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# Heavy-Duty Vehicle Fleet Characterization for Reduction of $NO_x$ and Particulate Matter Emissions in the South Coast Air Basin

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

# Heavy-Duty Vehicle Fleet Characterization for Reduction of $NO_X$ and Particulate Matter Emissions in the South Coast Air Basin

Final Report
Contract No. 96-317

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**Acknowledgments:**

This report was submitted in fulfillment of ARB Agreement No. 96-317 "Heavy-Duty Vehicle Fleet Characterization for Reduction of NOx and Particulate Matter Emissions in the South Coast Air Basin" by Jack Faucett Associates and its subcontractors under the sponsorship of the California Air Resources Board. Work was completed as of 3 December 2001.

Jack Faucett Associates (JFA) prepared this report. Michael Fischer, a former employee of JFA, was largely responsible for designing the analytical framework and project management in the early part of the project. Jeffery Ang-Olson, another former JFA employee, contributed to the analysis of the survey data and Joan Cutler, Myong Han, Vicky Hsu, and Michael Lawrence of JFA contributed to the analysis and final report.

Archana Agrawal, Hector Maldonado, and Ralph Propper of the California Air Resources Board (ARB) provided necessary guidance and technical input in conducting this study.

The scope of work for this project included an analysis of "incentive" programs for the reduction of emissions from heavy-duty diesel vehicles. However, the ARB now has several "clean air incentive programs" that differ greatly from those analyzed by JFA. Following are three examples:

- The Carl Moyer Program provides grants as a means to reduce emissions from heavy-duty engines. These grants offset the extra cost of vehicles that are cleaner than required.
- The Lower-Emission School Bus Program allows school districts to replace older buses with new, cleaner diesels and alternative fuel buses.
- The Emission Reduction Credit (ERC) Bank is a means of offsetting extra emissions created by power plants. Proceeds from the issuance of ERCs can be used to fund the purchase of cleaner heavy-duty engines.

Because the newer programs have displaced some of the incentive concepts analyzed by JFA, the reader should contact the ARB for more information on Clean Air Incentive Programs.

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## ABSTRACT

In this report, Jack Faucett Associates (JFA) and its subcontractors present their findings in a research project characterizing the heavy-duty vehicle (HDV) fleets and heavy-duty trucks (HDT) in the South Coast Air Basin (SoCAB, the Basin). Three main objectives this report accomplishes are the following: One) characterization of the fleet with respect to physical and operational characteristics of the trucks; Two) determination of the emissions associated with relevant sub-populations of trucks and; Three) development of an incentive strategy to accelerate and encourage the introduction of low-emission technology and operational practices for the fleets in the SoCAB to achieve NOx and PM emissions reductions.

## EXECUTIVE SUMMARY

This report presents Jack Faucett Associates (JFA) and its subcontractors' findings in a research project that studies heavy-duty vehicle (HDV) fleets and heavy-duty truck (HDT) operations in the South Coast Air Basin (SoCAB, the Basin). Because HDVs are considered to be major contributors to NOx and PM emissions in the SoCAB, HDV, HDT characteristics and their emissions need to be examined carefully in order to control their emissions more effectively.

Trucking plays a vital role in the Southern California economy. Developing potential incentive practices and options for reducing emissions from heavy-duty trucks in the region may be a cost effective way to encourage behavior by truck fleets that reduce harmful truck emissions. The California Air Resources Board's (ARB) State Implementation Plan (SIP) for the SoCAB has included measures dealing with truck operations and truck emissions. The SIP currently includes a measure, which would provide incentives for accelerating introduction of low-emitting heavy-duty engines. To better control HDV emissions in the Basin, this study focuses on the SoCAB to:

- characterize the HDT fleets;
- determine the emissions associated with relevant sub-populations of trucks and;
- develop an incentive strategy to accelerate and encourage the introduction of low-emission technology and operational practices for the fleets.

