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

Collection of Tractor-Trailer Activity Data

FINAL REPORT

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Disclaimer

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List of Acronyms

AB	Assembly Bill
ATA	American Trucking Association
CA	California
CARB	California Air Resources Board
CAN	Controller Area Network
CC	Container chassis
CRADA	Cooperative Research and Development Agreement
CSV	Comma-separated values
CTA	California Trucking Association
CV	Central Valley
ECU	Electronic Control Unit
EPA	(U.S.) Environmental Protection Agency
FB	Flatbed
GHG	Greenhouse gases
GPS	Global Positioning System
GVWR	Gross vehicle weight rating
HTA	Harbor Trucking Association
NC	Northern California
NO_x	Oxides of nitrogen
NTTC	National Tank Truck Carriers
OBD	On-Board Diagnostic
OEM	Original equipment manufacturer
PTO	Power take off
SAE	Society of Automotive Engineers
SC	Southern California
SCR	Selective catalytic reduction
TK	Tanker
TTMA	Truck Trailer Manufacturers Association
UCR	University of California at Riverside
VMT	Vehicle miles traveled

Abstract

The objective of this research is to collect tractor-trailer activity data that will be used by CARB staff to assess the potential greenhouse gas (GHG) emissions benefit from improved trailer aerodynamics. Four different trailer types (flatbed, tanker, curtainside, and container chassis) that are not currently required to meet aerodynamic equipment requirements of CARB’s existing Tractor-Trailer GHG regulation were targeted for evaluation. The study included an analysis of a national trailer registration database for the years 2000 through 2015 with 11,575 trailers for California that included 3,172 flatbed, 6,402 container chassis, 1,897 tankers, and 103 curtainside trailers. Fleet surveys were obtained from 51 fleets representing 17,032 trailers that provided information about fleets sizes, annual miles traveled and load types. A limited number of fleets utilizing the four trailer types were data logged to better understand their activity patterns. Based on this limited dataset, there was no clear association between trailer type and the different operating characteristics of the fleets. Distributions of vehicle miles traveled (VMT) by speed for the different fleets showed similar trends, with the majority of the VMT occurring at highway speeds between 50 and 65 mph, when aerodynamic devices provide the greatest benefit.

Executive Summary

Aerodynamic improvements to heavy duty tractors and trailers are a critical step to reducing California's (CA's) greenhouse gas (GHG) emissions. In order to meet the GHG emission reduction goals specified in California's Global Warming Solutions Act of 2006, Assembly Bill 32 (AB 32), GHG emission reductions are needed from heavy-duty tractors. The Tractor-Trailer GHG regulation was one of the discrete early action measures adopted by the CARB to contribute to the goals of AB 32. The regulation requires 53-foot or longer box-type trailers traveling in California to be equipped with aerodynamic technologies (e.g., side-skirts, front and rear trailer fairings, and undertray devices) and low-rolling resistance tires, resulting in improved fuel economy and reduced GHG emissions from the heavy-duty tractors that pull them. The Tractor-Trailer GHG regulation does not apply to other trailer types or sizes used in the freight transportation industry, such as drop deck, curtainside, flatbed, tanker, bulk, dump, grain, and other trailers. It also does not apply to box-type trailers shorter than 53 feet (typically 28 or 48 feet) in length.

The objective of this research is to collect tractor-trailer activity data that will be used by CARB staff to assess the potential greenhouse gas (GHG) emission reductions from improved aerodynamics for four types of trailers: flatbed, tanker, curtainside, and container chassis. These trailers are not currently required to meet aerodynamic equipment requirements of CARB's existing Tractor-Trailer GHG regulation. The research consists of three sequential investigations: identifying trailer populations, understanding trailer types and their business applications, and characterizing activity characteristics for the trailer types. An analysis of a trailer registration database, a fleet survey, and then analysis of tractor-trailer activity characterization were conducted, respectively. Tractors hauling the four trailer types were instrumented with portable activity dataloggers (HEM Data Corporation) to collect engine activity data. The data was analyzed to characterize activity patterns for each of these trailer types.

Registration Database Analysis

The Polk/IHS database included trailer registration records for calendar years 2000 through 2015 for 22,177 company fleets with at least one of the four trailer types described above, and a total of 253,191 trailers. A total of 11,575 trailers were registered in CA, representing about 5% of the total. It should be noted that the Polk/IHS database is based on the year that a specific trailer is first registered, and thus it does not represent the total population of trailers that are in-use at any given time. Specifically, the Polk/HIS database does not account for trailers that were first registered prior to 2000 or for trailers first registered between 2000 and 2015 that were subsequently taken out of service. It is also worth noting that while the trailer populations in the database are relatively large, the number of trailers found in the registration database for California is still substantially less than the number of heavy-duty trucks operating in California.

A summary of the data in the Polk/IHS database by trailer type and length is provided below, and in Figure ES-1 and Figure ES-2.

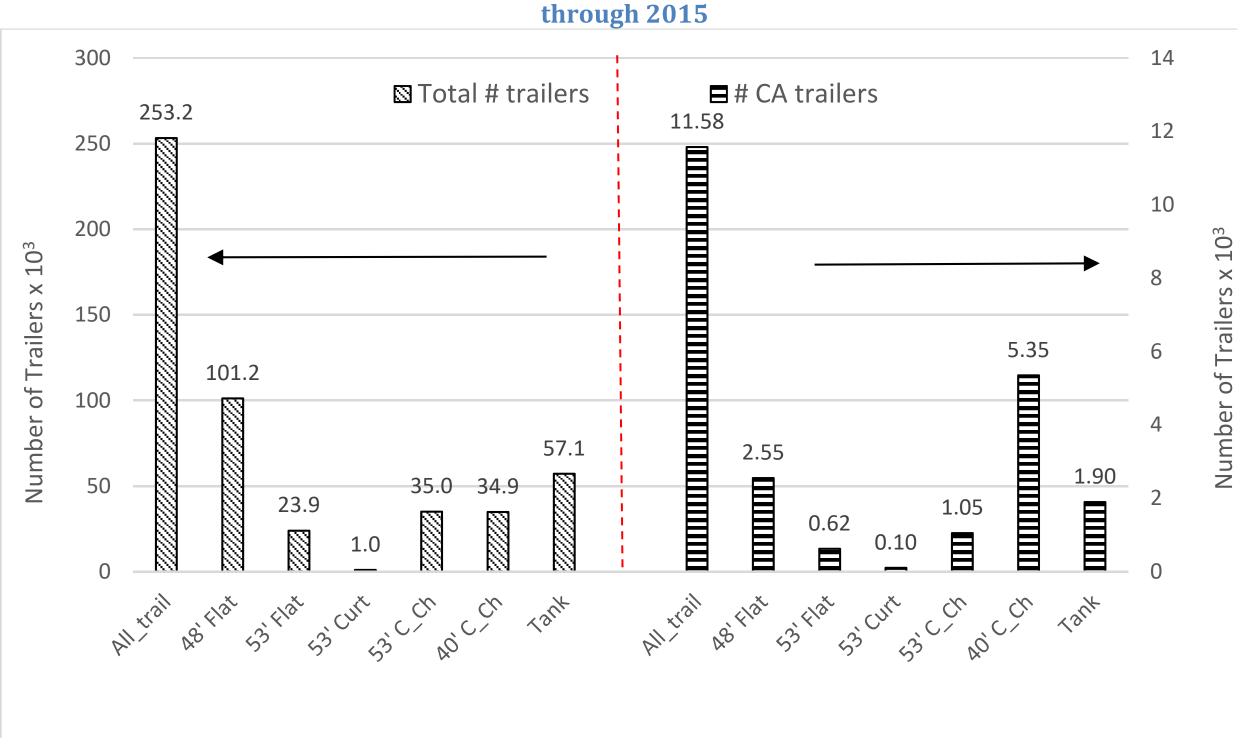
For California, a summary of the registration data by trailer type and length is as follows:

- Container chassis had the largest population (6,402) and represented the largest fraction of the CA database (55%), followed by flatbeds (3,172 - 28%), tankers (1,897 - 16%) and finally curtainside trailers (103 - 1%).
- For the flatbeds, approximately 80% were 48’ in length, while only 20% were 53’ in length. For the container chassis, 83.6% were 40’ in length, while only 16.4% were 53’ in length.
- Container chassis, flatbed, tanker, and curtainside trailers registered in CA corresponded to 9%, 3%, 3%, and 10%, respectively, of the overall populations by type in the Polk/IHS database. The 40’ container chassis trailers, in particular, showed the highest fraction of CA registrations (5,349 or 15%) compared to the full Polk/HIS database.

For the national registration data, a summary of the trailer type and length information is as follows:

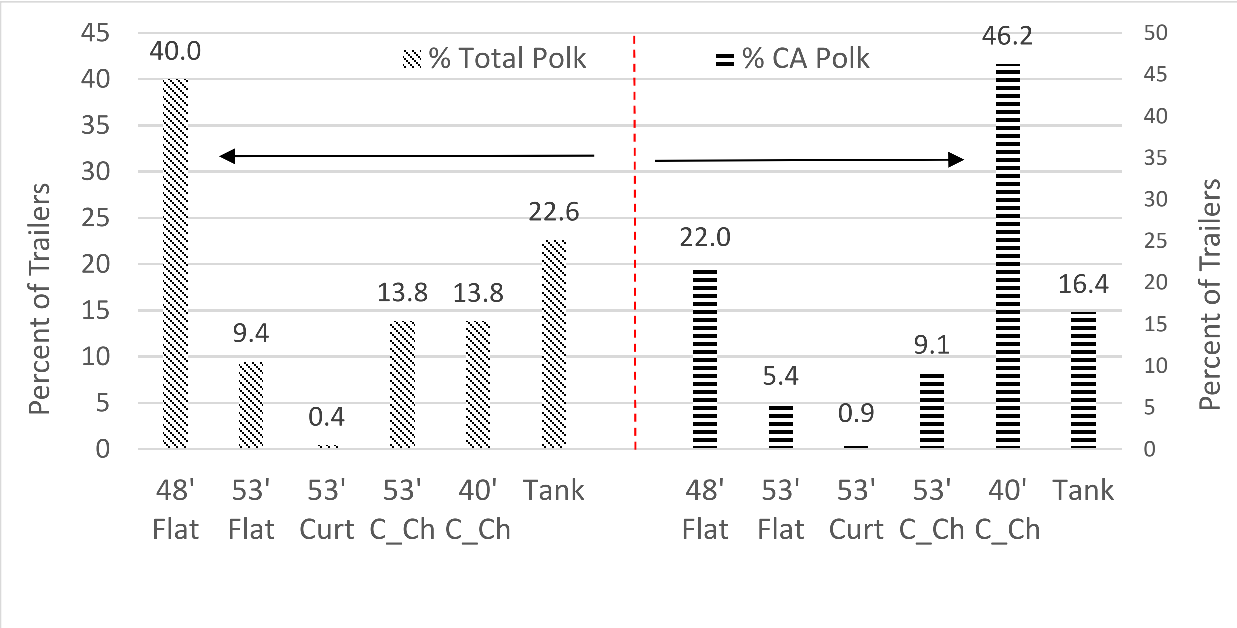
- Flatbeds had the highest populations with 125,081 registered trailers, followed by container chassis (69,939), tankers (57,148), and then curtainsides (1,023).
- The majority of the flatbeds were 48’ in length, while about half of the container chassis were 40’ while the other half were 53’ in length.
- Flatbeds, container chassis, tankers, and curtainsides represented 49.4%, 27.6%, 22.6%, and 0.4% of the total trailers, respectively.

Figure ES-1: Summary of U.S. and California Trailer Registration Data for Calendar Years 2000 through 2015



Notes Flat = flatbed, Curt = curtainsides, C_Ch = container chassis, and Tank = tanker

Figure ES-2: Percentage of Total and California trailer registration data by Trailer type from Polk/IHS database for calendar years 200 through 2015.

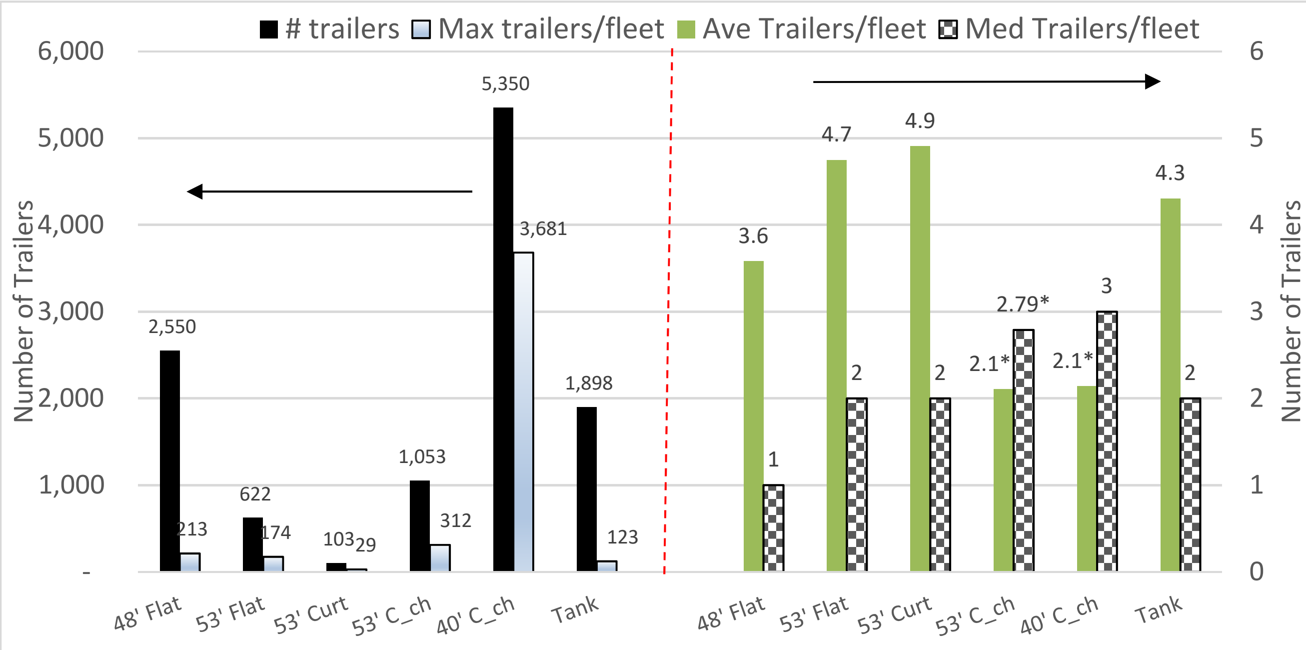


Notes Flat = flatbed, Curt = curtainsides, C_Ch = container chassis, and Tank = tanker

A summary of the California fleet registration data by trailer type and length is provided in Figure ES-3 and below as follows:

- For California, 789 fleets had registered flatbed trailers, followed by fleets with tanker trailers (414), with fewer fleets having registered container chassis (25) and curtainside (21) trailers.
- The average number of trailers/fleet in CA in descending order were as follows: container chassis (229), tankers (5) and curtainside (5), and flatbeds (4).
- The average over all trailer types examined was 10 trailers per fleet.

Figure ES-3: Fleet Statistics for Different Trailer Types and Lengths for CA Fleets in Polk/IHS database.



* These numbers are divided by 100; Notes: Flat = flatbed, Curt = curtainsides, C_Ch = container chassis, and Tank = tanker

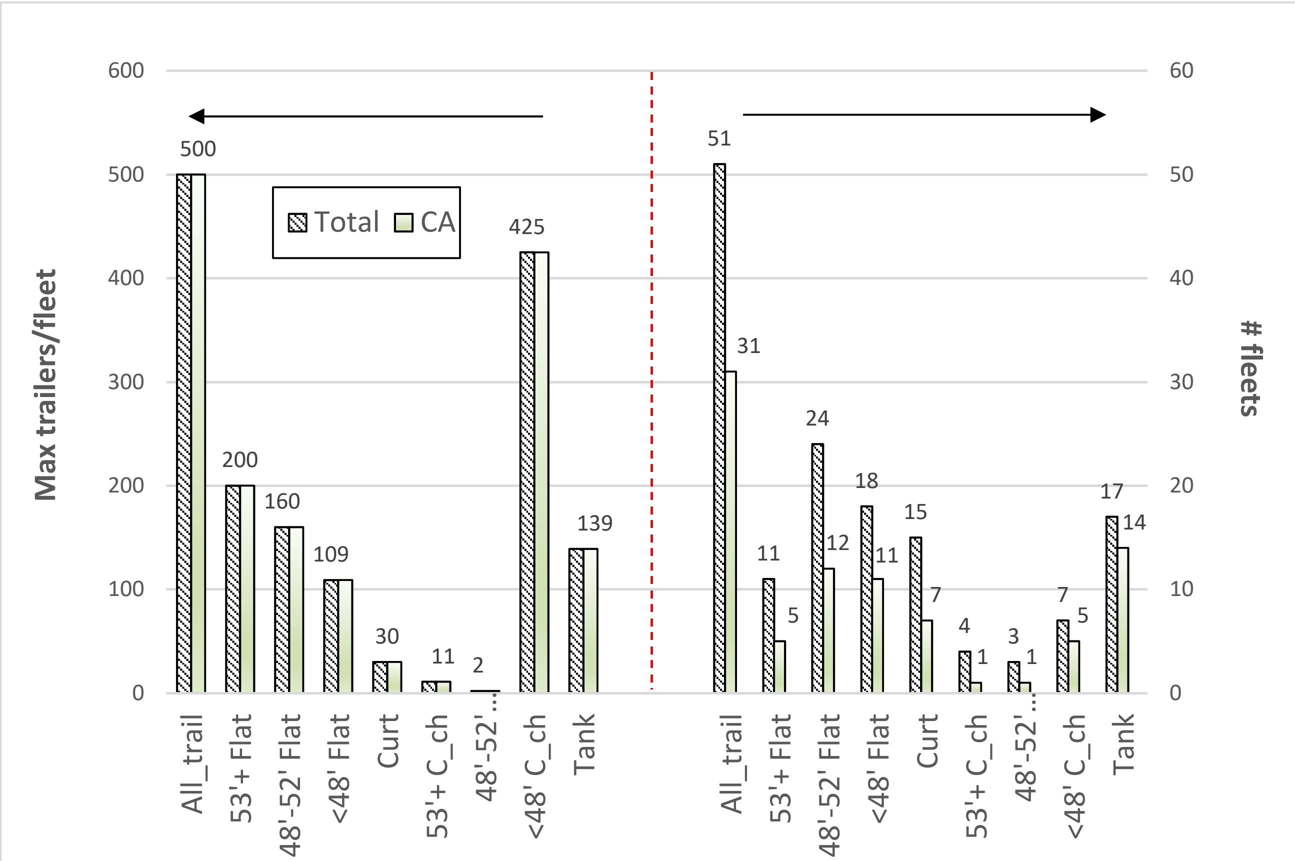
Fleet Survey

A survey was conducted for fleets possessing flatbed, tanker, curtainside, and container chassis trailer types. The survey included questions for fleets about the number of different types of trailers in their fleets, the applications and types of loads these trailers carry, and how these trailers are typically used. The survey was distributed to over 6,000 fleets identified through the national Polk/IHS database and other sources. A total of 59 surveys have been received to date, with a total of 51 surveys being from fleets that either own or operate one or more of the four trailer types being evaluated. A summary of the survey results based on the 51 surveys for fleets owning or operating the four trailer types is provided below, and in Figure ES-4 and Figure ES-5.

- The total number of trailers reported by all survey respondents was 17,032, with a company in NJ accounting for 13,000 trailers, which represented almost 80% of that total. It should be noted that this NJ fleet is excluded from Figure ES-4 to allow for a greater emphasis on the more typical fleets in the survey.
- Flatbed trailers were the most common for the fleets surveyed, found in 30 of the 44 fleets answering this question. The number of flatbed trailers for the different fleets ranged from 1 to 200, with 54% of the flatbeds being 48'-52' length size.
- The number of container chassis trailers for the different fleets ranged from 13 to 480, with 92% of container chassis trailers being in the 40'-47' size range.
- The number of tanker trailers for the different fleets ranged from 4 to 139, with 88% of the tanker trailers having lengths of less than 47'.

- The number of curtainside trailers for the different fleets ranged from 1 to 11,480, although this included one fleet that owned over 11,000 curtainside trailers. Excluding this fleet, the number of curtainside trailers ranged from 1 to ~30.

Figure ES-4: Fleet and trailer maximums data for fleet survey.



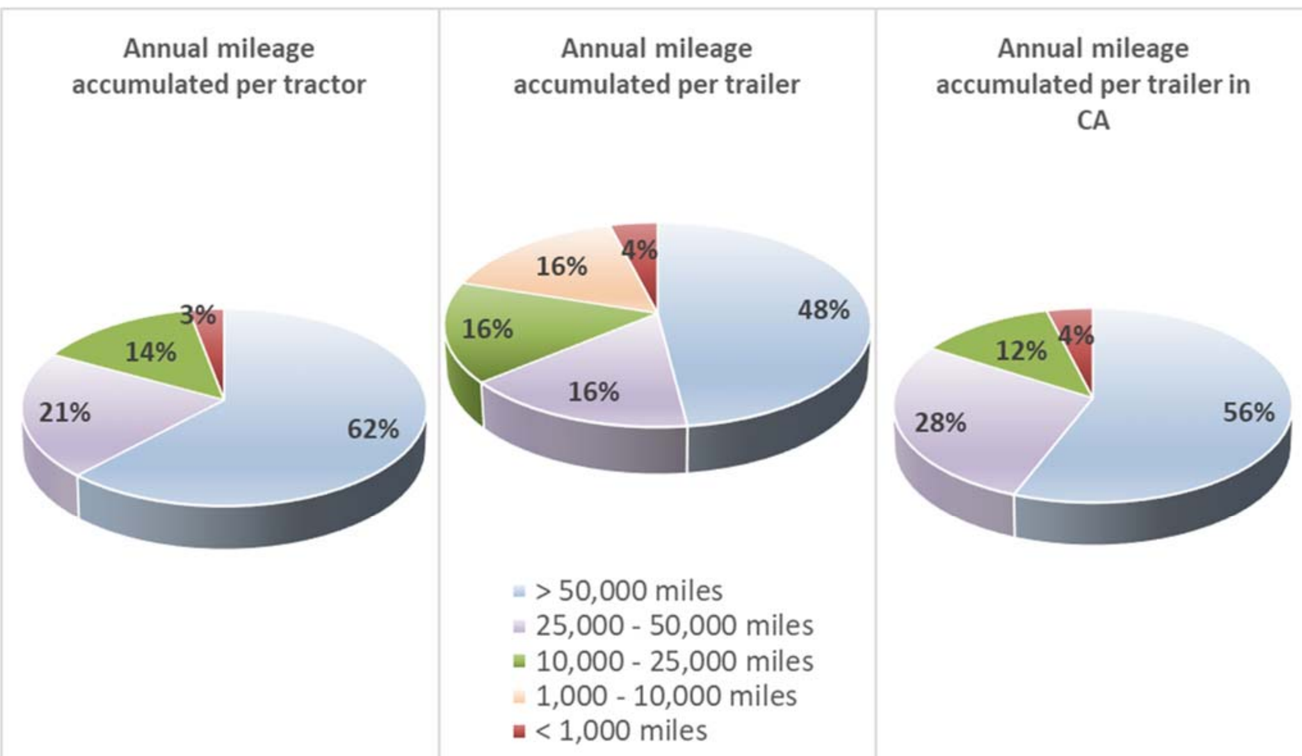
Notes: Flat = flatbed, Curt = curtainsides, C_Ch = container chassis, and Tank = tanker

- The breakdown of the types of loads carried by the trailers for CA-based fleets was 30% transporting construction materials, 22% transporting goods delivery products, 22% transporting agriculture products, 30% carrying liquid/gas, usually fuel or petroleum derivative, and 15% carrying other materials types. Note that some fleets carry multiple types of loads, so that the percentages add up to more than 100%.
- In 2015, the majority of the CA-based companies had average annual miles travelled of more than 50,000 miles (62%) per tractor, followed by an average between 25,000 - 50,000 miles (21%), and an average between 10,000 - 25,000 miles (14%). Only one CA-based company (3%) reported having an annual average of less than 1,000 miles per tractor, while no CA-based companies reported annual mileages of between 1,000-10,000 miles (0%) per tractor. The annual mileage numbers for the full fleet survey were very similar to those for the California-based fleets. In both CA and other states, more than 70% of companies indicated that they have an annual average of more than 25,000 miles travelled

per tractor in 2015. Figure ES-5 shows the average annual miles traveled for the California-based fleets per tractor, per trailer, and per trailer in California.

- In terms of trip distance, the average trip distance for the surveyed fleets was 270 miles, with 98%, 84%, and 73% of the fleets having average trips distances of greater than 25 miles, 50 miles, and 100 miles, respectively. Similar statistics were found for the CA-based fleets, with an average trip distance of 297 miles, with 96%, 85%, and 81% of the fleets having average trips distances of greater than 25 miles, 50 miles, and 100 miles, respectively. Less than 5% of the fleets for both the CA-based fleets and the full survey had average trip distances of greater than 1,000 miles.
- About 81% of the CA-based fleets indicated that they were participating in a fuel economy program, or using one or more fuel savings devices, with speed limiters, low resistance tires, and tire monitoring being the most popular strategies. Eight of the 25 CA-based fleets that responded to this question indicated that they are already using either SmartWay tractors or aerodynamic devices.

Figure ES-5: Annual vehicle miles traveled in 2015 by California fleets surveyed per tractor, per trailer, and per trailer for California.



Trailer Activity Analysis

The trailer activity analysis was focused on the trip distance and VMT by speed distributions for each fleet as well as for all fleets with the same trailer type combined. The fleet-specific results show that the trip distance distributions vary greatly, depending on the type of revenue service of the fleet (e.g., drayage vs. long haul), the location of the fleet (e.g., urban vs. rural), the operating area (e.g., local vs. regional), and possibly other factors. Based on the limited number of fleets in the dataset, there seems to be no clear association between trailer type and the different operating characteristics of the fleets. In general, all fleets were found to have a certain number of idle trips. However, the fraction of idle trips out of the total trips varied greatly from 25% to 74%. The trip distance distributions of non-idle trips also varied greatly, with some fleets having the majority of their non-idle trips being local (less than 25 miles) while other fleets having the majority of their non-idle trips being long-distance (over 100 miles).

On the other hand, the VMT by speed distributions for the different fleets show a similar trend where the majority of the VMT occurred at highway speeds between 50 and 65 mph. This speed range represents highway cruising given that the speed limit for trucks in California is 55 mph. The trend is true for almost all the fleets irrespective of the fraction of idle trips that the fleet made. This is because idle trips create almost no distance, and thus do not contribute much to the VMT by speed distribution. Also, for the same amount of time, traveling at low speeds does not result in as many miles as traveling at higher speeds. These results are not surprising given that fleets have inherent incentives to operate efficiently as that would affect their bottom line. Intuitively, drivers of tractor-trailers would also prefer driving on highways over surface streets, even for short trips as that will allow them to travel faster and maneuver the vehicles more easily.

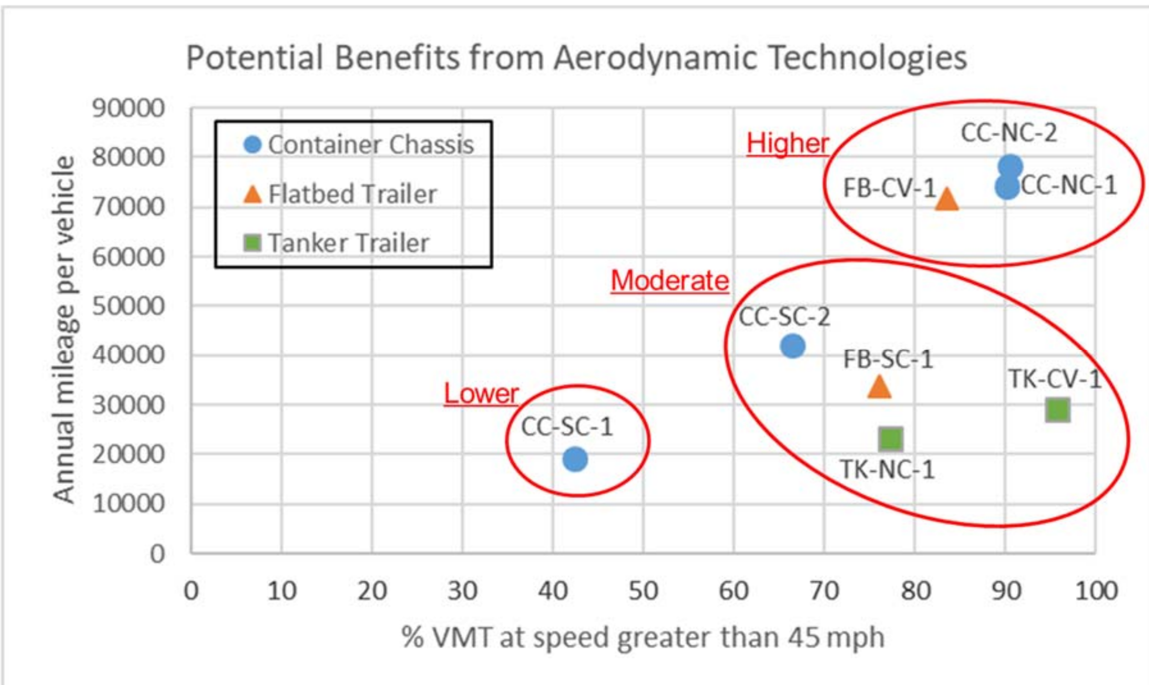
The benefits from aerodynamic improvements partly depend on the annual mileage of the tractor-trailers. Based on the vehicle activity statistics summarized in Table ES-1, six of the eight fleets data logged in this study were estimated to have an annual mileage per vehicle of more than 25,000 miles. And three of them were estimated to have an annual mileage per vehicle of more than 50,000 miles. Since aerodynamic drag is proportional to the square of the travel speed, aerodynamic improvements provide more benefits at higher speeds. The energy consumed due to aerodynamic drag increases sharply after 45 mph. Based on the data logged and analyzed in this study, the portion of VMT at speeds greater than 45 mph varied by fleet, ranging from 42% to 96%, with six of the eight fleets having at least 75% of their VMT at those high speeds.

Table ES-1. Summary of vehicle activity statistics from data logging study

Fleet	Trailer Type	Location	No. of Vehicle Samples	Estimated Annual Mileage per Vehicle	Percent of Mileage at 45+ mph
CC-NC-1	Container Chassis	Northern California	4	74,387	90.1
CC-NC-2	Container Chassis	Northern California	9	62,123	90.8
CC-SC-1	Container Chassis	Southern California	43	19,163	42.4
CC-SC-2	Container Chassis	Southern California	11	42,012	66.5
All Container Chassis Combined			**67**	***30,593***	***65.3***
FB-CV-1	Flatbed	Central Valley	65	71,905	83.5
FB-SC-1	Flatbed	Southern California	4	42,304	72.2
All Flatbed Combined			**69**	***71,147***	***83.3***
TK-NC-1	Tanker	Northern California	6	39,128	78.6
TK-CV-1	Tanker	Central Valley	6	28,981	95.8
All Tanker Combined			**12**	***29,982***	***93.7***

Figure ES-6 shows the potential benefits from aerodynamic technologies for each of the eight fleets, considering the estimated annual mileage per vehicle and the portion of VMT at speeds greater than 45 mph. Generally, fleets with high annual mileage per vehicle and high portion of VMT at speeds greater than 45 mph would gain a higher level of benefits from aerodynamic technologies. Three of the eight fleets in this study fall into this category. On the other hand, fleets with low annual mileage per vehicle and low portion of VMT at speeds greater than 45 mph would gain a lower level of benefits from aerodynamic technologies. One of the fleets in this study falls into this category. The other four fleets would gain a moderate level of benefits from aerodynamic technologies. While they have a relatively high portion of VMT at speeds greater than 45 mph, their vehicles do not accumulate as much annual mileage as the fleets in the higher benefits category.

Figure ES-6: Potential benefits from aerodynamic technologies for each fleet



Implications

Based on these results, it appears that extending the Tractor-Trailer GHG regulation to include additional trailer types, particularly some of the trailer types studied in this project, would result in additional GHG emission reductions from the heavy-duty sector. The fleet survey results indicated relatively high use for the trailers, with a 64% of the CA-based fleets having annual VMT above 25,000 per trailer. The fleet survey also indicated that average trip distances were largely greater than 50 miles (85%), although trip distanced varied more for specific fleets in the data logging study. Nevertheless, the majority of VMT each fleet generated in this study were at highway cruising speeds, with most fleets having at least 70% or their VMT above 45 mph. These results suggest that most of the fleets, irrespective of the trailer types they hauled, would benefit from aerodynamic improvements.

Some additional studies could be done to supplement the results of this study to better characterize what the potential GHG benefit of further application of aerodynamic devices to these trailer types might be. This could include data collection of trailer activity where data logging devices are installed on the trailers (as opposed to on the tractors). The data could be used to determine trip distance distribution, annual mileage, and fraction of distance traveled at high speeds as was done for the tractor activity in this study. The collection of additional information on the populations of flatbed, container chassis, and tanker trailers would also be of value. Truck traffic studies on freeways or elsewhere could also be used to better understand the relative populations of these trailer types in comparison with conventional box or other trailer types.

Additional studies of aerodynamic drag for different tractor-trailer combinations could also be of value. For example, tanker trailers are inherently more rounded than box trailers, and could provide less benefit on a per trailer basis than box trailers. Similarly, flatbed trailers, when loaded, will typically provide a lower profile than full box trailers. Container chassis trailers, once loaded, would have a profile more comparable to a box trailer, and hence would likely be more comparable in terms of aerodynamic drag. The issue of trailer length could also be investigated in such studies, as the effectiveness of aerodynamic devices could vary as a function of trailer length.

In the development of the expanded Tractor-Trailer GHG regulation, exemptions could and should still be allowed. These exemptions may be based on the annual mileage, the fraction of VMT at speeds greater than 45 mph, or a combination of these and other metrics. Nowadays, many fleets adopt some form of fleet monitoring systems that monitor and record the data necessary for calculating these metrics. Thus, fleets can gather data and submit them in the application for exemption from the expanded Tractor-Trailer GHG regulation. To alleviate the burden for fleets without existing fleet monitoring systems, CARB in collaboration with federal transportation agencies can provide assistance and resources in recording the data for the application of exemption.

1. Introduction

1.1. Background

The goods that move throughout the United States (U.S.) are a critical element of our nation's prosperity. The Commodity Flow Survey shows that trucks move the vast majority of freight in the U.S. (U.S. DOT & Department of Commerce, 2015), as highlighted by the following:

- In 2012, trucks moved 73.7% of all freight by value and 70% of the tonnage versus 3.3% of value and 15.8% of tonnage moved by rail;
- The average length of haul for trucks is 212 miles;
- Only 3% of freight tonnage moved on multiple modes – i.e., a train and a truck, or a barge and a truck;
- Just 15.1% of all freight shipments were longer than 500 miles, and only 9.7% traveled more than 750 miles;

While heavy-duty trucks represent an important part of the economy, they are also an important source of emissions and energy use. Medium-and heavy-duty vehicles currently account for about 20 percent of greenhouse gas (GHG) emissions and oil use in the U.S. transportation sector, even though they represent only about 5 percent of the vehicles on the road (U.S. EPA, 2015). Heavy-duty trucks are also the second largest and fastest growing segment of the U.S. transportation sector in terms of emissions and energy use. Globally, GHG emissions from heavy-duty vehicles are also growing rapidly and are expected to surpass emissions from passenger vehicles by 2030. The transportation sector also remains the largest source of GHG emissions in California, accounting for 36% of the total inventory (CARB, 2016). Within that, heavy-duty trucks account for 19% of the GHG emissions for the transportation sector in California.

In order to meet the GHG emission reduction goals specified in California's Global Warming Solutions Act of 2006, Assembly Bill 32 (AB 32), GHG emission reductions are needed from heavy-duty tractors. The Tractor-Trailer GHG regulation was one of the discrete early action measures adopted by the California Air Resources Board (CARB) to contribute to the goals of AB 32. The regulation requires 53-foot or longer box-type trailers traveling in California to be equipped with aerodynamic technologies (e.g., side-skirts, front and rear trailer fairings, and undertray devices) and low-rolling resistance tires, resulting in improved fuel economy and reduced GHG emissions from the heavy-duty tractors that pull them. The Tractor-Trailer GHG regulation does not apply to other trailer types or sizes used in the freight transportation industry, such as drop deck, curtainside, flatbed, tanker, bulk, dump, grain, and other trailers. It also does not apply to box trailers shorter (typically 28 or 48 feet) than 53 feet in length. CARB is currently preparing its California Phase 2 GHG standards, to be presented to its Board for approval in February 2018, that include amendments to the Tractor-Trailer GHG regulation (CARB, 2017). The proposed amendments to the Tractor-Trailer GHG regulation would identify Phase 2 certified trailers and Phase 2 approved aerodynamic devices and low-rolling resistance tires as compliant technologies. The amendments stop short of requiring aerodynamic technologies on the four types of trailers that are the subject of this study. In the future, based on the results of this study, as well as other information, CARB may consider further amendments to the Tractor-Trailer GHG regulation that could establish additional aerodynamic equipment requirements on model year 2024 and later non-box trailers, such as curtainside, container chassis, flatbeds, and tankers. An additional consideration in the amending of the CARB Tractor-Trailer GHG regulation is the fact that the U.S. Environmental Protection Agency (EPA) is currently revisiting its Phase 2 GHG trailer requirements in response to a petition by the Truck Trailer Manufacturers Association (TTMA) that questioned the EPA's authority to regulate trailers under the Clean Air Act, as well as the EPA's cost/benefit analysis for the standards (U.S. EPA, 2017).

To date, much of the work relating to aerodynamic improvements has been done to evaluate aerodynamic improvements for tractor and trailer combinations for a standard box-type trailer. For such combinations, the aerodynamic drag has been separated into different contributions with the trailer underbody, wheels, and trailer base making up 55% of the total drag on the trailer system, while the tractor contributes another 25%, and the gap between the tractor and trailer around 20% (ATDynamics). A variety of potential aerodynamic improvements can be implemented that include front and rear fairings, trailer skirts, trailer gap reducers, boat tails, etc., which can provide fuel savings ranging from 1% to 11% when combined (Curry et al., 2016; Kehs et al., 2013; CARB, 2016; Ragatz and Thornton, 2016).

While more characterization work has been done in studying tractor and trailer combinations for a standard box-type trailer, there are many other types of tractor-trailer combinations that have not been extensively studied and for which it is not known what potential benefits from aerodynamic improvements can be achieved, or how widely such improvements could be implemented. In particular, there are so many different types of tankers, flatbeds, and curtainside trailers that the potential for aerodynamic improvements for these applications has not been characterized. For example, there may be more than 20 unique tanker configurations. Different tractor-trailer combinations might also be used in different types of operations even within a similar industry, adding to the complexity of understanding aerodynamic impacts. In California, there is a large number of trailers that are not well characterized. These include 48-foot box-type trailers, "pup" trailers, flatbeds, curtainsides, and tanker trailers. These trailers potentially spend less time on highways, but may still represent a significant contribution to the GHG emissions similar to the 53-foot box-type trailers.

GHG emission reduction benefits from aerodynamic improvements are highly dependent on a vehicle's operational speed and the vehicle miles traveled (VMT) accrued at different speeds. Since aerodynamic drag is proportional to the square of the speed, aerodynamic improvements provide more benefits at higher operational speeds. For that reason, the Tractor-Trailer GHG regulation is focused on long-haul operations, characterized by high annual VMT accrued at highway speeds, allowing them to benefit greatly from installed aerodynamic technologies.

1.2. Objectives

To better estimate the potential benefits of applying aerodynamic improvements to the unregulated trailer types, it is first important to understand their relative populations, typical use patterns, and the conditions under which these trailers are used. Thus, one objective of this project is to conduct a detailed survey of trailer types to allow the benefits of applying improved aerodynamics to the excluded trailer types to be estimated. Another objective of this project is to collect tractor-trailer activity data that can be used by CARB staff to assess the potential GHG emissions benefit from improved trailer aerodynamics. Four different trailer types (flatbed, tanker, curtainside, and container chassis) that are not currently required to meet aerodynamic equipment requirements of CARB's existing Tractor-Trailer GHG regulation and the federal Phase 2 GHG regulations were targeted for evaluation.

