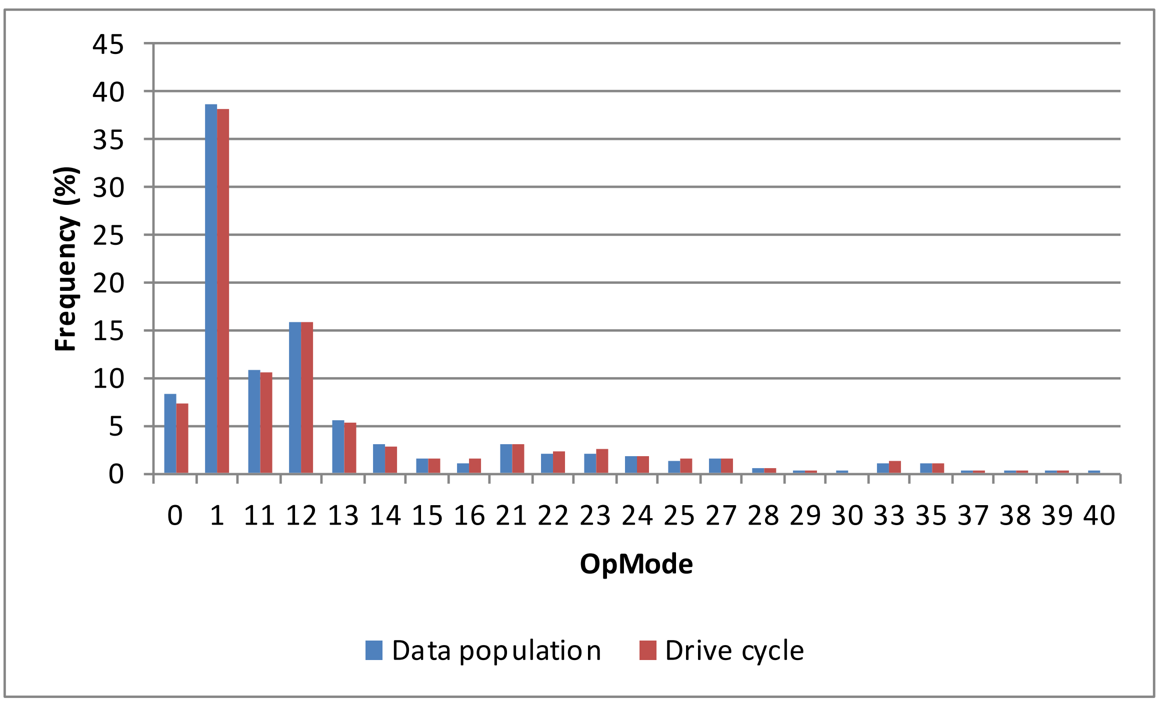


Figure F-24. Comparison of operating mode distribution for Group 7 (Refuse)

Urban Buses

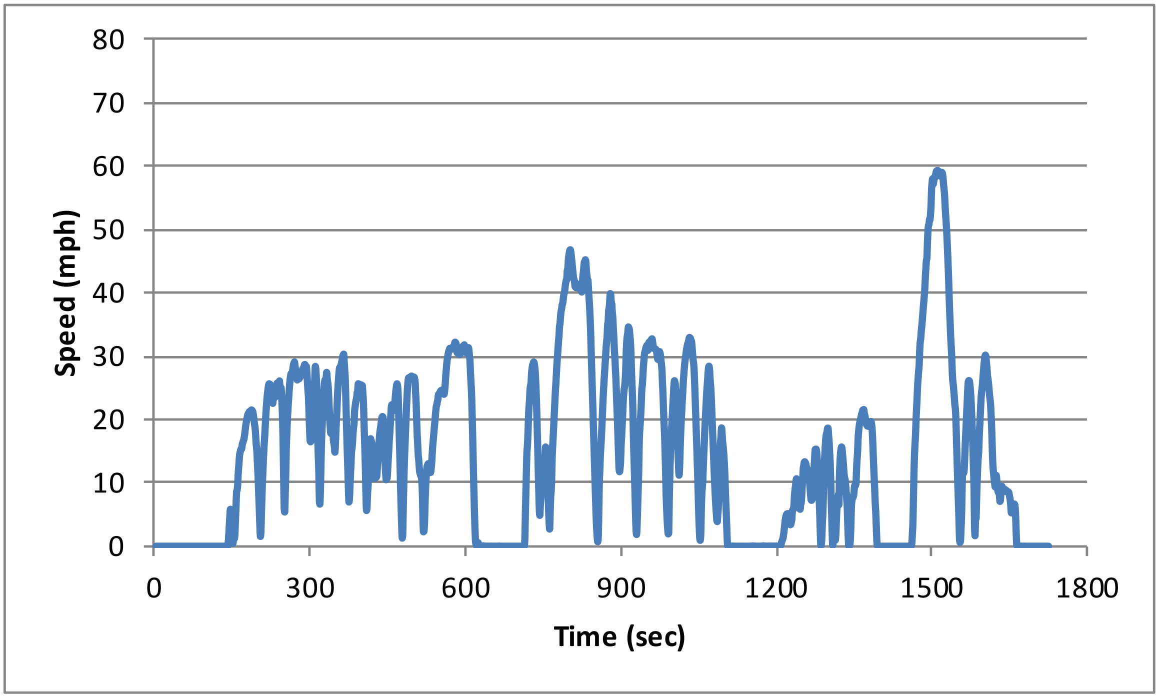


Figure F-25. Drive cycle for Group 8a (Urban buses)