The JFA team conducted telephone surveys of truck fleets to collect data that allow a better description of the physical and operational characteristics of heavy-duty trucks that travel in the SoCAB. An additional part of the survey effort used global positioning system (GPS) devices to track truck activities. JFA and its subcontractor collected data pertaining to detailed HDT activities and patterns in the SoCAB. Data collection involving GPS equipment can be broken down into four steps: Recruiting, Scheduling, Instrumentation, and Data Processing/Analysis. The JFA team conducted the first three parts. ARB handled the entire Data Processing/Analysis portion.

Logistical constraints and other factors dictated that the truck population targeted for the survey efforts be stratified into three manageable groups. All truck fleets were classified as Small (1 – 3 trucks), Medium (4 – 100 trucks) or Large (over 100 trucks). Collecting information from each group required different approaches, and surveys were conducted in different stages. A brief summary of sampled fleets and trucks represented in the telephone survey is presented in the following table, Table ES-1.

Table ES-1. Telephone Survey Responses (Number of Fleets and Trucks)

| Fleets Operating In Basin | Registration | Small Fleets: Fleets | Small Fleets: Trucks | Medium Fleets: Fleets | Medium Fleets: Trucks | Large Fleets: Fleets | Large Fleets: Trucks |
|---|---|---|---|---|---|---|---|
| Total for Analysis | In Basin | 131 | 197 | 138 (2) | 1058 (3) | 16 (2) | 835 |
| | Out Basin | 30 | 42 | 47 (2) | 250 (3) | 13 (2) | 151 |
| | All | 161 | 239 | 185 | 1308 | 29 | 986 |

| Fleets Not Operating In Basin | Registration | Small Fleets: Fleets | Small Fleets: Trucks | Medium Fleets: Fleets | Medium Fleets: Trucks | Large Fleets: Fleets | Large Fleets: Trucks |
|---|---|---|---|---|---|---|---|
| Total for Analysis | In Basin | 13 | 16 | 7 | 87 | 0 | 0 |
| | Out Basin | 99 | 165 | 145 | 2270 | 9 | 2475 |
| | All | 112 | 181 | 152 | 2357 | 9 | 2475 |

Notes:

(1) Includes some trucks that do not operate In Basin, but belong to Basin-operating fleets.

(2) Sum of Phase I and III

(3) Sum of Phase II and IV

The application of GPS technology to collect truck data was challenging. A data set from a limited sample of HDTs was developed for this study. ARB has been processing and analyzing the data collected, and has provided the JFA team a brief summary of HDT activity information collected. The following table shows the information made available by the ARB staff. Not all of the instrumented trucks are represented in the Table ES-2.

Table ES-2. GPS Data.

| | HHD | M-LHD | M-LHG |
|---|---|---|---|
| **Number of Trucks** | 14 | 11 | 6 |
| **Idle Time (min / % of total time)** | 204 / 42.5% | 163 / 61.2% | 151 / 54.9% |
| **Average Speed (mph)** | 19.34 | 11.21 | 18.39 |
| **Average Trip Length (mile)** | 48.41 | 19.41 | 16.18 |
| **Average Daily VMT (mile)** | 200.7 | 82.0 | 94.2 |
| **% of VMT within SCAB** | 69.3% | 65.5% | 98.1% |

* Since there is only one LHDD truck, it was combined into MHDD trucks.

* All gasoline trucks were combined as a single group.

The sample data were combined with other data from ARB, the California Department of Motor Vehicles, the U.S. Bureau of the Census and the U.S. Department of Transportation to develop a profile of trucks operating in the South Coast Air Basin (the Basin). Using this information it was estimated that the number of heavy-duty trucks (HDV) registered in the Basin in 1998 were about 302,000 out of a statewide total of about 780,000. The distribution of trucks by fuel type and fleet size was similar throughout the state. The likelihood that a truck registered anywhere in the state would operate in the Basin grows with GVW. For trucks registered outside the Basin, it is estimated that about 15 percent of the light-heavy trucks and about 45 percent of the super-heavy trucks will operate in the Basin some time over the year. It is estimated that about 185,000 gasoline- and about 180,000 diesel-HDVs operate in the Basin.