To achieve these project objectives, the research team at the University of California at Riverside (UCR) conducted a population and activity survey of fleets with the four targeted trailer types. A subset of fleets with these trailer types were then recruited for data logging. From the data logging, tractor-trailer activity data were analyzed in terms of VMT by speed bin, trip distance, geographic area of operation, etc. The data analysis was performed with the goal of generating results to support the consideration of possible inclusion of these currently excluded trailer types in the Phase 2 Tractor-Trailer GHG regulation for model years 2024 and later.

1.3. Report Organization

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 a description and analysis of the Polk/IHS trailer registration database and the methodology and results of a survey of fleets with the appropriate trailer types.
- Chapter 3 describes test fleets, vehicles, and methodology utilized for the data logging. This chapter also describes the commercial dataset that was used to supplement the data collected by the research team.
- Chapter 4 describes data processing and analysis procedures.
- Chapter 5 presents and discusses the vehicle activity results.
- Finally, Chapter 6 provides a summary of conclusions from this research and recommendations for future research.

2. Fleet Surveys

The initial task of this study was to conduct an extensive survey of fleets that had the trailer types of interest in their inventories. The purpose of the survey was to both characterize the trailer fleet and to gain information to assist with a successful implementation of the data logging task (Task 2). This task was organized into five subtasks: (i) developing the survey questionnaire for fleets that will provide information on the operational characteristics of targeted trailers, (ii) obtaining a detailed registration database from Polk/IHS for fleets and trailers of the four types of interest (flatbed, curtainside, container chassis, and tanker trailer) (iii) surveying the fleets and soliciting their participation in data logging activity, and (iv) analyzing the survey data collected to determine overall operational characteristics of the trailers.

2.1. Fleet survey questionnaire

A survey for trailer fleet owners and managers was developed by UCR. The fleet survey was based on the trailer types requested by CARB. The survey included questions for fleets about the trailers the fleets operate and how they are typically used. Survey answers included the following information: number of applicable trailers operated, trailer-to-tractor ratio, type of operation that the fleet conducts (long-haul, regional, local), average trip distance, average annual VMT per trailer, percent of annual VMT traveled in California for interstate carriers, any fuel-saving measures the fleet has adopted (voluntary participation in the U.S. EPA SmartWay[1] program, use of vehicle speed limiters, driver training, etc.), any trailer GPS tracking capabilities the fleet has adopted, whether the fleet would be interested in participating in the data logging aspect of this project, and any other pertinent information. The survey is provided below in Figure 2-1. The survey was reviewed and approved by CARB staff prior to beginning the survey.

[1] Launched in 2004, SmartWay is a voluntary U.S. EPA program that reduces transportation-related emissions by creating incentives to improve supply chain fuel efficiency. Under the SmartWay program, U.S. EPA establishes performance criteria and reviews test data to ensure that designated tractors and trailer models have been demonstrated to be more fuel efficient than their traditional counterparts.

Figure 2-1. Fleet Survey Questionnaire

UC Riverside Fleet Survey Form

Fleet Name:____Physical Address:____

Contact Name: _______________________Phone Number/Email: ____

TRACTOR FLEET INFORMATION

# of Tractors your company currently owns or leases: _______Day cabs _______ Sleeper Cabs _______ Total

How do you track fuel use: ☐ Hand logs ☐ Computerized tracking ☐ Real time GPS/engine signals ☐ other__________

TRAILER FLEET INFORMATION

Total # of trailers (all types) you own and operate: _____

# of these specific trailer types you own and operate (If you do not own a trailer-type specified below <u>but pull (operate) trailers of that type that are owned by others, please indicate that by putting "OP" in the appropriate box below)</u>:

Trailer Type	Trailer Length (feet)				
	53' plus	52'-48'	47'-40'	Less than 40'	
Flatbed (non-dropdeck)					
Curtainside					
Container Chassis					
Tanker					Grand Total
Total					

If the company does NOT own or operate any of above trailer types, please return form. Otherwise continue with the survey

Trailer GPS Tracking Capabilities: ☐ Yes ☐ No

Average Trailer Age: ☐ 0-3 years ☐ 3-5 years ☐ 5-10 years ☐ 10+ years

# of Trailers for each Tractor (on average): ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ More than 4

Load Types: ☐ Goods delivery ☐ Construction ☐ Agriculture ☐ Other ______________

	LTL	Parcel	Truckload	Food/Bev	Construction	Dry Bulk	Liquid/Gas	Other
% of Fleet								

FLEET OPERATION INFORMATION

Please provide approximate percentage (%) of fleet mileage by trip length in table below:

Trip Length	0-25 miles from home base	25-50 miles	51-75 miles	76-100 miles	101-500 miles	501- 1000 miles	1001- 1500 miles	1500+ miles
% of 2015 fleet mileage	%	%	%	%	%	%	%	%

Average Annual Vehicle Miles Traveled in 2015:

	0-1000mi	1000-10000 mi	10000-25000 mi	25000-50000 mi	50000+mi
a) Per Tractor:	☐	☐	☐	☐	☐
b) Per Trailer:	☐	☐	☐	☐	☐
c) California miles:	☐	☐	☐	☐	☐

Please indicate if your company participates in any existing fuel-economy programs or uses fuel saving technologies:

☐ "Good Driver" reward program ☐ US EPA SmartWay Verified Tractors ☐ Trailer aerodynamic devices (e.g. side-skirts, wheel covers) ☐ Tractor speed limiters ☐ Low rolling resistance tires ☐ Tire monitoring or auto inflation system

☐ Other ____

Would fleet be willing to participate in data logging study with UC Riverside where the fleet receives an incentive? ☐ Yes ☐ No

Comment:____

2.2. Polk/IHS Database Description

Because for this study CARB is interested in only four specific trailer types (container chassis, tanker, cutainside, and flatbed), it was important to identify fleets/owners by trailer type. Polk/IHS maintains and has access to DMV records throughout the United States, and has the most extensive resources in working with such databases in the industry. Polk/IHS provided needed registration information including fleet owner name, address and trailer type for the period from 2000 to 2015. The Polk/IHS data base included details about the trailers including the manufacturer of the trailer, a description of how the trailers are used, in many cases, the model year of the trailer, and the year in which the trailer was registered. Entries were provided for each fleet that had registered one or more trailers within any given year from January 2000 through December 2015, with each entry providing the count of trailers of a specific type registered in each year. It should be noted that the Polk/IHS database is based on the year that a specific trailer is first registered, and thus it does not represent the total population of trailers that are in-use at any given time. Specifically, the Polk/HIS database does not account for trailers that were first registered prior to 2000 or for trailers first registered between 2000 and 2015 that were subsequently taken out of service.

The list of information provided in the Polk/IHS database is presented in Table 2-1. Prior to purchasing the Polk/IHS database Polk/IHS required a final copy of the intended fleet survey, as provided above. This is because Polk/IHS is required to provide a copy of the survey to states providing registration data to Polk/IHS, as a condition of it obtaining the registration data.

Table 2-1. Polk/IHS database query fields

Fleet Name	Physical Address	Trailer Types	Registration Year
Registration Name	Registration Address	Registration City	Registration State
Registration Zip Code	Contact First Name*	Contact Last Name*	Contact Title*
Contact Phone Number*	Trailer Type	Trailer Model Year	Trailer Body Style
Trailer Count**			

*where available, ** by trailer type within each fleet for each each year at least one trailer was registered.

The database query was conducted for the four trailer types: flatbed (Flat), curtainside (Curt), container chassis (C_ch), and tanker (Tank) trailer. The specific groupings of trailers in these categories and the different sizes included the following trailer types listed below.

Group 1 - Flatbed - 48' (48' Flatbed)

Group 2 - Flatbed - 53' (53' Flatbed)

Group 3 - Curtainside - 53' (53' Curtainside)

Group 4 - Container Chassis - 53' (53' Container Chassis)

Group 5 - Container Chassis - 40’ (40’ Container Chassis)
Group 6 - Tank, Tank MC306/406, Tank MC 307/407, Tank MC312/412, Tank MC 331/431, 312-307/412-407, Tank Pneumatic - 42’ – 45’ (42’-45’ Tank)[2]

2.2.1. Analysis of Polk/IHS Registration Database

The database itself was analyzed for various information including the number of fleets and trailers by state in each of the trailer categories. A summary of the information provided in the Polk/IHS database for trailers registered from 2000 to 2015 is provided in Table 2-2. It should be noted that the Polk/IHS database is based on the year that a specific trailer is first registered, and thus it does not represent the total population of trailers that are in-use at any given time. Specifically, the Polk/IHS database does not account for trailers that were first registered prior to 2000 or for trailers first registered between 2000 and 2015 that were subsequently taken out of service.

Table 2-2. Summary of IHS Database Records

State	# of Fleets	Total #of trailers	48' Flatbed*	53' Flatbed	53' Curtainside	53' Container Chassis	40' Container Chassis	42'-45' Tank
AK	53	457	88	157	0	108	40	64
AL	671	9047	6885	933	10	2	129	1088
AR	443	2925	2029	216	4	2	68	606
CA	1139	11575	2550	622	103	1053	5350	1897
CT	107	196	131	14	1	0	7	43
DC	4	747	522	43	11	0	30	141
DE	63	6	5	0	0	0	0	1
FL	964	765	331	43	0	0	36	355
GA	725	9571	3703	749	37	899	808	3375
HI	18	6344	3912	849	21	0	140	1422
IA	680	47	7	0	0	0	7	33
ID	264	11431	6600	1303	51	0	259	3218
IL	1695	1017	619	195	23	0	13	167
IN	802	11287	6301	2283	31	0	718	1954
KY	379	2688	1162	104	81	0	87	1254
LA	675	3968	1613	550	0	0	50	1755
MA	233	1358	587	113	105	0	224	329
MD	295	688	345	36	6	104	78	119
ME	213	2987	709	493	15	1175	419	176
MI	785	4122	2191	843	23	251	89	725
MN	785	6650	2804	847	7	250	582	2160
MO	66	15284	6006	724	53	1400	2369	4732
MS	409	3627	1724	1079	0	0	54	770
MT	227	1269	846	203	1	0	10	209

[2] The numbers used to classify the tanker trailers are DOT numbers used to describe type, application, and design characteristics of the tank. MC-306/DOT 406 are non (low) pressure bulk liquid cargo tanks, MC-307/DOT407 are low pressure bulk liquid cargo tanks, MC-312/DOT 412 are corrosive cargo tanks, MC-331/DOT 431 are for gases that are liquid by pressure application only.

NC	692	7520	1809	534	4	0	2985	2188
ND	247	1560	495	552	1	0	33	479
NJ	521	35756	3993	352	149	16689	12710	1863
NM	204	867	311	60	0	0	9	487
NV	111	285	175	18	0	1	28	63
NY	645	7148	2103	122	0	1431	2516	976
OH	1215	9785	5720	812	14	1	336	2902
OK	828	14998	6507	2638	32	1632	141	4048
OR	276	1212	769	203	54	0	7	179
RI	37	278	108	5	0	0	0	165
SC	352	3175	2031	269	15	0	197	663
TN	587	23790	8819	2283	128	10037	1032	1491
TX	2774	24504	9350	2512	31	2	3172	9437
UT	536	3714	1887	207	3	1	51	1565
VT	84	363	221	27	0	0	2	113
WI	914	365	223	27	0	0	2	113
WV	178	9303	4649	878	9	1	109	3657
WY	205	512	325	18	0	0	3	166
Totals	22101	253191	101165	23916	1023	35039	34900	57148

* Note the lengths indicate only trailers of that specific length, with the exception of tankers where there was a range from 42' to 45'

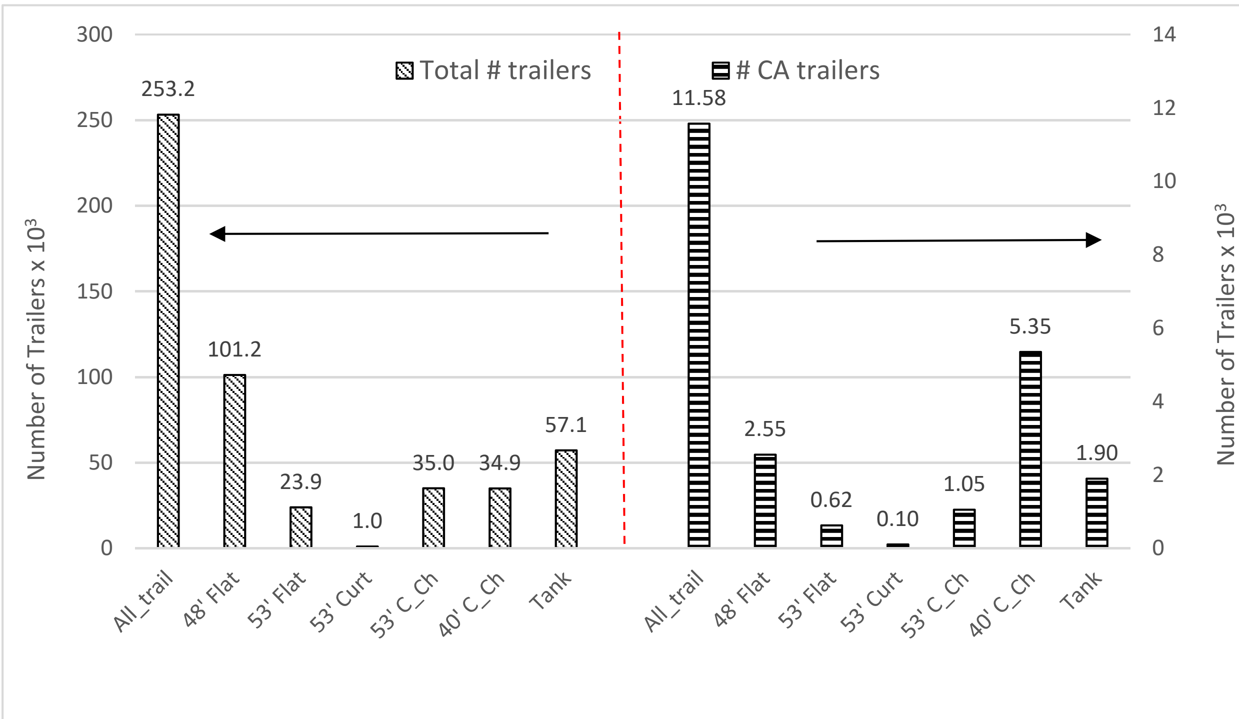
The results showed that the Polk/IHS database included an extensive listing of trailers and fleets from California, as well as other states. The Polk/IHS database included registration records for 22,177 company fleets with at least one of the six trailer types described above, based on fleets being defined by unique company names. These registration records included 42 US states and a total of 253,191 trailers. The population of registered trailers within CA was 11,575, or 5% of the total. States not included in the Polk/IHS database provided were Arizona, Colorado, Nebraska, New Hampshire, Pennsylvania, South Dakota, Virginia, and Washington, some of which appear to have restrictions in terms of releasing registration data. The number of fleets ranged from 4 (Missouri - MO) to 2,774 (Texas - TX), while the number of trailers varied from 6 (Delaware - DE) to 35,756 (New Jersey - NJ).

Registration Populations by Trailer Type

A breakdown of the number of trailers in the Polk/IHS database by trailer type and length is provided in Figure 2-2 on a population basis and in Figure 2-3 on a percentage basis for both the national database and for California only.

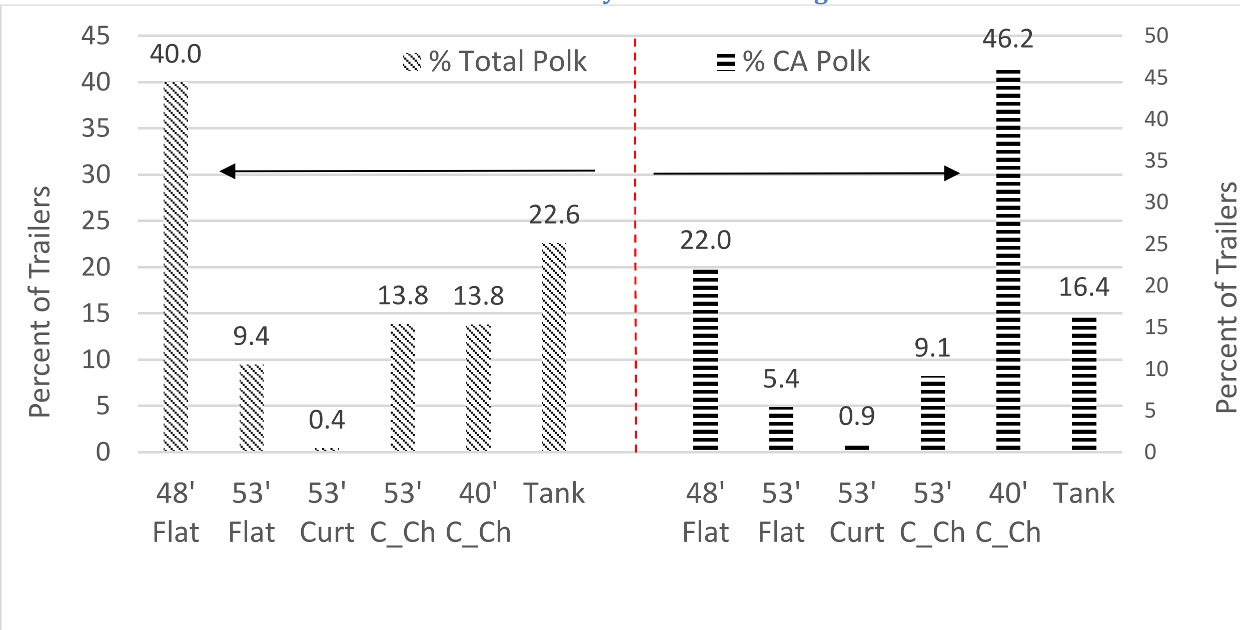
For California, container chassis had the largest population (6,402) and represented the largest fraction of the CA database (55%), followed by flatbeds (3,172 - 28%), tankers (1,897 - 16%) and finally curtainside trailers (103 - 1%). For the flatbeds, approximately 80% were 48' in length, while only 20% were 53' in length. For the container chassis, 83.6% were 40' in length, while only 16.4% were 53' in length. Container chassis, flatbed, tanker, and curtainside trailers registered in CA corresponded to 9%, 3%, 3%, and 10%, respectively, of the overall populations by type in the Polk/IHS database. The 40' container chassis trailers, in particular, showed the highest fraction of CA registrations (5,349 or 15%) compared to the full Polk/HIS database.

Figure 2-2: Summary of U.S. and California Trailer Registration Data for Calendar Years 2000 through 2015



Notes Flat = flatbed, Curt = curtainsides, C_Ch = container chassis, and Tank = tanker

Figure 2-3: Percentage of Total and California trailer registration data by Trailer type from Polk/IHS database for calendar years 2000 through 2015.



Notes: Flat = flatbed, Curt = curtainsides, C_Ch = container chassis, and Tank = tanker

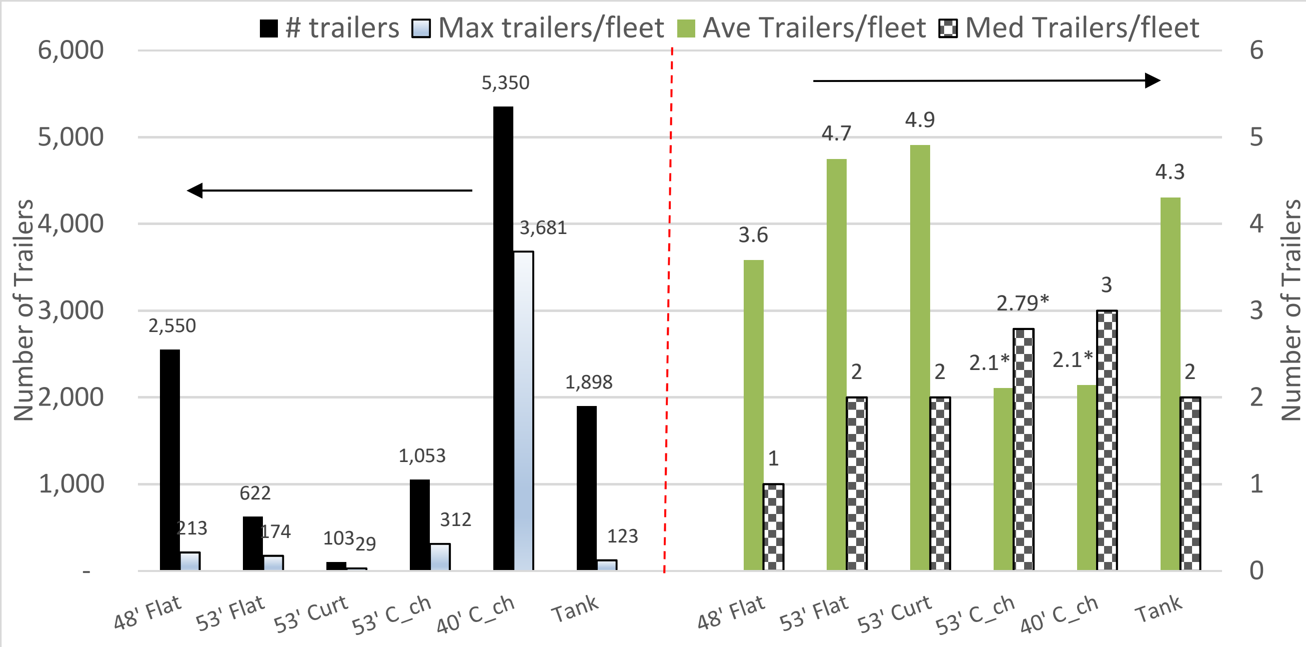
Nationally, flatbeds had the highest populations with 125,081 registered trailers, followed by container chassis (69,939), tankers (57,148), and then curtainsides (1,023). Flatbeds, container chassis, tankers, and curtainsides represented 49.4%, 27.6%, 22.6%, and 0.4% of the total trailers, respectively. The majority of the flatbeds were 48' in length, while about half of the container chassis were 40' while the other half were 53' in length.

California Fleet Statistics

The fleet data indicated that approximately 1,215 or 5% of the fleets registered in Polk/IHS database were based in California. For California, fleets that had registered at least one flatbed trailer (789) were the most prevalent, followed by those that had registered at least one tanker trailer (414). The number of fleets in California that had registered container chassis and curtainside trailers were 25 and 21, respectively, considerably fewer than those for the other trailer types.

A breakdown of the fleet statistics for the California fleets is shown in Figure 2-4. This includes the maximum, average, and median number of fleets by trailer type and trailer length. The number of trailers per fleet varied from 1 to 216 for 48' flatbed trailers, from 1 to 174 for 53' flatbed trailers, from 1 to 29 for 53' curtainside trailers, from 1 – 123 for 42 – 45' tanker trailers, from 70 to 312 for 53' container chassis, and from 1 to 3,681 for 40' container chassis. In terms of average number of trailers/fleet in CA, the trailer types in descending order were as follows: container chassis (229), tankers (5) and curtainside (5), and flatbeds (4). Overall, there was an average of 10 trailers/fleet for all types. The median number of trailers/fleet was highest for 53' container chassis trailers (279), with much lower numbers for the other trailer types, as follows: 40' container chassis (3), tankers and curtainsides (2), and 48' and 53' flatbeds (1).

Figure 2-4: Fleet Statistics for Different Trailer Types and Lengths for CA Fleets in Polk/IHS database.



* these numbers are divided by100

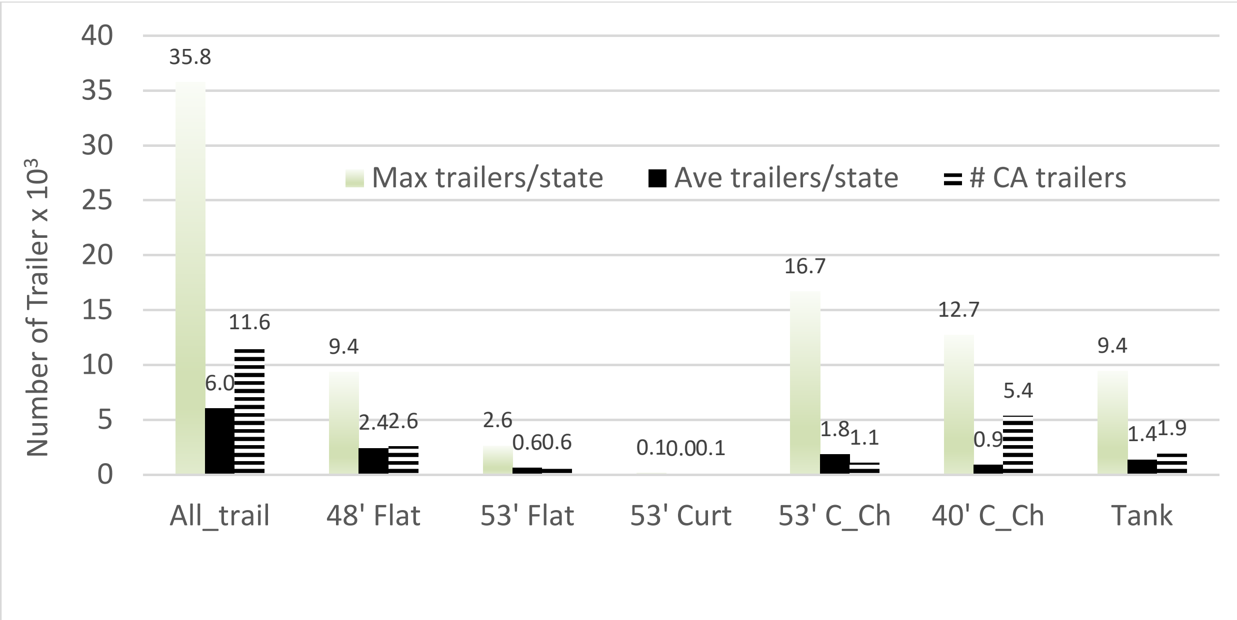
Trailer Registration Statistics by State

A majority of the states (69%) included registrations for all four trailer types, with smaller numbers of states having registrations for only 3 different trailers types (26%) or two or less different trailers types (5%). All 42 states in the Polk/IHS database included fleets that had registered 48’ flatbed and tanker trailers, while 40 states included fleets with registered 53’ flatbeds and container chassis, and 29 states included registered curtainside trailers.

The maximum and average numbers of trailers/state is provided in Figure 2-5 for different trailer types and lengths. California totals are also included in the Figure for comparison. The maximum number of trailers/state and average number of trailers/state were 35,756 and 6,028, respectively. The overall average in terms of trailers per fleet was 11 trailers/fleet. Some states stood out with a much larger average number of trailers per fleet. States that averaged more than 100 trailers/fleet, included the District of Columbia (187 trailers/fleet), Missouri (232 trailers/fleet) and the Hawaiian Islands (352 trailer/fleet). A majority of the states (69%) included registrations for all four trailer types, with smaller numbers of states having registrations for only 3 different trailers types (26%) or two or less different trailers types (5%).

States with the largest populations of different trailer types included TX for flatbeds (11,862), NJ for container chassis (29,399), TX for tanker trucks (9,437), and NJ for curtainsides (149). The average number of trailers of specific types per state were 2,978 flatbeds/state, 1,665 for container chassis/state, 1,361 tankers/state, and 35 curtainsides/state.

Figure 2-5: Maximum and average number of trailers by type and Length by State



2.3. Comprehensive Fleet Survey

A comprehensive fleet survey of fleets identified from the Polk/IHS database was conducted using the questions identified in the fleet survey questionnaire (Figure 2-1). A tiered strategy was utilized to maximize the survey responses and overcome, to the extent possible, any issues related to a potentially low response rate. The tiered strategy emphasized 1) mailers, 2) e-mail distribution, and then 3) phone calls or direct e-mail inquiries. A summary of the response for the different methods is provided below in Table 2-3, with more specific details about each of the methods provided below.

Table 2-3. Survey response for different methods adopted

Methods	Sent surveys	Answered surveys
Mailers	6,000	47
Electronic/e-mail distribution	1,000	1
Phone calls or direct e-mail inquiries	121	11

To facilitate responding to the survey, potential responders were offered four different methods of returning the surveys. All of the mailers included a self-addressed stamped envelope that could be returned directly. Potential respondents were also given the option to fax or e-mail the survey back. Finally, an internet survey questionnaire was provided through Survey Monkey for potential respondents who preferred that approach. Each survey was accompanied by a cover letter describing the broad goals of the survey, the different methods that could be used to return the surveys, the incentives for completing the survey, and also the possibility of participating as part of the data logging portion of the study. A $25 incentive was also provided to fleet managers who completed the survey in an effort to increase the potential response rate.

The most extensive part of the survey was the mailer distributions, and this provided the source for most of the responses. A total of 6,000 mailers were sent out in four different waves. Initially, 1,000 mailers were sent out to evaluate the potential response rate. Given the relatively low response rate obtained from the initial mailer distribution, three additional mailer distributions of 1,000, 2,000, and 2,000 mailers, respectively were sent out. A total 47 responses received from the mailer distributions, including 32 returned mailers, 3 faxed responses, and 12 survey monkey responses.

E-mail surveys were the second tier of the survey distribution. For this study, 1,000 surveys were distributed through e-mail. The responses to the e-mail surveys were very low, however, with only 1 returned survey for the 1,000 e-mail distribution. Initially, it was thought that e-mails would be the main method used to distribute surveys. However, in discussions with Polk/IHS, it was determined that an extra charge was assessed for each e-mail contact provided. Given the low response rate from the initial e-mail distribution, and the additional cost of getting the e-mail contact information, it was decided that additional e-mails would not be purchased.

The final tier of the survey distribution was via direct contact with fleet managers via either telephone calls, e-mails, or both. For this part of the survey, a call list of approximately 100 fleets was developed. This call list focused on California fleets that had 5 or more of the trailer types of interest. The fleet information included telephone information for many, but not all of the fleets. For fleets where telephone information was not provided, an internet search was conducted to determine if the company was still in existence, and if there was any publicly available telephone numbers to call. An additional list of SmartWay program fleets based in California was also obtained and a subset of these fleets were also contacted. The phone calls had a slightly higher response rate, in that 4 completed surveys were obtained as a result of phone contacts. An additional 7 surveys were also obtained from direct contacts with fleets that UCR has an on-going relationship with.

It should be noted that an additional effort was made to reach out to trucking trade associations, including the American Trucking Association and Harbor Trucking Association (HTA). This included attending a number of meetings of the HTA, and making a presentation about the program at one of the meetings. Fleet surveys were mailed and e-mailed to all the fleet representatives from the HTA, but we did not receive any return responses from HTA members, outside of fleets that we already had a relationship with.

2.4. Fleet Survey Results

The survey results were compiled into an Excel spreadsheet database. A summary of the survey results is provided below for the following topic areas: number of surveys by state, number of tractors fleets currently own or lease, how fuel use is tracked, total number of trailers (of all types) owned and operated, number of specific trailer types, types of loads, information of typical trip distances and annual mileages, and participation in existing fuel economy programs or using aerodynamic devices.

Some potential participants for the data logging portion of this study were also identified through the survey of the Polk/IHS database fleets. These potential data logger participants were contacted to determine their level of interest in the data logging, based on positive responses to that survey question. We were not able to complete the arrangements with any of these fleets to conduct the actual data logging, however.

2.4.1. Physical address and number of surveys

A total of 59 survey responses were received. Of these, only 51 responses were from fleets that either own or operate trailers that were either flatbeds, tankers, container chassis, or curtainsides, and it is the results from these 51 fleets that are discussed below. The 51 responses came from 13 states (CA, GA, IL, MA, MI, MN, MO, NJ, NY, OK, TX, UT, WI), with most of them coming from California (61%). The responses from the 12 other states provided between 1 - 3 responses each.

A summary of the survey results for each state is provided in Table 2-4, including the number of fleets, the number of trailers, the types of trailers, and the load types. For the California fleets in particular, the information for each of the fleets is listed separately.

Table 2-4. Summary information from the survey responses by state or by fleet for California-based fleets

States	# of fleets	CA Fleet ID	# of Trailers per State/Fleet	Trailer type	Load type
CA	31		3,511	FB/CS/CC/T	Goods Delivery/ Construction/ Agriculture/ Liquid-Gas
		CA1	27	T	Liquid-Gas
		CA2	4	FB	Construction
		CA3	120	FB/CC/T	Goods Delivery/ Agriculture
		CA4	200	FB	Construction
		CA5	65	T	Liquid-Gas
		CA6	100	CS	Goods Delivery
		CA7	10	FB/CS	Construction
		CA8	133	FB/T	Agriculture
		CA9	108	CS/T	Liquid-Gas
		CA10	209	FB	Construction
		CA11	n/a	FB	Construction
		CA12	11	FB	Goods Delivery
		CA13	200	FB/CS/T	Goods Delivery
		CA14	361	CC	Others
		CA15	62	T	Agriculture/ Liquid-Gas
		CA16	176	FB/CS	Construction/ Agriculture/ Others

		CA17	13	CC	n/a
		CA18	139	T	n/a
		CA19	60	T	Agriculture/ Liquid-Gas
		CA20	62	T	Construction
		CA21	n/a	n/a	Construction/ Liquid-Gas
		CA22	300	FB/T	n/a
		CA23	27	FB	Construction
		CA24	13	T	Liquid-Gas
		CA25	12	FB	Construction
		CA26	35	FB/T	Liquid-Gas/ Others
		CA27	200	FB	Agriculture
		CA28	500	FB/CC	Goods Delivery/ Construction/ Agriculture/ Others
		CA29	45	FB/CC	Goods Delivery
		CA30	241	FB/CS	Others
		CA31	78	FB/CS/CC/T	Goods Delivery
GA	1		11	FB	Goods Delivery
IL	4		57	FB/CS/CC/T	Goods Delivery/ Construction/ Agriculture
MA	1		1	FB	Construction
MI	3		296	CS	Goods Delivery
MN	1		16	FB/CS	Goods Delivery/ Agriculture
MO	2		44	FB	Goods Delivery/ Construction/ Agriculture
NJ	1		13,000	FB/CS/CC/T	n/a
NY	1		7	FB	Construction
OK	1		19	FB	Goods Delivery/ Construction/ Agriculture
TX	1		5	FB/CC	Agriculture
UT	1		33	FB/CS	n/a
WI	3		31	FB/CS/CC	Goods Delivery/Construction

Note: n/a - no answer, FB=flatbed, CS = curtainside, CC = container chassis, T = tanker

2.4.2. Number of tractors companies currently own or lease

A total of 49 fleets responded to this question. For the number of tractors the fleet owns or leases, a total of 1,722 tractors were accounted for in the survey, which included 60% day cabs and 28% sleeper cabs. Of this total, 86% were registered in California. The average number of tractors per fleet for CA was 51, which was about 4.2 times higher than the average of 12 tractors per fleet for out-of-state fleets.

The number of day cabs ranged from 0 to 150 for the California fleets and from 0 to 200 for the fleets from other states. The percentage of day cab vehicles in the Californian fleet (66%) was similar to that for the other 12 states (60%). For sleeper cabs, this number varied from 0 to 27 for California fleets and 0 to 53 for the other 12 states.

2.4.3. How you track fuel use

In terms of tracking fuel consumption, 48 fleets answered this question, with 27% using hand logs, 25% using some sort of computerized tracking such as a data logger, and 13% using real-time GPS / Engine signals. More than one monitoring method was used by some companies, with 8% using both hand logs and computerized tracking, 8% using computerized tracking and real-time GPS / Engine signals, and 2% using all three methods, and 10% using other methods.

For the California fleets, a larger fraction of fleets used computerized tracking (39%), while fewer used hand logs (14%), showing a greater emphasis on technology to help monitor fuel consumption, as well as using combinations of more than one method of monitoring fuel consumption (32%).

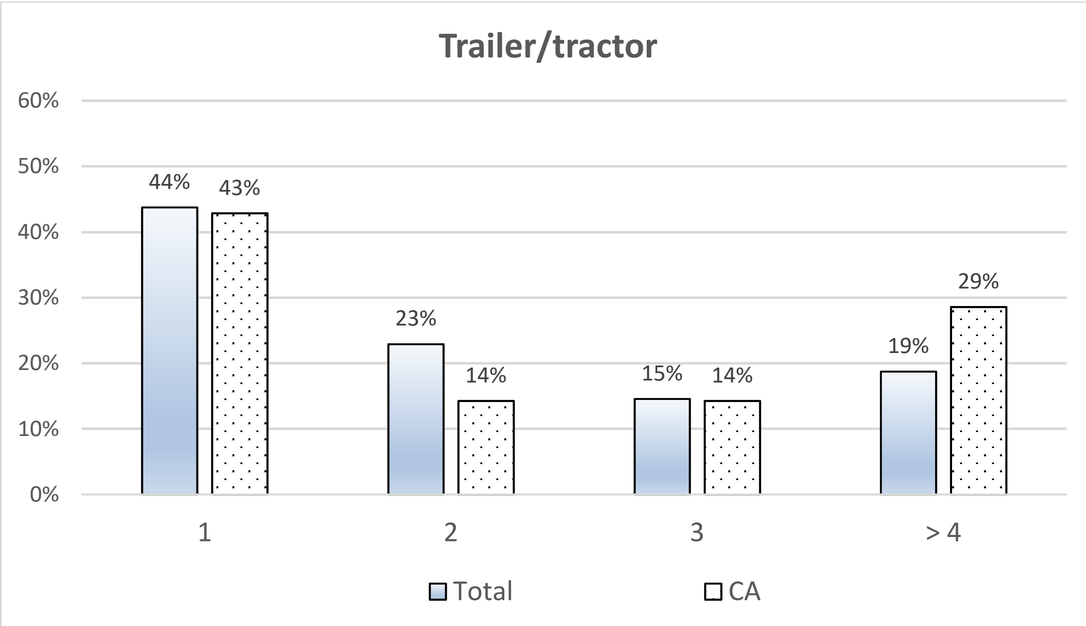
A potential benefit of fleets utilizing more advanced or multiple methods of tracking fuel use is that it might allow for the evaluation of whether aerodynamic devices are achieving the expected fuel economy benefits under in-use conditions.

2.4.4. Total number of trailers (all types) owned and operated

A total of 49 fleets responded to this question. The total number of trailers reported by all survey respondents was 17,032, but a single NJ fleet accounted for 13,000 trailers, which represented almost 80% of that total. It should be noted that we contacted this fleet directly to verify their survey response, and they indicated that in fact the numbers were correct, and that their fleet had actually expanded since the time the survey was filled out to 15,000. Excluding this fleet, other companies had from 1 to 500 trailers each, with an average of 84 trailers each. For California fleets, this average was slightly higher per company (121). Except for the NJ fleet, California fleets represented more than 86% (3,511) of the trailers in operation of the companies surveyed.

The ratio of trailers per tractor was also characterized. Figure 2-6 shows the fraction of fleets for different ratios of trailers per tractor for both the full survey and the California-based fleets. The largest fraction of fleets (43-44%) had a trailer-to-tractor ratio of 1. The full survey had larger fraction of fleets with trailer-to-tractor ratios of 2 (23%), while the California-based fleets had a higher fraction of fleets with trailer-to-tractor ratios >4 (29%). Both the full survey of fleets and the California-based fleets had similar fractions (14-15%) of fleets that had 3 trailers per tractor. The average trailer-to-tractor ratio was slightly over 2 for both the full survey and the CA-based fleets. The average number was based on utilizing a value of 4 for ratios >4, so it represents a lower end estimate.