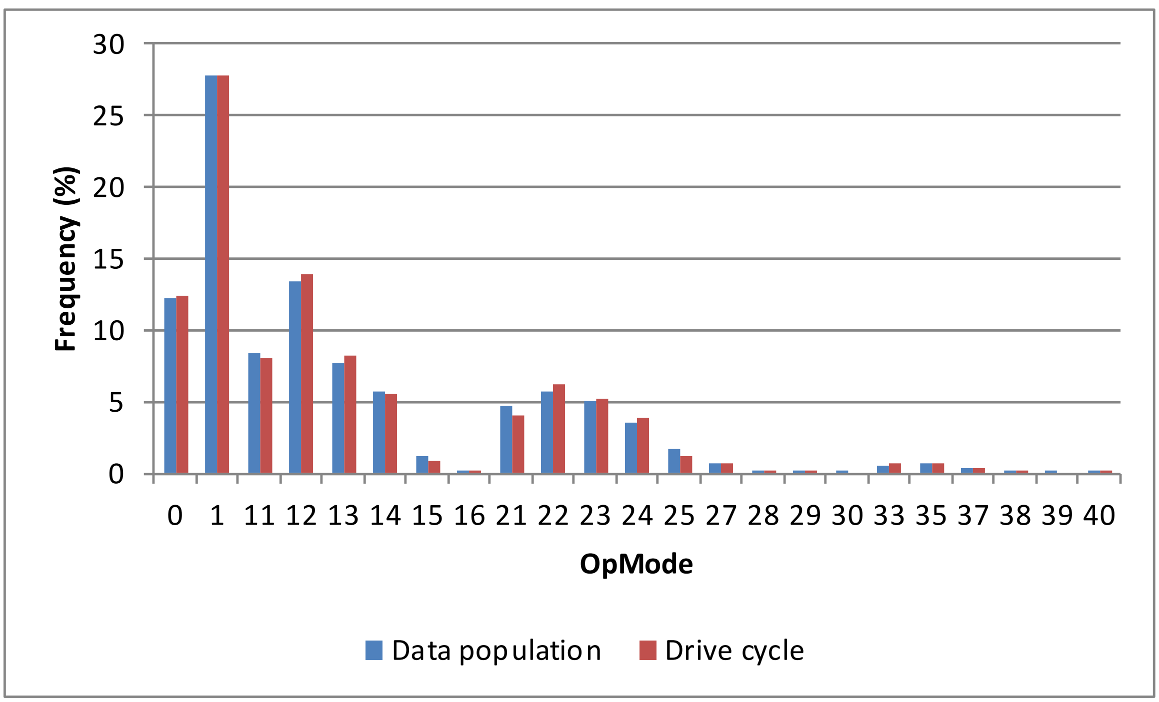


Figure F-26. Comparison of operating mode distribution for Group 8a (Urban buses)

Express Buses

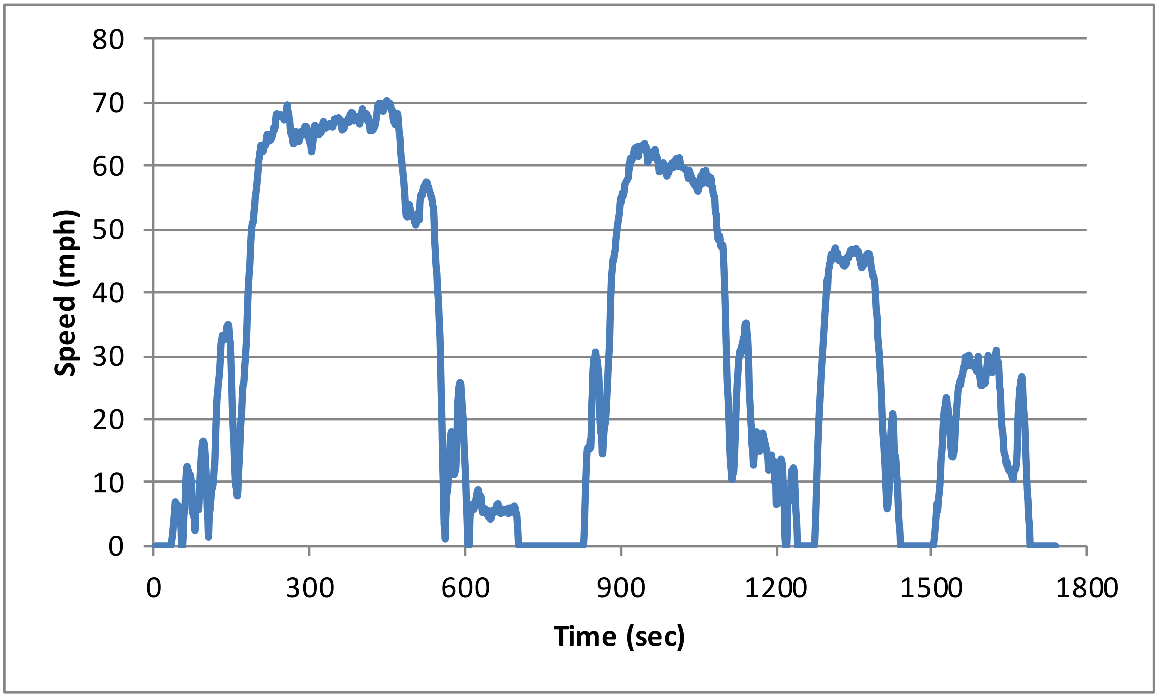


Figure F-27. Drive cycle for Group 8b (Express buses)