The survey sought to gather information on the characteristics of trucks operating in the Basin. For example, the survey indicated that about 4.4 percent of HDVs owned by fleets that participated in the survey had engines that were newer then the age of the truck. About 30 percent of the HDVs were vintage year 1987 or older and about 35 percent were 1994-1998 vintage. The survey also indicated that trucks used in daily rental were much newer on average, while construction, service/utility and waste-hauling trucks are considerable older then average. Average mileage of older trucks is less then that of newer trucks.

Small fleets (1-4 trucks) are more likely to operate locally (less then 50-mile range) while about 40 percent of the large fleets (100 or more trucks) and 54 percent of their vehicles operate in long haul service. Truck range was also a function of the type of service provided. The likelihood that a truck was centrally fueled rose from only 20 percent in small fleets to over 70 percent in large fleets. It is estimated that there are about 106,000 HDVs in the Basin that are centrally fueled. 20 percent of the fleets responding operated their vehicles six days per week and twenty percent operated their vehicles seven days per week. Data on service frequencies for HDVs were also collected and are presented in Chapter 5.

This study evaluates a number of incentive options that would encourage trucking and transportation industries to adopt measures and technologies that could reduce harmful emissions JFA considered four major pollutants (NOx, PM, HC and CO) when calculating emissions. JFA also considered three different levels of hypothetical penetration percentage (1 percent, 5 percent and 20 percent) to examine varying degrees of effectiveness of the incentive options. The penetration levels can be interpreted to mean that either a set percentage of the targeted population will change their behavior (*e.g.* convert their vehicle to an alternative-fuel), or the target population will change their behavior by a set percentage (*e.g.* reduce their idle time of operation).

A summary of the major findings with respect to the incentive programs follows:

- For reducing NOx emission levels, modifying idle time appears to be the most promising incentive program.
- For reducing PM, purchasing new AFVs or converting conventional HDVs to AFVs appears to have the greatest effects on reducing PM emissions.
- For reducing HC and CO emission levels, the most promising incentive program appears to be that of shifting the operating hours of HDVs in the Basin.

Table ES-3 shows detailed emission reduction as well as baseline figures by pollutants and incentive programs at the 1 percent penetration level. The table also shows the emission information in terms of percentage.

Table ES-3. Potential HDV Emissions and Percentage Reductions in the South Coast Air Basin, with and without Incentive Programs, 2010
(grams/mile with 1 percent incentive penetration)

| | | NOX | | PM | | HC | | CO | |
|---|---|---|---|---|---|---|---|---|---|
| BC | Base Case Emission | 9.647031 | 100.00% | 0.497895 | 100.00% | 0.404625 | 100.00% | 2.703605 | 100.00% |
| | ***Alternative Fuels*** | | | | | | | | |
| AF1 | New Vehicle Purchase & Vehicle Conversion | ***0.078341*** | ***0.81%*** | ***0.004012*** | ***0.81%*** | ***0.002354*** | ***0.58%*** | ***0.023410*** | ***0.87%*** |
| AF2 | Fuel Pruchase | ***0.040911*** | ***0.42%*** | ***0.002107*** | ***0.42%*** | 0.001237 | 0.31% | 0.011956 | 0.44% |
| | ***Conventional Fuels*** | | | | | | | | |
| CF1 | New Vehicle Purchase | N/A | N/A | 0.002259 | 0.45% | 0.001590 | 0.39% | 0.013203 | 0.49% |
| CF2 | Vehicle Retirement | 0.006629 | 0.07% | 0.000396 | 0.08% | 0.000343 | 0.08% | 0.001718 | 0.06% |
| CF3 | Replacing Engines | 0.002921 | 0.03% | 0.000060 | 0.01% | 0.000131 | 0.03% | 0.000228 | 0.01% |
| CF4 | Emission Control | N/A | N/A | 0.002922 | 0.59% | 0.002428 | 0.60% | 0.016222 | 0.60% |
| CF5 | Fuel Addictive Purchase | 0.001505 | 0.02% | 0.000338 | 0.07% | 0.000273 | 0.07% | 0.000828 | 0.03% |
| | ***Operations & Practice*** | | | | | | | | |
| OP1 | Idle Time Modification | ***0.139041*** | ***1.44%*** | 0.000430 | 0.09% | 0.000059 | 0.01% | 0.000694 | 0.03% |
| OP2 | Shifting Operating Hours | (0.002243) | -0.02% | N/A | N/A | 0.003576 | 0.88% | 0.038516 | ***1.42%*** |
| | ***Infrastructure Improvements*** | | | | | | | | |
| II1 | Intermodal Improvements | 0.000490 | 0.01% | 0.000002 | 0.00% | 0.000000 | 0.00% | 0.000002 | 0.00% |
| II2 | Truck Terminals/Freight Centers | 0.000806 | 0.01% | 0.000003 | 0.00% | 0.000000 | 0.00% | 0.000004 | 0.00% |
| II3 | Truck Stops/Parking Area | 0.000146 | 0.00% | 0.000000 | 0.00% | 0.000000 | 0.00% | 0.000001 | 0.00% |
| II4 | Trucks-Only Roadways/Truck Lanes | (0.001684) | -0.02% | N/A | N/A | 0.002626 | 0.65% | 0.028701 | ***1.06%*** |