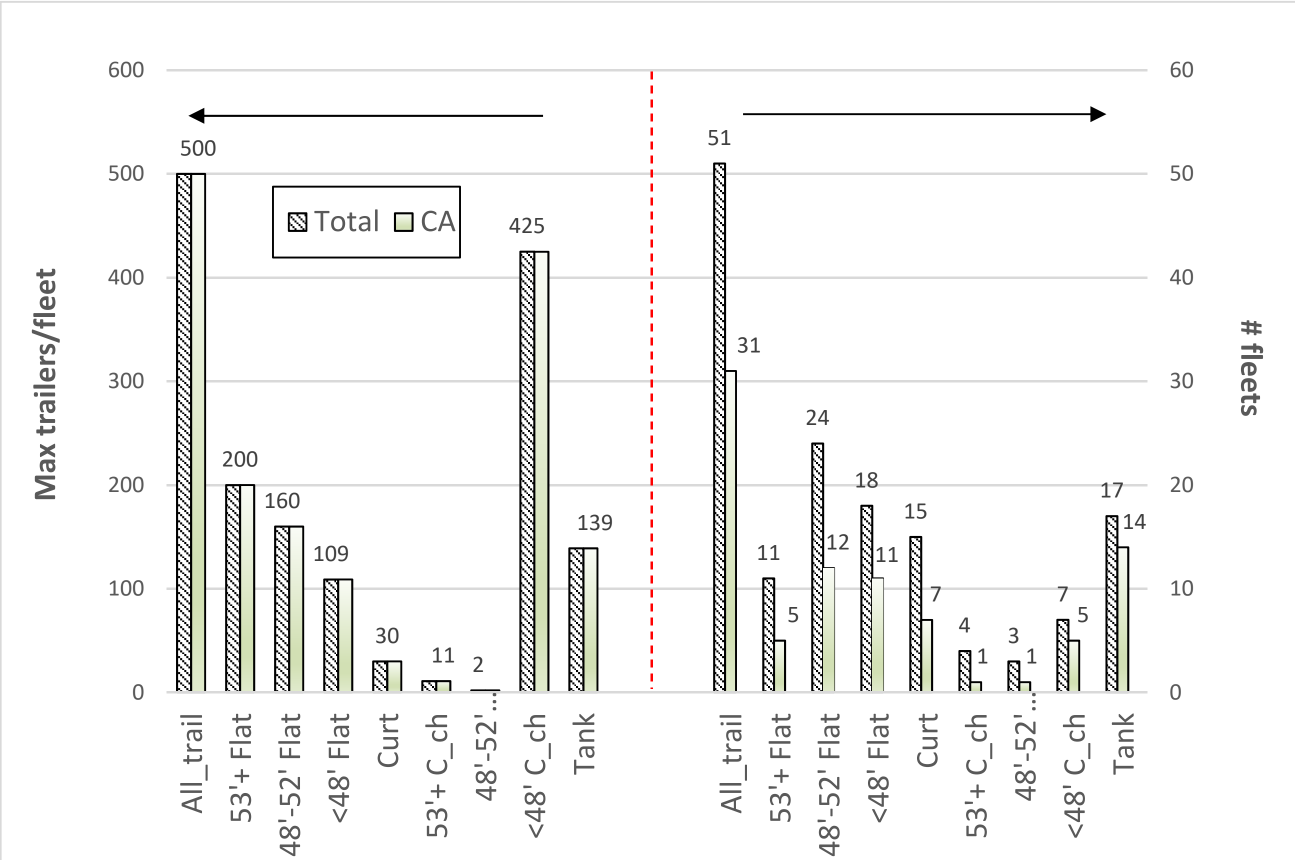
Figure 2-6: Percentage distribution of the ratio of trailers per tractor for the total of all surveyed fleets and for California-based fleets



2.4.5. Number of specific trailer types

A total of 49 of the 51 fleets responded to the question on the number of trailers by trailer type. A significant number of companies utilized only one trailer type (59%), followed by 2 different trailers types (27%), while a smaller number of fleets have more than 3 different trailers types (14%). A breakdown of the number of fleets that owned or operated specific types of trailers is provided in Figure 2-7 for all survey responders and for the California-based fleets that responded. Figure 2-7 also includes the maximum number of trailers for a given fleet for both the full survey and for the California-based responders.

Figure 2-7: Total number of fleets and maximum trailers per fleet recorded in survey data for all states and California State broken down for all trailers and each of the four trailer types.



Of the 49 fleets that answered this question, a total of 36 had flatbed trailers in their fleets. The number of flatbed trailers for the different fleets ranged from 1 to 200 (Figure 2-7). The flatbeds for most of the carriers (54%) were in the 48'-52' length size, with roughly similar fractions for the 47' and shorter (21.9%) and 53' and longer (24.6%) flatbeds.

A total of 14 carriers had curtainside trailers in their fleets. The number of curtainside trailers for the different fleets ranged from 1 to 11,480. Again, this included a single company that indicated they owned over 11,000 curtainside trailers, compared to the Polk/IHS database, which showed this company registered less than 200 trailers between 2000 and 2015, with a majority of these being container chassis. Excluding this fleet, the number of curtainside trailers ranged from 1 to 30 for the 13 remaining fleets (Figure 2-7).

Only 11 carriers responding to the survey had container chassis trailers in their fleets. The number of container chassis trailers for the different fleets ranged from 2 to 480 (Figure 2-7). The largest number of this type of container chassis trailers were in the size range of 40'-47', representing approximately 92% of the container chassis.

Of the total survey fleets, 17 had tanker trailers in their fleets. Just over half of these fleets (59%) were from California. The number of tanker trailers for the different fleets ranged from 4 to 139 (Figure 2-7). Most carriers (88%) had tanker trailers with lengths of less than 47'.

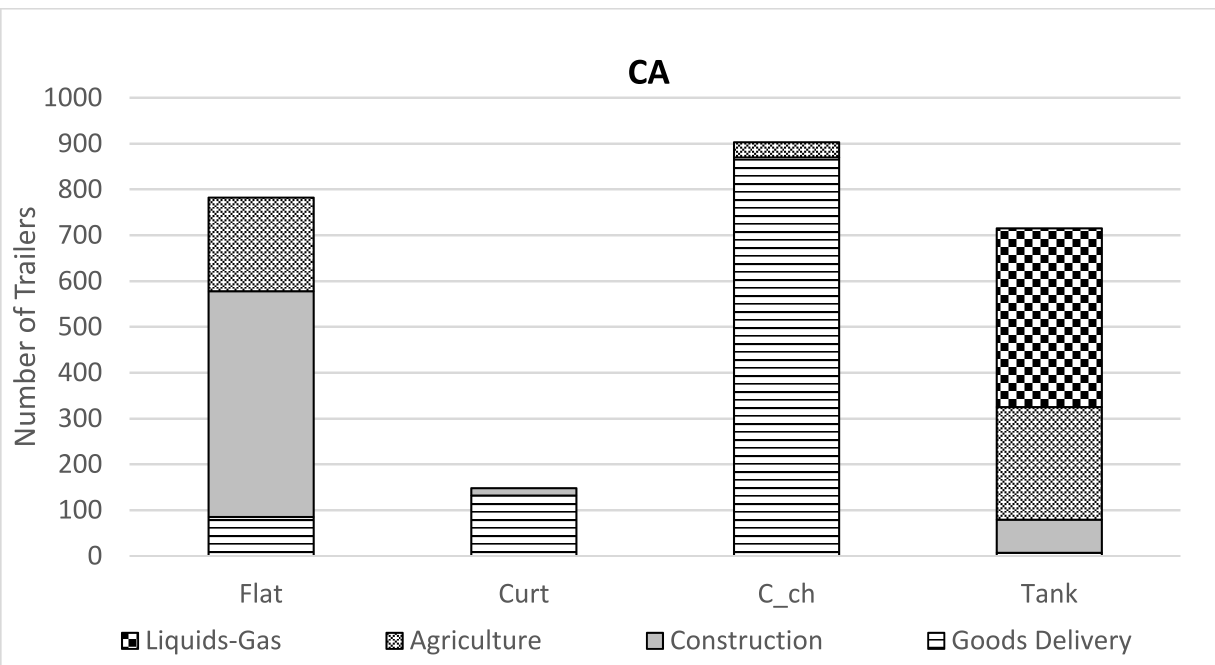
2.4.6. Load types

Figure 2-8 provides a breakdown of load type by trailer type for the California fleets from the fleet survey.

A total of 45 fleets responded to the question regarding what type of load the fleet carried, with 33% transporting goods delivery products, 33% transporting construction materials, 24% transporting agriculture products, 20% carrying liquid/gas, usually fuel or petroleum derivative, and 18% carrying other materials types. The goods movement products and construction materials were predominantly carried by flatbeds for the out-of-state fleets. Additionally, 12 of these companies carried more than one load type.

In California, 27 fleets responded, with 22% transporting goods delivery products, 30% transporting construction materials, 22% transporting agriculture products, 30% carrying liquid/gas and 15% transporting other materials types. Seven of the California fleets carried more than one load type. The most prevalent load types for different trailer types for California were construction materials for flatbeds, agriculture for container chassis trailers, and miscellaneous liquids and agriculture products for tankers.

Figure 2-8: Distribution of Load types by Trailer Type for California in the survey



2.4.7. Fleet operation information

A total of 48 fleets responded to the question about annual mileage accumulation per tractor. The distribution of annual miles traveled per tractor and per trailer, as well as the amount of miles traveled in California are presented in Figure 2-9 and Figure 2-10 for the California and the out-of-state fleets, respectively.

The average annual mileage accumulation rates per tractor were similar for the California and for the full number of fleets surveyed. In 2015, the majority of fleets for both the full number of fleets and for the California-based fleets had an average annual miles travelled of more than 50,000 miles (60-62%) per tractor, followed by an average between 25,000 - 50,000 miles (21%), an average between 10,000 - 25,000 miles (10-14%), and an average of between 1,000-10,000 miles (0-6%) per tractor, with only one company (2-3%) having an annual average of less than 1,000 miles per tractor. In both CA and other states, more than 80% of companies indicated that they had an annual average of more than 25,000 miles travelled per tractor in 2015.

For the question about the average annual miles travelled by trailer rather than tractor, a total of 43 fleets responded, slightly less than the number that responded for the same question about the tractors. The survey found that the annual average mileage accumulation in 2015 by trailer for Californian carriers was very similar to the general profile of the full set of companies surveyed. A breakdown of the annual trailer mileages from most to least prevalent for the range of all fleets and for California-based fleets was as follows: more than 50,000 miles (44-48%) > 25,000-50,000 miles (16-19%) > 1,000-10,000 miles (16-19%) > 10,000-25,000 miles (16%) > 0-1,000 miles (2-4%). The percentage of trailers with an annual average of over 25,000 miles per trailer in 2015 was 63-64%, somewhat lower than the same average for the tractors. This suggests that tractors likely haul loads with a variety of different trailers, given that the trailer to tractor ratio is >1 for many fleets, as opposed to hauling a dedicated trailer, suggesting that some fraction of trailers are inactive at any given time. This depends on the trailer/tractor ratio of a given fleet.

A total of 40 fleets, or slightly fewer, responded to the question regarding mileage in California. Of these, 35% reported that the average annual miles travelled per trailer in 2015 by California was 0-1,000 miles, 10% stated that it was 10,000-25,000 miles, 20% said that was 25,000-50,000 and 35% indicated that it was more than 50,000 miles. These numbers were considerably higher when only the California-based fleets were evaluated. Most of these Californian companies (56%) had an average more than 50,000 miles travelled in California in 2015, followed by those with an average of 25,000-50,000 miles (28%), with the other three categories of mileage representing 16%. Therefore, 84% of California companies had an average annual miles travelled of more than 25,000 miles.

In terms of trip distance, the average trip distance for the surveyed fleets was 270 miles. About 73% of the fleets had an average trip distance of greater than 100 miles, with 84% of the fleets having average trip distances of greater than 50 miles, and 98% of the fleets indicating average trips distances of greater than 25 miles. Similar statistics were found for the CA-based fleets, with an average trip distance of 297 miles, with 96%, 85%, and 81% of the fleets having average trips distances of greater than 25 miles, 50 miles, and 100 miles, respectively. Less than 5% of the fleets for both the CA-based fleets and the full survey had average trip distances of greater than 1,000 miles.

Additional analyses were also conducted to see if the reported activity in terms of typical trip distance and annual mileage were a function of fleet size. These analyses showed that there was no correlation between fleet size and either typical trip distance or annual mileage.

Figure 2-9: Annual vehicle miles traveled in 2015 by California fleets' surveyed

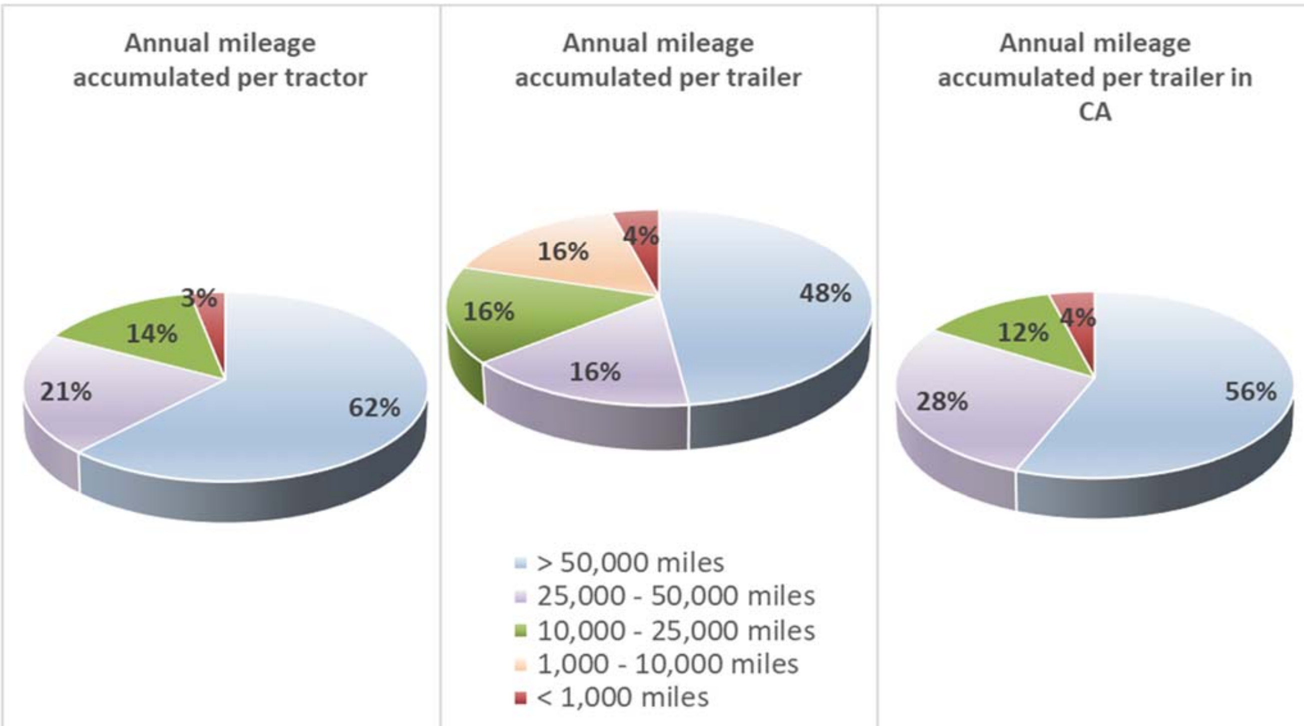
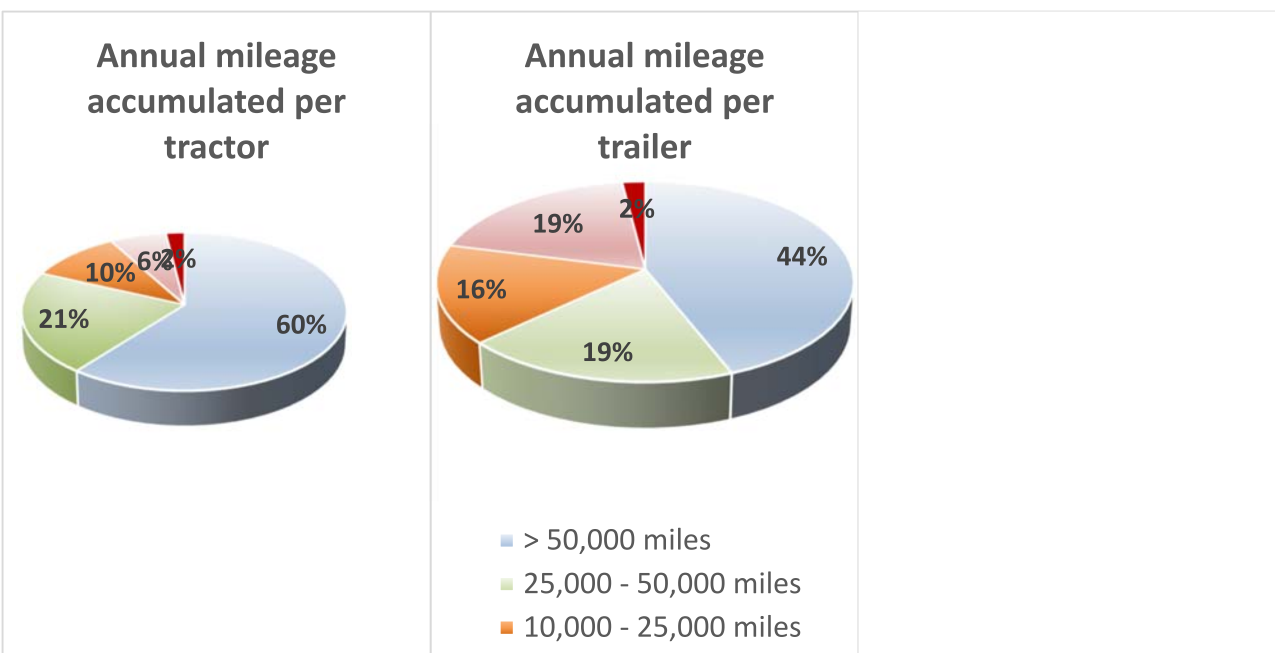


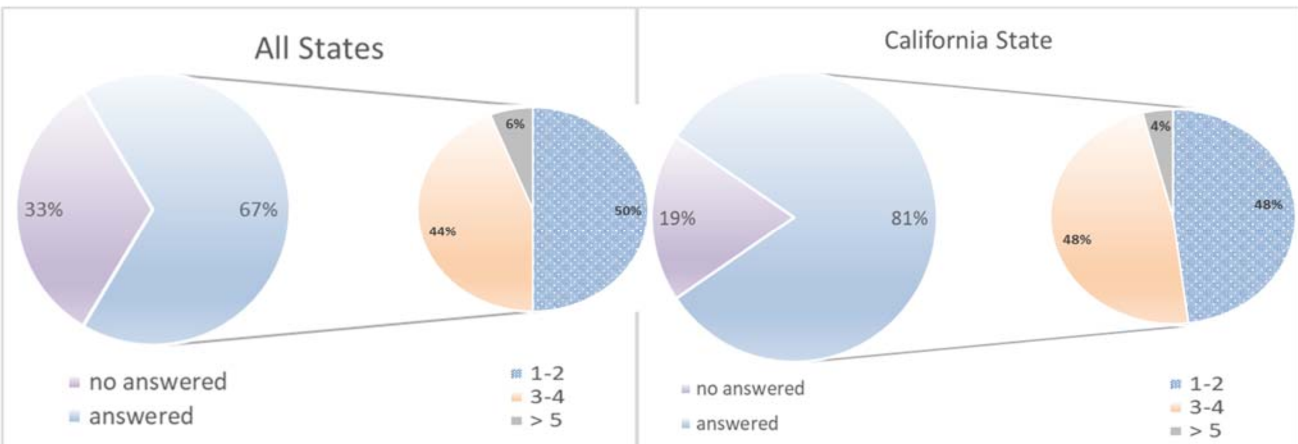
Figure 2-10: Annual mileage accumulated by the out-of-state fleets surveyed



2.4.8. Participation in existing fuel economy programs or using aerodynamic devices

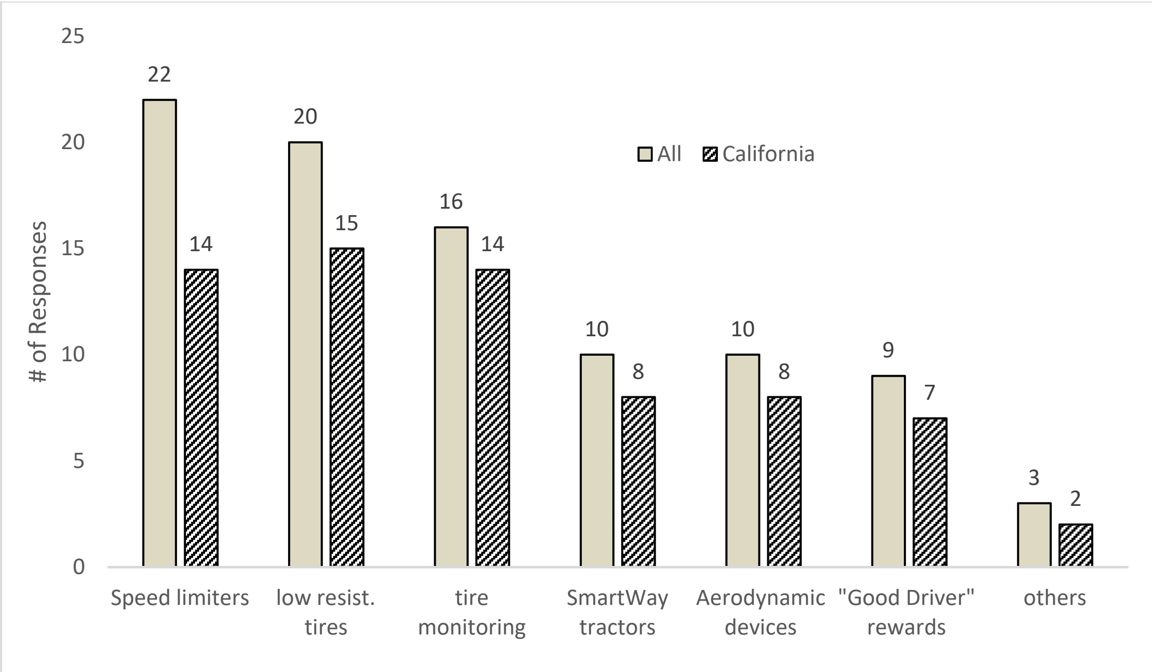
Only 34 fleets (67%) answered the question about which fuel economy programs they participated in or if they used a fuel saving technology, making this the question with the lowest response rate. Among responders, half reported using 1 to 2 of the response alternatives, with another 44% using 3 to 4 of the alternatives, while 6% were using 5 to 7 alternatives (see Figure 2-11). The number of fleets using different alternatives, from most to least used, was: tractor speed limiters (22), low rolling resistance tires (20), tire monitoring or auto inflation systems (16), U.S. EPA SmartWay verified tractors (10) and trailer aerodynamic devices (e.g., side- wheel covers) (10), "Good Driver" reward program (9), and others (3) (see Figure 2-12).

Figure 2-11: Summary of participation rates fuel economy programs or use of aerodynamic devices from fleet survey



Note: The pie charts with the larger circles depict the percentage of fleets that responded to the question about participating in fuel economy programs. The pie charts with the smaller circles indicate how many different types of fuel economy devices they utilize.

Figure 2-12: Methods Adopted by fleets in the survey to improve fuel economy



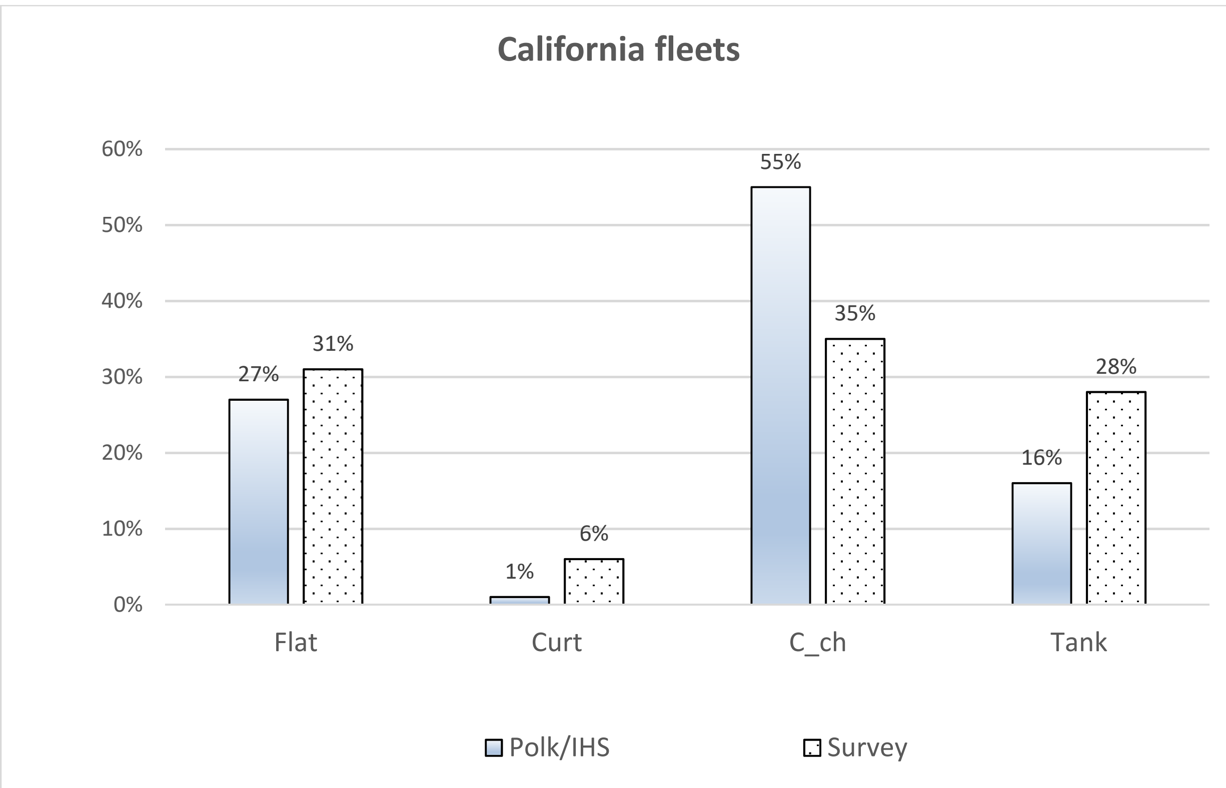
When the CA companies' results were evaluated separately, the percentage of companies that did not respond was lower (19%). Of the 25 Californian companies that responded to the survey, 48% reported using 1 to 2 of the response alternatives, 48% reported using 3 to 4 of the alternatives and only 4% using 5 to 7 of them (see Figure 2-11). The most adopted alternatives followed a similar order of prevalence as was found for the full list of surveyed fleets, as shown in Figure 2-12, with speed limiters, low resistance tires, and tire monitoring systems being the most prevalent alternatives, followed by SmartWay verified tractors, aerodynamic devices, and good driver incentives, with a limited number of “other” alternatives.

2.4.9. Comparison to Registration Database

Some additional cross checks were conducted to evaluate the survey responses against the associated Polk/IHS database. In nearly all cases, the number of trailers reported in the Polk/IHS database was less than the number of trailers reported in the survey. This included the company with the 13,000+ trailers, for which the Polk/IHS registration database showed less than 200 trailers registered to the company between 2000 and 2015. There was at least qualitatively reasonable agreement between the survey responses and the Polk/IHS database for about half of the survey fleets. For example, both the survey and Polk/IHS database showed the fleet owning fewer than 10 trailers, or in the ballpark of 10 trailers, or conversely both the survey and the Polk/IHS database showed that the fleet owned considerably more than 10 trailers. In other cases, however, the number of trailers reported in the survey was considerably higher than that in the Polk/IHS database. Overall, this suggests that the Polk/IHS database likely underrepresents the total number of trailers that are in existence throughout the U.S. This could be due in part to trailers that are older or were registered prior to 2000 and post 2015, although this does not appear to be the only factor. In some cases, the Polk/IHS database could also overrepresent the in-use populations of trailers, in cases where trailers first registered between 2000 through 2015, although this likely has a smaller impact.

The distribution of trailer types can also be compared between the survey fleets and Polk/IHS database. A breakdown of the fraction of trailers by type is provided in Figure 2-13. Overall, the distributions are roughly comparable between the survey fleets and Polk/IHS database, with the Polk/IHS database having a slightly higher fraction of container chassis trailers, while the fleet survey had a higher fraction of tankers, with the fraction of flatbeds being very similar for both.

Figure 2-13: Percentage distribution of California-registered types of trailers recorded in the Polk/IHS database and in the survey



3. Data Logging

3.1. Fleets and Vehicle Samples

Potential fleets for the data logging were identified through a number of different sources. The effort to recruit fleets for data logging was extensive and involved contacting potential fleets on a variety of levels. The majority of the fleets participating in the data logging portion of this project are ones that we have identified through one of these means.

- ***Based on fleet survey responses***: In the fleet survey based on the Polk/IHS database, we asked whether the fleet would be willing to participate in the data logging portion of the project. Several fleets indicated yes in their survey responses, but we were unable to complete arrangements with any of the fleets from the Polk/HIS database to actually conduct the data logging.

- ***From UCR contacts***: We have 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.

- ***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.

Initially, it was anticipated that a sufficient number of participating fleets might be obtained from the fleet survey portion of this study. Of the responses received from the fleet survey, a total of five California-based fleets indicated that they would be interested in participating in the data logging portion of the project. All of these fleets were contacted, but we were not able to arrange the logistics to data log any of these fleets. As part of the fleet survey, attempts were also made to contact all fleets within the Polk/IHS registration database with greater than five trailers registered in California within at least one of the years covered in the database to determine if they would be willing to participate in the data logging activity. We did not find any fleets through this method willing to participate in the data logging effort either. Finally, we reached out to the U.S. EPA and obtained a list of California fleets that participate in the SmartWay program and have a number of flatbed and tanker trailers. We reached out to about a dozen of these fleets that have favorable characteristics with more than five flatbed or tanker trailers that were accessible for data logging in the Northern or Southern California areas.

We also reached out to a number of industry groups, including the American Trucking Association (ATA), the California Trucking Association (CTA), the National Tank Truck Carriers (NTTC), and the Harbor Trucking Association (HTA). We attended several meetings of the HTA and made a presentation about the program, but did not identify any new fleets working in the goods movement area in the ports that were willing to participate. We also reached out to some of the largest drayage companies servicing the ports of Los Angeles and Long Beach.

The most successful source for recruiting fleets for data logging was fleets with which UCR or our subcontractors had a working relationship with or developed through our other contacts in the industry. To supplement the data obtained from the field data logging, additional data were obtained from a source that does commercial data logging for fleets. This commercial dataset includes a smaller number of data parameters than we typically collect through the J1939 port.

A summary of the fleets participating in the data logging is provided below in Table 3-1. Pictures of an example tractor-trailer from each fleet are provided in Figure 3-1.

Table 3-1. Fleets participating in the data logging

No.	Trailer Type	Primary Revenue Service	Location	Code Name[b]	Number of Vehicles	
					Installed	**Completed**
1	Container Chassis	Goods Movement	Northern California	CC-NC-1	4	4
2	Container Chassis	Goods Movement	Northern California	CC-NC-2	20	14
3	Container Chassis	Goods Movement	Southern California	CC-SC-1	44	43
4	Container Chassis	Refuse Transfer	Southern California	CC-SC-2	11	11
				Container Chassis subtotal	*79*	*72*
5[a]	Flatbed	Agricultural Products	Central Valley	FB-CV-1	65	65
6	Flatbed	Construction Materials	Southern California	FB-SC-1	4	4
				Flatbed subtotal	*69*	*69*
7	Tanker	Petroleum Fuels	Northern California	TK-NC-1	6	6
8	Tanker	Dairy Products	Central Valley	TK-CV-1	8	6
				Tanker subtotal	*14*	*12*
				Grand Total	**162**	**153**

[a]Data for this fleet is from a commercial source.
[b]CC = container chassis; FB = flatbed; TK = tanker
NC = Northern California; SC = Southern California; CV = Central Valley

Figure 3-1. Example vehicles and trailers


Fleet CC-NC-1


Fleet CC-NC-2


Fleet CC-SC-1


Fleet CC-SC-2


Fleet FB-CV-1


Fleet FB-SC-1

Fleet TK-NC-1


Fleet TK-CV-1

3.2. Data Loggers and Installation

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. 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.

This project took advantage of UCR's Cooperative Research and Development Agreement (CRADA) with the U.S. (EPA) on portable vehicle measurement research. Through this CRADA, the U.S. EPA provided various resources in support of this project, for example, lending combined GPS&ECU data loggers for use in the data collection.

The combined GPS&ECU data loggers used in this project were the J1939 Mini Logger™ produced by HEM Data. It consists mainly of a CAN reader capable of acquiring CAN bus data in SAE J1939 standard and an on-board data storage. 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. For this project, the data loggers were configured to log more than 170 ECU parameters, as listed in Appendix A, at the frequency of 1 Hz. The J1939 Mini Logger™ 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 3-2 shows the J1939 Mini Logger™ used in this project.

Figure 3-2. J1939 Mini Logger™ used in this project

The data loggers used by the commercial data logging source collected a smaller subset of information than the HEM data loggers. A listing of all the parameters obtained in this dataset is provided in Appendix A. The recorded data was processed into 1 Hz (i.e., second-by-second) before it was provided to UCR.

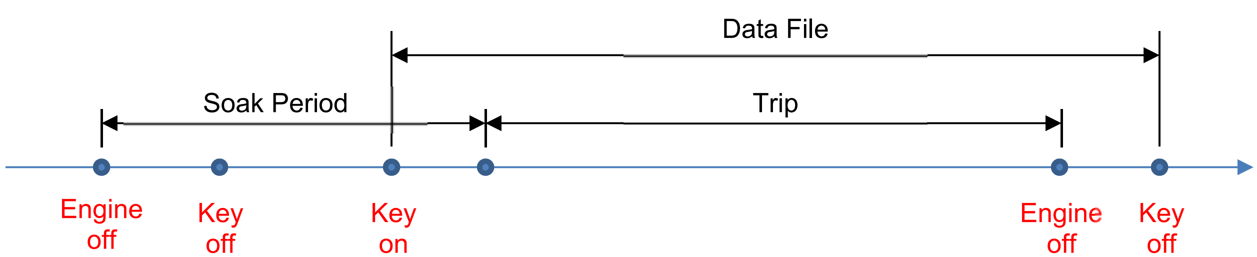
Once vehicles had been recruited, an installation date and time was scheduled and the preparation work followed. This included gathering data loggers and miscellaneous supplies and configuring them. The preparation work also included activating SIM cards in the cellular modems and registering them with 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. This was done by taking 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.