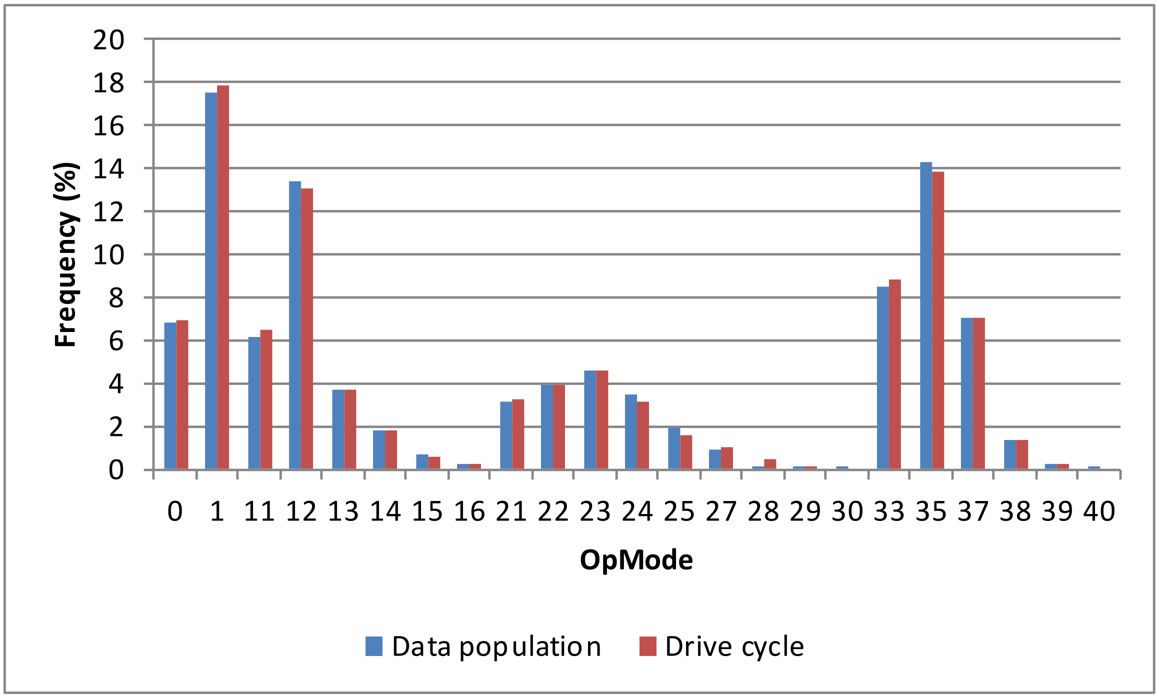


Figure F-28. Comparison of operating mode distribution for Group 8b (Express buses)