N/A - Data Not Available

# 1 INTRODUCTION

This report presents Jack Faucett Associates (JFA) and its subcontractors' findings in a research project that studies heavy-duty vehicle (HDV) fleets and heavy-duty trucks (HDT) in the South Coast Air Basin (SoCAB, the Basin).

Three main objectives of this report are: to characterize the fleet with respect to physical and operational characteristics of the trucks; to determine the emissions associated with relevant sub-populations of trucks and; to develop incentives to encouraging low-emission technology and operational practices for the fleets. Because of their significance as a source of NOx and PM emissions in the SoCAB, HDV, HDT characteristics and their emissions need to be examined carefully. Since trucking plays a vital role in the Southern California economy, it would be beneficial to develop incentive practices rather than mandating control measures and restrictions that could negatively impact the trucking industry in the Basin. In order to design and select the most effective incentives, more information on truck populations, activity and usage in the Basin is necessary.

The remainder of this report is divided into seven chapters. Chapter 2 discusses telephone surveys and approaches used to collect data on the physical and operational characteristics of HDV fleets. Chapter 3 provides some of HDV characteristics revealed from the surveys. This section also discusses development of HDV population control totals for further analyses. Chapter 4 presents various relevant patterns observed among the HDTs in the SoCAB. These patterns include usage, range of operation, fueling practice, mileage, etc. Chapter 5 discusses detailed information on many trucks' maintenance operations and practices. Maintenance frequencies, costs and other variables noted in this section shed insight on designing effective incentives for emission reduction. Chapter 6 describes data collection procedures using global positioning system (GPS) equipment. The JFA team installed the GPS data logger and collected data from a limited number of trucks in the Basin for the study. Chapter 7 provides analyses of emission reduction incentives based on the information collected. This chapter also identifies relevant sub-populations of HDT population in the Basin targeted for incentives to reduce emissions. Chapter 7 also presents profiles of the sub-populations and associated emission estimates.

# 2 FLEET SURVEY METHODOLOGY

Jack Faucett Associates (JFA) and its subcontractor have conducted telephone surveys of truck fleets to collect data that will allow us to better describe the physical and operational characteristics of heavy-duty trucks that travel in the SoCAB.

## 2.1. Stratification of Fleets

Logistical constraints require that the methodology used for collecting this information vary with the size of the truck fleet. All truck fleets have been classified as Small (1 – 3 trucks), Medium (4 – 100 trucks) or Large (over 100 trucks). The survey methodologies used for each of these fleet size categories is described below. Appendix A shows the number of fleets and trucks surveyed in each phase of the process. Appendix B contains a tabulation of the response frequencies for each survey variable.

### 2.1.1. Small Fleets

For trucks in small fleets, all data were collected in telephone surveys by JFA's subcontractor Freeman, Sullivan & Company (FSC). FSC used the initial survey sampling frame provided by ARB. This sampling frame consisted of two files containing DMV truck registrations, one for trucks registered within the Basin and the other for trucks registered outside of the Basin. The sampling frame was drawn with the intention that all fleets would have 100 or fewer trucks. All data on small fleet trucks were collected in this initial survey. If the fleet did not operate any trucks in the Basin, only gross vehicle weight (GVW) and fuel information were collected. If the fleet did operate trucks in the Basin, full data was collected on those trucks and on the maintenance and operation practices of the fleet.