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

The data processing followed much of the procedures used in a previous similar research project (Boriboonsomsin et al., 2017). There are multiple steps of processing the collected data. These 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. ***Data Quality Assurance*:** The CSV data files then 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 tires. 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 was found to be 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 4-4 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 4-2. Example of questionable ECU-based speed data with periods of unreasonably high values

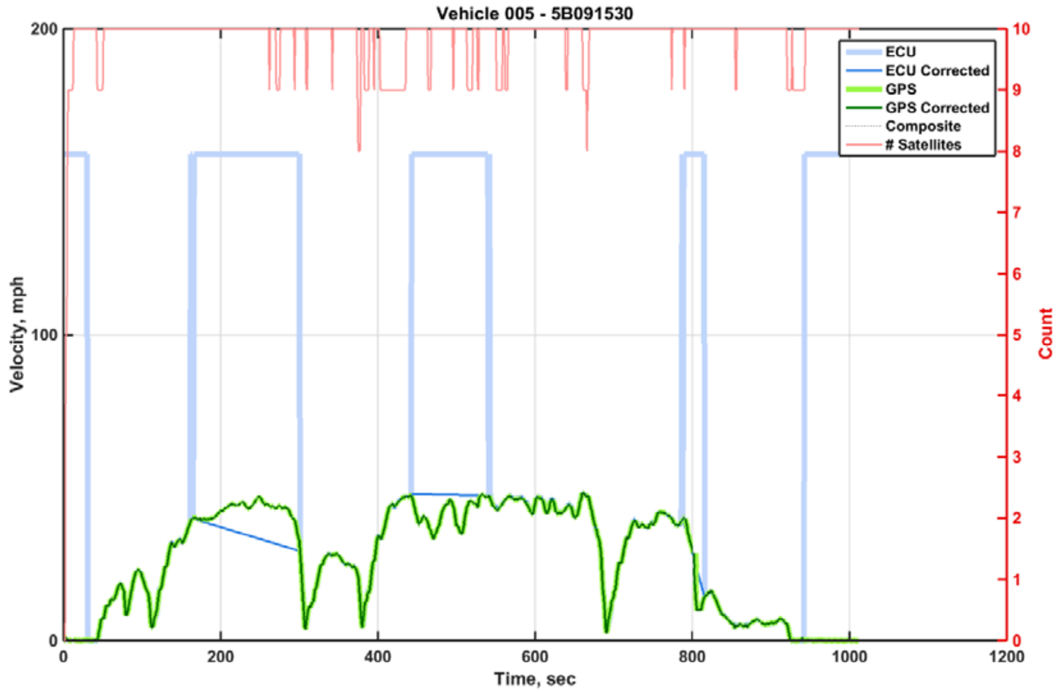


Figure 4-3. Example of questionable ECU-based speed data with sporadic offsets

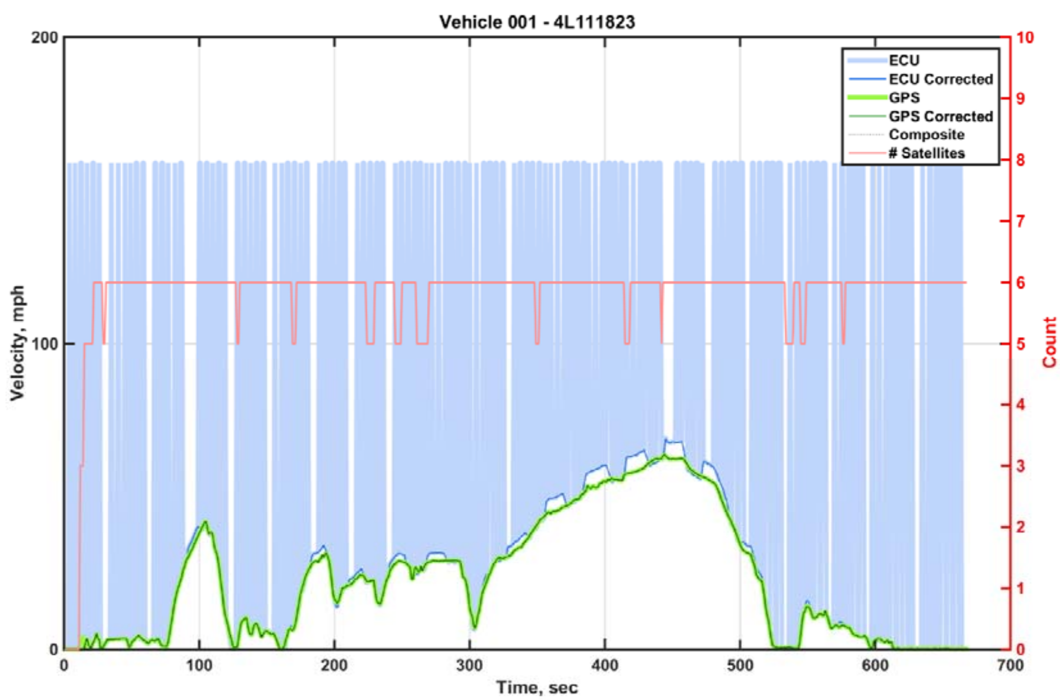


Figure 4-4. Example of a good match between GPS-based speed and ECU-based speed data

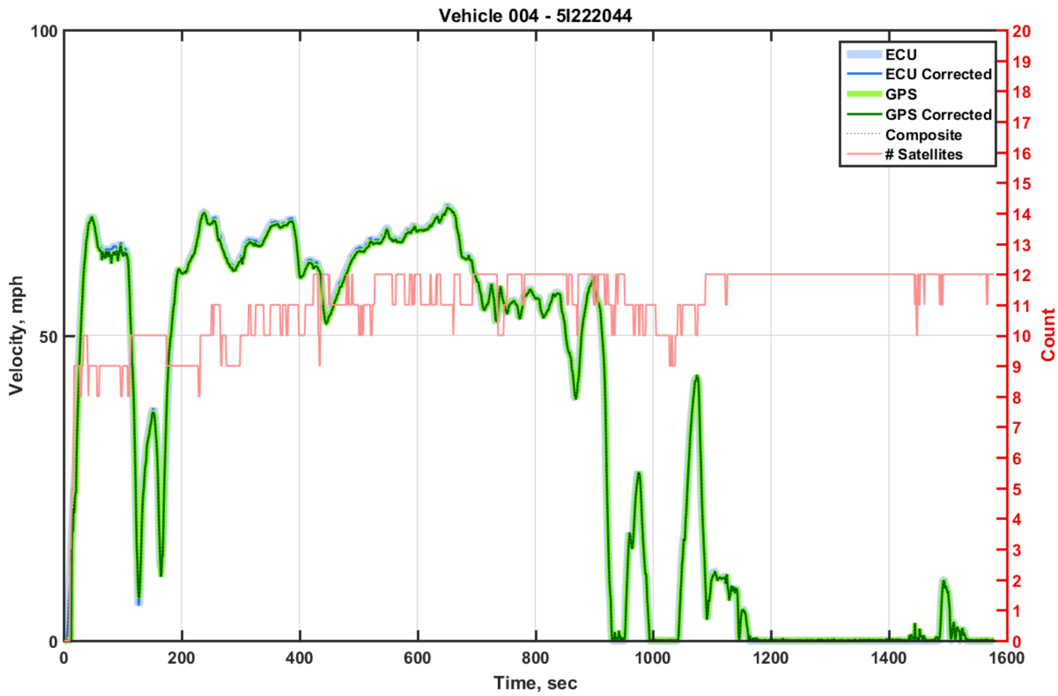
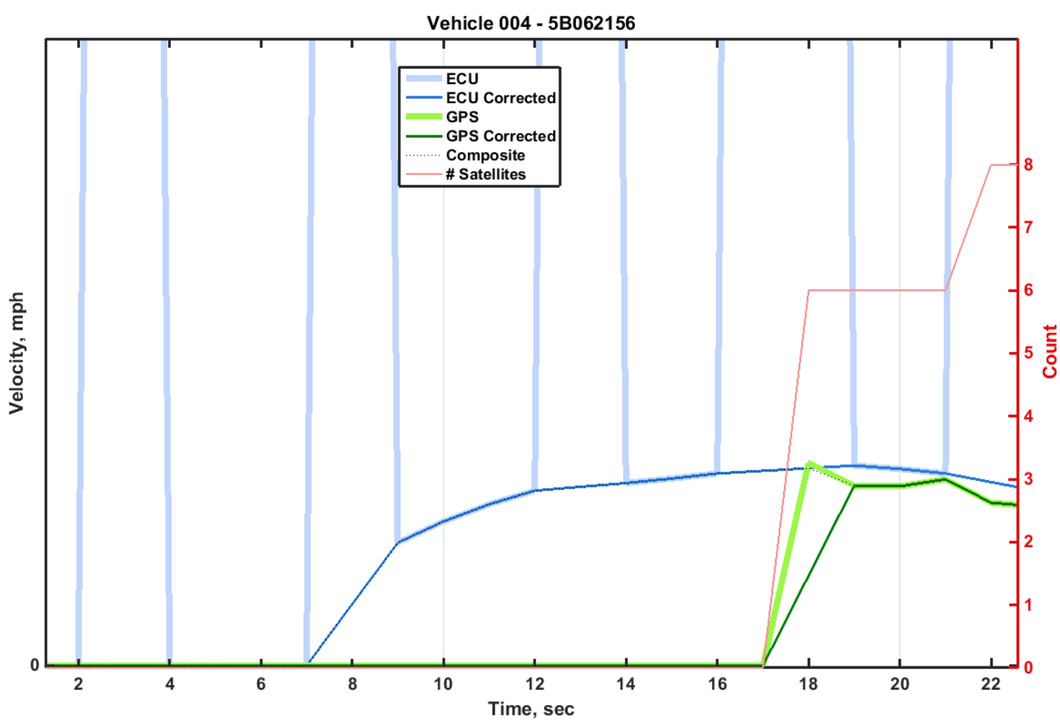


Figure 4-5. Example of replacing questionable GPS-based speed with ECU-based speed

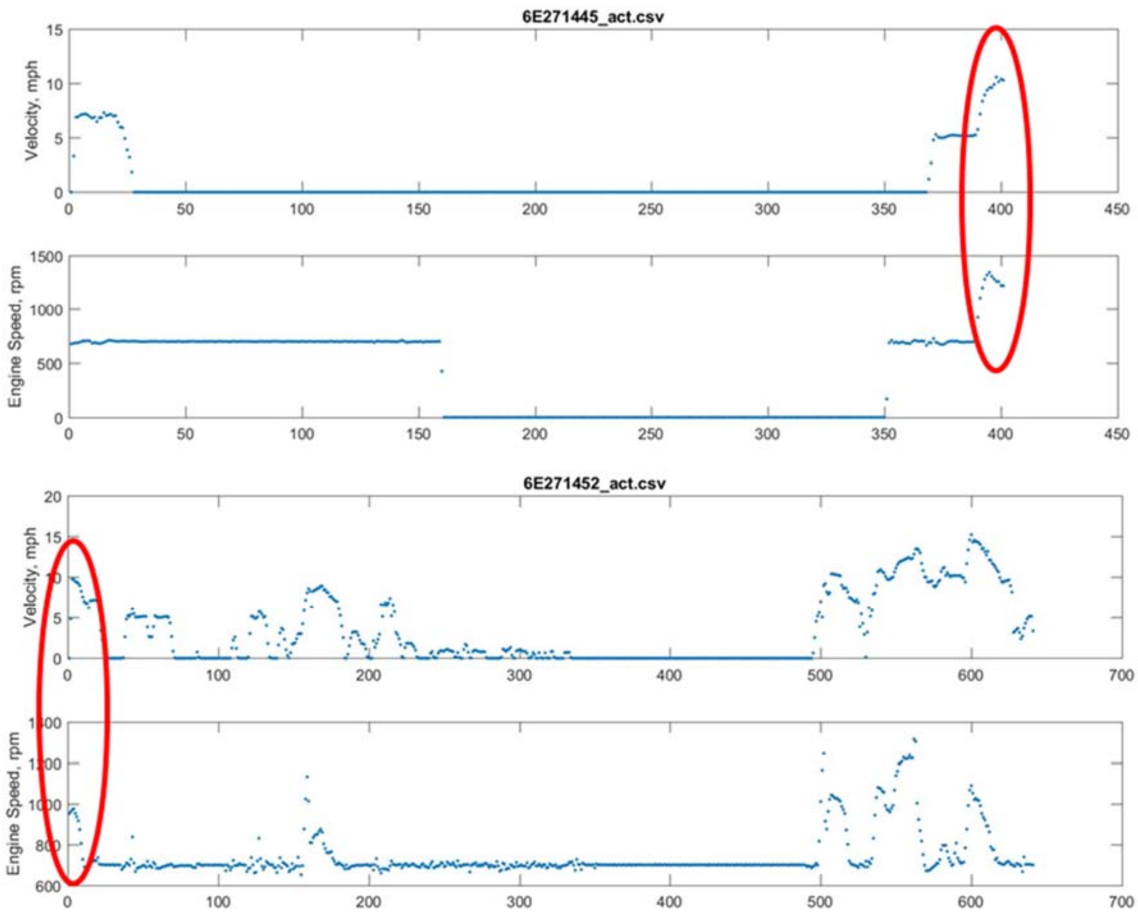


3. ***Trip Identification***: As noted earlier, a trip in the context of this research is from an engine-on event to an engine-off event. Therefore, trips needed to be identified and indexed in the master data files before they could be used for analyses. Engine speed was used to identify engine-on and 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.

   Sometimes data files may be 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 reasonable 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 as part of the trip identification step. 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. Almost all the cases where conditions a) and b) are true have a lapsed time of fewer than 60 seconds, and the two data files were merged. The remaining cases were manually examined to determine whether the data files 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



4. ***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.

5. ***Data Aggregation*:** As the logged 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 fleet were aggregated into a master data file for the fleet. A "Vehicle ID" field was added to this master data file to identify which data records belong to which vehicle. 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. Data Analysis

Vehicle speed distribution represents the primary information that is needed for evaluating the potential GHG emission reduction benefits of requiring aerodynamic technologies on the different types of trailers. As such, the data analysis in this project was focused on the development of speed distributions. Additionally, trip distance distribution and other descriptive statistics were also developed to provide the information about the operating characteristics of each fleet, which in turn provide the context for interpreting the speed distribution.

Trip Distance Distribution

Trip distance distribution shows the percent of trips within various distance groups (0-5 miles, 5-10 miles, 10-15 miles, …, 95-100 mile, and longer than 100 miles). It can inform whether a fleet operates locally, regionally, or statewide. In general, longer distance trips tend to have more mileage on highways and involve driving at higher speeds. Thus, tractor-trailers with a high percentage of long distance trips are more likely to benefit from aerodynamic improvements than those making mostly short distance trips. Note that in the current CARB's Tractor-Trailer GHG regulation, there are exemptions for tractor-trailers operating within a 100-mile radius. In the report, trip distance distributions are presented as both frequency distribution and cumulative frequency distribution in the same plot.

It was found that many of the tractor-trailers data logged in this project made a substantial amount of very short trips consisting mostly of engine idling. Examples of these very short trips include idling activities at trip origins or destinations, rest stops, or work sites. In a previous research on truck activity characterization (Boriboonsomsin et al., 2017), this type of trip is referred to as an "idle trip" and defined as 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. This type of trip will not benefit from aerodynamic improvements. Thus, as part of the data analysis in this project, we determined whether a trip was an idle trip. Then, for each fleet we created a separate trip distance distribution for non-idle trips.

Vehicle Miles Traveled by Speed Distribution

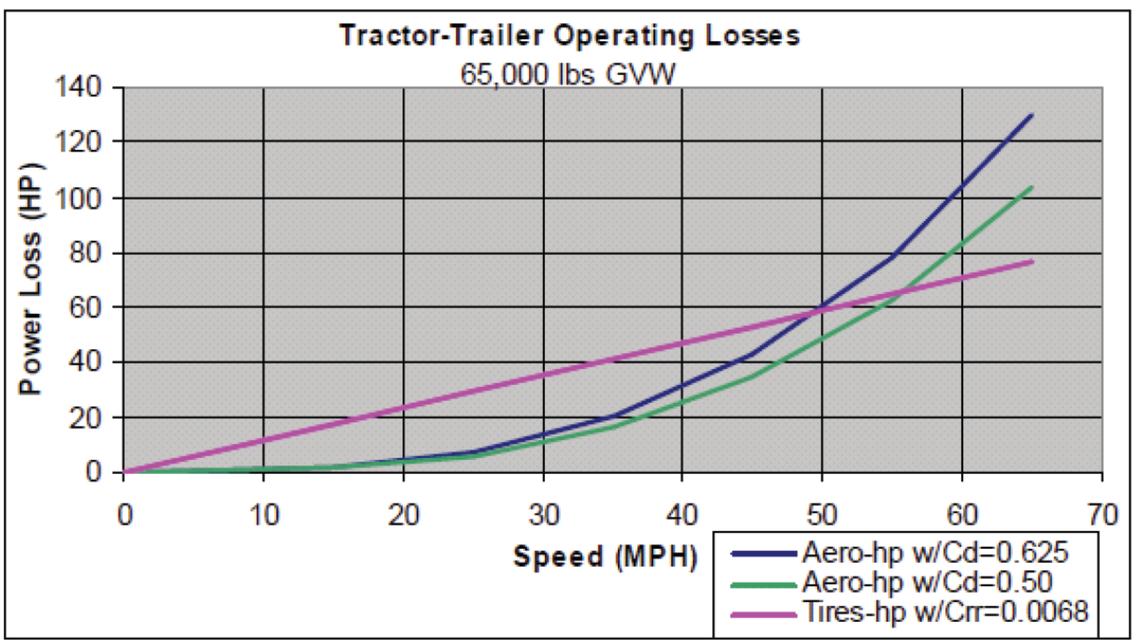
VMT by speed distribution represents the distance traveled by a vehicle or vehicles in different speed bins. CARB defines 18 speed bins according to Table 4-1. In this report, VMT by speed distribution is expressed as the percentage of the total miles traveled in each of the 18 speed bins. Separate VMT by speed distributions can also be created for the different hours of day, resulting in a two-dimensional distribution. 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.

Table 4-1. 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

VMT by speed distribution is critical information for estimating potential GHG emission reduction benefits from aerodynamic improvements. Since aerodynamic drag is proportional to the square of the speed (see Figure 4-7), aerodynamic improvements provide more benefits at higher operational speeds. In Figure 4-7, it is shown that the power loss due to aerodynamic drag increases sharply after 45 mph. Thus, in this report we calculate and report the percent of distance traveled at speeds greater than 45 mph.

Figure 4-7. Heavy-duty tractor-trailers operating losses [source: NRC, 2010]



5. Vehicle Activity Results

This chapter presents the results of the vehicle activity analysis for each trailer type. The results are also disaggregated by fleet and presented in the latter part of each section.

5.1. Container Chassis Trailers

Figure 5-1 shows the trip distance distributions of all 30,808 trips made by 72 container chassis tractor-trailers from four different fleets. About 67% of the trips were shorter than 5 miles; however, 15,272 trips or 50% were idle trips. Figure 5-2 shows the trip distance distributions of only non-idle trips (15,363 trips). It shows that about 72% of the non-idle trips were shorter than 25 miles while about 10% were longer than 100 miles.

Together, the logged data from all trips represent a total VMT of 433,946 miles over 4,487 vehicle-days. This equates to a projected annual mileage per vehicle of 35,300 miles. Figure 5-3 presents the VMT by speed distribution of all trips. The prevalent speeds were 55-65 mph, and approximately 65% of the VMT were at speeds greater than 45 mph. These results indicate that the container chassis tractor-trailers data logged in this study, on average, would benefit moderately from aerodynamic technologies. However, the level of benefit experienced may vary by fleet. The results for each container chassis fleet are presented in the following subsections.

Figure 5-1. Trip distance distributions of all trips for all container chassis trailers combined

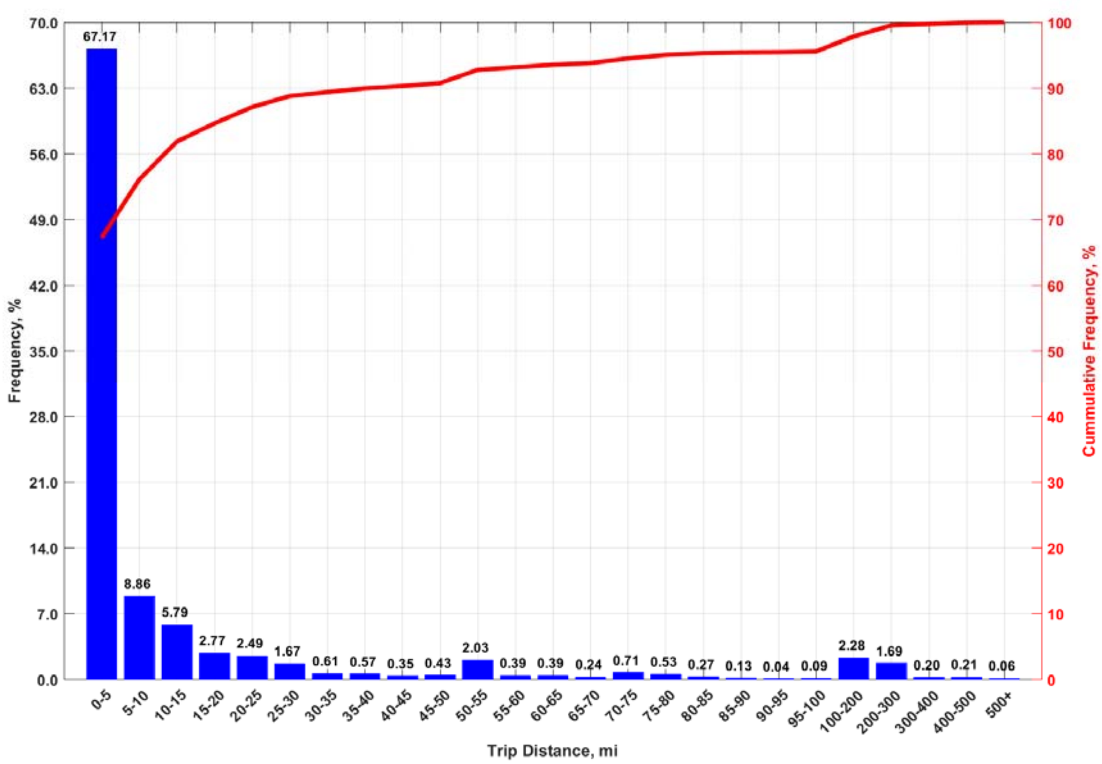


Figure 5-2. Trip distance distributions of non-idle trips for all container chassis trailers combined

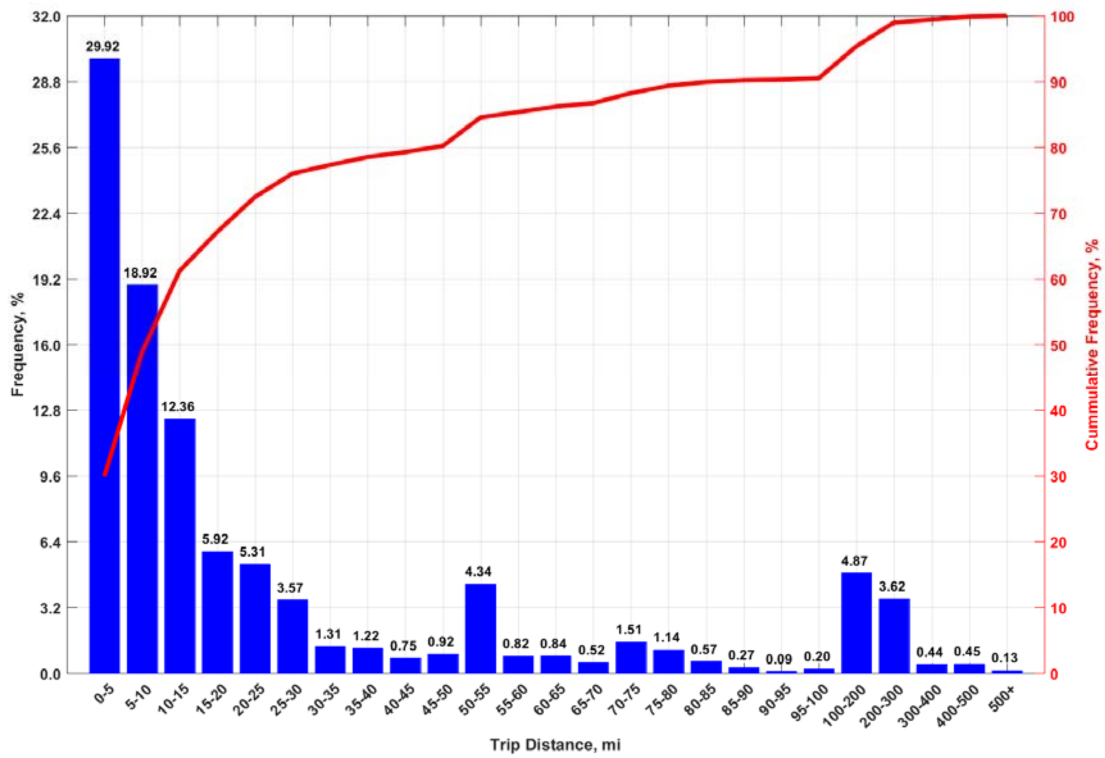


Figure 5-3. VMT by speed distribution of all trips for all container chassis trailers combined

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	1.48	3.09	3.67	3.54	3.41	3.76	4.36	5.25	6.23	7.43	11.07	18.94	22.64	4.93	0.20	0	0	0	*100*
Hour	Total																			
0	1.97	0.05	0.12	0.14	0.13	0.11	0.12	0.14	0.17	0.20	0.19	0.19	0.21	0.16	0.03	0.00	0	0	0	
1	2.32	0.05	0.11	0.12	0.12	0.11	0.12	0.15	0.17	0.21	0.22	0.22	0.26	0.36	0.09	0.00	0	0	0	
2	3.31	0.03	0.06	0.07	0.07	0.07	0.09	0.13	0.16	0.21	0.23	0.32	0.66	1.04	0.18	0.00	0	0	0	
3	3.23	0.01	0.02	0.02	0.02	0.02	0.03	0.05	0.06	0.08	0.13	0.27	0.83	1.42	0.26	0.01	0	0	0	
4	4.67	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.08	0.15	0.29	1.18	2.42	0.35	0.01	0	0	0	
5	5.82	0.02	0.06	0.07	0.07	0.08	0.09	0.11	0.14	0.20	0.32	0.66	1.51	2.13	0.35	0.01	0	0	0	
6	6.01	0.06	0.12	0.13	0.14	0.15	0.18	0.20	0.25	0.30	0.40	0.74	1.41	1.62	0.30	0.01	0	0	0	
7	5.56	0.10	0.21	0.26	0.26	0.25	0.26	0.28	0.32	0.34	0.40	0.63	1.07	0.87	0.29	0.01	0	0	0	
8	5.67	0.11	0.25	0.32	0.30	0.27	0.28	0.30	0.36	0.40	0.44	0.60	0.94	0.80	0.26	0.01	0	0	0	
9	6.49	0.10	0.22	0.29	0.29	0.26	0.28	0.31	0.37	0.44	0.51	0.79	1.20	1.12	0.29	0.01	0	0	0	
10	6.86	0.09	0.20	0.25	0.24	0.23	0.25	0.28	0.35	0.40	0.52	0.83	1.42	1.51	0.28	0.01	0	0	0	
11	7.30	0.09	0.18	0.22	0.23	0.22	0.25	0.28	0.35	0.43	0.52	0.84	1.54	1.79	0.34	0.01	0	0	0	
12	7.19	0.08	0.15	0.19	0.19	0.19	0.20	0.25	0.30	0.37	0.50	0.83	1.53	1.97	0.42	0.02	0	0	0	
13	6.39	0.09	0.19	0.22	0.21	0.19	0.21	0.24	0.29	0.35	0.43	0.75	1.26	1.53	0.42	0.02	0	0	0	
14	5.92	0.08	0.18	0.22	0.21	0.21	0.23	0.25	0.30	0.37	0.46	0.71	1.05	1.24	0.38	0.03	0	0	0	
15	4.87	0.06	0.15	0.18	0.19	0.19	0.21	0.23	0.28	0.33	0.40	0.60	0.84	0.93	0.28	0.02	0	0	0	
16	3.03	0.05	0.11	0.12	0.12	0.12	0.15	0.18	0.21	0.23	0.25	0.34	0.45	0.54	0.16	0.01	0	0	0	
17	2.30	0.06	0.11	0.11	0.11	0.12	0.14	0.17	0.19	0.20	0.19	0.22	0.27	0.33	0.08	0.00	0	0	0	
18	1.94	0.07	0.12	0.14	0.12	0.11	0.13	0.15	0.18	0.18	0.18	0.17	0.17	0.14	0.06	0.00	0	0	0	
19	1.82	0.06	0.12	0.13	0.12	0.10	0.11	0.13	0.15	0.18	0.20	0.20	0.17	0.11	0.02	0.00	0	0	0	
20	1.98	0.06	0.11	0.12	0.12	0.10	0.12	0.13	0.16	0.20	0.22	0.23	0.27	0.13	0.02	0.00	0	0	0	
21	2.07	0.05	0.10	0.12	0.11	0.10	0.12	0.14	0.17	0.19	0.23	0.25	0.27	0.18	0.03	0.00	0	0	0	
22	1.61	0.04	0.08	0.09	0.08	0.08	0.09	0.10	0.13	0.16	0.17	0.19	0.25	0.15	0.02	0.00	0	0	0	
23	1.67	0.05	0.11	0.12	0.10	0.08	0.09	0.11	0.13	0.15	0.16	0.19	0.21	0.14	0.01	0.00	0	0	0	
Sum	*100*																			*100*

5.1.1. Northern California Fleet #1 (CC-NC-1)

This is a truck fleet in Northern California that hauls container chassis trailers. We data logged four tractor-trailers from this fleet. Figure 5-4 and Figure 5-5 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. In all the heat maps presented in this report, yellow represents areas with dense data points. Then, the color transitions to magenta, dark blue, and light blue as the density of data points goes down. According to Figure 5-4 and Figure 5-5, the fleet made stops at the port of Oakland and several other locations in the Bay Area close to the port, the Greater Sacramento region, and the Tahoe National Forest. The fleet also serviced locations in the state of Nevada. The data logged tractor-trailers heavily used the I-80 freeway that connects the port of Oakland and the state of Nevada.

Figure 5-6 shows the trip distance distributions of all 4,464 trips for this fleet where almost 90% of the trips were shorter than 5 miles. However, 2,925 trips or 66% were idle trips. Figure 5-7 presents the trip distance distributions of only non-idle trips (1,539 trips). It shows that the majority (about two-thirds) of the non-idle trips were still shorter than 5 miles. These very short trips represent a drayage operation near the port. The remaining non-idle trips consisted mostly of long-distance trips over 100 miles (around 22%) and regional trips 70-75 miles (around 7%).

Figure 5-8 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 73,976 miles. About half of the VMT were at speeds of 60-65 mph and about a quarter of the VMT were at speeds of 55-60 mph, which are typical highway speeds. The majority of these VMT were generated during the early morning hours (3-6 a.m.) and midday (11 a.m. – 2 p.m.). Note that albeit having almost 90% of the trips being shorter than 5 miles, there is not a lot of VMT fraction at low speeds. This is because the amount of time traveling at low speeds does not result in as many miles as traveling at higher speeds.

Table 5-1 summarizes key statistics of this fleet. Based on the data logged from the four vehicle samples of this fleet, the projected annual mileage for each vehicle is 74,387 miles. Approximately 90% of these miles would be at speeds greater than 45 mph, which stand to benefit from aerodynamic improvements.

Figure 5-4. Heat map of trip origins for fleet CC-NC-1

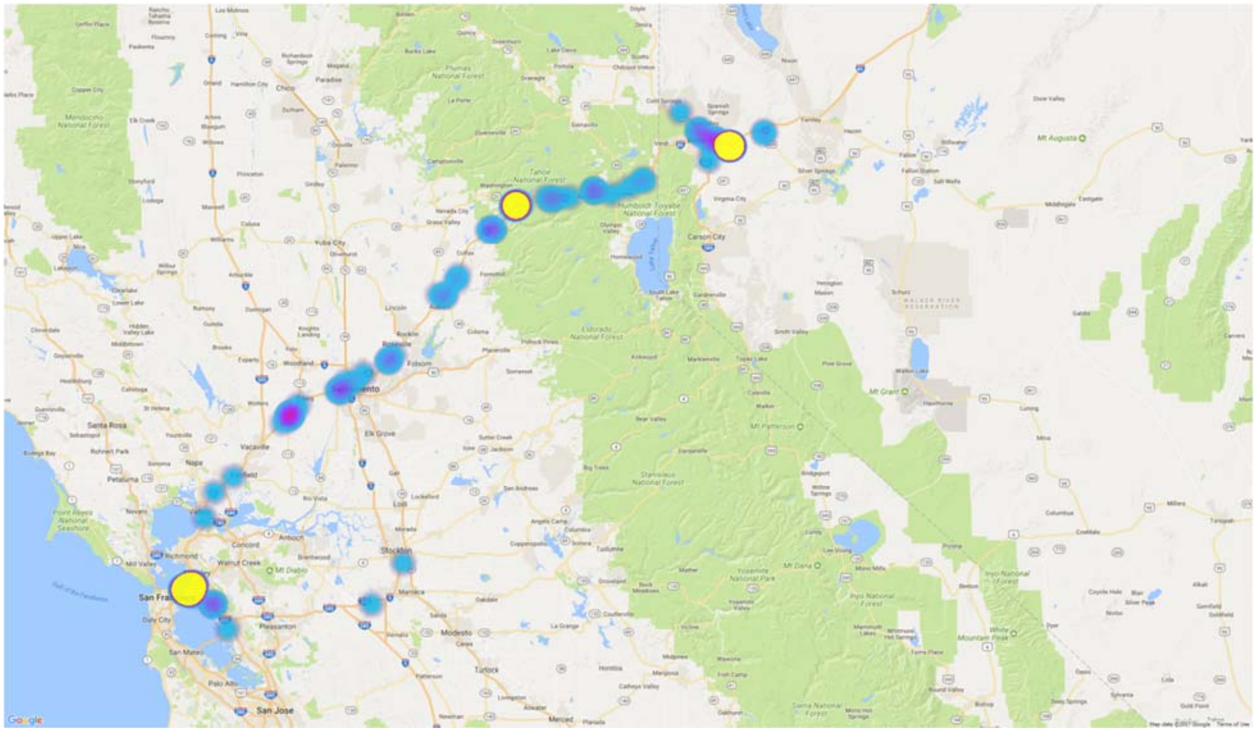


Figure 5-5. Heat map of trip destinations for fleet CC-NC-1

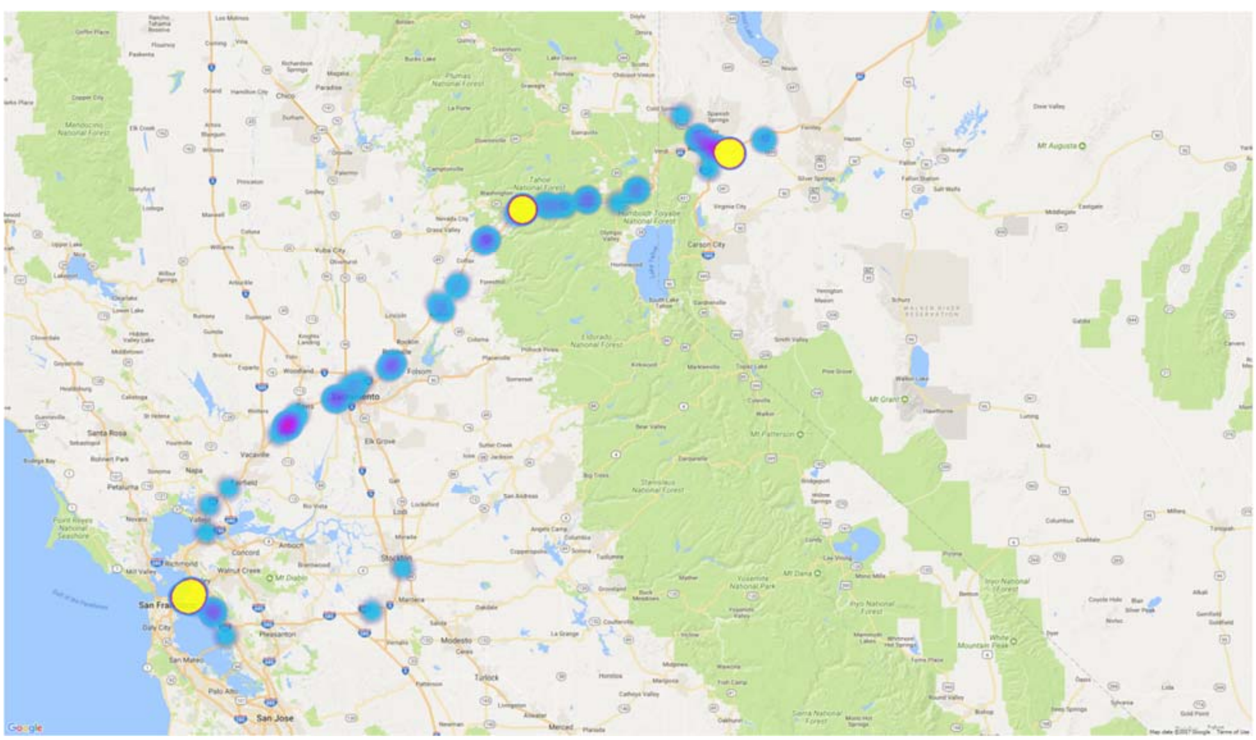


Figure 5-6. Trip distance distributions of all trips for fleet CC-NC-1

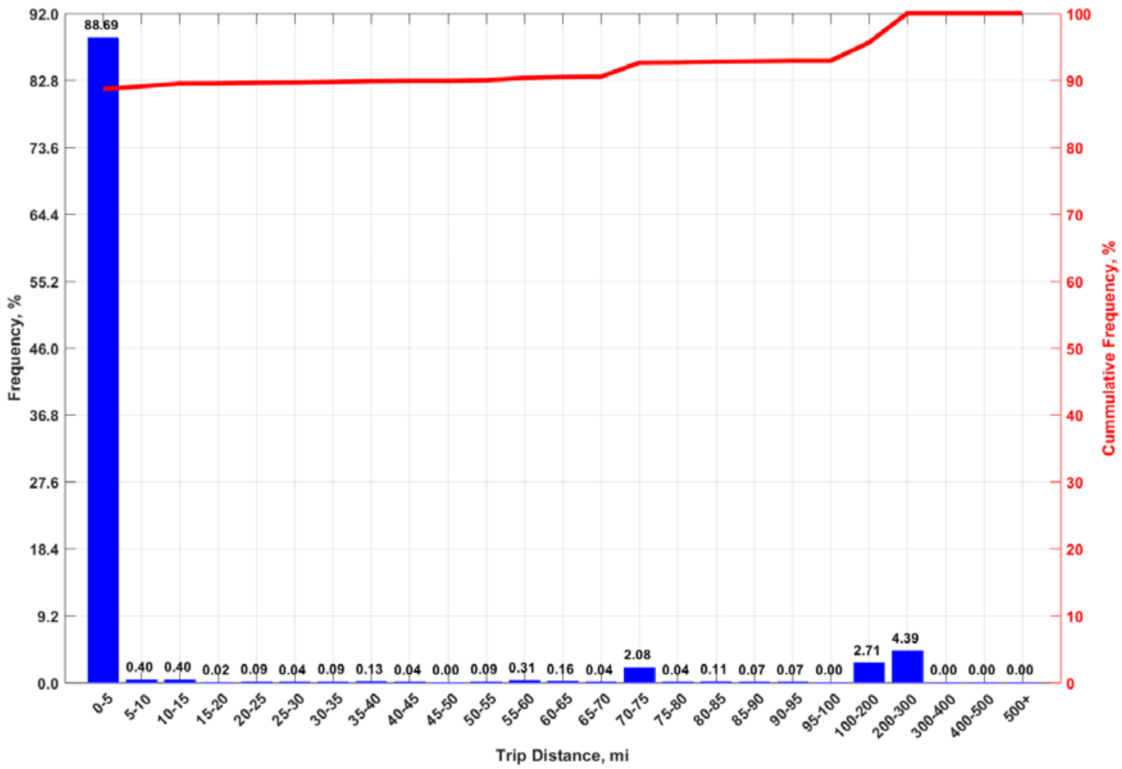


Figure 5-7. Trip distance distributions of non-idle trips for fleet CC-NC-1

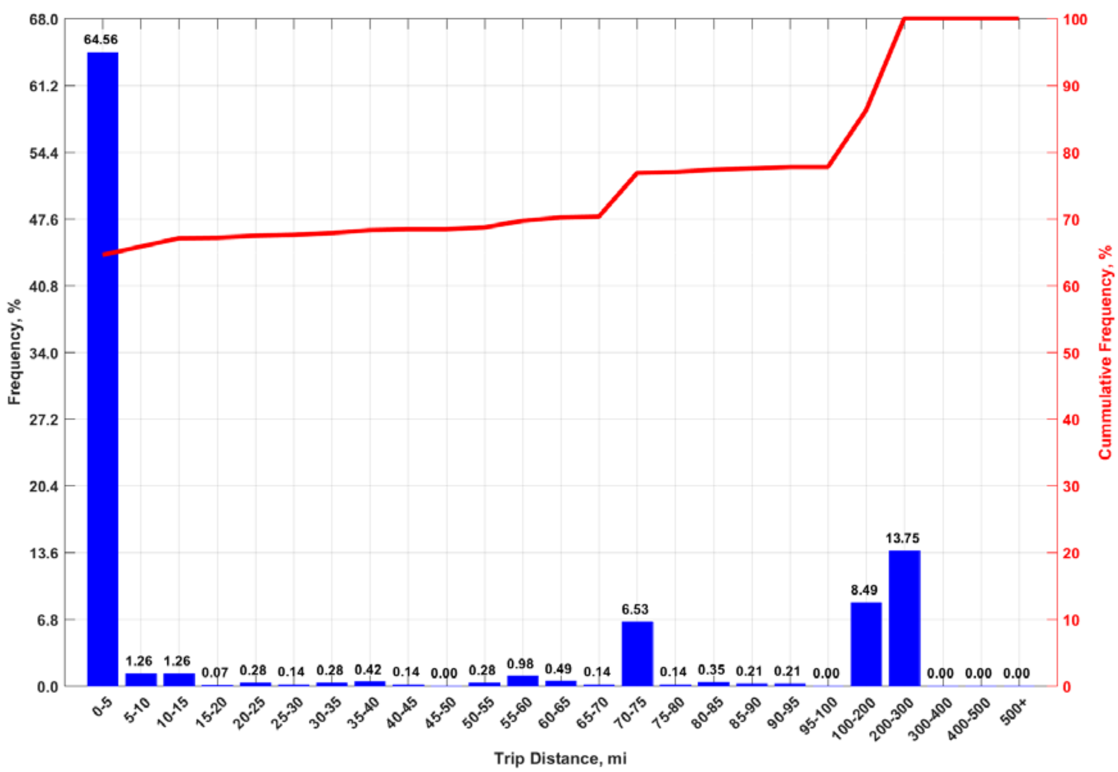


Figure 5-8. VMT fraction by speed bin of all trips for fleet CC-NC-1

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.43	0.86	1.01	0.97	0.92	0.92	1.44	1.34	2.00	3.28	7.91	26.91	51.50	0.53	0.00	0	0	0	*100*
Hour	Total																			
0	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.10	0.09	0.00	0	0	0	0	
1	1.44	0.01	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.02	0.04	0.09	0.30	0.81	0.00	0	0	0	0	
2	6.85	0.01	0.01	0.02	0.02	0.03	0.04	0.11	0.07	0.13	0.29	0.79	2.13	3.19	0.01	0.00	0	0	0	
3	8.97	0.01	0.01	0.02	0.02	0.03	0.04	0.08	0.05	0.10	0.28	0.87	3.10	4.34	0.05	0	0	0	0	
4	12.79	0.00	0.01	0.01	0.01	0.01	0.02	0.09	0.06	0.11	0.27	0.66	3.30	8.17	0.07	0.00	0	0	0	
5	11.65	0.01	0.01	0.02	0.02	0.03	0.03	0.05	0.07	0.15	0.32	0.96	3.30	6.60	0.08	0	0	0	0	
6	6.67	0.03	0.03	0.04	0.05	0.07	0.07	0.08	0.08	0.10	0.16	0.45	1.43	4.06	0.01	0.00	0	0	0	
7	3.48	0.07	0.13	0.18	0.20	0.20	0.16	0.14	0.10	0.11	0.15	0.28	0.64	1.12	0.01	0	0	0	0	
8	2.33	0.07	0.14	0.19	0.15	0.12	0.11	0.11	0.09	0.07	0.08	0.15	0.49	0.55	0.01	0	0	0	0	
9	3.27	0.05	0.10	0.13	0.10	0.07	0.07	0.07	0.06	0.06	0.08	0.24	0.88	1.35	0.00	0	0	0	0	
10	5.42	0.03	0.07	0.08	0.06	0.05	0.05	0.06	0.08	0.09	0.12	0.31	1.62	2.78	0.01	0	0	0	0	
11	7.69	0.03	0.07	0.08	0.06	0.05	0.06	0.11	0.12	0.16	0.24	0.57	2.27	3.85	0.01	0.00	0	0	0	
12	8.77	0.01	0.03	0.03	0.03	0.04	0.04	0.12	0.14	0.24	0.34	0.73	2.41	4.57	0.02	0	0	0	0	
13	7.55	0.03	0.06	0.06	0.05	0.05	0.04	0.12	0.13	0.23	0.33	0.68	2.05	3.67	0.06	0.00	0	0	0	
14	5.65	0.03	0.06	0.05	0.05	0.05	0.05	0.11	0.11	0.18	0.27	0.49	1.38	2.76	0.05	0.00	0	0	0	
15	3.71	0.02	0.05	0.04	0.04	0.05	0.05	0.08	0.08	0.12	0.15	0.32	0.80	1.87	0.05	0.00	0	0	0	
16	2.14	0.02	0.03	0.04	0.04	0.04	0.04	0.05	0.06	0.07	0.10	0.20	0.43	0.97	0.04	0	0	0	0	
17	1.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.08	0.17	0.54	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	0.03	0.10	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*

Table 5-1. Summary statistics of data for fleet CC-NC-1

Description	Value
Number of vehicle samples	4
Total number of vehicle-days data logged	363
Total operating time (hours)	1,961
Total operating distance (miles)	73,976
Distance traveled per day per vehicle (miles)	203.8
Projected annual mileage per vehicle (miles)	74,387
Distance traveled at speed greater than 45 mph (%)	90.1
Total number of trips	4,464
Total number of idle trips	2,925
Total number of non-idle trips	1,539
Maximum trip distance (miles)	263.7
Mean trip distance of all trips (miles)	16.6
Mean trip distance of non-idle trips (miles)	47.7

5.1.2. Northern California Fleet #2 (CC-NC-2)

This is another truck fleet in Northern California that hauls container chassis trailers. We data logged 20 tractor-trailers from this fleet but only 14 tractor-trailers provided usable data. Figure 5-9 and Figure 5-10 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. Similar to the previous fleet, this fleet primarily made stops at the port of Oakland and several other locations in the Bay Area, the Greater Sacramento region, and the Tahoe National Forest. The fleet also serviced locations in the state of Nevada. The data logged tractor-trailers heavily used the I-80 freeway that connects the port of Oakland and the state of Nevada. However, unlike the previous fleet, this fleet also occasionally serviced locations in the southern part of the Central Valley and in the Inland Empire.