Freeway Work

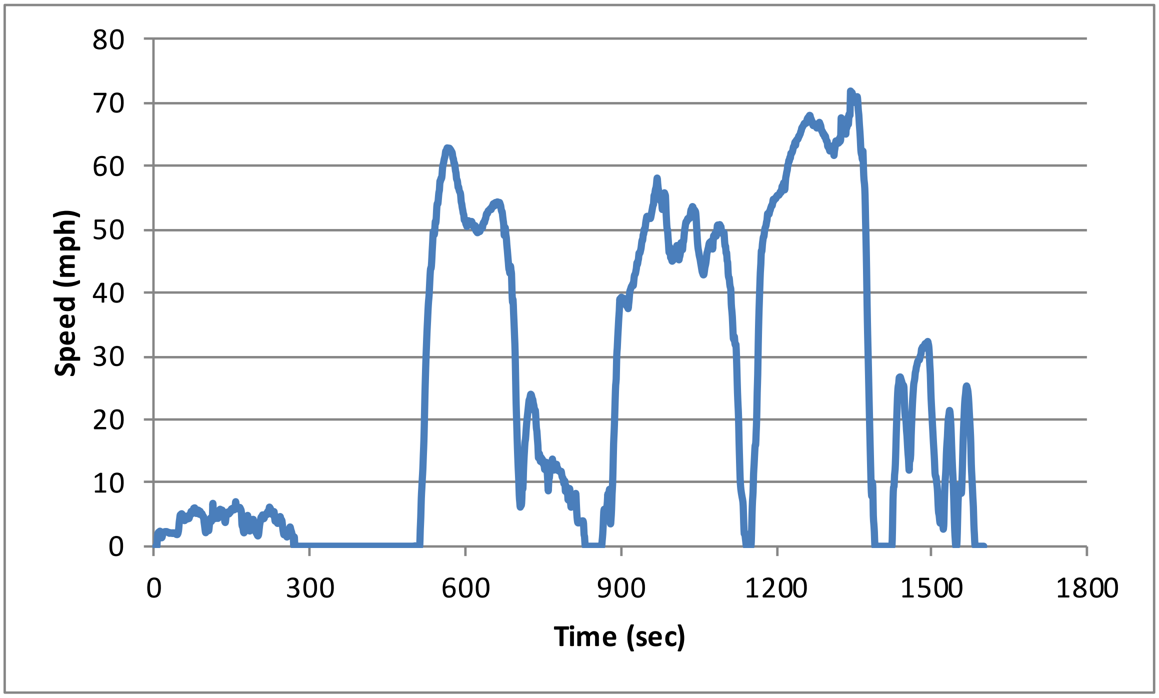


Figure F-29. Drive cycle for Group 9a (Freeway work)

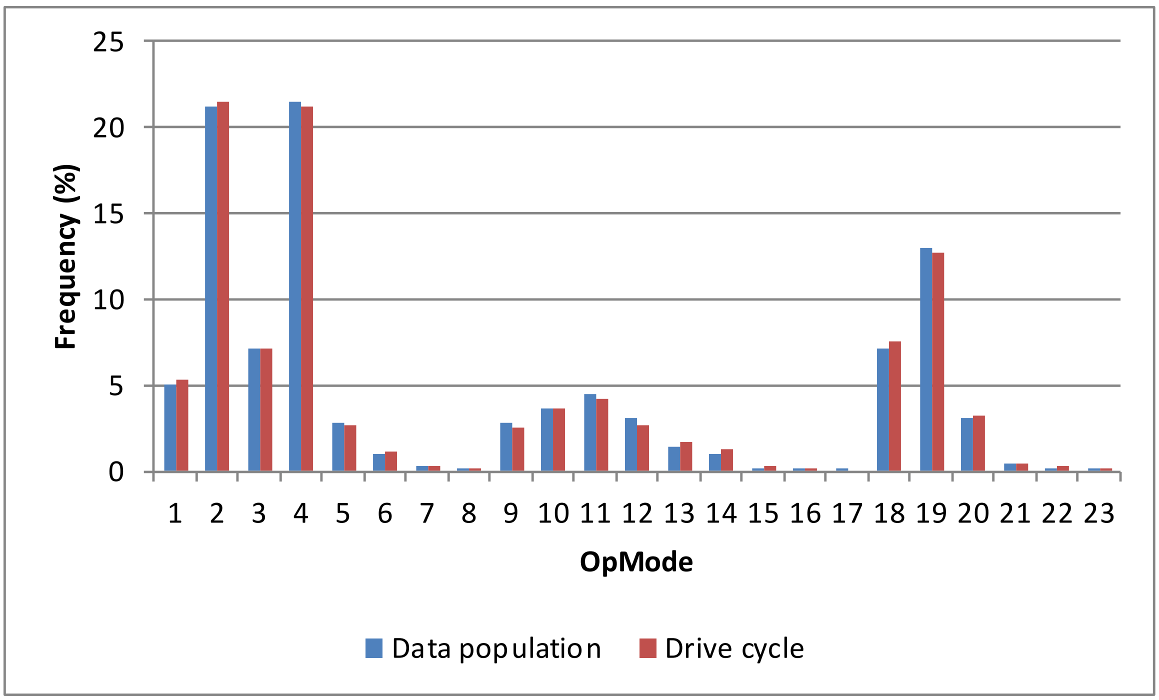


Figure F-30. Comparison of operating mode distribution for Group 9a (Freeway work)