### 2.1.2. Medium Fleets

Medium fleet trucks were surveyed in three different stages. During the initial survey by FSC (Phase I), medium fleets were surveyed about maintenance and operation practices of the fleet. Individual truck information (such as GVW, fuel and age) was not collected in this phase. JFA then made follow-up calls to the medium fleets identified by FSC to obtain information on individual trucks. Only a subset of the fleets initially contacted provided the detailed truck information. More data on medium fleet trucks was collected during JFA's survey of large fleets (Phase III). This phase of the survey is described next.

### 2.1.3. Large Fleets

Large fleets were not intended to be included in the original sampling frame. Due to address matching errors, some large fleets were present in the sampling frame and 15 of them were surveyed in Phase I by FSC. Only data on maintenance and operation practices of the fleet was collected in this phase. JFA then conducted a supplemental survey of large fleets (Phase III). The sample was drawn from the Transportation Technical Services (TTS) Fleet Directories for California, for both private fleets and motor carriers. All fleets in these directories with over 100 trucks were identified, and fleets were selected randomly from this set for the survey. Contact was attempted with roughly two-thirds of the sample population of 492 fleets. Useable surveys were completed with 57 fleets. If the fleet did not operate any trucks in the Basin, only GVW and fuel information was collected. For fleets that did operate trucks in the Basin, the initial survey collected information on the number of trucks and the maintenance and operation practices of the fleet. A follow-up fax survey was then sent to these fleets to obtain more information on the truck characteristics (Phase IV). The follow-up survey was in the form of a table broken down by GVW class, fuel type, and model year categories. Respondents were asked to complete the table by entering the number of trucks in each cell. Fourteen fleets completed the Phase IV survey.

For many fleets contacted in Phase III, the total number of trucks indicated in the TTS directories was found to be incorrect. Thus, 34 of the 57 fleets surveyed actually had less than 100 heavy-duty trucks. The data collected on these fleets in Phases III and IV were added to the medium fleet data collected in Phases I and II.

## 2.2. Sampling Error and Bias

Sampling error occurs when the statistics obtained from a sample differ from those that would be obtained if the entire population were to respond to the survey. The smaller the sample size, the larger is the potential sampling error. Appendix A shows the sampling errors at the 95 percent confidence level if the entire sample is used in calculating a percentage. The sampling error is higher when only a portion of the sample can be used for analysis. Statistics based on fleet-wide averages are subject to a larger sampling error than statistics based on individual truck information.

While JFA believes that the survey sample is a representative cross-section of California trucks, several factors may introduce bias in the sample and should be acknowledged. First, difficulty in contacting truck owner-operators may cause an under-representation of small fleet trucking firms. These establishments typically have only one employee, the truck driver, and thus are often not available to answer a telephone survey. Second, none of the well-known large parcel delivery fleets were included in the sample, so this usage category may be underrepresented. Third, the address matching techniques used to develop the sample may cause an overrepresentation of small fleet trucks. If an establishment registers trucks at different addresses, this will appear as multiple fleets in the sample, even if the trucks are actually based at the same location. While the extent of these biases is unknown, JFA believes that they do not jeopardize the conclusions drawn from the survey analysis.

# 3 HEAVY-DUTY VEHICLE POPULATIONS AND CHARACTERISTICS

This section describes the development of HDV populations to serve as the basis for further analysis. Control totals were developed for the number of trucks operating in the Basin by registration location (In Basin or Out of Basin), fleet size (small, medium, large), weight class (Light-Heavy, LH: 8,500 – 14,000 lbs.; Medium-Heavy, MH: 14,001 – 33,000 lbs.; Heavy-Heavy, HH: 33,001 – 60,000 lbs.; Super-Heavy, SH: over 60,001 lbs.), and fuel type (gasoline, diesel, other). Also included in this section is a description of urban public transit bus data that was collected.