Figure 5-11 shows the trip distance distributions of all 1,296 trips for this fleet where about 44% of the trips were shorter than 5 miles. However, 320 trips or about 25% were idle trips. These percentage numbers are much smaller than the numbers for the previous fleet. Figure 5-12 presents the trip distance distributions of only non-idle trips (976 trips). It shows that only about 10% of the non-idle trips were shorter than 5 miles while the majority (about 63%) of the non-idle trips were long-distance trips over 100 miles. Again, these numbers are in contrast with the numbers for the previous fleet, indicating that this fleet is focused more on long-distance hauling than drayage operation.

Figure 5-13 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 143,901 miles. About 42% of the VMT were at speeds of 60-65 mph and about a quarter of the VMT were at speeds of 65-70 mph, which are typical highway speeds. The majority of these VMT were generated during the early morning hours (4-7 a.m.) and midday (11 a.m. – 3 p.m.).

Table 5-2 summarizes key statistics of this fleet. Based on the data logged from the 14 vehicle samples of this fleet, the projected annual mileage for each vehicle is 78,402 miles. Approximately 91% of these miles would be at speeds greater than 45 mph, which stand to benefit from aerodynamic improvements.

Figure 5-9. Heat map of trip origins for fleet CC-NC-2

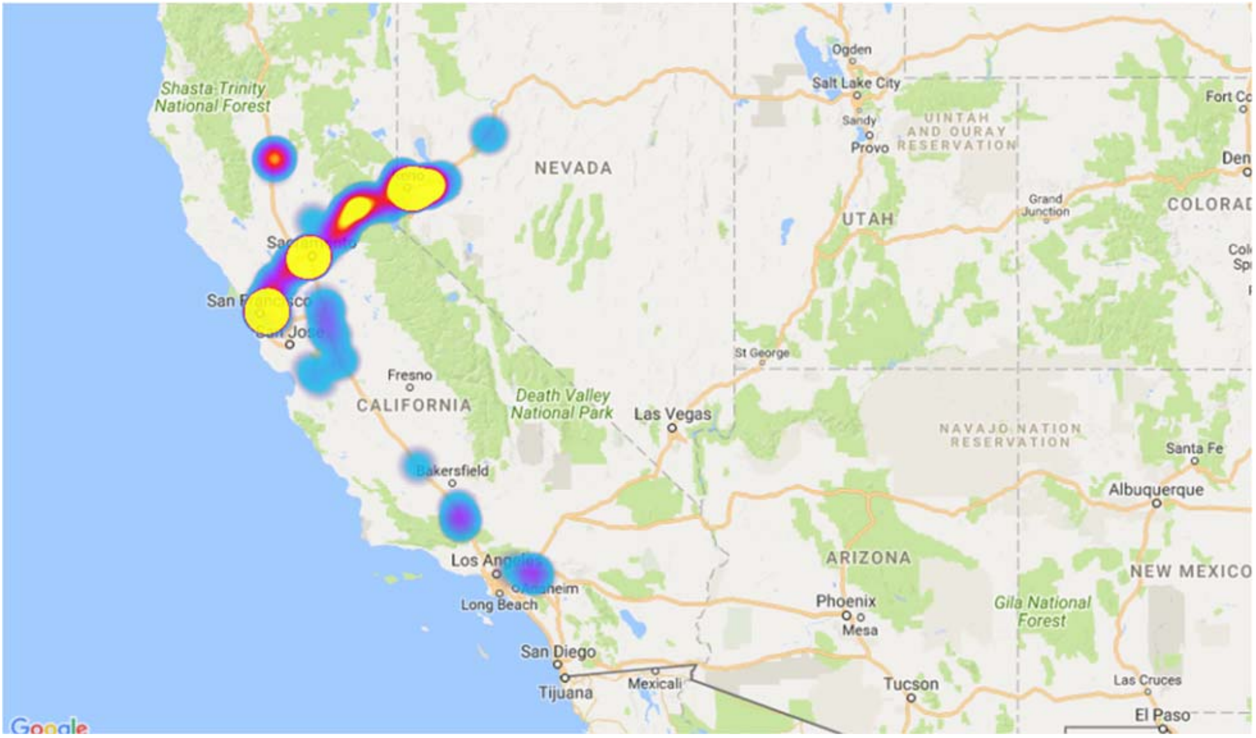


Figure 5-10. Heat map of trip destinations for fleet CC-NC-2

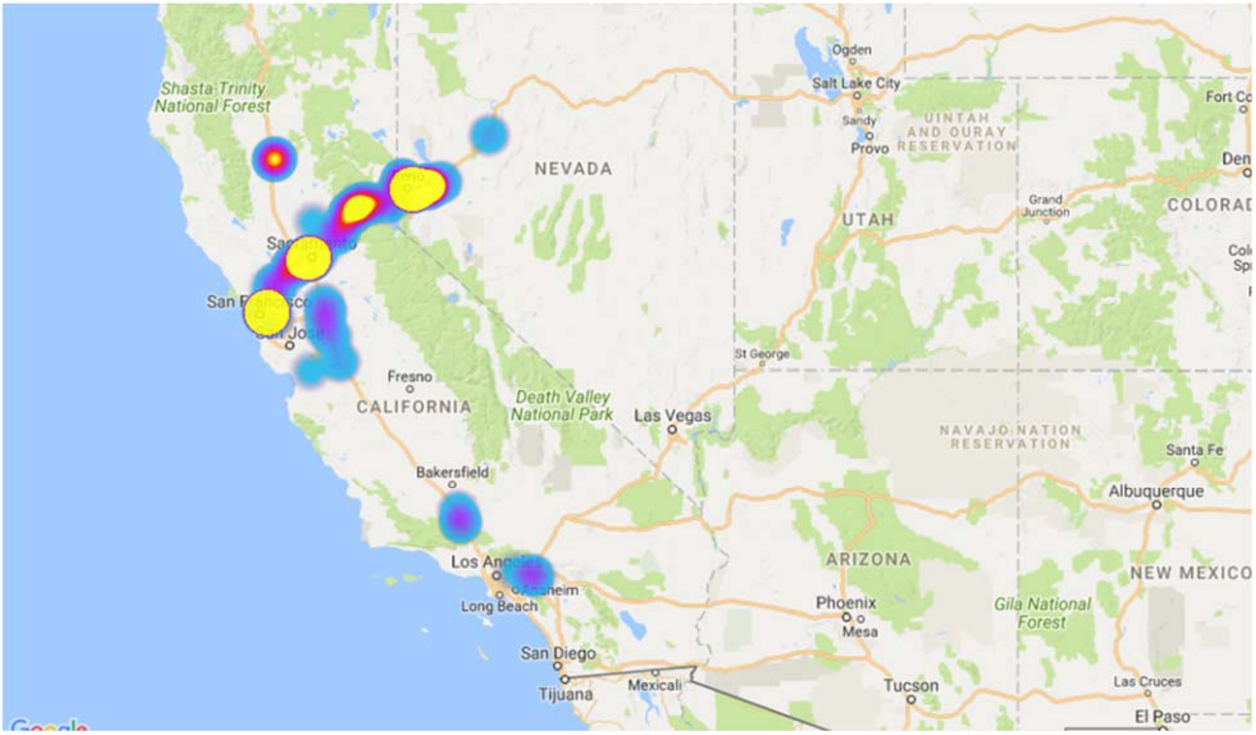


Figure 5-11. Trip distance distributions of all trips for fleet CC-NC-2

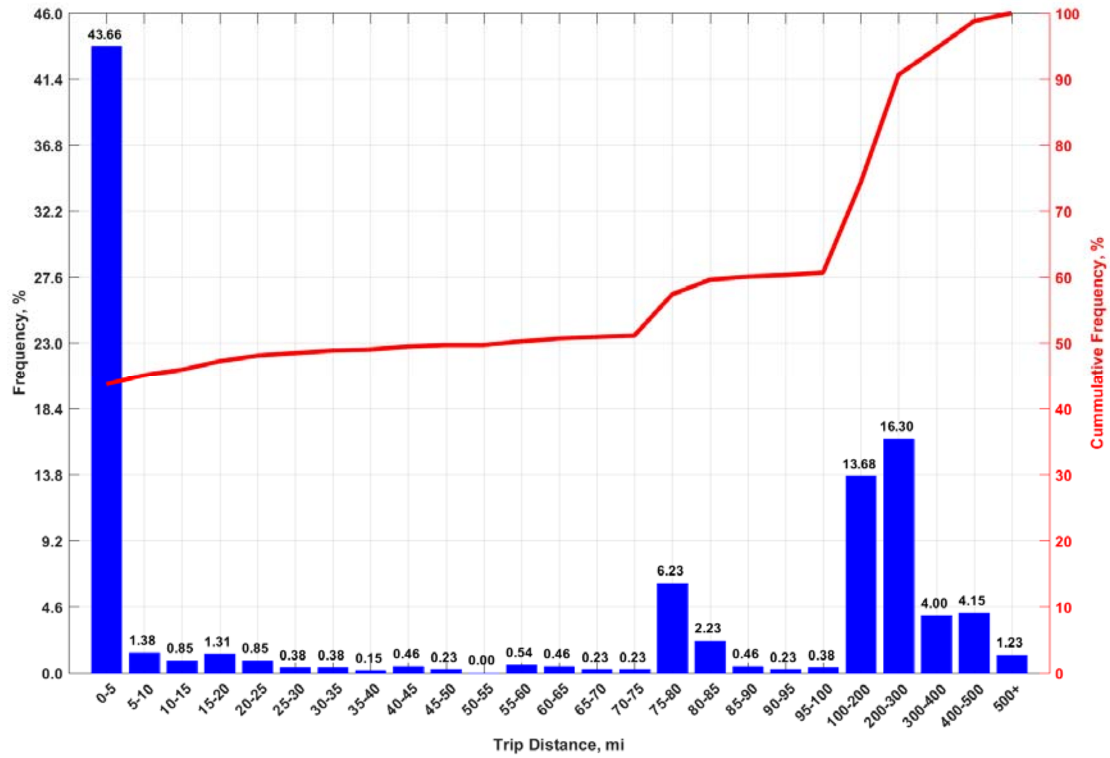


Figure 5-12. Trip distance distributions of non-idle trips for fleet CC-NC-2

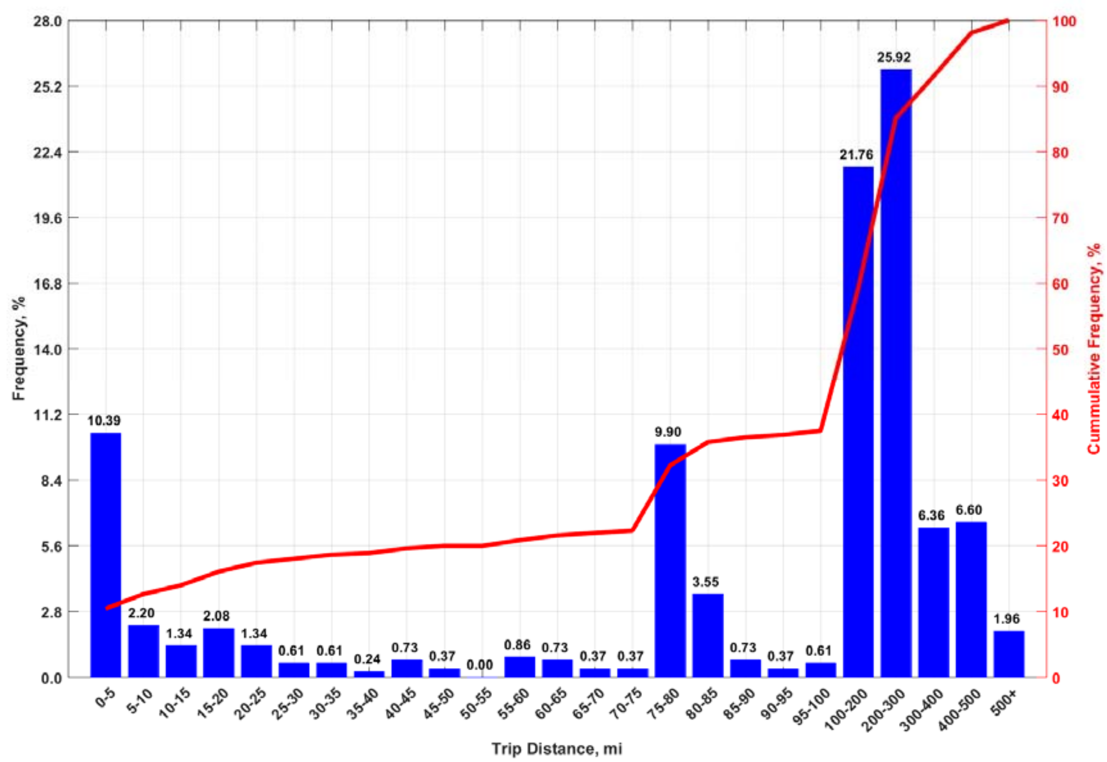


Figure 5-13. VMT by speed distribution of all trips for fleet CC-NC-2

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.44	0.60	0.81	0.79	0.82	1.02	1.36	1.71	1.92	2.79	5.53	14.69	41.71	24.73	1.08	0	0	0	*100*
Hour	Total																			
0	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.02	0.00	0	0	0	
1	1.41	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.03	0.05	0.04	0.06	0.20	0.52	0.40	0.00	0	0	0	
2	3.59	0.01	0.01	0.01	0.01	0.02	0.02	0.05	0.08	0.07	0.08	0.19	0.57	1.55	0.90	0.02	0	0	0	
3	5.29	0.01	0.01	0.01	0.01	0.02	0.02	0.06	0.07	0.06	0.11	0.22	0.70	2.62	1.35	0.03	0	0	0	
4	6.26	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.07	0.11	0.24	0.82	3.11	1.69	0.02	0	0	0	
5	6.60	0.01	0.02	0.02	0.03	0.04	0.06	0.09	0.11	0.14	0.20	0.43	1.05	2.62	1.76	0.04	0	0	0	
6	6.46	0.03	0.03	0.04	0.07	0.09	0.11	0.12	0.14	0.17	0.21	0.39	1.04	2.45	1.52	0.06	0	0	0	
7	5.50	0.04	0.08	0.12	0.11	0.10	0.10	0.11	0.12	0.11	0.14	0.26	0.77	1.95	1.42	0.08	0	0	0	
8	5.97	0.04	0.09	0.12	0.09	0.08	0.10	0.11	0.12	0.11	0.14	0.28	0.80	2.47	1.35	0.07	0	0	0	
9	6.33	0.03	0.07	0.10	0.08	0.07	0.09	0.12	0.12	0.10	0.12	0.26	0.84	2.81	1.46	0.05	0	0	0	
10	6.44	0.03	0.05	0.06	0.05	0.05	0.06	0.08	0.09	0.09	0.15	0.34	0.85	3.11	1.38	0.04	0	0	0	
11	8.05	0.03	0.05	0.06	0.06	0.05	0.06	0.07	0.12	0.13	0.20	0.49	1.20	3.70	1.77	0.05	0	0	0	
12	8.98	0.02	0.03	0.04	0.04	0.04	0.06	0.09	0.14	0.17	0.30	0.58	1.47	3.62	2.27	0.11	0	0	0	
13	8.10	0.02	0.04	0.05	0.05	0.05	0.06	0.09	0.13	0.16	0.25	0.52	1.21	3.04	2.29	0.13	0	0	0	
14	7.30	0.02	0.03	0.04	0.04	0.05	0.07	0.08	0.13	0.17	0.25	0.43	1.07	2.76	2.02	0.15	0	0	0	
15	5.34	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.10	0.12	0.18	0.29	0.74	2.06	1.44	0.10	0	0	0	
16	3.69	0.02	0.02	0.03	0.03	0.04	0.04	0.06	0.07	0.09	0.14	0.24	0.64	1.42	0.80	0.06	0	0	0	
17	2.36	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.06	0.11	0.19	0.42	0.97	0.39	0.02	0	0	0	
18	1.31	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.07	0.20	0.51	0.30	0.02	0	0	0	
19	0.36	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.10	0.07	0.00	0	0	0	
20	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.00	0	0	0	
21	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.03	0.00	0	0	0	
22	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.02	0.00	0	0	0	
23	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.09	0.02	0	0	0	0	
Sum	*100*																			*100*

Table 5-2. Summary statistics of data for fleet CC-NC-2

Description	Value
Number of vehicle samples	14
Total number of vehicle-days data logged	670
Total operating time (hours)	6,629
Total operating distance (miles)	143,901
Distance traveled per day per vehicle (miles)	214.8
Projected annual mileage per vehicle (miles)	78,402
Distance traveled at speed greater than 45 mph (%)	90.5
Total number of trips	1,296
Total number of idle trips	320
Total number of non-idle trips	976
Maximum trip distance (miles)	843.5
Mean trip distance of all trips (miles)	110.6
Mean trip distance of non-idle trips (miles)	146.9

5.1.3. Southern California Fleet #1 (CC-SC-1)

This is a truck fleet in Southern California that hauls container chassis trailers. We data logged 44 tractor-trailers from this fleet but one tractor-trailer did not provide usable data. Figure 5-14 and Figure 5-15 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. According to these figures, the fleet primarily serviced the San Pedro port complex and several other locations in the Greater Los Angeles Metropolitan area and the Inland Empire area. The fleet also occasionally serviced locations in the Central Valley and the inland part of Northern California.

Figure 5-16 shows the trip distance distributions of all 22,433 trips for this fleet where almost 70% of the trips were shorter than 5 miles. However, 10,665 trips or 48% were idle trips. Figure 5-17 presents the trip distance distributions of only non-idle trips (11,768 trips). It shows that the majority (about 90%) of the non-idle trips were shorter than 30 miles and almost all (about 99%) of the non-idle trips were shorter than 100 miles. These trip distance distributions represent a drayage operation near the port complex.

Figure 5-18 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 151,950 miles. Only about 12% of the VMT were at speeds of 55-60 mph and about another 12% of the VMT were at speeds of 50-55 mph, which are typical highway speeds for trucks in urban areas. Note that the speed limit for trucks in California is 55 mph. This fraction of VMT at highway speeds is much lower than the container chassis fleets in Northern California because, unlike the tractor-trailers in those fleets, the tractor-trailers in this fleet rarely traveled long distance. Another notable difference in the VMT by speed distribution of this fleet as compared to the distributions for the container chassis fleets in Northern California is that it has substantially more fraction of VMT at medium speeds of 35-50 mph. This could be contributed by the vehicles traveling less on highways and more on surface streets, and also by the fact that highways in this urban part of Southern California are more congested. The VMT generated by this fleet occurred the most during the morning hours (8 a.m.-12 p.m.).

Table 5-3 summarizes key statistics of this fleet. Based on the data logged from the 43 vehicle samples of this fleet, the projected annual mileage for each vehicle is only 19,163 miles. Approximately 42% of these miles would be at speeds greater than 45 mph, which is much lower than the container chassis fleets in Northern California. Given the relatively low annual mileage and the relatively low fraction of VMT at speed greater than 45 mph, this fleet is not likely to benefit much from aerodynamic improvements, as compared to the other two fleets in Northern California.

Figure 5-14. Heat map of trip origins for fleet CC-SC-1

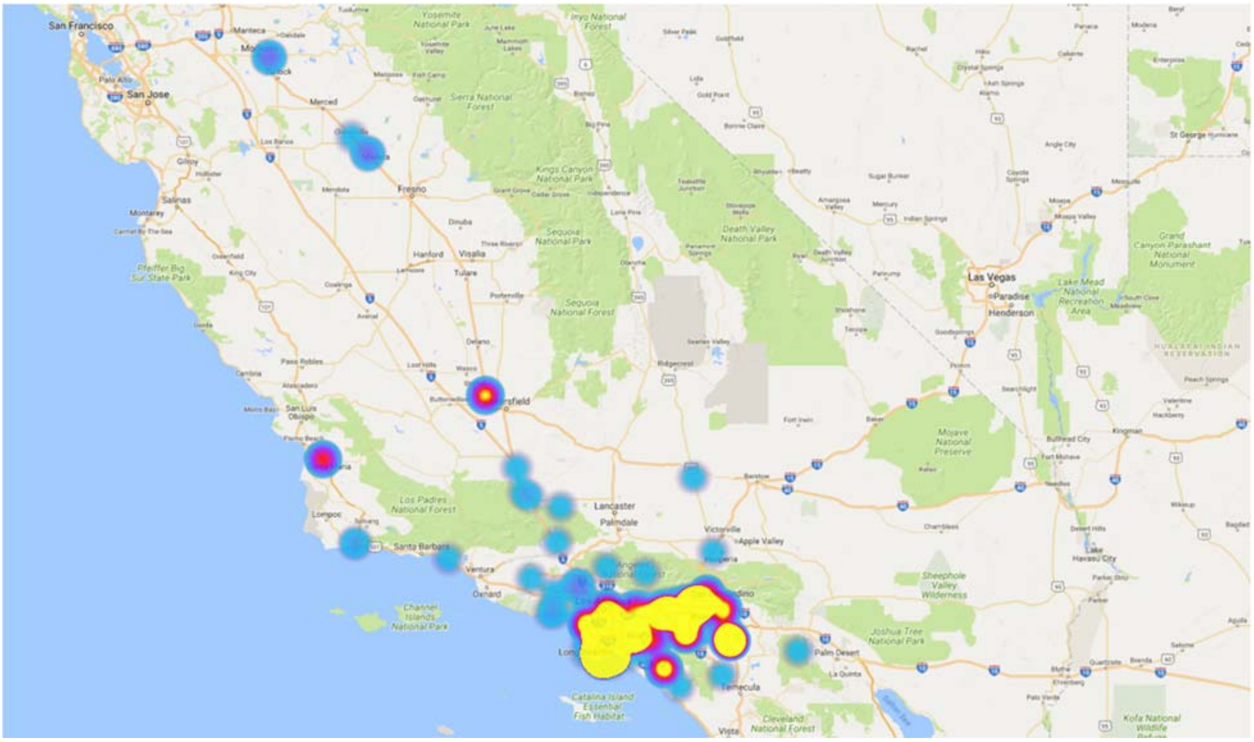


Figure 5-15. Heat map of trip destinations for fleet CC-SC-1

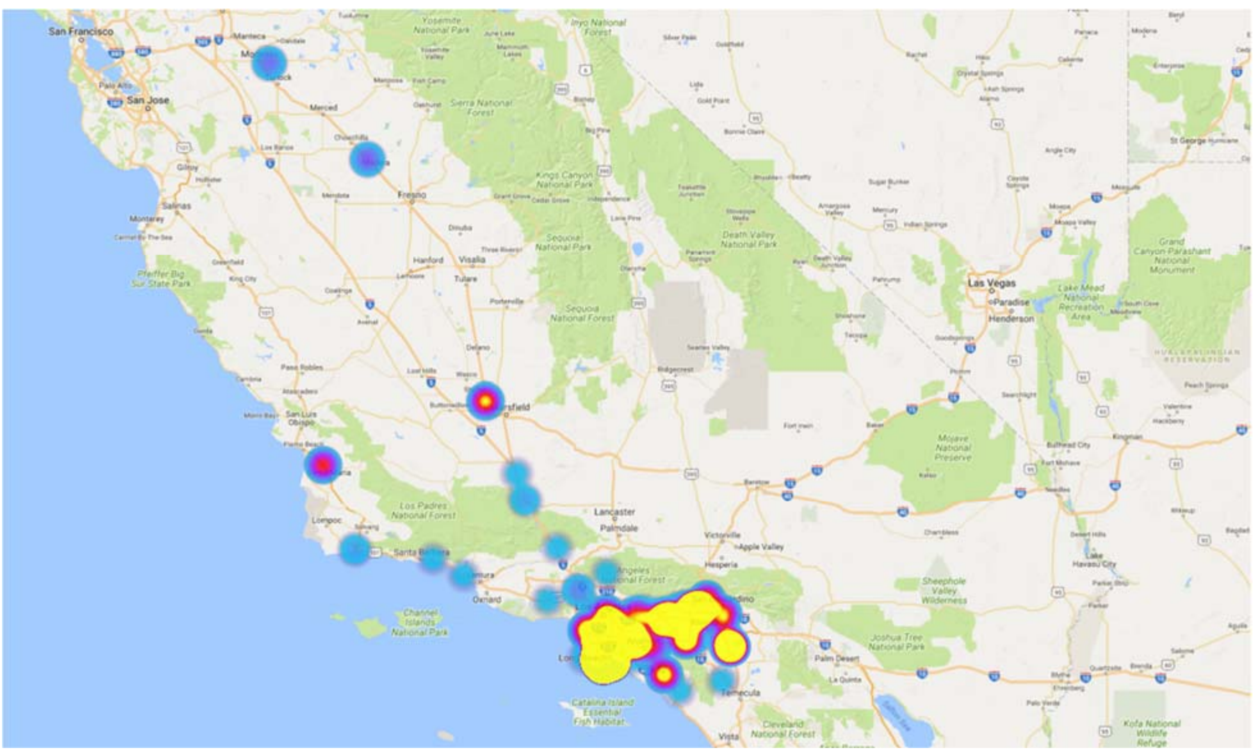


Figure 5-16. Trip distance distributions of all trips for fleet CC-SC-1

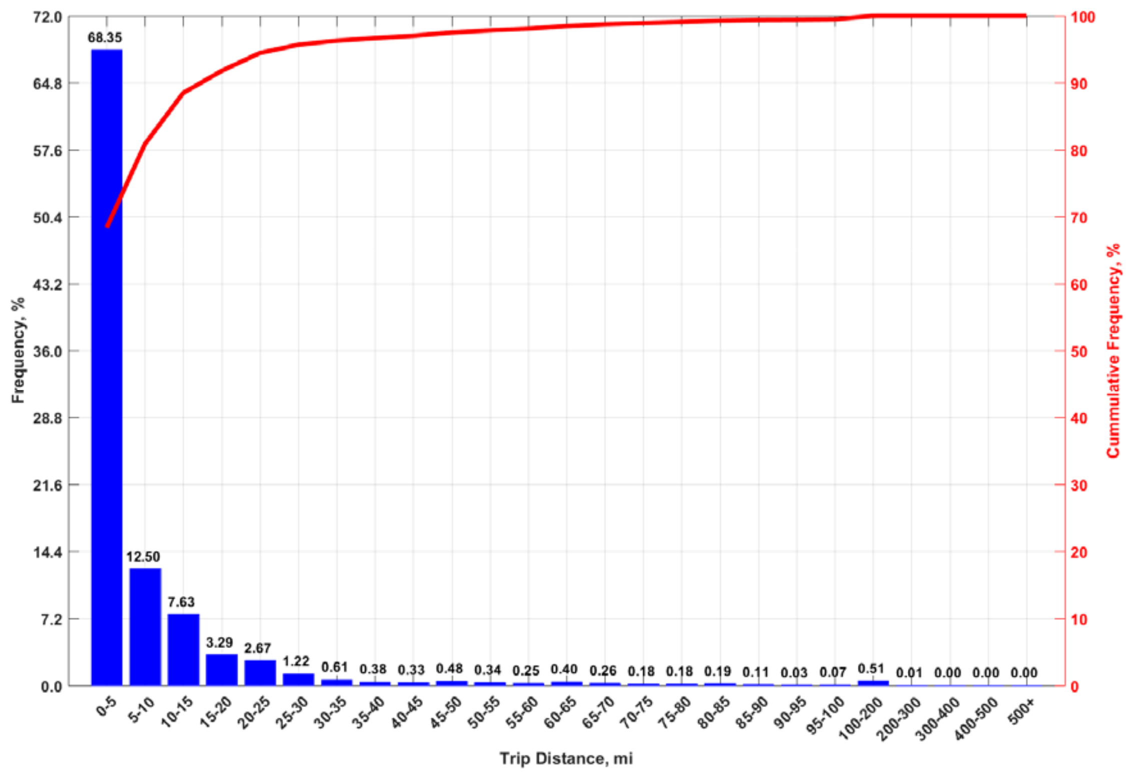


Figure 5-17. Trip distance distributions of non-idle trips for fleet CC-SC-1

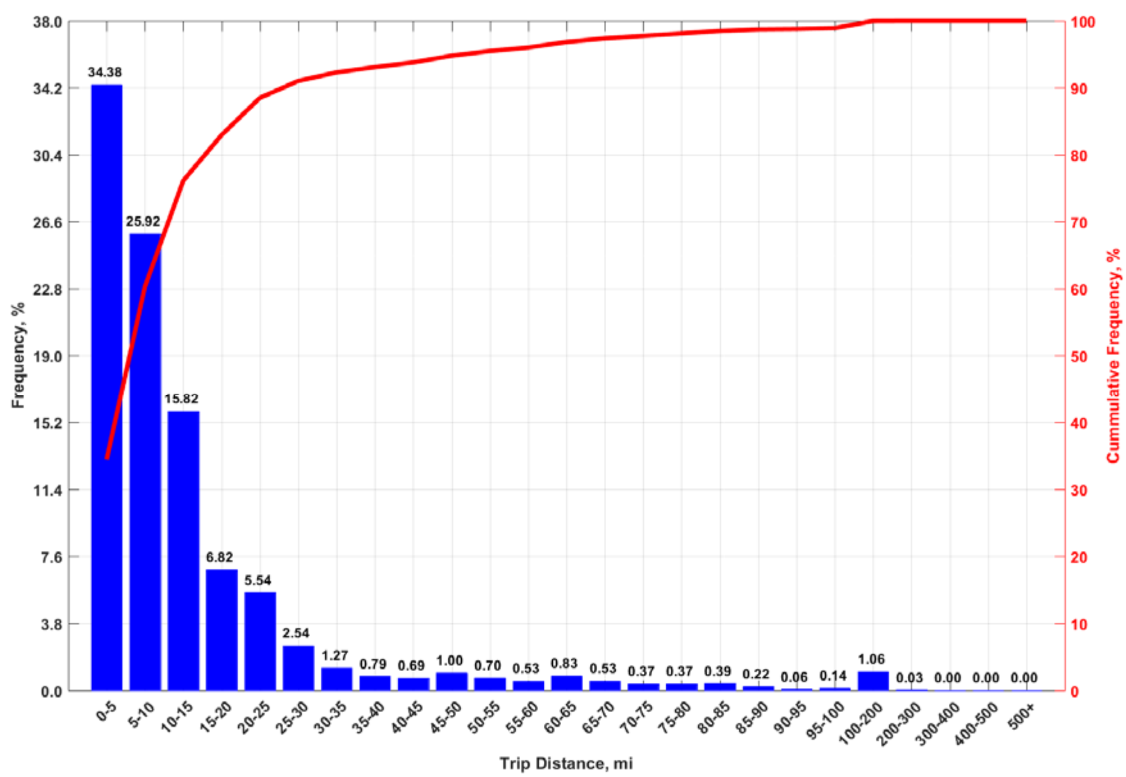


Figure 5-18. VMT by speed distribution of all trips for fleet CC-SC-1

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	2.64	5.28	6.25	5.98	5.55	6.10	7.19	8.71	9.89	10.61	11.57	11.65	7.44	1.14	0.03	0	0	0	*100*
Hour	Total																			
0	4.23	0.12	0.27	0.32	0.28	0.25	0.27	0.32	0.39	0.42	0.40	0.41	0.42	0.30	0.06	0.00	0	0	0	
1	3.80	0.10	0.22	0.26	0.24	0.22	0.25	0.30	0.36	0.44	0.46	0.38	0.29	0.23	0.05	0.00	0	0	0	
2	2.69	0.05	0.12	0.14	0.13	0.14	0.17	0.21	0.29	0.34	0.33	0.25	0.21	0.23	0.07	0.00	0	0	0	
3	0.94	0.01	0.02	0.03	0.03	0.03	0.05	0.06	0.09	0.12	0.11	0.11	0.12	0.12	0.05	0.00	0	0	0	
4	0.55	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.07	0.16	0.15	0.03	0.00	0	0	0	
5	1.44	0.02	0.04	0.03	0.03	0.03	0.04	0.05	0.06	0.08	0.11	0.20	0.37	0.36	0.05	0.00	0	0	0	
6	3.57	0.09	0.15	0.14	0.14	0.15	0.18	0.23	0.26	0.31	0.37	0.48	0.58	0.43	0.06	0.00	0	0	0	
7	5.29	0.14	0.29	0.36	0.36	0.33	0.36	0.42	0.50	0.52	0.52	0.52	0.51	0.36	0.08	0.00	0	0	0	
8	6.39	0.17	0.37	0.50	0.49	0.42	0.44	0.49	0.58	0.65	0.65	0.66	0.58	0.33	0.05	0.00	0	0	0	
9	7.51	0.17	0.35	0.45	0.46	0.42	0.44	0.51	0.63	0.75	0.81	0.93	0.94	0.56	0.07	0.00	0	0	0	
10	7.53	0.16	0.32	0.41	0.41	0.38	0.40	0.48	0.60	0.69	0.84	1.04	1.12	0.60	0.08	0.00	0	0	0	
11	6.72	0.15	0.28	0.34	0.36	0.34	0.37	0.44	0.54	0.63	0.70	0.88	1.00	0.61	0.07	0.00	0	0	0	
12	5.31	0.13	0.24	0.28	0.28	0.27	0.29	0.35	0.41	0.48	0.57	0.68	0.75	0.51	0.06	0.00	0	0	0	
13	5.06	0.15	0.29	0.35	0.33	0.29	0.30	0.34	0.41	0.46	0.50	0.65	0.62	0.32	0.04	0.00	0	0	0	
14	5.06	0.13	0.27	0.34	0.33	0.30	0.33	0.37	0.42	0.50	0.53	0.60	0.57	0.33	0.04	0.00	0	0	0	
15	4.36	0.10	0.21	0.26	0.27	0.27	0.29	0.35	0.41	0.47	0.50	0.52	0.43	0.23	0.04	0.00	0	0	0	
16	3.22	0.08	0.16	0.18	0.18	0.20	0.24	0.29	0.35	0.38	0.35	0.32	0.28	0.17	0.03	0.00	0	0	0	
17	3.39	0.12	0.22	0.23	0.21	0.23	0.28	0.34	0.38	0.39	0.33	0.30	0.24	0.11	0.01	0.00	0	0	0	
18	3.58	0.15	0.27	0.30	0.27	0.24	0.27	0.32	0.38	0.40	0.37	0.32	0.20	0.07	0.02	0.00	0	0	0	
19	3.80	0.14	0.26	0.30	0.27	0.23	0.24	0.28	0.34	0.38	0.43	0.41	0.33	0.18	0.03	0.00	0	0	0	
20	4.25	0.13	0.24	0.27	0.25	0.23	0.25	0.28	0.35	0.44	0.50	0.50	0.51	0.27	0.03	0.00	0	0	0	
21	4.50	0.12	0.23	0.27	0.25	0.23	0.26	0.31	0.37	0.40	0.50	0.56	0.56	0.40	0.06	0.00	0	0	0	
22	3.36	0.09	0.18	0.20	0.18	0.16	0.18	0.22	0.28	0.31	0.35	0.39	0.48	0.29	0.04	0.00	0	0	0	
23	3.46	0.12	0.24	0.27	0.23	0.18	0.20	0.23	0.28	0.31	0.34	0.39	0.38	0.26	0.02	0.00	0	0	0	
Sum	*100*																			*100*

Table 5-3. Summary statistics of data for fleet CC-SC-1

Description	Value
Number of vehicle samples	43
Total number of vehicle-days data logged	2,897
Total operating time (hours)	16,806
Total operating distance (miles)	151,950
Distance traveled per day per vehicle (miles)	52.5
Projected annual mileage per vehicle (miles)	19,163
Distance traveled at speed greater than 45 mph (%)	42.4
Total number of trips	22,433
Total number of idle trips	10,665
Total number of non-idle trips	11,768
Maximum trip distance (miles)	273.7
Mean trip distance of all trips (miles)	6.8
Mean trip distance of non-idle trips (miles)	12.4

5.1.4. Southern California Fleet #2 (CC-SC-2)

This is another truck fleet in Southern California that hauls container chassis trailers. We data logged 11 tractor-trailers from this fleet. Figure 5-19 and Figure 5-20 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. According to these figures, the fleet operated mostly in the Inland Empire area with some trips also involving locations in San Diego County.

Figure 5-21 shows the trip distance distributions of all 2,615 trips for this fleet where about 58% of the trips were shorter than 5 miles. However, 1,362 trips or 52% were idle trips. Figure 5-22 presents the trip distance distributions of only non-idle trips (1,253 trips). It shows that a large portion (about 39%) of the non-idle trips were regional, between 50 and 55 miles, and another 16% of the non-idle trips were long-distance trips over 100 miles.

Figure 5-23 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 64,119 miles. About 30% of the VMT were at speeds of 55-60 mph and another 19% of the VMT were at speeds of 50-55 mph. The majority of the VMT generated by this fleet occurred throughout the morning and early afternoon, with the peak between 6 and 7 a.m.

Table 5-4 summarizes key statistics of this fleet. Based on the data logged from the 11 vehicle samples of this fleet, the projected annual mileage per vehicle is 42,012 miles. Approximately 67% or two-thirds of these miles would be at speeds greater than 45 mph, which is lower than the container chassis fleets in Northern California but higher than the other container chassis fleet in Southern California. Thus, this fleet is likely to gain moderate benefits from aerodynamic improvements as compared to those fleets.