Sweeping

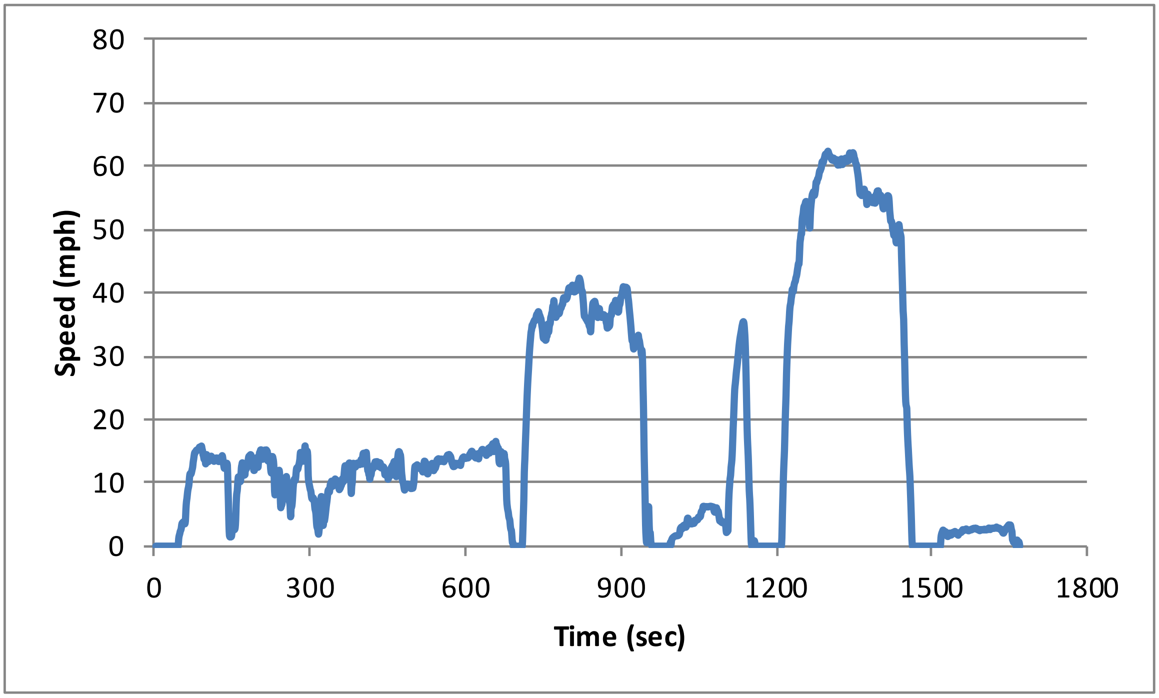


Figure F-31. Drive cycle for Group 9b (Sweeping)

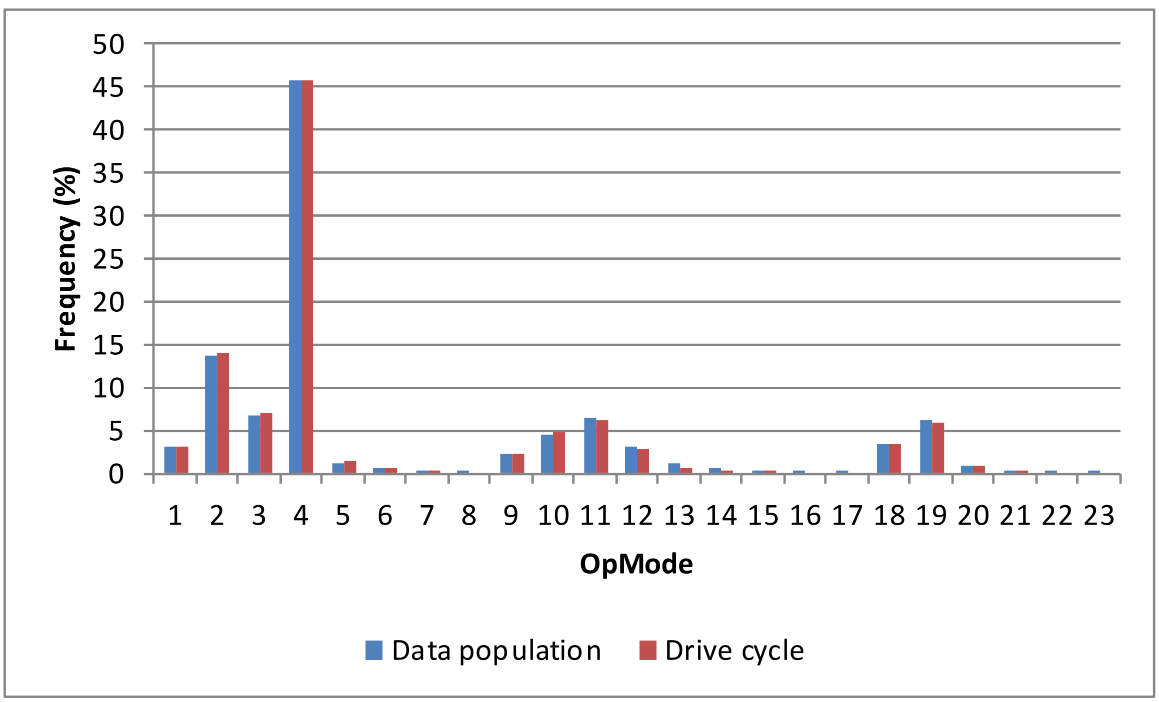


Figure F-32. Comparison of operating mode distribution for Group 9b (Sweeping)