## 3.1. DMV Registration Data and Weight Class

The basis for the sub-populations is the DMV data from which the initial survey sample was drawn. ARB has provided truck registration figures by registration location (In Basin or Out of Basin), fleet size (small, medium, large), fuel (gasoline, diesel, other) and by the following GVW classes: 10,001- 14,000 lbs, 14,001 – 33,000 lbs, over 33,000 lbs. JFA estimated the number of trucks in the 8,500 -10,000 lbs group, and JFA split the trucks over 33,000 lbs into heavy-heavy (HH) (33,001 – 60,000 lbs) and super-heavy (SH) (over 60,001 lbs) weight classes. The distinction between heavy-heavy duty and super-heavy duty weight classes is not currently required for emission factor models, and was done at the request of ARB.

To estimate the number of trucks that are 8,500 – 10,000 lbs GVW by registration location, JFA relied on statewide truck population control totals supplied by ARB for use in the EMFAC model. These figures indicate that for light heavy-duty (8,500 – 14,000 lbs) gasoline trucks statewide, 83.4 percent are 8,500 – 10,000 lbs GVW, and for light-heavy diesel trucks statewide, 34.0 percent are 8,500 – 10,000 lbs GVW. JFA applied these fractions to the truck registration figures by registration location (In Basin or Out of Basin) in order to estimate the population of all light-heavy trucks by registration location. Note that in doing so, JFA must assume that the weight distribution within the light-heavy truck class (the portion above or below 10,000 lbs) does not vary with fleet size or with registration location.

To split the trucks over 33,000 lbs into heavy-heavy and super-heavy weight classes, JFA has two sources of information, the survey data and the TIUS dataset. While it seems possible that the HH/SH split may vary across fleet size, JFA survey data is not extensive enough to calculate the split by all three fleet size categories and by registration location simultaneously. Therefore, JFA used the survey data to estimate a separate HH/SH weight class split for trucks registered In Basin versus Out of Basin, combining fleet sizes. To do this, JFA weighted the survey data by fleet size, so that small fleet trucks account for 60 percent of the total, medium fleets account for 29 percent, and large fleets account for 11 percent. This weighting is consistent with the truck registration data supplied by ARB. The factors developed to split the two weight classes are 47 percent HH, 53 percent SH for In Basin trucks, and 55 percent HH, 45 percent SH for Out of Basin trucks. As shown in Table 1, these fractions are fairly consistent with the 1992 TIUS dataset.

Table 1. Data for Splitting Heavy-Heavy and Super-Heavy Truck Populations
(Survey data from 1998 – 1999*)

**Number of Trucks, from Survey**

| Fleet size | GVW | Reg. In Basin | | Reg. Out of Basin | | All CA Trucks | |
|---|---|---|---|---|---|---|---|
| Small | HH | 15 | 58% | 13 | 54% | 28 | 56% |
| | SH | 11 | 42% | 11 | 46% | 22 | 44% |
| | Sub-Total | 26 | | 24 | | 50 | |
| | | (15 fleets) | | (15 fleets) | | | |
| Medium | HH | 363 | 29% | 348 | 46% | 711 | 35% |
| | SH | 907 | 71% | 413 | 54% | 1320 | 65% |
| | Sub-Total | 1270 | | 761 | | 2031 | |
| | | (55 fleets) | | (34 fleets) | | | |
| Large | HH | 87 | 33% | 438 | 81% | 525 | 65% |
| | SH | 174 | 67% | 105 | 19% | 279 | 35% |
| | Sub-Total | 261 | | 543 | | 804 | |
| | | (7 fleets) | | (4 fleets) | | | |
| All Flts | HH | 465 | 30% | 799 | 60% | 1264 | 44% |
| *Unweighted* | SH | 1092 | 70% | 529 | 40% | 1621 | 56% |
| | Sub-Total | 1557 | | 1328 | | 2885 | |
| All Flts | HH | 1108 | 47% | 2624 | 55% | 3732 | 52% |
| *Weighted by* | SH | 1269 | 53% | 2168 | 45% | 3437 | 48% |
| *Fleet Size* | Sub-Total | 2377 | | 4793 | | 7170 | |

**Estimated Truck Population, from TIUS 1992**

| | All States | | | CA Only | |
|---|---|---|---|---|---|
| HH | 797,906 | 49% | HH | 66,956 | 47% |
| SH | 831,333 | 51% | SH | 75,030 | 53% |
| Sub-Total | 1,629,239 | | Sub-Total | 141,986 | |
| | | | | (974 records) | |

*Some follow-up to the 1998 survey was done in 1999.