Figure 5-19. Heat map of trip origins for fleet CC-SC-2

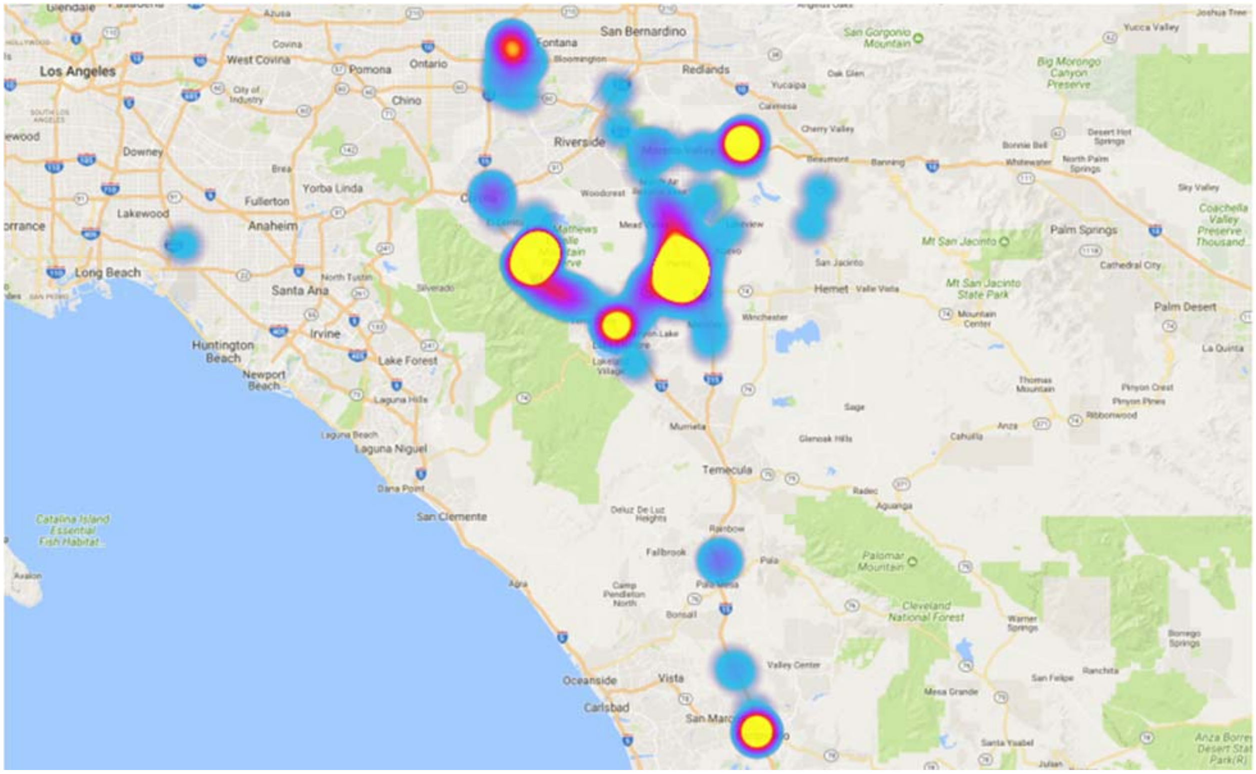


Figure 5-20. Heat map of trip destinations for fleet CC-SC-2

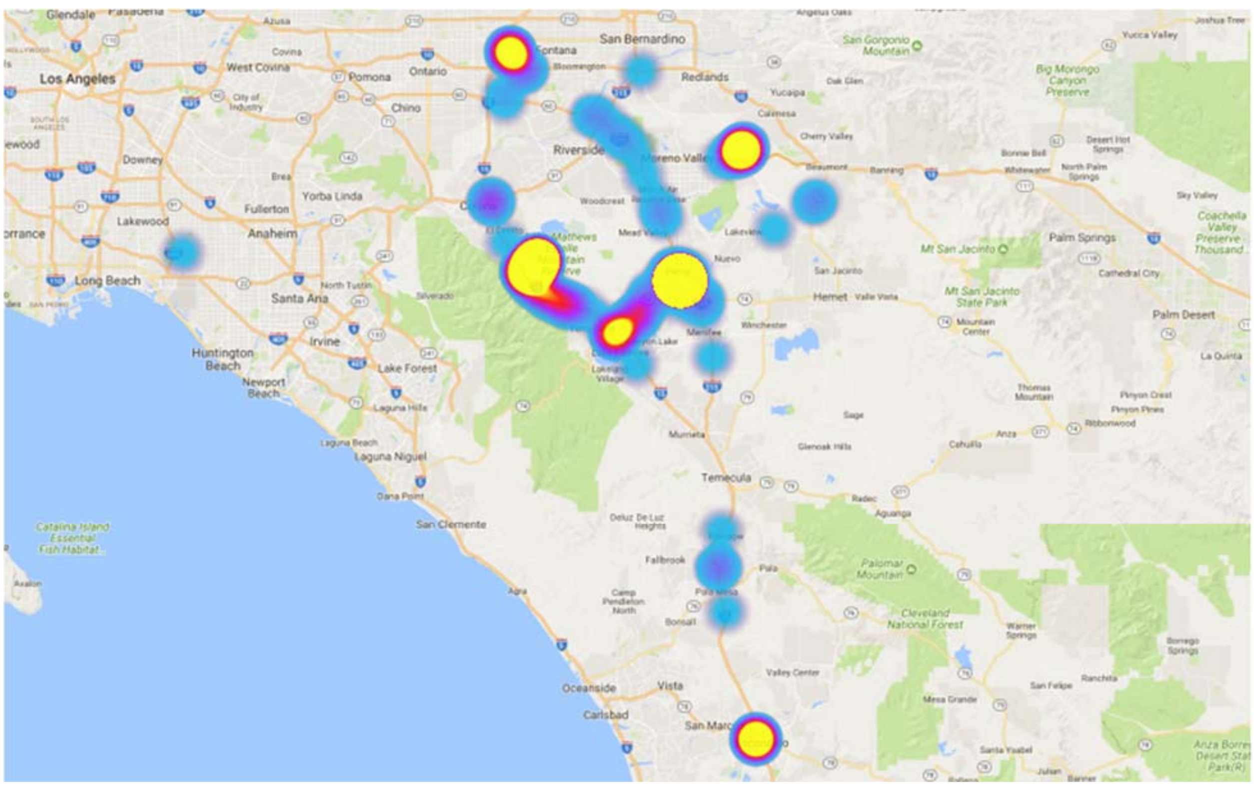


Figure 5-21. Trip distance distributions of all trips for fleet CC-SC-2

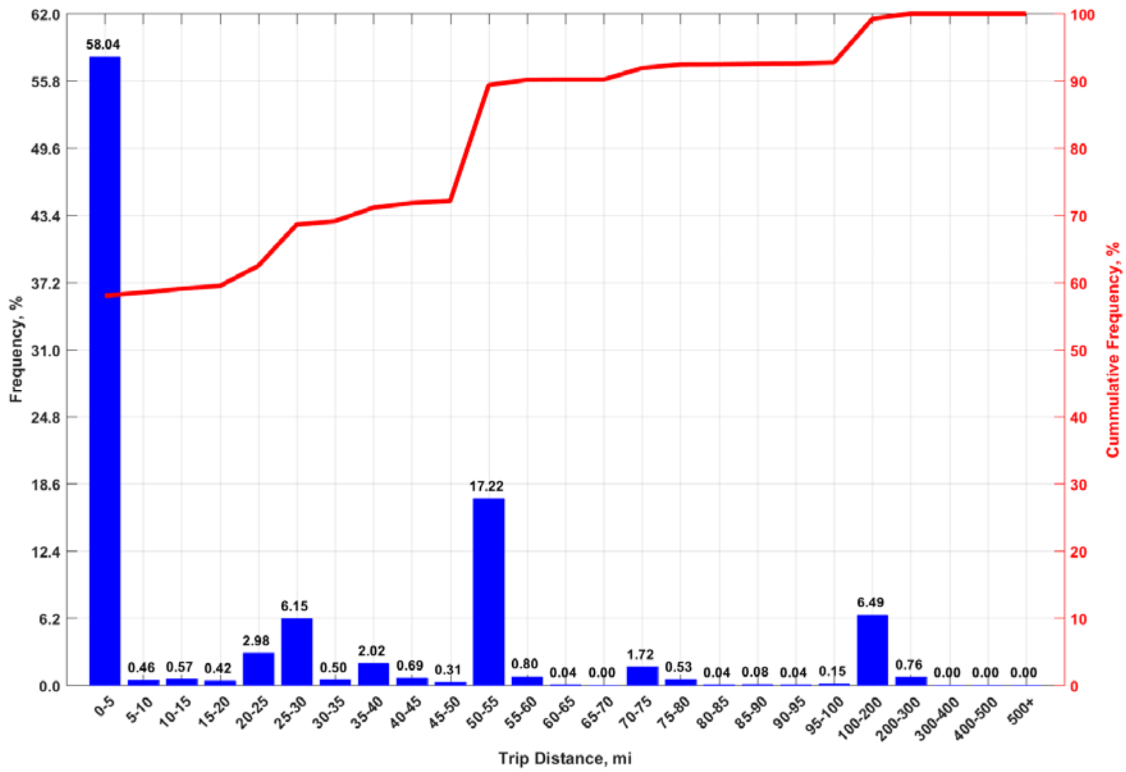


Figure 5-22. Trip distance distributions of non-idle trips for fleet CC-SC-2

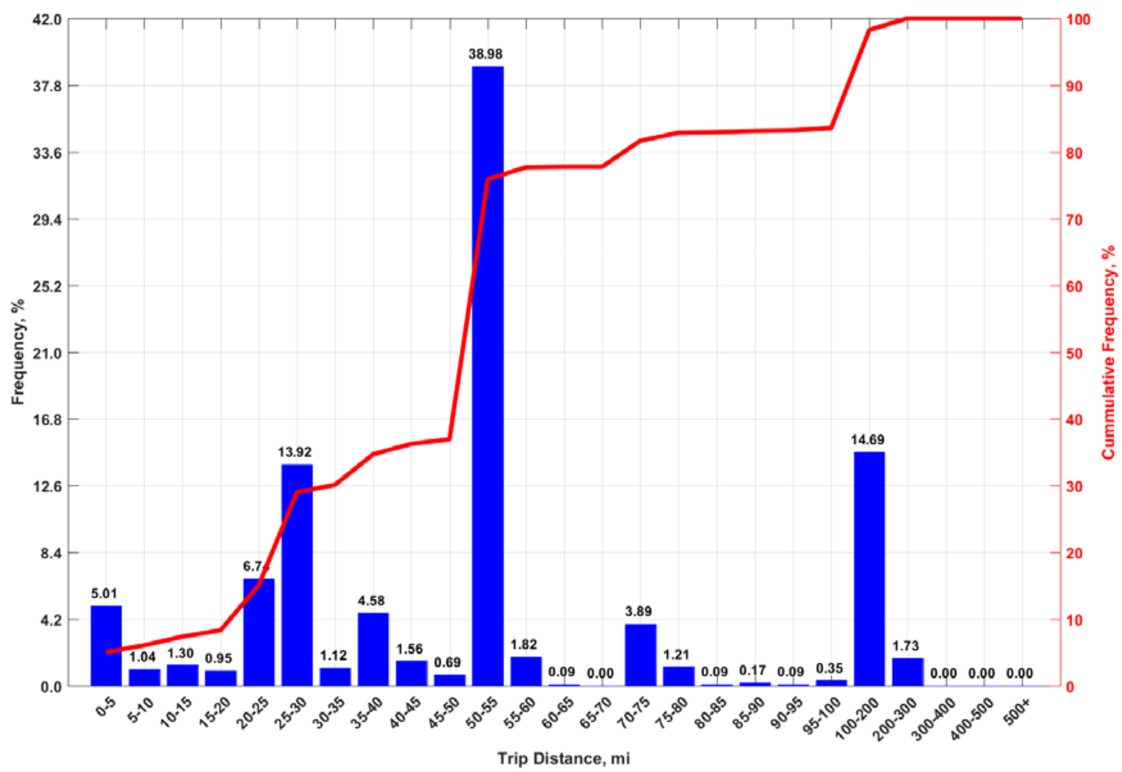


Figure 5-23. VMT by speed distribution of all trips for fleet CC-SC-2

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.92	2.85	3.38	3.34	3.66	4.09	3.87	4.87	6.51	9.11	18.97	30.38	7.31	0.74	0.02	0	0	0	*100*
Hour	Total																			
0	0.29	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.08	0.05	0.03	0.01	0	0	0	0	0	0	
1	0.64	0.00	0.02	0.02	0.02	0.03	0.04	0.03	0.02	0.03	0.04	0.15	0.21	0.02	0	0	0	0	0	
2	0.46	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.07	0.11	0.04	0.05	0.11	0.00	0	0	0	0	0	
3	0.13	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.03	0.02	0.00	0.00	0	0	0	
4	3.61	0.02	0.04	0.04	0.05	0.06	0.07	0.06	0.11	0.21	0.28	0.42	1.49	0.58	0.18	0.01	0	0	0	
5	8.72	0.07	0.20	0.24	0.27	0.32	0.35	0.35	0.44	0.61	0.92	1.68	2.49	0.67	0.09	0.00	0	0	0	
6	10.90	0.08	0.24	0.30	0.30	0.32	0.36	0.38	0.52	0.66	0.95	2.06	3.76	0.88	0.07	0.00	0	0	0	
7	8.37	0.08	0.24	0.24	0.21	0.24	0.29	0.28	0.35	0.40	0.64	1.66	3.01	0.69	0.04	0.00	0	0	0	
8	7.31	0.07	0.22	0.26	0.25	0.29	0.30	0.29	0.37	0.47	0.62	1.27	2.28	0.56	0.06	0.00	0	0	0	
9	7.88	0.06	0.20	0.28	0.28	0.30	0.29	0.31	0.37	0.49	0.67	1.59	2.42	0.56	0.05	0.00	0	0	0	
10	6.98	0.07	0.20	0.23	0.21	0.23	0.26	0.26	0.33	0.36	0.58	1.39	2.24	0.58	0.04	0.00	0	0	0	
11	7.62	0.07	0.21	0.27	0.28	0.32	0.34	0.31	0.39	0.52	0.71	1.43	2.29	0.43	0.06	0.00	0	0	0	
12	8.20	0.07	0.23	0.29	0.29	0.29	0.32	0.31	0.37	0.46	0.71	1.57	2.35	0.89	0.05	0.00	0	0	0	
13	6.52	0.07	0.22	0.26	0.25	0.26	0.30	0.27	0.32	0.38	0.56	1.29	1.83	0.46	0.05	0.00	0	0	0	
14	6.91	0.07	0.23	0.30	0.29	0.33	0.34	0.29	0.37	0.50	0.70	1.50	1.72	0.26	0.03	0	0	0	0	
15	7.02	0.06	0.23	0.29	0.29	0.29	0.33	0.30	0.36	0.45	0.69	1.42	1.87	0.43	0.02	0.00	0	0	0	
16	3.20	0.06	0.15	0.15	0.14	0.15	0.18	0.16	0.17	0.18	0.32	0.67	0.78	0.09	0.00	0	0	0	0	
17	1.29	0.02	0.07	0.06	0.05	0.06	0.08	0.06	0.06	0.08	0.14	0.24	0.34	0.02	0	0	0	0	0	
18	0.76	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.11	0.10	0.27	0.04	0	0	0	0	0	
19	0.54	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.08	0.07	0.11	0.11	0.01	0	0	0	0	0	
20	0.65	0.01	0.02	0.03	0.03	0.03	0.04	0.03	0.04	0.06	0.03	0.06	0.25	0.03	0	0	0	0	0	
21	0.53	0.00	0.01	0.02	0.02	0.02	0.03	0.02	0.03	0.11	0.08	0.05	0.13	0.02	0	0	0	0	0	
22	0.74	0.00	0.01	0.02	0.02	0.03	0.04	0.03	0.04	0.11	0.08	0.10	0.20	0.04	0	0	0	0	0	
23	0.74	0.00	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.10	0.09	0.11	0.21	0.03	0	0	0	0	0	
Sum	*100*																			*100*

Table 5-4. Summary statistics of data for fleet CC-SC-2

Description	Value
Number of vehicle samples	11
Total number of vehicle-days data logged	557
Total operating time (hours)	3,266
Total operating distance (miles)	64,119
Distance traveled per day per vehicle (miles)	115.1
Projected annual mileage per vehicle (miles)	42,012
Distance traveled at speed greater than 45 mph (%)	66.5
Total number of trips	2,615
Total number of idle trips	1,362
Total number of non-idle trips	1,253
Maximum trip distance (miles)	289.5
Mean trip distance of all trips (miles)	24.5
Mean trip distance of non-idle trips (miles)	50.8

5.2. Flatbed Trailers

Figure 5-24 shows the trip distance distributions of all 6,767 trips made by 69 flatbed tractor-trailers from two different fleets. About 41% of the trips were shorter than 5 miles; however, 2,510 trips or 37% were idle trips. Figure 5-25 shows the trip distance distributions of only non-idle trips (4,257 trips). It shows that about 23% of the non-idle trips were shorter than 25 miles while 29% were longer than 100 miles.

Together, the logged data from all trips represent a total VMT of 321,617 miles over 1,736 vehicle-days. This equates to a projected annual mileage per vehicle of 67,621 miles. Figure 5-26 presents the VMT by speed distribution of all trips. The prevalent speeds were 55-60 mph, and approximately 83% of the VMT were at speeds greater than 45 mph. These results indicate that the flatbed tractor-trailers data logged in this study, on average, would benefit substantially from aerodynamic technologies. However, the level of benefit experienced may vary by fleet. The results for each flatbed fleet are presented in the following subsections.

Figure 5-24. Trip distance distributions of all trips for all flatbed trailers combined

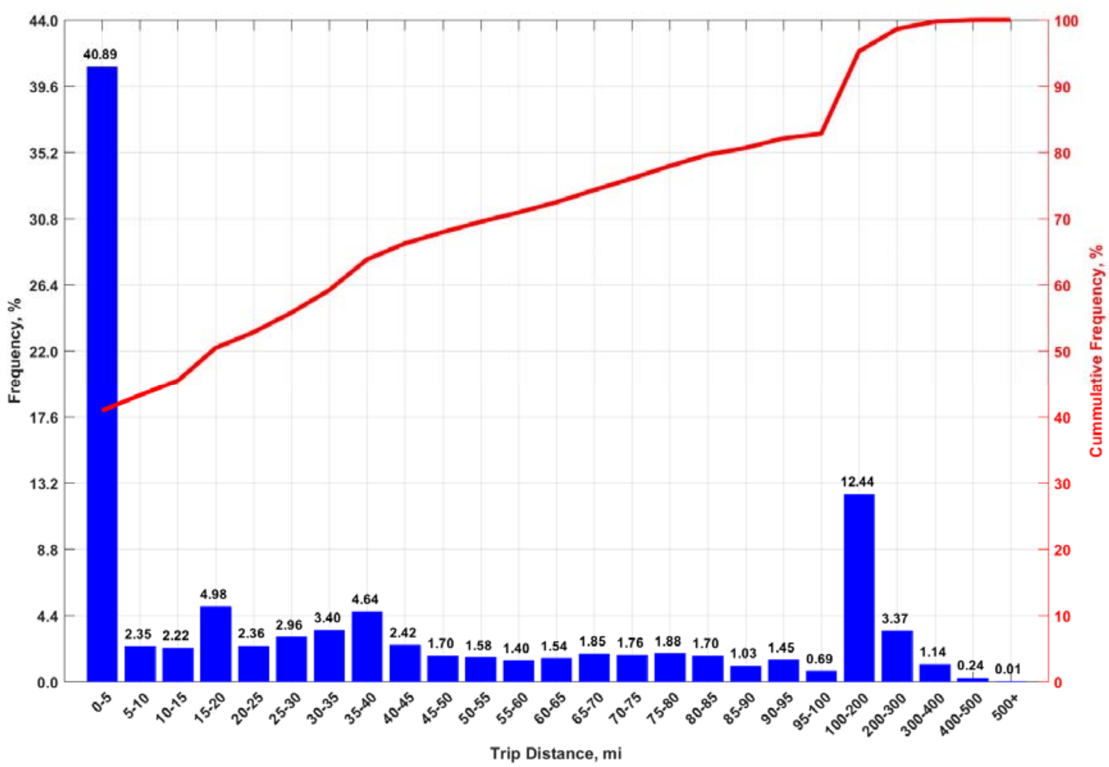


Figure 5-25. Trip distance distributions of non-idle trips for all flatbed trailers combined

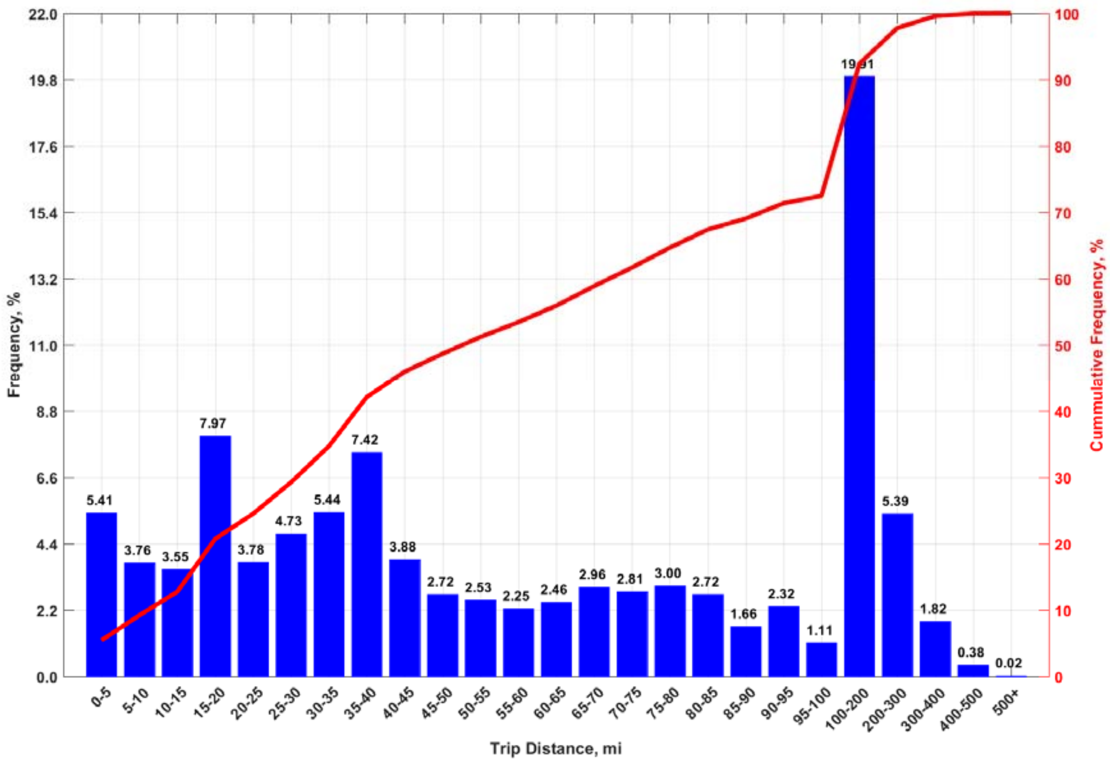


Figure 5-26. VMT by speed distribution of all trips for all flatbed trailers combined

		Speed Bin	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
		Total	0.29	0.89	1.05	1.08	1.42	1.85	2.56	3.20	4.31	6.39	10.57	50.15	16.16	0.09	0.01	0.00	0	0	*100*
Hour	Total																				
0	3.84		0.01	0.04	0.05	0.05	0.08	0.09	0.12	0.14	0.17	0.25	0.41	1.80	0.63	0.00	0	0	0	0	
1	3.59		0.01	0.04	0.04	0.04	0.06	0.08	0.10	0.14	0.19	0.23	0.36	1.71	0.59	0.00	0	0	0	0	
2	3.48		0.01	0.03	0.04	0.04	0.05	0.07	0.09	0.12	0.16	0.23	0.36	1.72	0.57	0.00	0	0	0	0	
3	3.31		0.01	0.03	0.03	0.03	0.05	0.06	0.08	0.11	0.15	0.23	0.36	1.62	0.54	0.00	0.00	0	0	0	
4	3.10		0.01	0.03	0.03	0.03	0.04	0.05	0.08	0.10	0.13	0.21	0.32	1.50	0.56	0.00	0	0	0	0	
5	3.57		0.01	0.03	0.03	0.03	0.05	0.06	0.08	0.11	0.17	0.26	0.40	1.70	0.64	0.00	0.00	0	0	0	
6	3.09		0.01	0.03	0.03	0.03	0.04	0.05	0.07	0.10	0.15	0.21	0.29	1.50	0.57	0.00	0.00	0	0	0	
7	2.64		0.01	0.02	0.02	0.02	0.03	0.05	0.06	0.08	0.12	0.15	0.25	1.36	0.45	0.00	0.00	0	0	0	
8	2.64		0.01	0.02	0.02	0.02	0.03	0.04	0.05	0.08	0.10	0.14	0.24	1.38	0.51	0.01	0.00	0.00	0	0	
9	2.63		0.01	0.02	0.02	0.02	0.03	0.04	0.06	0.07	0.09	0.13	0.26	1.39	0.48	0.01	0.00	0.00	0	0	
10	3.27		0.01	0.02	0.02	0.02	0.03	0.03	0.05	0.07	0.09	0.15	0.30	1.83	0.63	0.01	0.00	0.00	0	0	
11	3.84		0.01	0.03	0.03	0.03	0.04	0.05	0.07	0.08	0.12	0.18	0.30	2.20	0.71	0.01	0.00	0	0	0	
12	4.78		0.01	0.03	0.04	0.04	0.05	0.06	0.10	0.14	0.20	0.31	0.52	2.57	0.73	0.00	0.00	0	0	0	
13	5.00		0.01	0.04	0.05	0.05	0.07	0.08	0.12	0.15	0.21	0.30	0.51	2.63	0.76	0.00	0	0	0	0	
14	5.38		0.02	0.04	0.05	0.06	0.07	0.09	0.13	0.17	0.24	0.33	0.51	2.78	0.88	0.00	0.00	0	0	0	
15	5.28		0.02	0.06	0.07	0.07	0.08	0.10	0.14	0.17	0.23	0.34	0.54	2.65	0.81	0.00	0.00	0.00	0	0	
16	5.70		0.02	0.05	0.07	0.07	0.09	0.12	0.16	0.18	0.24	0.39	0.62	2.84	0.86	0.00	0.00	0	0	0	
17	5.39		0.02	0.05	0.06	0.06	0.08	0.11	0.16	0.19	0.25	0.39	0.67	2.59	0.76	0.00	0	0	0	0	
18	5.71		0.01	0.05	0.06	0.06	0.08	0.11	0.15	0.19	0.25	0.39	0.66	2.86	0.82	0.00	0.00	0	0	0	
19	5.24		0.01	0.04	0.05	0.06	0.08	0.10	0.14	0.18	0.25	0.36	0.62	2.52	0.81	0.00	0.00	0	0	0	
20	4.79		0.02	0.05	0.06	0.06	0.08	0.10	0.13	0.16	0.22	0.33	0.57	2.33	0.70	0.00	0	0	0	0	
21	4.81		0.02	0.05	0.05	0.06	0.08	0.10	0.15	0.17	0.22	0.33	0.57	2.29	0.71	0.00	0.00	0	0	0	
22	4.59		0.02	0.05	0.05	0.06	0.08	0.10	0.14	0.15	0.19	0.29	0.49	2.21	0.77	0.00	0	0	0	0	
23	4.35		0.02	0.05	0.06	0.06	0.07	0.09	0.12	0.14	0.17	0.27	0.45	2.17	0.68	0.00	0	0	0	0	
Sum	*100*																				*100*

5.2.1. Central Valley Fleet #1 (FB-CV-1)

This is a truck fleet in the Central Valley that hauls flatbed trailers. The data for this fleet were for 65 tractor-trailers, which were obtained from a commercial fleet monitoring source. Figure 5-27 and Figure 5-28 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. According to these figures, the fleet operated throughout California, all the way from the Greater Sacramento region to the border with Mexico, and also from the Pacific coast to the border with the state of Nevada.

Figure 5-29 shows the trip distance distributions of all 5,727 trips for this fleet where about 37% of the trips were shorter than 5 miles. However, 1,929 trips or about a third were idle trips. Figure 5-30 presents the trip distance distributions of only non-idle trips (3,798 trips). It shows that only about 5% of the non-idle trips were shorter than 5 miles while a large portion (about 30%) of the non-idle trips were long-distance trips over 100 miles.

Figure 5-31 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 303,423 miles. About a half of the VMT were at speeds of 55-60 mph and about 16% of the VMT were at speeds of 60-65 mph, which are typical highway speeds. These VMT were generated almost twice as much in the second half of the day (12 p.m. – 12 a.m.) than in the first half of the day (12 a.m. – 12 p.m.).

Table 5-5 summarizes key statistics of this fleet. Based on the data logged from the 65 vehicle samples of this fleet, the projected annual mileage for each vehicle is 71,905 miles. Approximately 84% of these miles would be at speeds greater than 45 mph, which stand to benefit from aerodynamic improvements.

Figure 5-27. Heat map of trip origins for fleet FB-CV-1

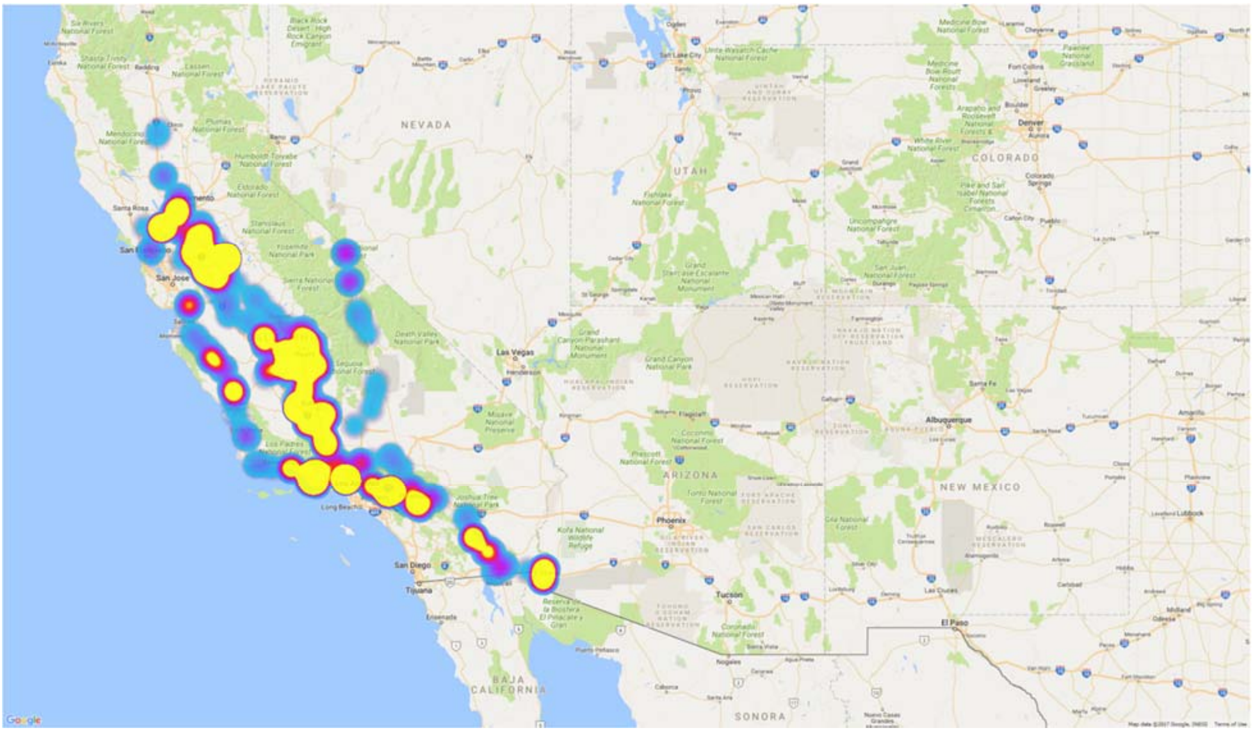


Figure 5-28. Heat map of trip destinations for fleet FB-CV-1

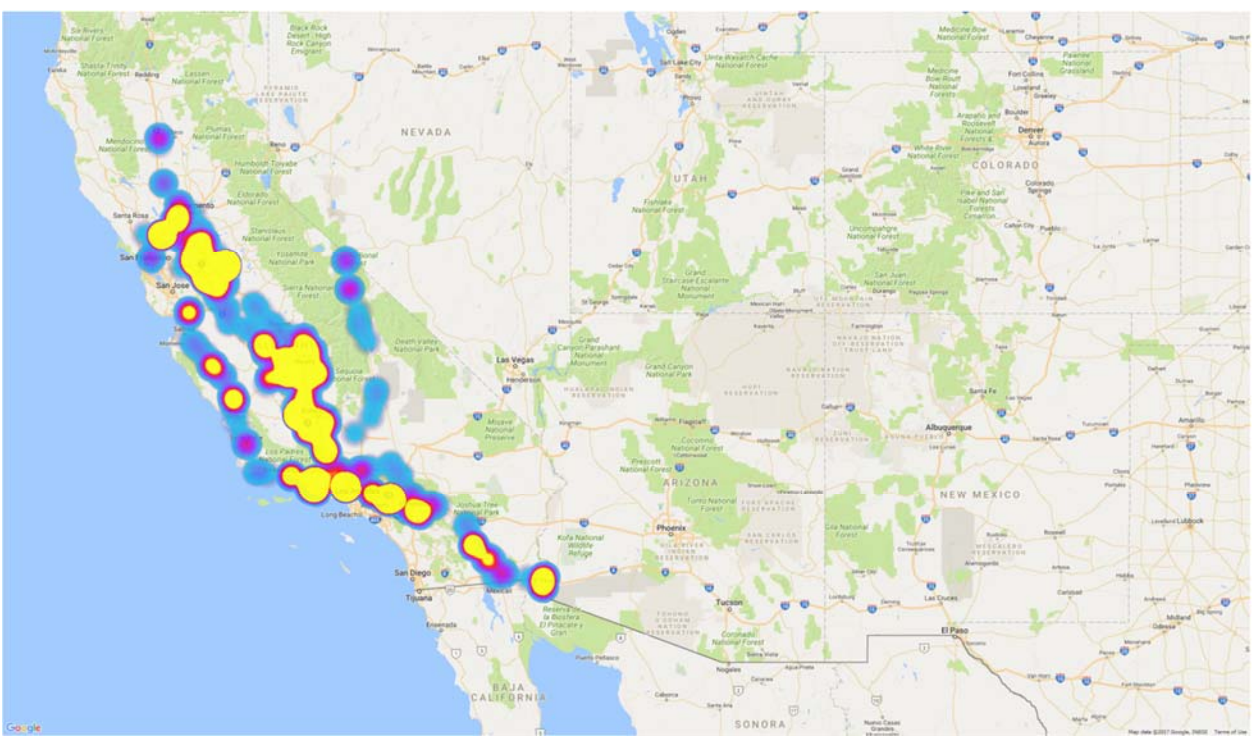


Figure 5-29. Trip distance distributions of all trips for fleet FB-CV-1

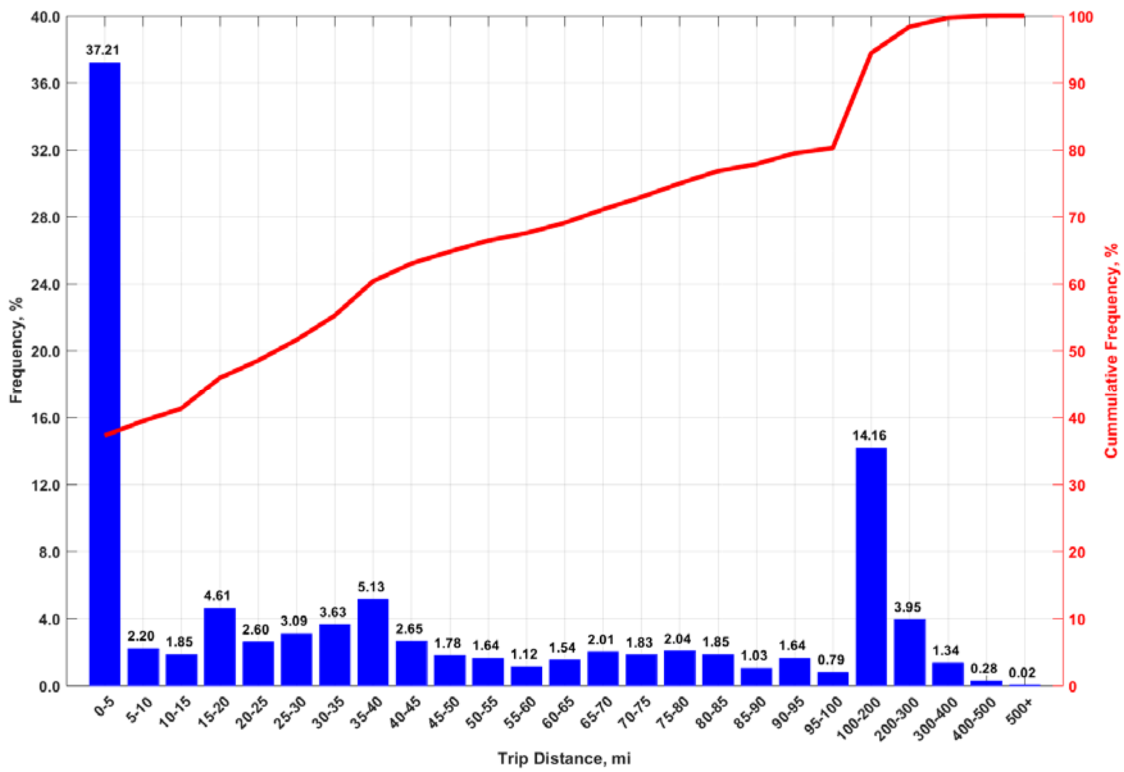


Figure 5-30. Trip distance distributions of non-idle trips for fleet FB-CV-1

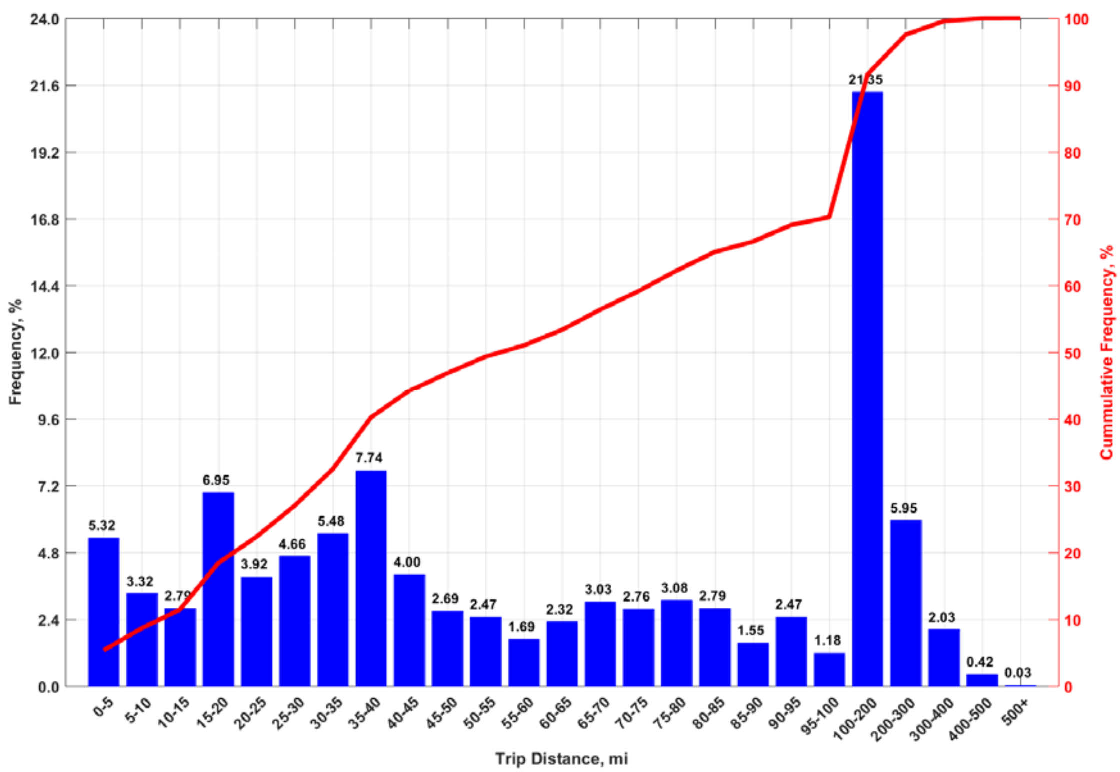


Figure 5-31. VMT by speed distribution of all trips for fleet FB-CV-1

	Speed Bin	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.28	0.88	1.04	1.06	1.40	1.83	2.54	3.19	4.30	6.34	10.39	50.46	16.19	0.08	0.01	0.00	0	0	*100*
Hour	Total																			
0	3.90	0.01	0.04	0.05	0.06	0.08	0.09	0.12	0.14	0.17	0.25	0.41	1.83	0.64	0.00	0	0	0	0	
1	3.65	0.01	0.04	0.04	0.05	0.06	0.08	0.10	0.14	0.19	0.24	0.36	1.74	0.60	0.00	0	0	0	0	
2	3.54	0.01	0.03	0.04	0.04	0.05	0.07	0.09	0.12	0.16	0.24	0.37	1.75	0.58	0.00	0	0	0	0	
3	3.36	0.01	0.03	0.03	0.03	0.05	0.06	0.08	0.11	0.15	0.23	0.37	1.64	0.54	0.00	0.00	0	0	0	
4	3.12	0.01	0.03	0.03	0.03	0.04	0.05	0.08	0.10	0.13	0.21	0.32	1.51	0.57	0.00	0	0	0	0	
5	3.36	0.01	0.02	0.03	0.03	0.04	0.05	0.07	0.11	0.16	0.23	0.32	1.66	0.62	0.00	0.00	0	0	0	
6	2.97	0.01	0.03	0.03	0.03	0.04	0.05	0.07	0.09	0.14	0.18	0.25	1.50	0.56	0.00	0	0	0	0	
7	2.62	0.01	0.02	0.02	0.02	0.03	0.05	0.06	0.08	0.11	0.15	0.24	1.36	0.45	0.00	0.00	0	0	0	
8	2.52	0.01	0.02	0.02	0.02	0.03	0.03	0.05	0.07	0.09	0.13	0.20	1.35	0.49	0.01	0.00	0.00	0	0	
9	2.49	0.01	0.02	0.02	0.02	0.03	0.04	0.05	0.07	0.08	0.12	0.23	1.34	0.46	0.01	0.00	0.00	0	0	
10	3.15	0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.09	0.14	0.27	1.80	0.62	0.01	0.00	0.00	0	0	
11	3.76	0.01	0.02	0.03	0.03	0.03	0.04	0.06	0.08	0.11	0.17	0.27	2.19	0.69	0.00	0.00	0	0	0	
12	4.73	0.01	0.03	0.03	0.03	0.05	0.06	0.10	0.13	0.19	0.30	0.50	2.57	0.72	0.00	0	0	0	0	
13	4.95	0.01	0.04	0.05	0.05	0.06	0.08	0.12	0.15	0.21	0.29	0.50	2.63	0.76	0.00	0	0	0	0	
14	5.36	0.02	0.04	0.05	0.05	0.07	0.09	0.12	0.17	0.23	0.33	0.51	2.79	0.87	0.00	0.00	0	0	0	
15	5.32	0.02	0.06	0.07	0.07	0.08	0.10	0.14	0.17	0.23	0.34	0.55	2.68	0.81	0.00	0.00	0.00	0	0	
16	5.78	0.02	0.06	0.07	0.07	0.09	0.12	0.16	0.18	0.24	0.39	0.62	2.88	0.87	0.00	0.00	0	0	0	
17	5.47	0.02	0.05	0.06	0.06	0.08	0.11	0.16	0.19	0.26	0.40	0.68	2.63	0.77	0.00	0	0	0	0	
18	5.80	0.02	0.05	0.06	0.06	0.08	0.12	0.16	0.19	0.25	0.39	0.68	2.91	0.84	0.00	0.00	0	0	0	
19	5.32	0.02	0.05	0.05	0.06	0.08	0.10	0.15	0.19	0.25	0.37	0.63	2.56	0.83	0.00	0.00	0	0	0	
20	4.87	0.02	0.05	0.06	0.06	0.08	0.10	0.13	0.16	0.22	0.33	0.58	2.37	0.71	0.00	0	0	0	0	
21	4.88	0.02	0.05	0.05	0.06	0.08	0.11	0.15	0.17	0.22	0.34	0.58	2.33	0.72	0.00	0.00	0	0	0	
22	4.66	0.02	0.05	0.05	0.06	0.08	0.10	0.14	0.15	0.20	0.29	0.50	2.25	0.78	0.00	0	0	0	0	
23	4.42	0.02	0.05	0.06	0.06	0.07	0.09	0.12	0.14	0.18	0.27	0.46	2.20	0.69	0.00	0	0	0	0	
Sum	*100*																			*100*

Table 5-5. Summary statistics of data for fleet FB-CV-1

Description	Value
Number of vehicle samples	65
Total number of vehicle-days data logged	1,540
Total operating time (hours)	8,400
Total operating distance (miles)	303,423
Distance traveled per day per vehicle (miles)	197.0
Projected annual mileage per vehicle (miles)	71,905
Distance traveled at speed greater than 45 mph (%)	83.5
Total number of trips	5,727
Total number of idle trips	1,929
Total number of non-idle trips	3,798
Maximum trip distance (miles)	574.2
Mean trip distance of all trips (miles)	53.0
Mean trip distance of non-idle trips (miles)	79.8

5.2.2. Southern California Fleet #1 (FB-SC-1)

This is a truck fleet in Southern California that hauls flatbed trailers. We data logged four tractor-trailers from this fleet. Figure 5-32 and Figure 5-33 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. According to these figures, the fleet had operation mostly in the Inland Empire and the Greater Los Angeles Metropolitan area with some operation also in the San Diego County.