Municipal Work

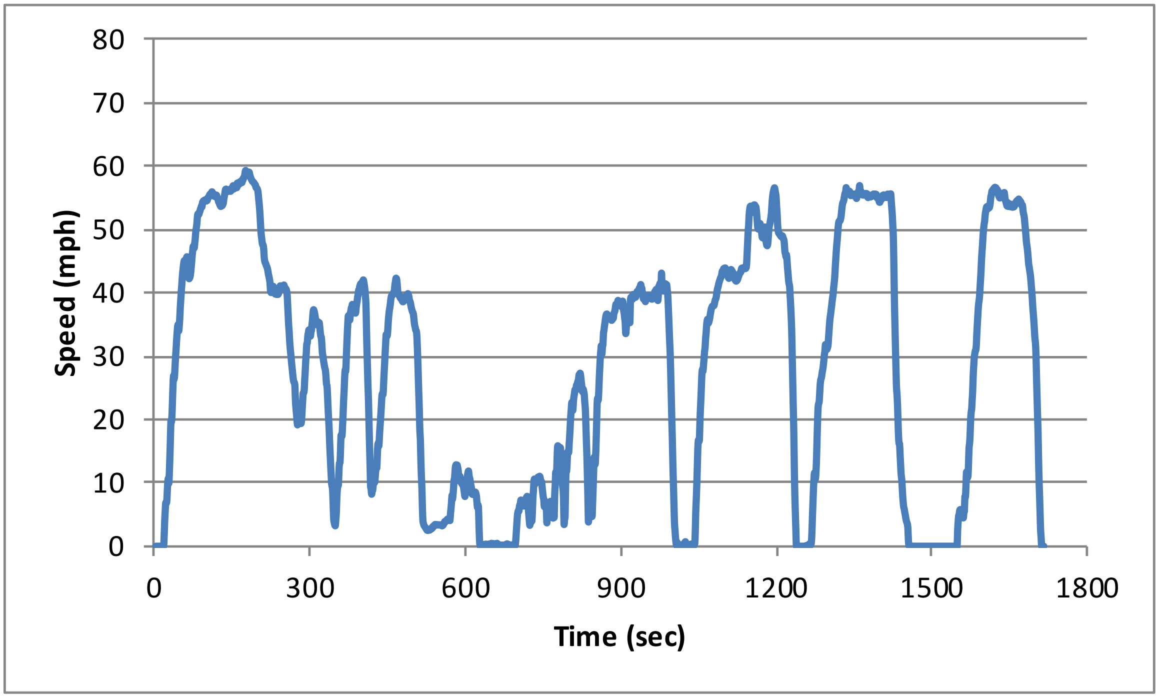


Figure F-33. Drive cycle for Group 9c (Municipal work)

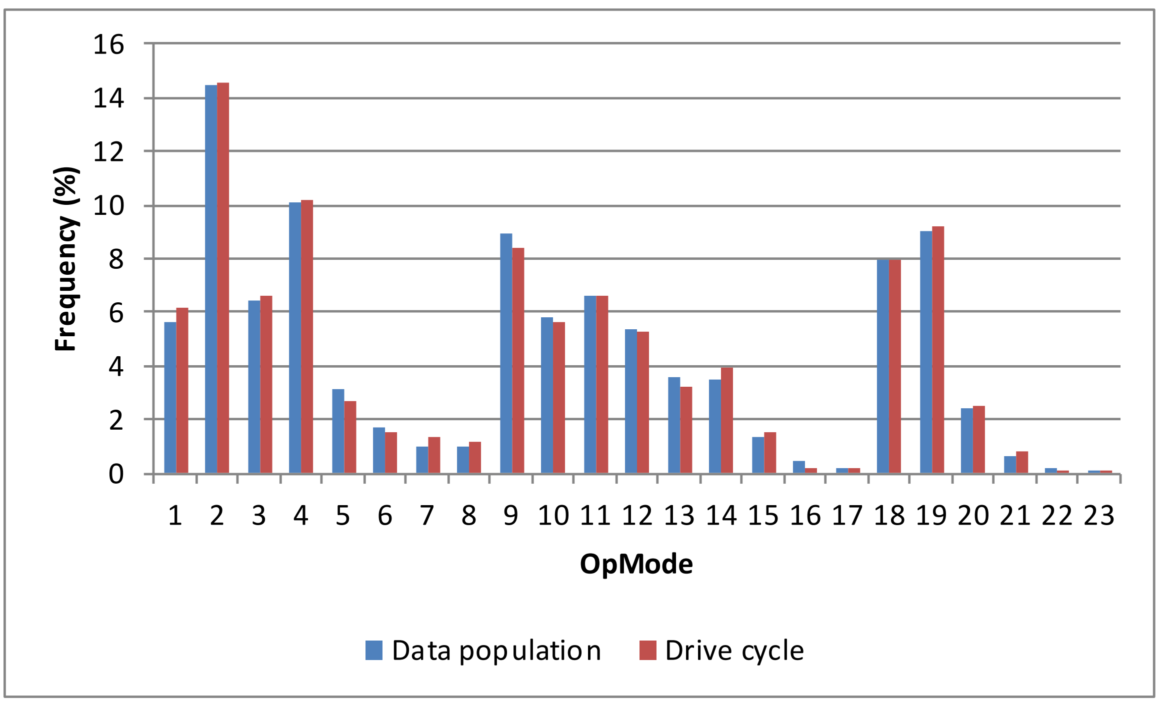


Figure F-34. Comparison of operating mode distribution for Group 9c (Municipal work)

Towing

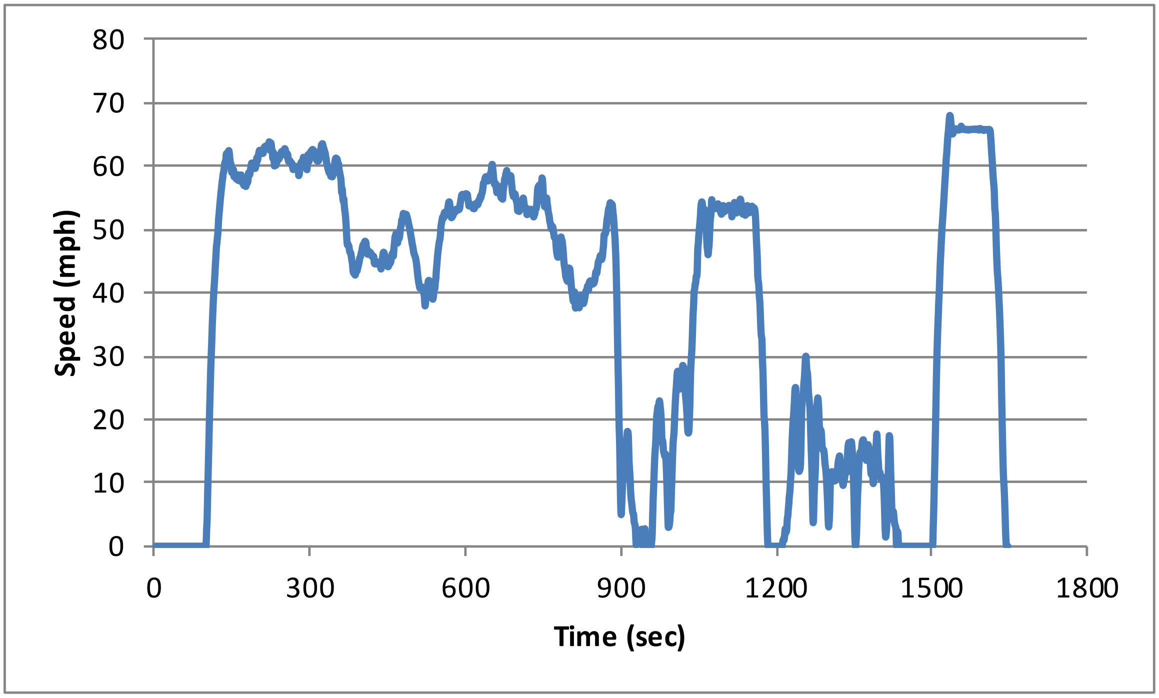


Figure F-35. Drive cycle for Group 9d (Towing)

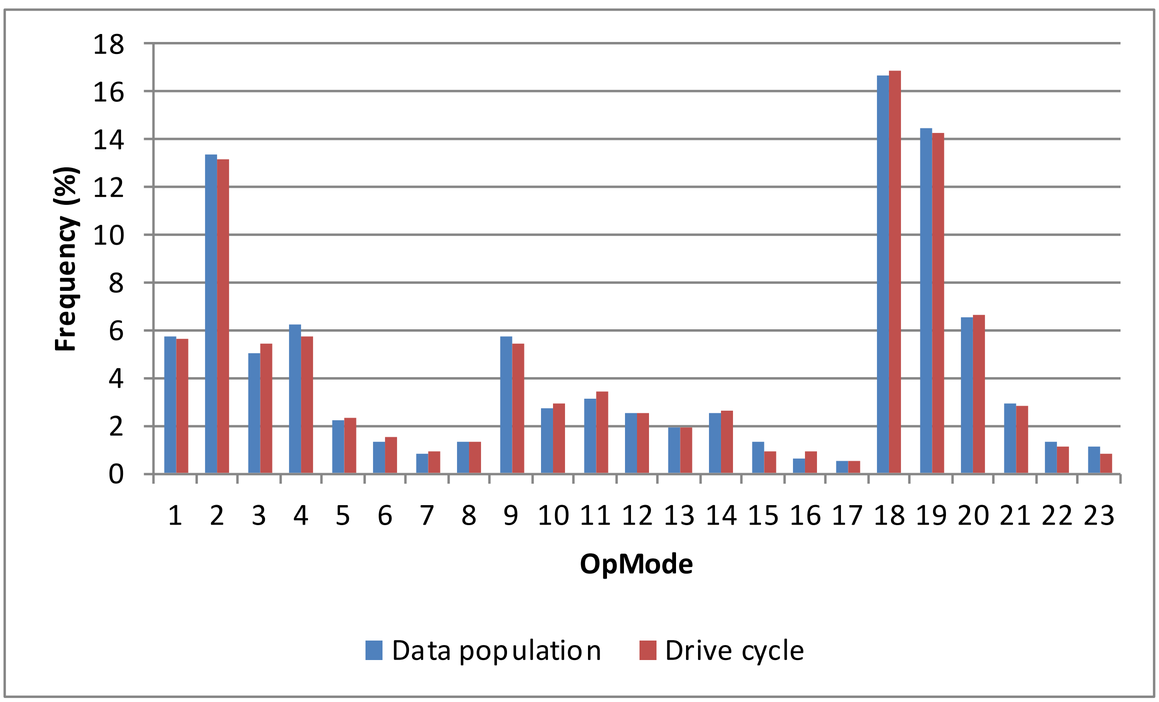


Figure F-36. Comparison of operating mode distribution for Group 9d (Towing)