Figure 5-34 shows the trip distance distributions of all 1,040 trips for this fleet where about 61% of the trips were shorter than 5 miles. However, 581 trips or 56% were idle trips. Figure 5-35 presents the trip distance distributions of only non-idle trips (459 trips). It shows that only 6% of the non-idle trips were shorter than 5 miles while about 17% of the non-idle trips were local trips of 15-20 miles and another 8% were long-distance trips over 100 miles.

Figure 5-36 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 18,194 miles. About 30% of the VMT were at speeds of 55-60 mph and about 22% of the VMT were at speeds of 50-55 mph, which are typical highway speeds in urban areas. These VMT were generated the most during the windows between 5 a.m. and 7 a.m. as well as between 9 a.m. and 11 a.m.

Table 5-6 summarizes key statistics of this fleet. Based on the data logged from the four vehicle samples of this fleet, the projected annual mileage per vehicle is 33,872 miles. Approximately 76% of these miles would be at speeds greater than 45 mph, which is lower than the flatbed fleet in the Central Valley. Thus, this fleet is likely to gain slightly lower benefits from aerodynamic improvements as compared to the other flatbed fleet.

Figure 5-32. Heat map of trip origins for fleet FB-SC-1

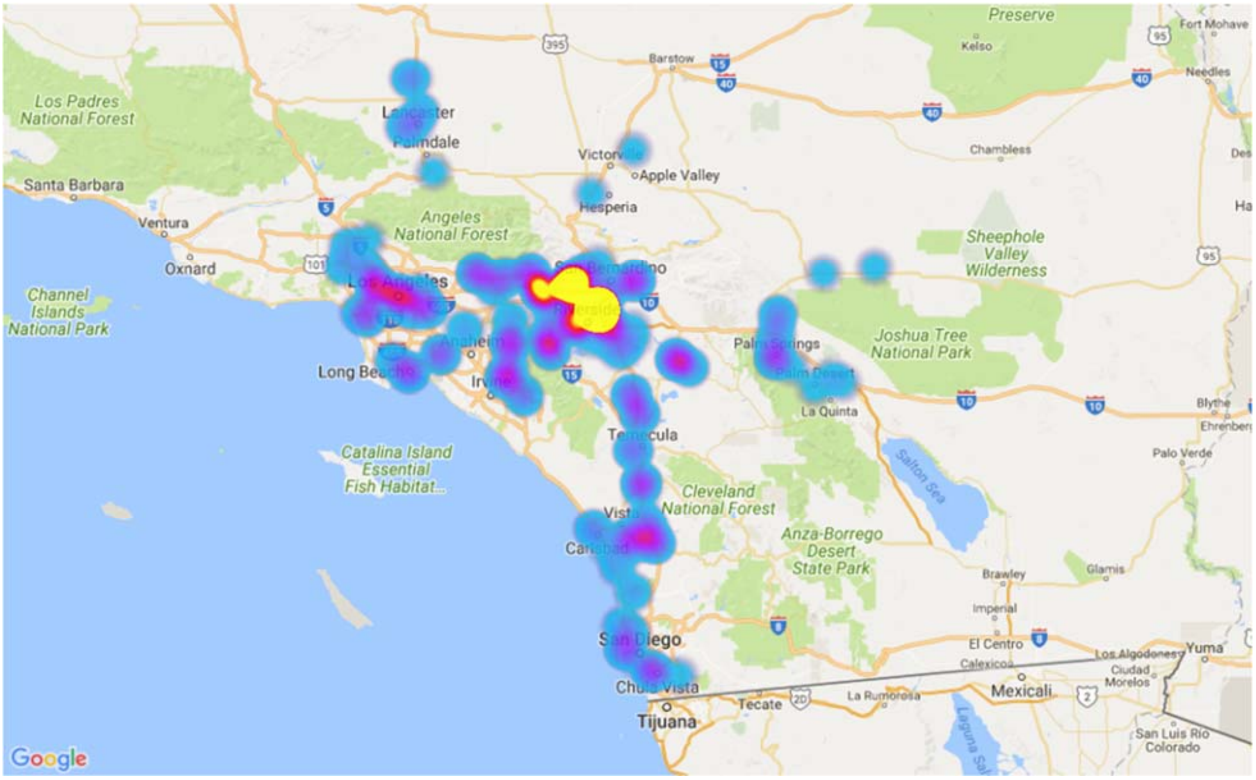


Figure 5-33. Heat map of trip destinations for fleet FB-SC-1

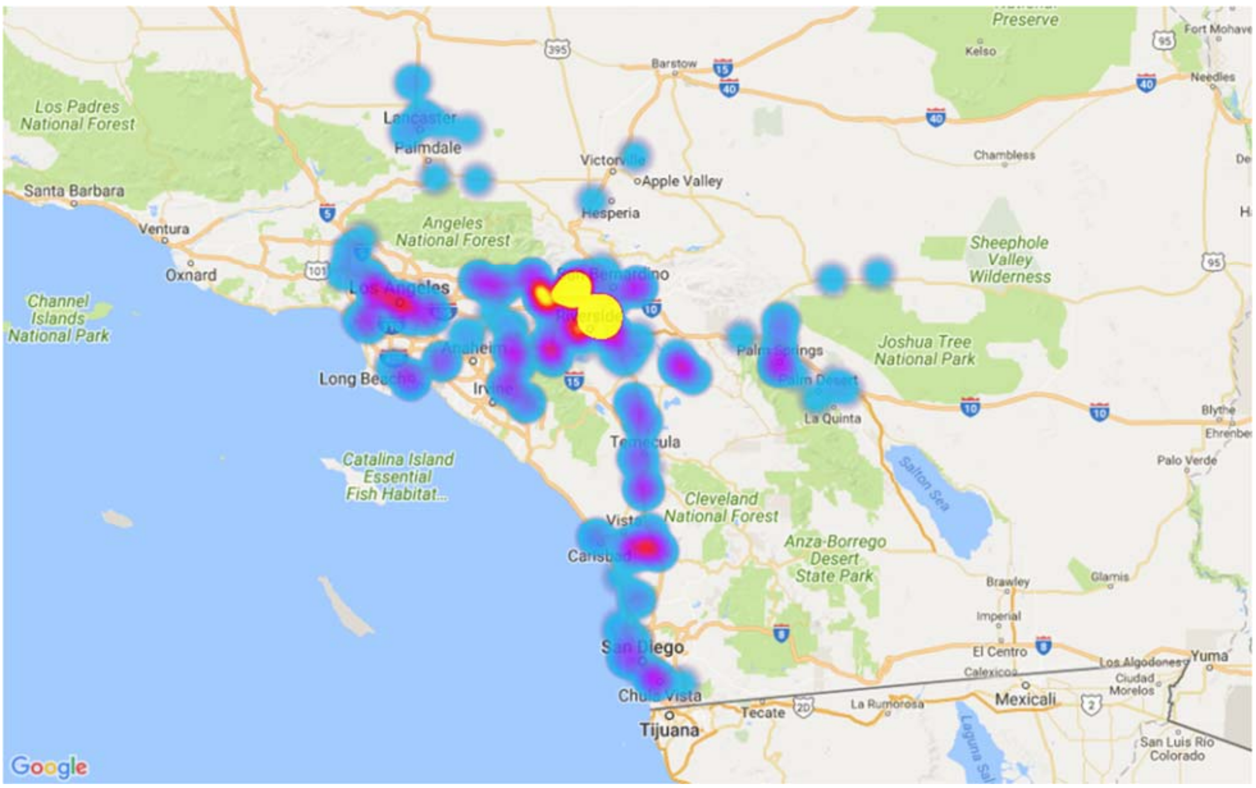


Figure 5-34. Trip distance distributions of all trips for fleet FB-SC-1

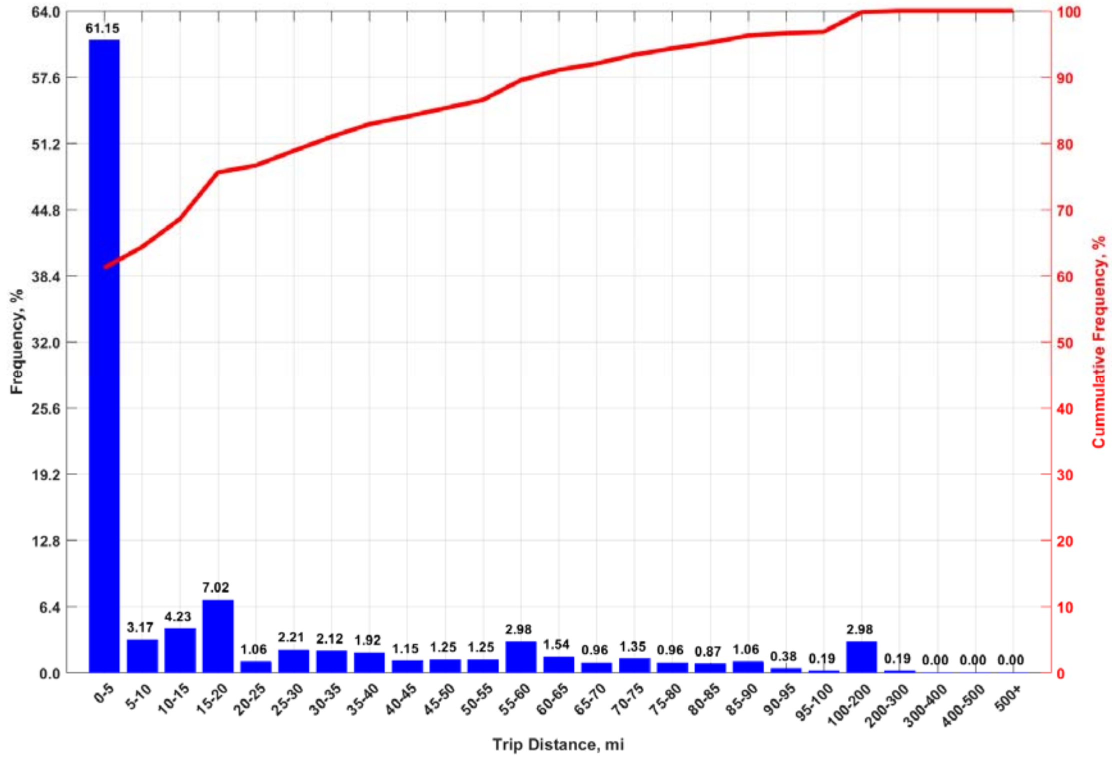


Figure 5-35. Trip distance distributions of non-idle trips for fleet FB-SC-1

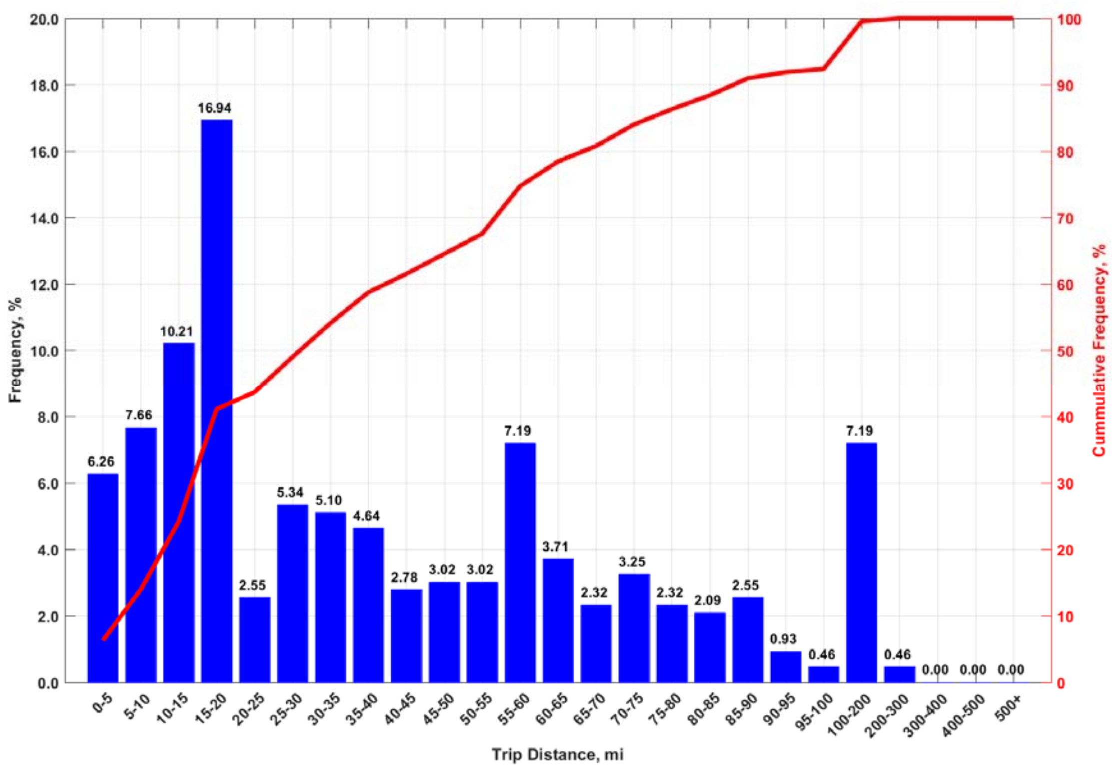


Figure 5-36. VMT by speed distribution of all trips for fleet FB-SC-1

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.61	1.39	1.75	2.14	2.57	2.94	3.47	3.98	5.01	9.04	22.19	30.00	14.18	0.69	0.04	0	0	0	*100*
Hour	Total																			
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	1.76	0.01	0.02	0.04	0.03	0.03	0.03	0.03	0.05	0.09	0.21	0.45	0.52	0.23	0.01	0	0	0	0	
5	16.97	0.05	0.17	0.24	0.27	0.29	0.35	0.40	0.52	0.84	2.09	5.30	4.35	2.02	0.08	0.01	0	0	0	
6	10.30	0.06	0.18	0.27	0.35	0.41	0.48	0.52	0.64	0.92	1.77	2.41	1.45	0.78	0.04	0.01	0	0	0	
7	4.07	0.08	0.13	0.15	0.18	0.20	0.22	0.27	0.25	0.25	0.36	0.82	0.76	0.38	0.03	0	0	0	0	
8	10.18	0.05	0.13	0.17	0.24	0.31	0.32	0.39	0.41	0.48	0.76	2.30	3.26	1.34	0.04	0.00	0	0	0	
9	11.53	0.05	0.10	0.13	0.15	0.18	0.19	0.23	0.27	0.39	0.72	2.35	4.73	1.97	0.07	0	0	0	0	
10	10.95	0.05	0.10	0.11	0.13	0.15	0.20	0.24	0.31	0.37	0.79	2.55	4.11	1.75	0.09	0.01	0	0	0	
11	8.85	0.05	0.11	0.14	0.16	0.18	0.21	0.24	0.25	0.34	0.55	1.78	3.17	1.57	0.09	0	0	0	0	
12	8.28	0.06	0.14	0.16	0.19	0.23	0.24	0.32	0.36	0.37	0.56	1.75	2.60	1.24	0.06	0.01	0	0	0	
13	7.76	0.06	0.12	0.14	0.17	0.24	0.26	0.34	0.34	0.36	0.52	1.47	2.64	1.05	0.06	0	0	0	0	
14	6.10	0.05	0.10	0.12	0.16	0.23	0.27	0.31	0.37	0.37	0.43	0.66	1.69	1.27	0.08	0	0	0	0	
15	2.49	0.03	0.06	0.06	0.07	0.10	0.12	0.15	0.17	0.19	0.21	0.25	0.60	0.42	0.03	0	0	0	0	
16	0.74	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.08	0.10	0.13	0.17	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	0.00	0.00	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*

Table 5-6. Summary statistics of data for fleet FB-SC-1

Description	Value
Number of vehicle samples	4
Total number of vehicle-days data logged	196
Total operating time (hours)	804
Total operating distance (miles)	18,194
Distance traveled per day per vehicle (miles)	92.8
Projected annual mileage per vehicle (miles)	33,872
Distance traveled at speed greater than 45 mph (%)	76.1
Total number of trips	1,040
Total number of idle trips	581
Total number of non-idle trips	459
Maximum trip distance (miles)	233.5
Mean trip distance of all trips (miles)	17.5
Mean trip distance of non-idle trips (miles)	39.5

5.3. Tanker Trailers

Figure 5-37 shows the trip distance distributions of all 1,851 trips made by 12 tanker tractor-trailers from two different fleets. About 75% of the trips were shorter than 5 miles; however, 1,222 trips or 66% were idle trips. Figure 5-38 shows the trip distance distributions of only non-idle trips (629 trips). It shows that about 41% of the non-idle trips were shorter than 25 miles while 25% were longer than 100 miles.

Together, the logged data from all trips represent a total VMT of 48,593 miles over 647 vehicle-days. This equates to a projected annual mileage per vehicle of 27,413 miles. Figure 5-39 presents the VMT by speed distribution of all trips. The prevalent speeds were 55-65 mph, and approximately 93% of the VMT were at speeds greater than 45 mph. These results indicate that the tanker tractor-trailers data logged in this study, on average, would benefit significantly from aerodynamic technologies. However, the level of benefit experienced may vary by fleet. The results for each tanker fleet are presented in the following subsections.

Figure 5-37. Trip distance distributions of all trips for all tanker trailers combined

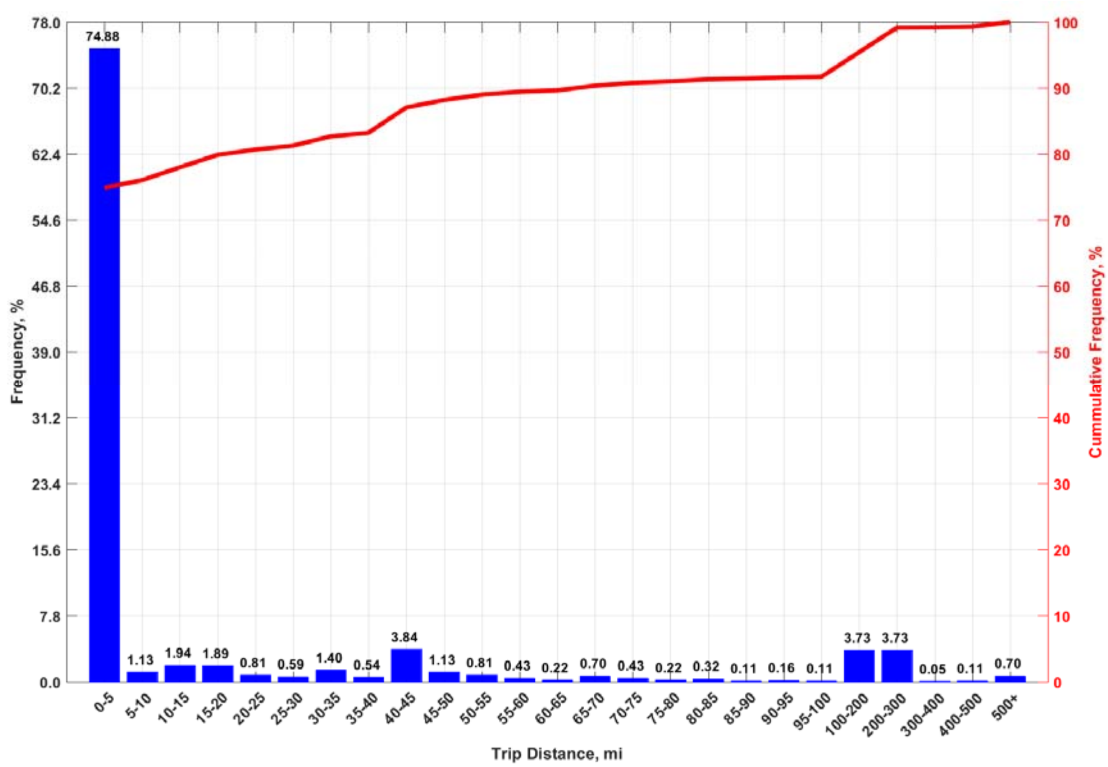


Figure 5-38. Trip distance distributions of non-idle trips for all tanker trailers combined

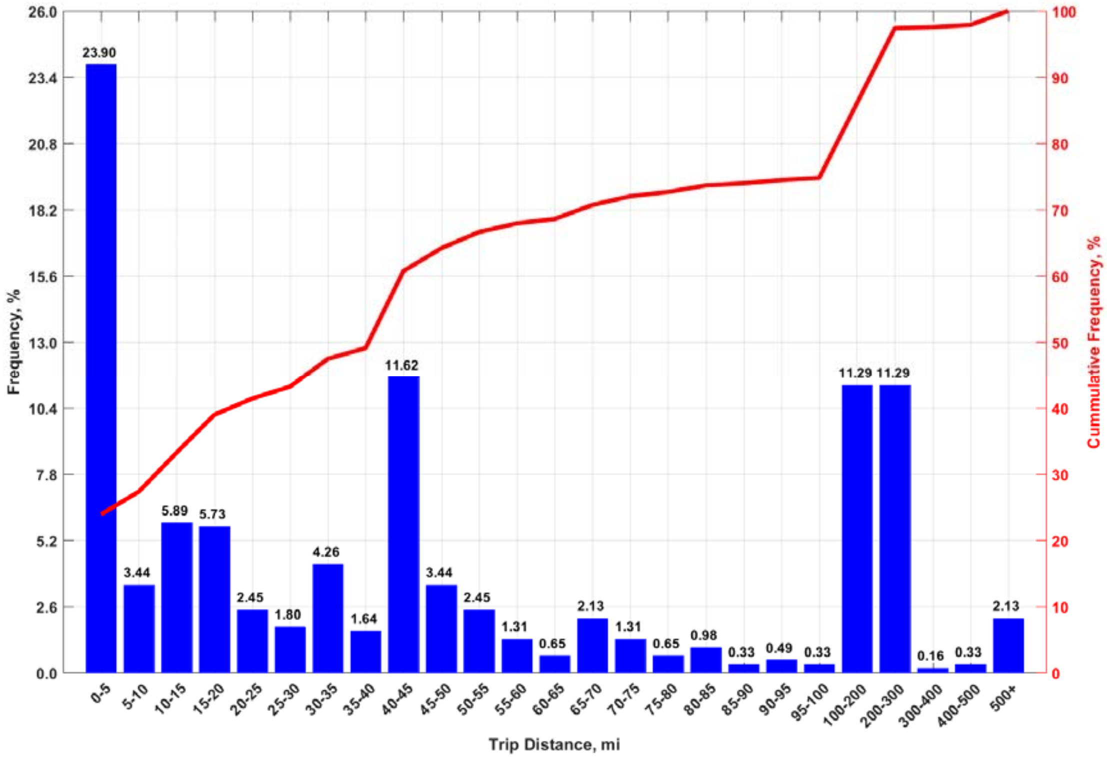


Figure 5-39. VMT by speed distribution of all trips for all tanker trailers combined

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.24	0.74	0.72	0.56	0.58	0.77	0.86	1.01	1.17	1.37	3.75	28.97	58.97	0.28	0.00	0	0	0	*100*
Hour	Total																			
0	1.61	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.03	0.35	1.11	0.01	0.00	0	0	0	
1	1.96	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.30	1.51	0.01	0	0	0	0	
2	3.22	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.33	2.73	0.00	0	0	0	0	
3	3.29	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.53	2.57	0.01	0	0	0	0	
4	3.94	0.00	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.08	1.39	2.27	0.01	0	0	0	0	
5	4.96	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.17	2.01	2.57	0.01	0.00	0	0	0	
6	4.91	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.27	1.69	2.62	0.01	0.00	0	0	0	
7	4.23	0.01	0.05	0.06	0.06	0.04	0.05	0.06	0.06	0.06	0.08	0.22	1.44	2.02	0.02	0	0	0	0	
8	8.66	0.01	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.05	0.06	0.26	2.18	5.86	0.01	0	0	0	0	
9	9.40	0.01	0.03	0.03	0.03	0.04	0.06	0.06	0.08	0.11	0.10	0.32	2.64	5.86	0.01	0	0	0	0	
10	5.10	0.02	0.08	0.06	0.05	0.06	0.08	0.09	0.11	0.13	0.15	0.30	1.63	2.34	0.01	0.00	0	0	0	
11	8.13	0.01	0.05	0.04	0.04	0.05	0.07	0.09	0.10	0.12	0.13	0.29	2.73	4.36	0.04	0	0	0	0	
12	9.29	0.01	0.04	0.03	0.03	0.04	0.05	0.06	0.08	0.11	0.15	0.39	2.54	5.75	0.02	0.00	0	0	0	
13	6.13	0.02	0.10	0.10	0.06	0.05	0.07	0.10	0.11	0.13	0.15	0.34	1.60	3.27	0.02	0	0	0	0	
14	4.47	0.02	0.06	0.06	0.05	0.05	0.06	0.07	0.08	0.09	0.10	0.28	1.77	1.75	0.02	0.00	0	0	0	
15	4.71	0.02	0.04	0.03	0.03	0.04	0.05	0.05	0.05	0.06	0.08	0.18	2.03	2.05	0.02	0.00	0	0	0	
16	3.47	0.01	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.06	0.07	0.15	1.05	1.87	0.01	0.00	0	0	0	
17	1.85	0.01	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.06	0.39	1.12	0.01	0	0	0	0	
18	1.87	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.43	1.24	0.02	0.00	0	0	0	
19	2.29	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.55	1.57	0.01	0	0	0	0	
20	1.68	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.32	1.23	0.00	0	0	0	0	
21	1.34	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.03	0.31	0.90	0.00	0	0	0	0	
22	1.91	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.36	1.41	0.01	0	0	0	0	
23	1.57	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.03	0.40	1.00	0.00	0	0	0	0	
Sum	*100*																			*100*

5.3.1. Northern California Fleet #1 (TK-NC-1)

This is a truck fleet in Northern California that hauls tanker trailers. We data logged six tractor-trailers from this fleet. Figure 5-40 and Figure 5-41 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. According to these figures, the fleet had operation mostly in the Greater Sacramento area with some operation also further north.

Figure 5-42 shows the trip distance distributions of all 655 trips for this fleet where about 56% of the trips were shorter than 5 miles. However, 160 trips or 51% were idle trips. Figure 5-43 presents the trip distance distributions of only non-idle trips (321trips). It shows that only 10% of the non-idle trips were shorter than 5 miles while about 22% of the non-idle trips were regional trips of 40-45 miles.

Figure 5-44 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 10,819 miles. About 49% of the VMT were at speeds of 55-60 mph, 11% at speeds of 60-65 mph, and another 11% at speeds of 50-55 mph, which all are typical highway speeds. These VMT were generated the most in the late morning and during midday between 9 a.m. and 2 p.m.

Table 5-7 summarizes key statistics of this fleet. Based on the data logged from the six vehicle samples of this fleet, the projected annual mileage per vehicle is 23,105 miles. Approximately 77% of these miles would be at speeds greater than 45 mph, which will benefit from aerodynamic improvements.