Utility Repair

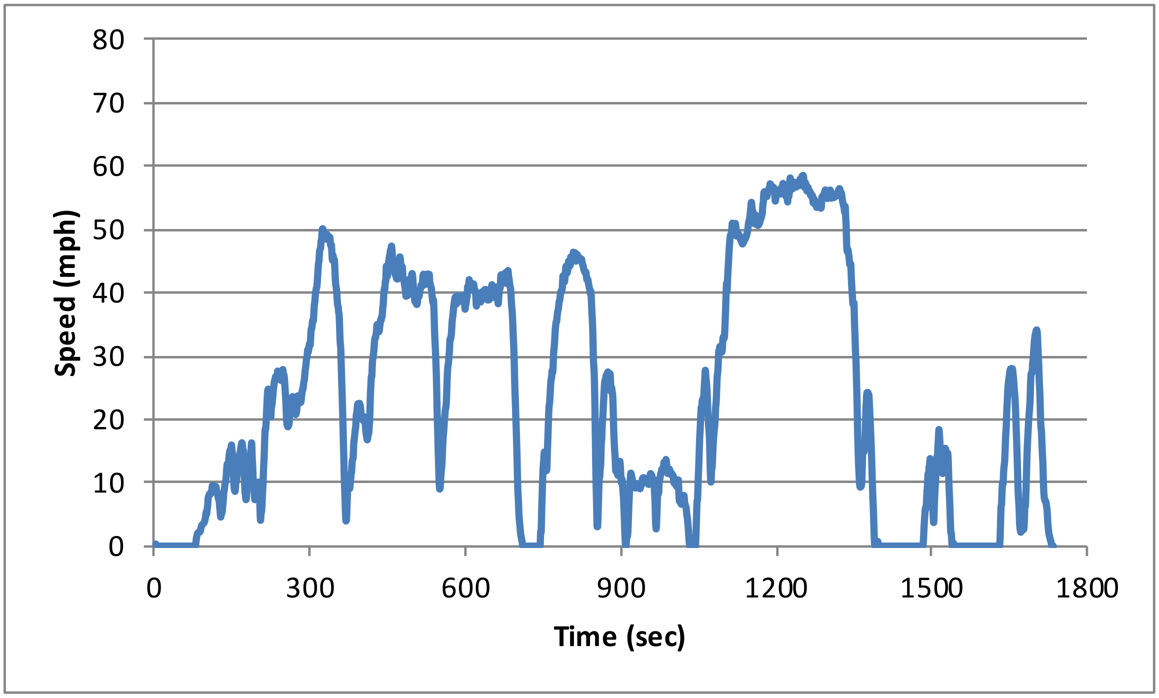


Figure F-37. Drive cycle for Group 10 (Utility repair)

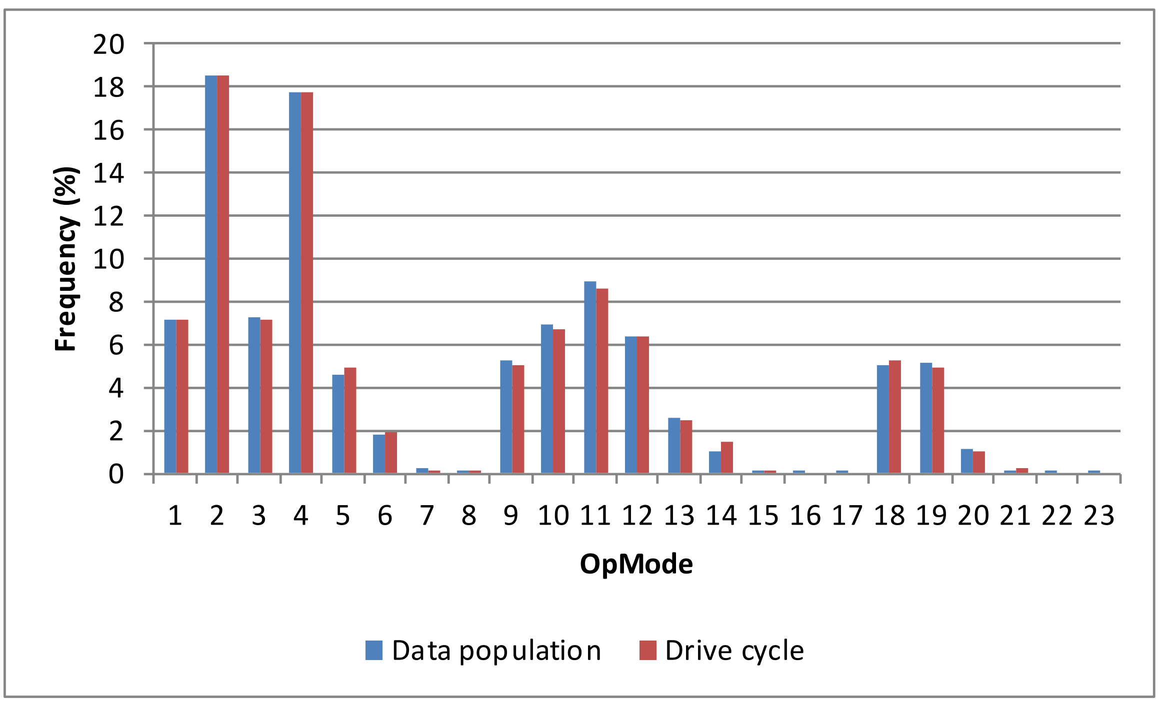


Figure F-38. Comparison of operating mode distribution for Group 10 (Utility repair)