Figure 5-40. Heat map of trip origins for fleet TK-NC-1

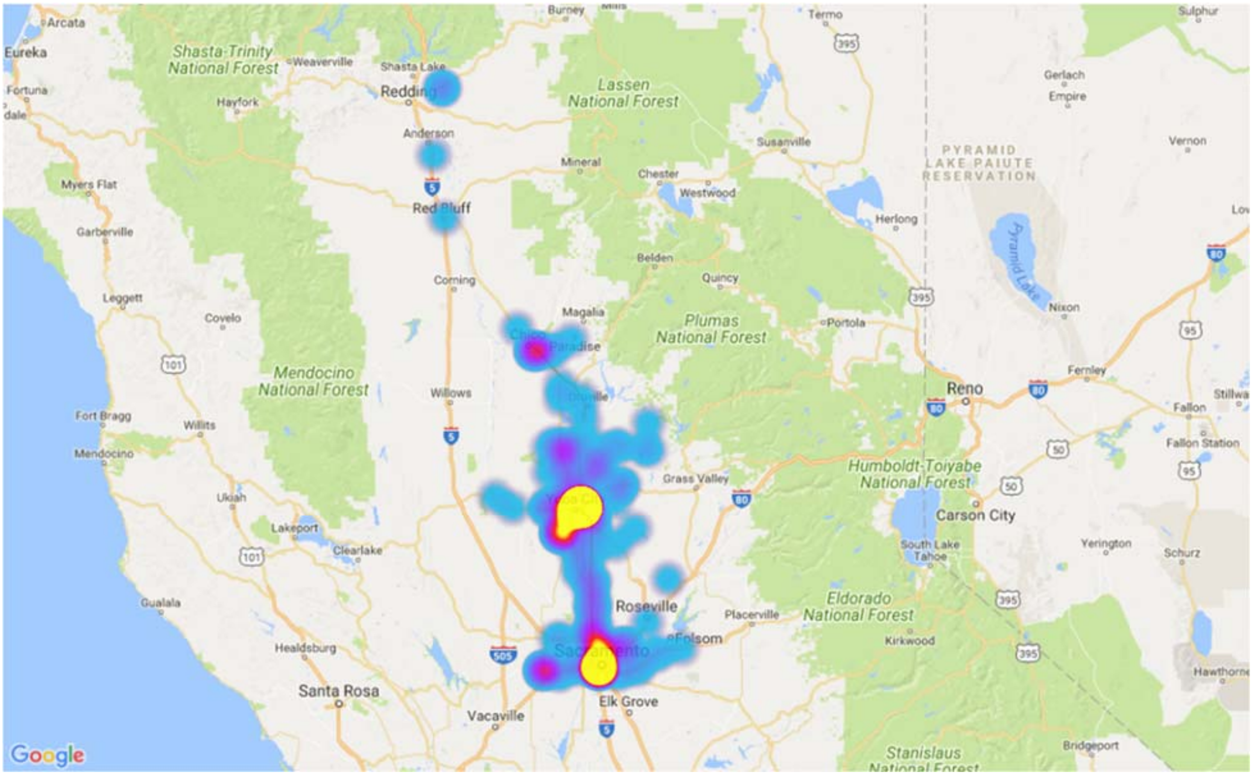


Figure 5-41. Heat map of trip destinations for fleet TK-NC-1

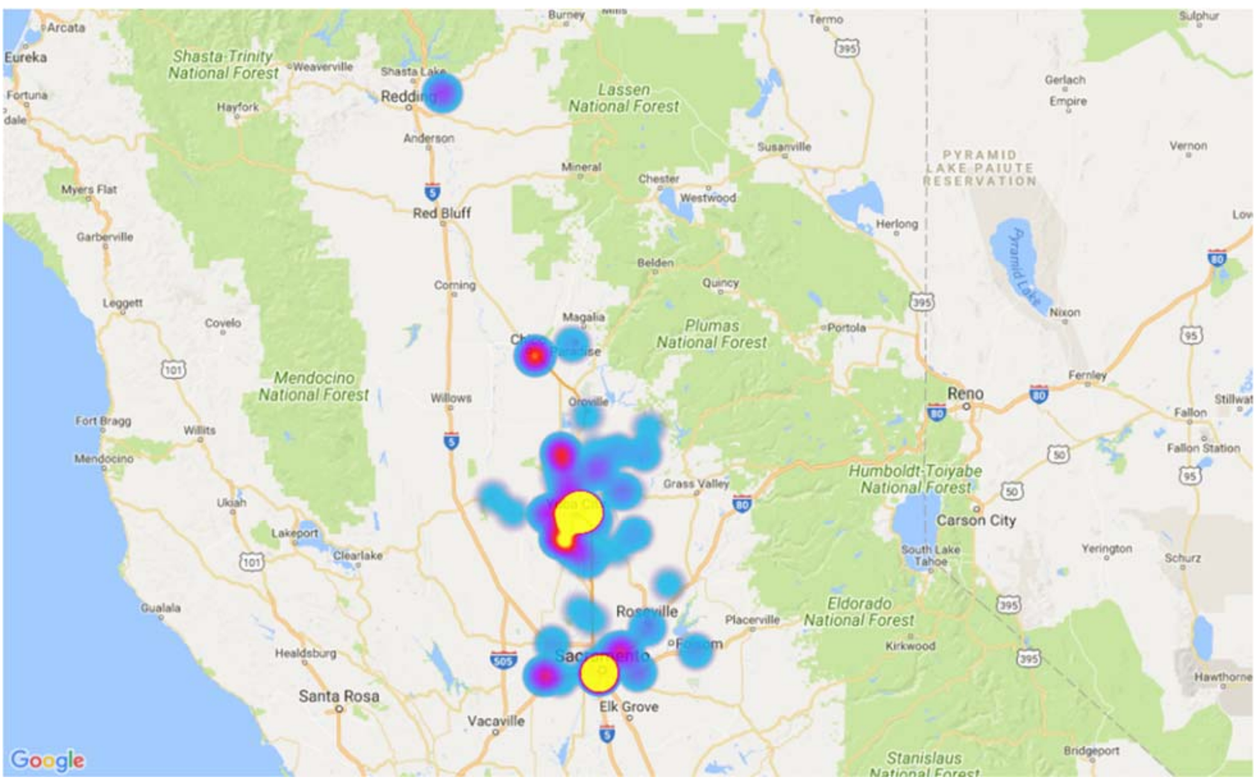


Figure 5-42. Trip distance distributions of all trips for fleet TK-NC-1

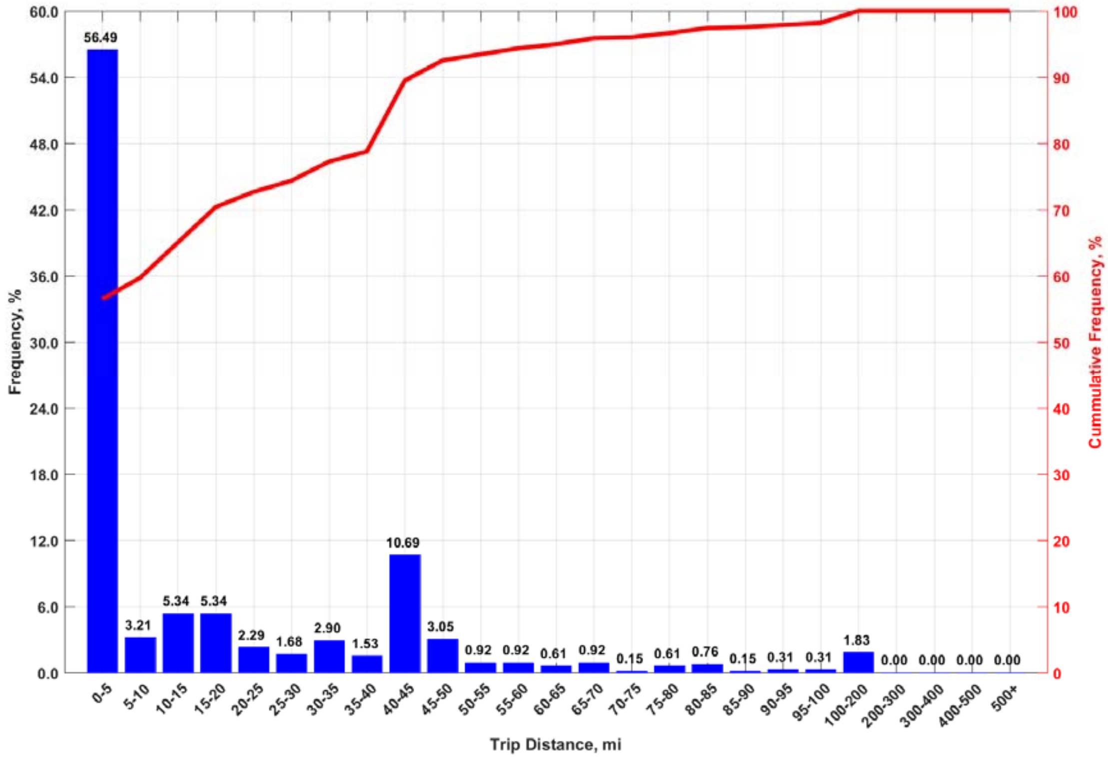


Figure 5-43. Trip distance distributions of non-idle trips for fleet TK-NC-1

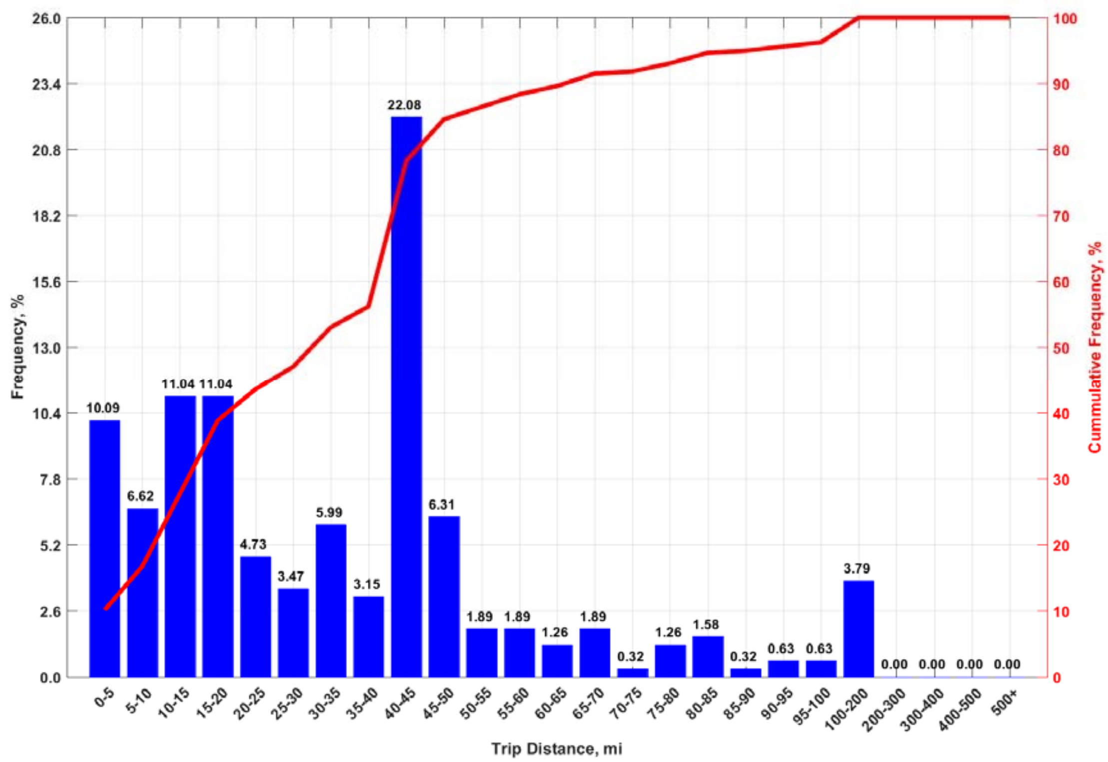


Figure 5-44. VMT by speed distribution of all trips for fleet TK-NC-1

Speed Bin		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.49	1.32	1.32	1.54	2.05	2.83	3.47	4.36	5.35	5.79	11.27	49.02	11.11	0.07	0.00	0	0	0	*100*
Hour	Total																			
0	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	0.00	0.00	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	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.00	0	0	0	0	
5	1.68	0.01	0.01	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.08	1.15	0.23	0.01	0.00	0	0	0	
6	6.75	0.02	0.03	0.03	0.04	0.05	0.07	0.08	0.09	0.12	0.12	0.46	4.24	1.39	0.00	0.00	0	0	0	
7	6.78	0.03	0.08	0.09	0.13	0.15	0.18	0.18	0.16	0.18	0.23	0.49	4.00	0.89	0.00	0	0	0	0	
8	6.59	0.05	0.08	0.09	0.10	0.13	0.17	0.16	0.20	0.24	0.25	0.74	3.35	1.03	0.00	0	0	0	0	
9	11.50	0.07	0.16	0.15	0.17	0.26	0.39	0.44	0.59	0.73	0.59	1.40	5.61	0.93	0.01	0	0	0	0	
10	11.89	0.07	0.19	0.15	0.16	0.23	0.33	0.45	0.61	0.68	0.75	1.52	5.52	1.23	0.00	0.00	0	0	0	
11	12.23	0.05	0.18	0.16	0.18	0.25	0.34	0.48	0.60	0.77	0.83	1.36	5.72	1.29	0.01	0	0	0	0	
12	11.38	0.05	0.14	0.14	0.16	0.23	0.32	0.41	0.52	0.74	0.94	1.49	5.08	1.13	0.01	0.00	0	0	0	
13	10.97	0.05	0.13	0.14	0.16	0.21	0.31	0.46	0.59	0.68	0.69	1.32	5.14	1.09	0.00	0	0	0	0	
14	8.97	0.04	0.13	0.15	0.16	0.21	0.30	0.37	0.43	0.54	0.58	1.21	3.94	0.92	0.01	0	0	0	0	
15	6.95	0.04	0.10	0.11	0.14	0.18	0.21	0.22	0.28	0.37	0.46	0.66	3.40	0.79	0.00	0	0	0	0	
16	3.23	0.02	0.06	0.06	0.08	0.12	0.15	0.16	0.19	0.22	0.23	0.36	1.47	0.12	0	0	0	0	0	
17	0.95	0.01	0.02	0.02	0.03	0.02	0.03	0.04	0.07	0.05	0.10	0.18	0.33	0.06	0.00	0	0	0	0	
18	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	
19	0.00	0.00	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	0.00	0.00	0.00	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*

Table 5-7. Summary statistics of data for fleet TK-NC-1

Description	Value
Number of vehicle samples	6
Total number of vehicle-days data logged	171
Total operating time (hours)	471
Total operating distance (miles)	10,819
Distance traveled per day per vehicle (miles)	63.3
Projected annual mileage per vehicle (miles)	23,105
Distance traveled at speed greater than 45 mph (%)	77.3
Total number of trips	655
Total number of idle trips	334
Total number of non-idle trips	321
Maximum trip distance (miles)	127.9
Mean trip distance of all trips (miles)	16.5
Mean trip distance of non-idle trips (miles)	33.6

5.3.2. Central Valley Fleet #1 (TK-CV-1)

This is a truck fleet in the Central Valley that hauls tanker trailers. We data logged eight tractor-trailers from this fleet but two data loggers were lost, resulting in usable data from six tractor-trailers. Figure 5-45 and Figure 5-46 show the heat maps of approximate trip origins and destinations based on the logged data, respectively. According to these figures, the fleet operated mostly in the Central Valley, along the I-5 corridor.

Figure 5-47 shows the trip distance distributions of all 1,196 trips for this fleet where about 85% of the trips were shorter than 5 miles. However, 888 trips or 74% were idle trips. Figure 5-48 presents the trip distance distributions of only non-idle trips (308 trips). It shows that about 39% of the non-idle trips were still shorter than 5 miles while almost half (about 48%) of the non-idle trips were long-distance trips over 100 miles.

Figure 5-49 presents the VMT by speed distribution of all trips, which resulted in a total VMT of 37,774 miles. About two-thirds of the VMT were at speeds of 60-65 mph and about a quarter of the VMT were at speeds of 55-60 mph, which are typical highway speeds. These VMT were generated the most during the windows between 8 a.m. and 10 a.m. as well as between 11 a.m. and 1 p.m.

Table 5-8 summarizes key statistics of this fleet. Based on the data logged from the six vehicle samples of this fleet, the distance traveled per calendar day per vehicle is 79.4 miles. The low daily mileage per vehicle is a result of the vehicle samples not being used on many days during the data logging period. It equates to a projected annual mileage per vehicle of 28,981 miles. Approximately 96% of these miles would be at speeds greater than 45 mph, which stand to benefit from aerodynamic improvements.

Figure 5-45. Heat map of trip origins for fleet TK-CV-1

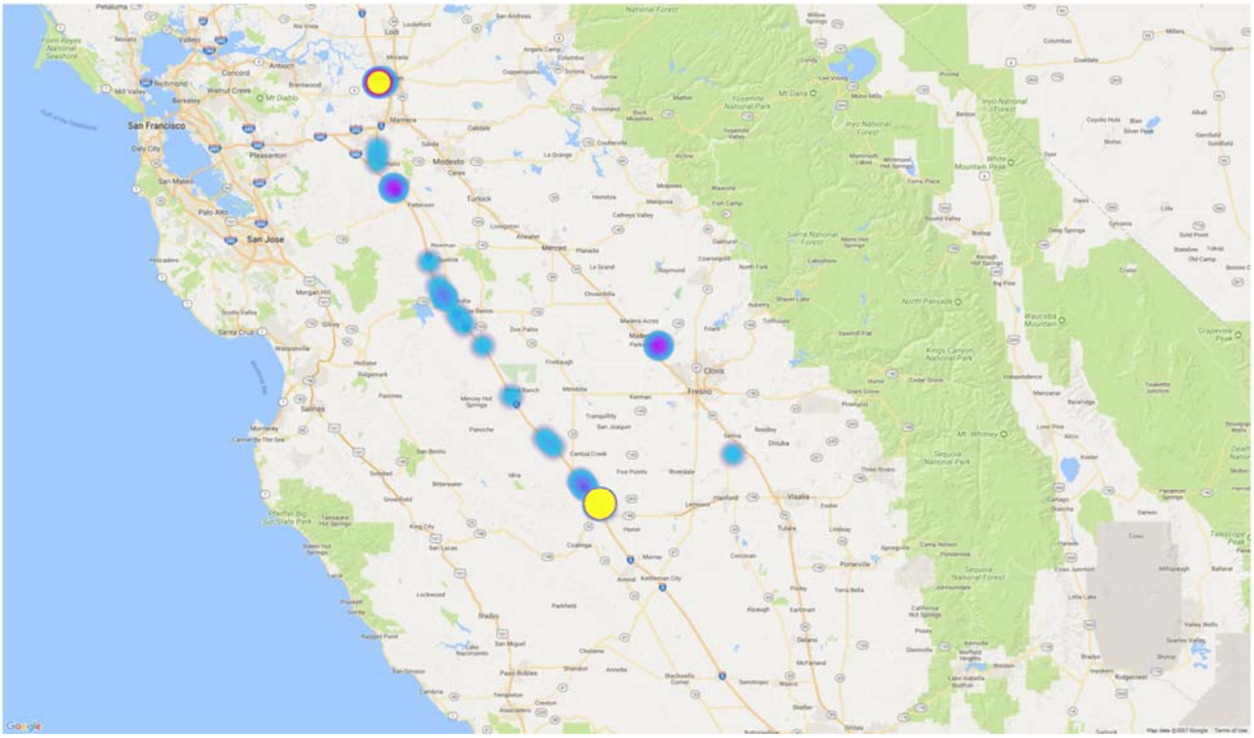


Figure 5-46. Heat map of trip destinations for fleet TK-CV-1

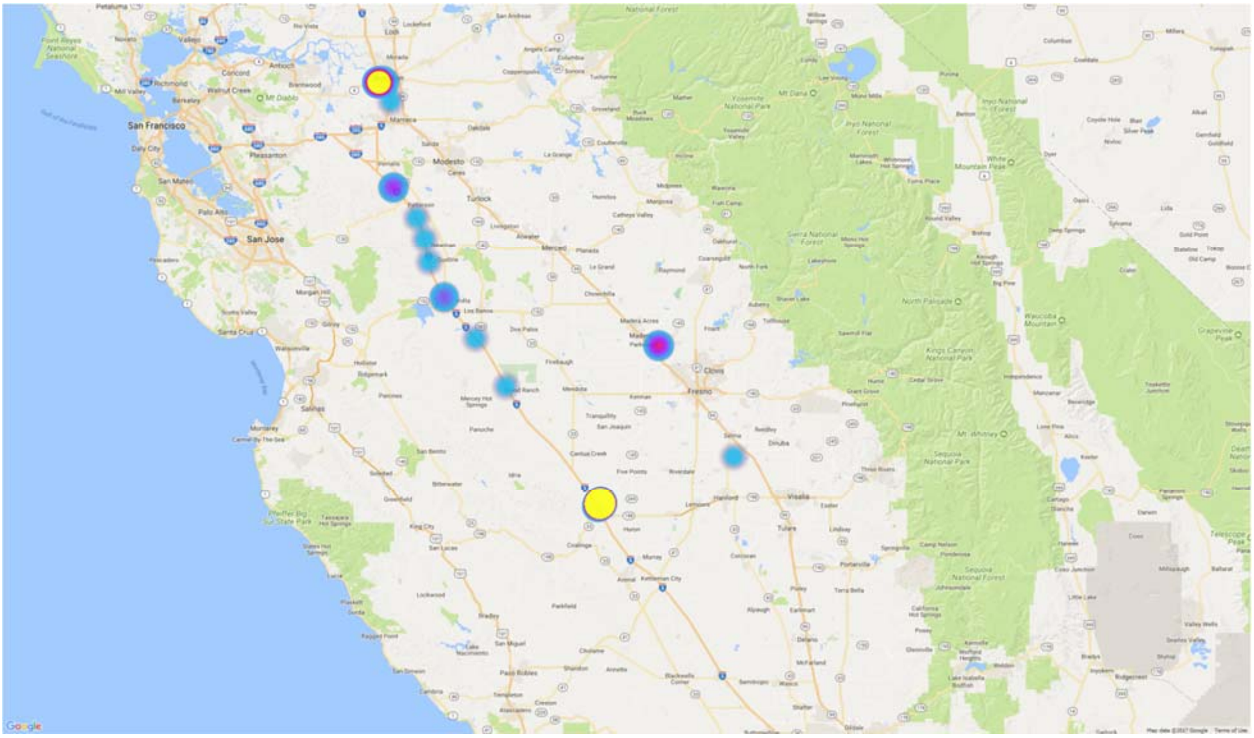


Figure 5-47. Trip distance distributions of all trips for fleet TK-CV-1

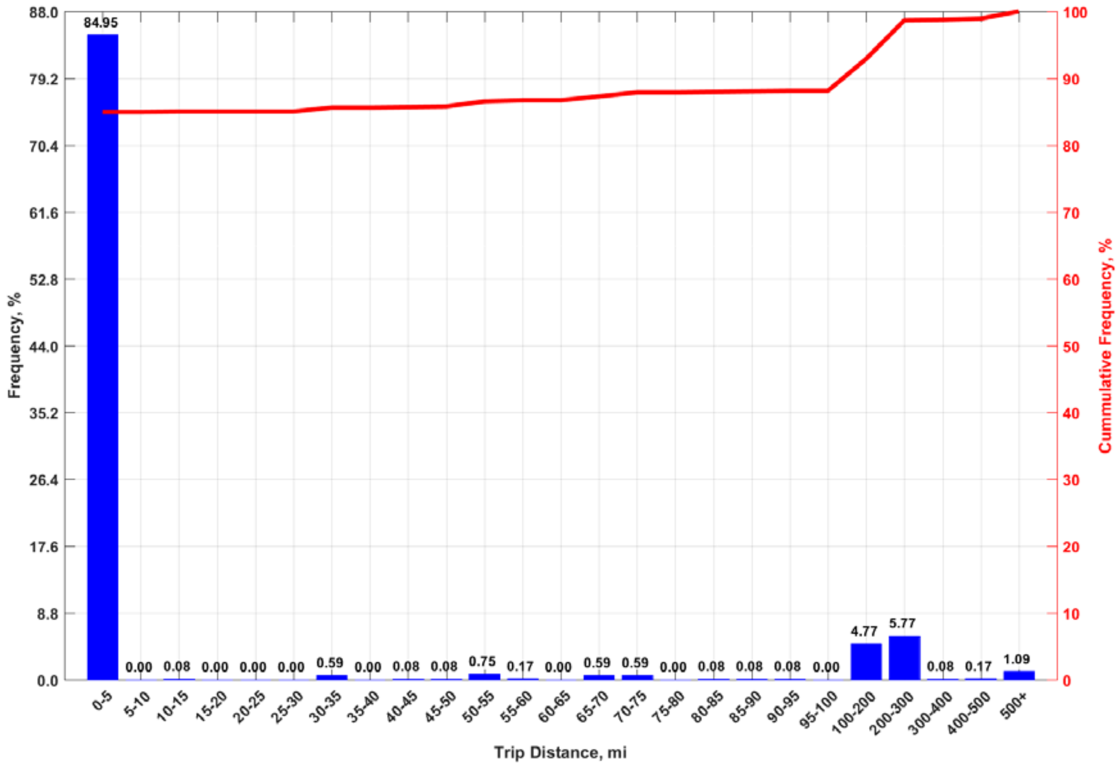


Figure 5-48. Trip distance distributions of non-idle trips for fleet TK-CV-1

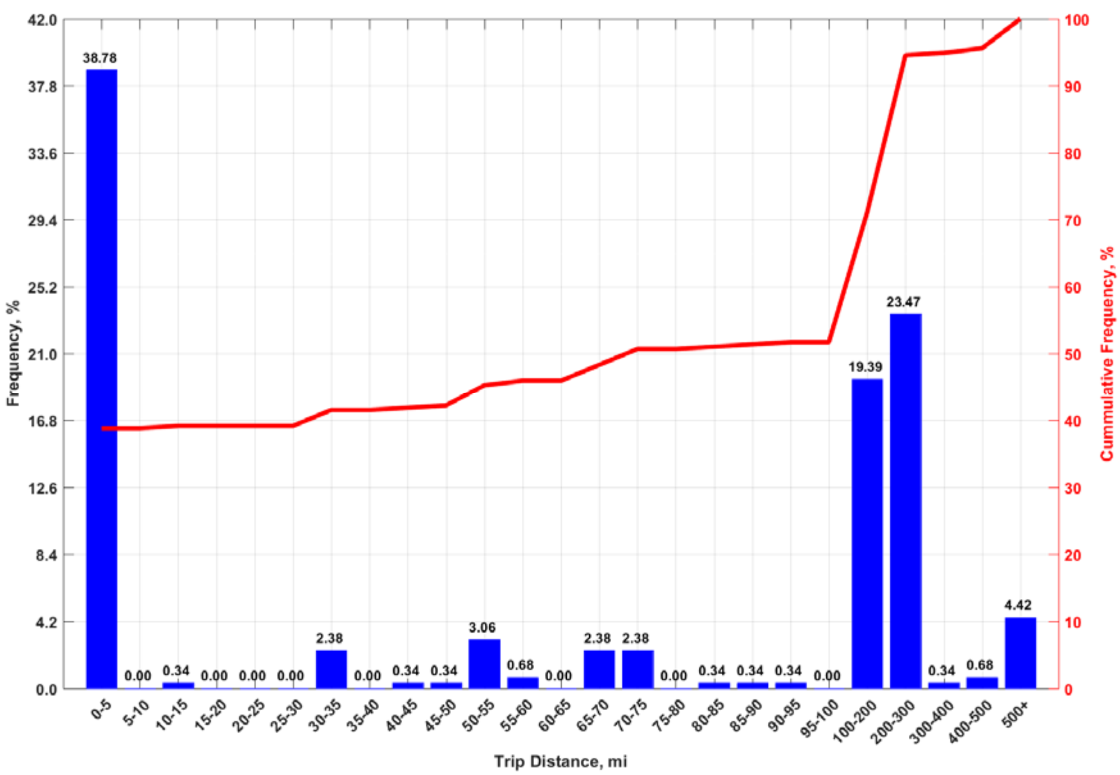


Figure 5-49. VMT by speed distribution of all trips for fleet TK-CV-1

	Speed Bin	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	*Sum*
	Total	0.20	0.66	0.63	0.41	0.36	0.46	0.47	0.51	0.54	0.70	2.62	25.95	66.17	0.32	0.00	0	0	0	*100*
Hour	Total																			
0	1.85	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.04	0.40	1.28	0.01	0.00	0	0	0	
1	2.26	0.00	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.35	1.74	0.01	0	0	0	0	
2	3.70	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.38	3.14	0.01	0	0	0	0	
3	3.79	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.07	0.61	2.96	0.01	0	0	0	0	
4	4.52	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.09	1.59	2.60	0.01	0	0	0	0	
5	5.45	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.04	0.18	2.13	2.92	0.01	0	0	0	0	
6	4.64	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.06	0.25	1.31	2.80	0.01	0	0	0	0	
7	3.85	0.01	0.05	0.06	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.18	1.05	2.19	0.02	0	0	0	0	
8	8.97	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.04	0.19	2.00	6.58	0.01	0	0	0	0	
9	9.08	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.16	2.19	6.61	0.01	0	0	0	0	
10	4.08	0.02	0.07	0.05	0.03	0.03	0.04	0.03	0.03	0.04	0.06	0.12	1.05	2.51	0.01	0	0	0	0	
11	7.51	0.01	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.13	2.28	4.82	0.05	0	0	0	0	
12	8.98	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.23	2.15	6.44	0.02	0	0	0	0	
13	5.40	0.02	0.09	0.10	0.04	0.03	0.03	0.04	0.04	0.04	0.07	0.19	1.07	3.60	0.02	0	0	0	0	
14	3.80	0.02	0.05	0.05	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.14	1.44	1.88	0.02	0.00	0	0	0	
15	4.38	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.11	1.82	2.24	0.02	0.00	0	0	0	
16	3.51	0.01	0.03	0.03	0.02	0.01	0.02	0.02	0.03	0.04	0.05	0.12	0.99	2.13	0.02	0.00	0	0	0	
17	1.98	0.01	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.39	1.28	0.01	0	0	0	0	
18	2.15	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.07	0.50	1.42	0.02	0.00	0	0	0	
19	2.63	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.06	0.64	1.80	0.01	0	0	0	0	
20	1.94	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.37	1.42	0.00	0	0	0	0	
21	1.54	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.03	0.35	1.03	0.00	0	0	0	0	
22	2.19	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.42	1.62	0.01	0	0	0	0	
23	1.81	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.04	0.47	1.15	0.00	0	0	0	0	
Sum	*100*																			*100*

Table 5-8. Summary statistics of data for fleet TK-CV-1

Description	Value
Number of vehicle samples	6
Total number of vehicle-days data logged	476
Total operating time (hours)	997
Total operating distance (miles)	37,774
Distance traveled per day per vehicle (miles)	79.4
Projected annual mileage per vehicle (miles)	28,981
Distance traveled at speed greater than 45 mph (%)	95.8
Total number of trips	1,196
Total number of idle trips	888
Total number of non-idle trips	308
Maximum trip distance (miles)	566.4
Mean trip distance of all trips (miles)	31.6
Mean trip distance of non-idle trips (miles)	122.0

6. Conclusions

Aerodynamic improvements to trucks are a critical step to reducing our nation's GHG emissions inventory and represent a large source for potential improvements. To date, much of the work relating to aerodynamic improvements has been done to evaluate aerodynamic improvements for tractor and trailer combinations for a standard box-type trailer. The objective of this research is to collect tractor-trailer activity data that will be used by CARB staff to assess the potential GHG emissions benefit from improved trailer aerodynamics. Four different trailer-types (flatbed, tanker, curtainside, and container chassis) that are not currently required to meet aerodynamic equipment requirements of CARB's existing Tractor-Trailer GHG regulation were targeted for evaluation. A population and activity survey of fleets with excluded trailers was conducted. An analysis of a trailer registration database was also conducted. Data logging was then conducted on a number of trucks in different fleets that haul the trailers of interest. This data logger data was analyzed to determine the speed distributions for different fleets as a percent of distance and time traveled for different trip distance groups.

6.1. Summary Results

Registration Database Analysis

The Polk/IHS database included registration records for 22,177 company fleets with at least one of the four trailer types described above, and a total of 253,191 trailers. A total of 11,575 trailers were registered in CA, representing about 5% of the total. A total of 6,402 container chassis, 3,172 flatbed, 1,897 tankers, and 103 curtainside trailers were registered in CA. The majority of the flatbeds were with a 48' length, while about half of the container chassis were 40' and the other half were 53' in length. Container chassis, flatbed, tanker, and curtainside trailers registered in CA corresponded to 9%, 3%, 3%, and 10%, respectively, of the overall populations by type in the Polk/IHS database. The 40' container chassis trailers, in particular, showed the highest fraction of CA registrations (5,349 or 15%) compared to the full Polk/HIS database. The higher fraction of container chassis trailers for California relative to the national number is consistent with the importance of California as a center for goods movement.

It should be noted that the Polk/IHS database is based on the year that a specific trailer is first registered, and thus it does not represent the total population of trailers that are in-use at any given time, as it does not account for trailers that were registered prior to 2000 or for trailers that were subsequently taken out of service after being registered.

Fleet Survey

A survey was developed for fleets possessing the four main trailer types being evaluated. The survey included questions for fleets about the number of different types of trailers, the applications and types of loads these trailers carry, and how these trailers are typically used. The survey was distributed to over 6,000 fleets nationwide identified through a Polk/IHS and other sources. A total of 51 survey responses were received from fleets that either own or operate one or more of the four trailer types being evaluated, with 31 of the fleets being based in California. The most prevalent trailers for the fleet responders were flatbeds, with the number per fleet ranging from 1 to 200. The number of trailers of different types per fleet ranged from 13 to 480 for container chassis, from 4 to 139 for tankers, and from 1 to ~30 for curtainsides, excluding a large NJ fleet. The average trailer-to-tractor ratio was slightly greater than 2 for both the California-based fleets and the full survey.

The survey responses indicated relatively high usage for both the tractors and trailer in the fleets surveyed. In 2015, the majority of the CA-based companies had average annual miles travelled of more than 50,000 miles (62%) per tractor, followed by an average between 25,000 - 50,000 miles (21%), and an average between 10,000 - 25,000 miles (14%). In both CA and other states, more than 70% of companies indicated that they have an annual average of more than 25,000 miles travelled per tractor in 2015. Similarly, the average annual mileage for the trailers was greater than 25,000 miles for 64% of the CA-based fleets. In terms of trip distance, the average trip distance for the surveyed fleets was 297 miles, with 96%, 85%, and 81% of the fleets having average trip distances of greater than 25 miles, 50 miles, and 100 miles, respectively. Less than 5% of the CA-based fleets had average trip distances of greater than 1,000 miles. The main types of loads for the CA-based fleets were 30% transporting construction materials, 22% transporting goods delivery products, 22% transporting agriculture products, 30% carrying liquid/gas, usually fuel or petroleum derivative, and 15% carrying other materials types.

The majority of the CA-based fleets indicated that they were already utilizing some methods of improving fuel economy, with 25 of the 31 CA-based fleets responding to this questions. Of the responders, about 52% indicated that they were using 3 or more different techniques to improve fuel economy, with speed limiters, low resistance tires, and tire monitoring being the most popular strategies for improving fuel economy. Eight of the 25 CA-based fleets that responded to this question indicated that they were already using either SmartWay tractors or aerodynamic devices.

Vehicle Activity Analysis

The vehicle activity analysis was focused on the trip distance and VMT by speed distributions for each fleet as well as for all fleets with the same trailer type combined. The fleet-specific results show that the trip distance distributions vary greatly, depending on the type of revenue service of the fleet (e.g., drayage vs. long haul), the location of the fleet (e.g., urban vs. rural), the operating area (e.g., local vs. regional), and possibly other factors. Based on the limited number of fleets in the dataset, there seems to be no clear association between trailer type and the different operating characteristics of the fleets. In general, all fleets were found to have a certain number of idle trips. However, the fraction of idle trips out of the total trips varied greatly from 25% to 74%. The trip distance distributions of non-idle trips also varied greatly, with some fleets having the majority of their non-idle trips being local (less than 25 miles) while other fleets having the majority of their non-idle trips being long-distance (over 100 miles).

On the other hand, the VMT by speed distributions for the different fleets show a similar trend where the majority of the VMT occurred at highway speeds between 50 and 65 mph. This speed range represents highway cruising given that the speed limit for trucks in California is 55 mph. The trend is true for almost all the fleets irrespective of the fraction of idle trips that the fleet made. This is because idle trips create almost no distance, and thus do not contribute much to the VMT by speed distribution. Also, for the same amount of time, traveling at low speeds does not result in as many miles as traveling at higher speeds. These results are not surprising given that fleets have inherent incentives to operate efficiently as that would affect their bottom line. Intuitively, drivers of tractor-trailers would also prefer driving on highways over surface streets, even for short trips as that will allow them to travel faster and maneuver the vehicles more easily.

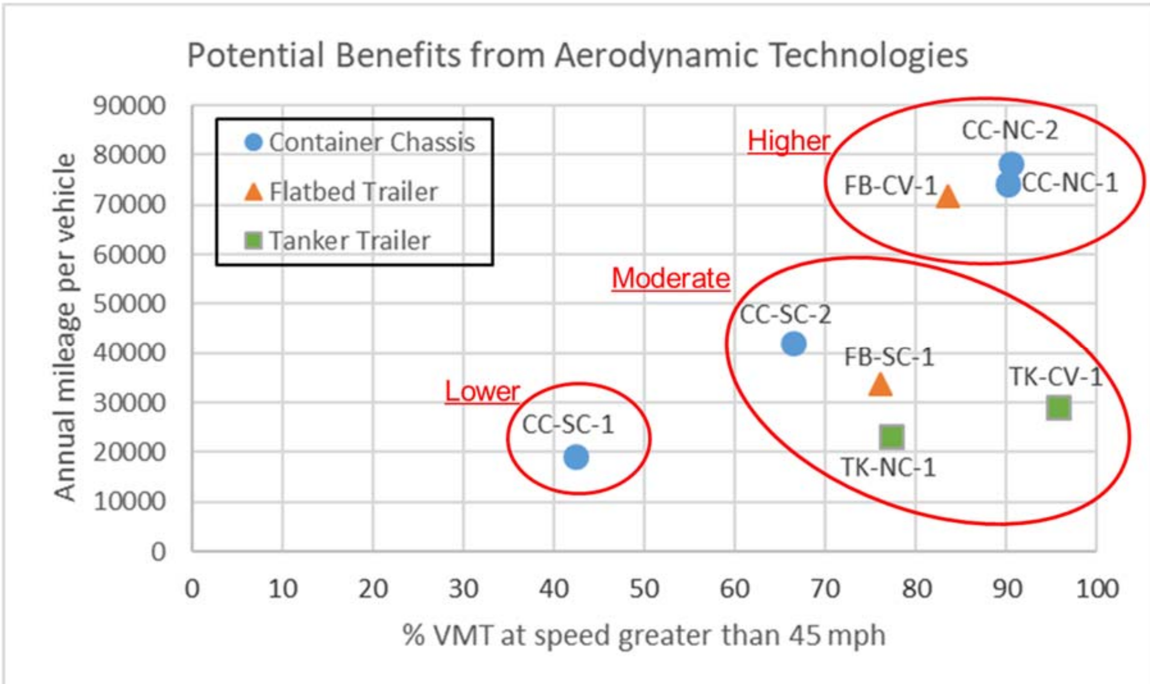
The benefits from aerodynamic improvements partly depend on the annual mileage of the tractor-trailers. Based on the vehicle activity statistics summarized in Table 6-1, six of the eight fleets data logged in this study were estimated to have an annual mileage per vehicle of more than 25,000 miles. And three of them were estimated to have an annual mileage per vehicle of more than 50,000 miles. Since aerodynamic drag is proportional to the square of the travel speed, aerodynamic improvements provide more benefits at higher speeds. As shown in Figure 4-7, the energy consumed due to aerodynamic drag increases sharply after 45 mph. Based on the data logged and analyzed in this study, the portion of VMT at speeds greater than 45 mph varied by fleet, ranging from 42% to 96%, with six of the eight fleets having at least 75% of their VMT at those high speeds.

Table 6-1. Summary of vehicle activity statistics from data logging study

Fleet	Trailer Type	Location	No. of Vehicle Samples	Estimated Annual Mileage per Vehicle	Percent of Mileage at 45+ mph
CC-NC-1	Container Chassis	Northern California	4	74,387	90.1
CC-NC-2	Container Chassis	Northern California	14	78,402	90.5
CC-SC-1	Container Chassis	Southern California	43	19,163	42.4
CC-SC-2	Container Chassis	Southern California	11	42,012	66.5
		All Container Chassis Combined	***72***	***35,300***	***65.2***
FB-CV-1	Flatbed	Central Valley	65	71,905	83.5
FB-SC-1	Flatbed	Southern California	4	33,872	76.1
		All Flatbed Combined	***69***	***67,621***	***83.4***
TK-NC-1	Tanker	Northern California	6	23,105	77.3
TK-CV-1	Tanker	Central Valley	6	28,981	95.8
		All Tanker Combined	***12***	***27,413***	***93.3***

Figure 6-1 shows the potential benefits from aerodynamic technologies for each of the eight fleets, considering the estimated annual mileage per vehicle and the portion of VMT at speeds greater than 45 mph. Generally, fleets with high annual mileage per vehicle and high portion of VMT at speeds greater than 45 mph would gain a higher level of benefits from aerodynamic technologies. Three of the eight fleets in this study fall into this category. On the other hand, fleets with low annual mileage per vehicle and low portion of VMT at speeds greater than 45 mph would gain a lower level of benefits from aerodynamic technologies. One of the fleets in this study falls into this category. The other four fleets would gain a moderate level of benefits from aerodynamic technologies. While they have a relatively high portion of VMT at speeds greater than 45 mph, their vehicles do not accumulate as much annual mileage as the fleets in the higher benefits category.

Figure 6-1. Potential benefits from aerodynamic technologies for each fleet



6.2. Conclusions and Recommendations

Based on the results presented in this report, it appears that extending the Tractor-Trailer GHG regulation to include additional trailer types, particularly some of the trailer types studied in this project, would result in additional GHG emission reductions from the heavy-duty sector. Since both the fleet survey and logged data do not show clear association between trailer type and different operating characteristics of the fleets, the extension of the Tractor-Trailer GHG regulation may focus on the trailer types with large population in CA. In that respect, one trailer type that does not seem to be worth considering for further regulations is the curtainsides, due to the relatively low population of these trailers (only 103 registered in CA).

The fleet survey data indicated that flatbed, container chassis, and tanker trailers are relatively heavily used, with 64% of the CA-based fleets indicating annual VMT per trailer of greater than 25,000 miles and 83% of the CA-based fleets indicating annual VMT per tractor of greater than 25,000 miles. Similarly, the data logging study showed that the estimated annual mileage per tractor is greater than 25,000 miles for 88% of the fleets. The combined results of the surveys and the data logging suggest that the travel patterns for these trailer types are ones that could benefit from aerodynamic devices. Although the data logging indicated that trip distances can vary based on application, the fleet survey suggested a high percentage of trips at 50 to 100 miles or above. Additionally, the majority of VMT each fleet generated in this study were at highway cruising speeds, with most fleets having at least 70% or their VMT above 45 mph. These results suggest that most of the fleets, irrespective of the trailer types they hauled, would benefit from aerodynamic improvements.

Some additional studies could be done to supplement the results of this study to better characterize what the potential GHG benefit of further application of aerodynamic devices to these trailer types might be. This could include data collection of trailer activity where data logging devices are installed on the trailers (as opposed to on the tractors). The data could be used to determine trip distance distribution, annual mileage, and fraction of distance traveled at high speeds as was done for the tractor activity in this study. The collection of additional information on the populations of flatbed, container chassis, and tanker trailers would also be of value. Although the Polk/IHS registration database included over 11,000 trailers, this number is considerably less than the population of heavy-duty trucks that operate within the state. Again, this could be due to the limited number of years available in the database (2000 through 2015), the limited number of trailer lengths examined, or other reasons. Truck traffic studies on freeways or elsewhere could also be used to better understand the relative populations of these trailer types in comparison with conventional box or other trailer types.

Additional studies of aerodynamic drag for different tractor-trailer combinations could also be of value. For example, tanker trailers are inherently more rounded than box trailers, and could provide less benefit on a per trailer basis than box trailers. Similarly, flatbed trailers, when loaded, will typically provide a lower profile than full box trailers. Container chassis trailers, once loaded, would have a profile more comparable to a box trailer, and hence would likely be more comparable in terms of aerodynamic drag. The issue of trailer length could also be investigated in such studies, as the effectiveness of aerodynamic devices could vary as a function of trailer length.

In the development of the expanded Tractor-Trailer GHG regulation, exemptions could and should still be allowed. These exemptions may be based on the annual mileage, the fraction of VMT at speeds greater than 45 mph, or a combination of these and other metrics. Nowadays, many fleets adopt some form of fleet monitoring systems that monitor and record the data necessary for calculating these metrics. Thus, fleets can gather data and submit them in the application for exemption from the expanded Tractor-Trailer GHG regulation. To alleviate the burden of fleets without existing fleet monitoring systems, CARB in collaboration with federal transportation agencies can provide assistance and resources in recording the data for the application of exemption.

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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.

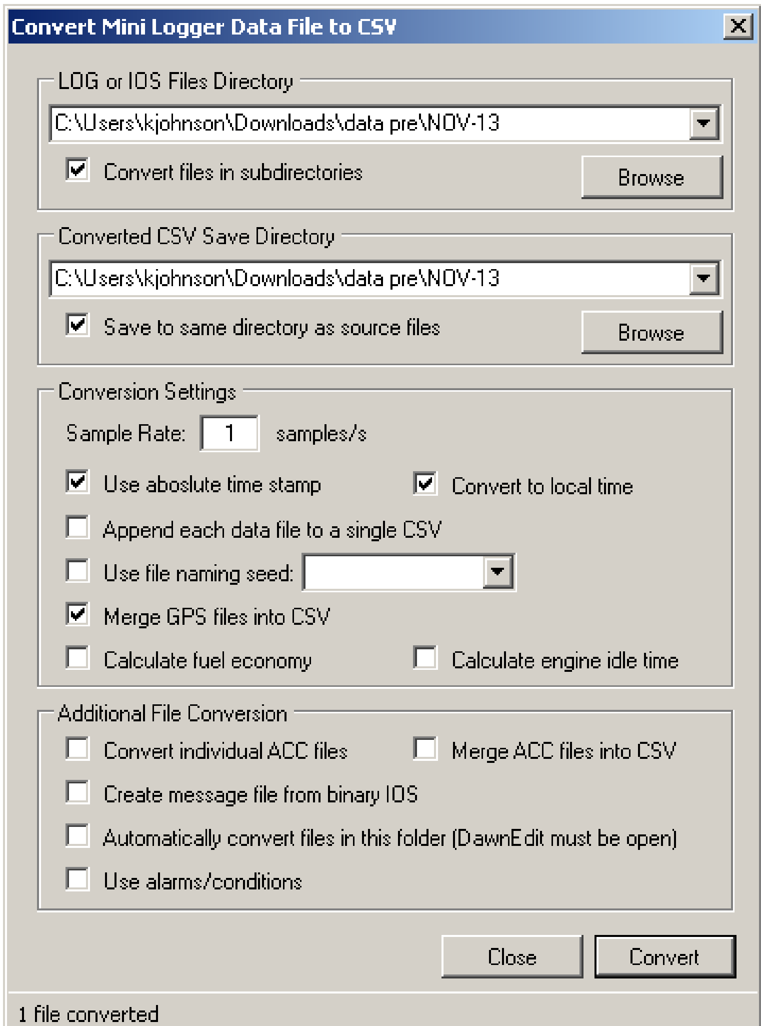

Figure B-1. Convert mini logger files to CVS window

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 ☐