When these adjustments are made, the total number of HDTs in the state is estimated as 696,069. The EMFAC statewide population of HDTs is 779,745. Therefore, all population cells have been scaled up by about 12 percent so these totals are consistent. Making these adjustments to the DMV registration data results in the population figures shown in Table 2.

Table 2. Truck Registration Numbers, based on DMV Registration Data (1997)

**Registered In Basin**

| Flt Size | GVW | Gas | Diesel | Other | *sub-total* |
|---|---|---|---|---|---|
| 1-3 | LH | 89,330 | 12,115 | 14 | *101,459* |
| | MH | 27,945 | 23,194 | 161 | *51,300* |
| | HH | 125 | 10,359 | 73 | *10,558* |
| | SH | 144 | 11,862 | 84 | *12,090* |
| | *Sub-total* | *117,543* | *57,531* | *332* | *175,406* |
| 4-100 | LH | 31,473 | 4,781 | 7 | *36,260* |
| | MH | 11,846 | 22,256 | 259 | *34,361* |
| | HH | 85 | 8,127 | 35 | *8,247* |
| | SH | 97 | 9,307 | 40 | *9,444* |
| | *Sub-total* | *43,501* | *44,471* | *341* | *88,313* |
| over 100 | LH | 12,787 | 1,370 | - | *14,158* |
| | MH | 4,791 | 10,985 | 20 | *15,796* |
| | HH | 11 | 3,945 | 3 | *3,959* |
| | SH | 13 | 4,518 | 4 | *4,534* |
| | *Sub-total* | *17,602* | *20,818* | *27* | *38,447* |
| All Flts | LH | 133,590 | 18,267 | 20 | 151,877 |
| | MH | 44,582 | 56,435 | 440 | 101,458 |
| | HH | 221 | 22,432 | 111 | 22,765 |
| | SH | 254 | 25,687 | 127 | 26,068 |
| | *Total* | 178,647 | 122,820 | 699 | 302,167 |

**Registered Out Basin**

| Flt Size | GVW | Gas | Diesel | Other | *sub-total* |
|---|---|---|---|---|---|
| 1-3 | LH | 138,610 | 23,350 | 34 | *161,994* |
| | MH | 60,490 | 35,098 | 407 | *95,995* |
| | HH | 509 | 16,441 | 107 | *17,058* |
| | SH | 421 | 13,585 | 89 | *14,094* |
| | *Sub-total* | *200,030* | *88,474* | *637* | *289,141* |
| 4-100 | LH | 40,697 | 8,294 | 14 | *49,004* |
| | MH | 22,828 | 36,731 | 334 | *59,892* |
| | HH | 313 | 16,551 | 101 | *16,964* |
| | SH | 258 | 13,675 | 83 | *14,017* |
| | *Sub-total* | *64,096* | *75,250* | *531* | *139,877* |
| over 100 | LH | 17,788 | 2,102 | 2 | *19,891* |
| | MH | 6,877 | 14,584 | 36 | *21,497* |
| | HH | 37 | 3,886 | 4 | *3,927* |
| | SH | 31 | 3,211 | 3 | *3,245* |
| | *Sub-total* | *24,733* | *23,782* | *44* | *48,560* |
| All Flts | LH | 197,095 | 33,745 | 49 | 230,890 |
| | MH | 90,195 | 86,413 | 776 | 177,385 |
| | HH | 859 | 36,878 | 212 | 37,949 |
| | SH | 710 | 30,470 | 175 | 31,355 |
| | *Total* | 288,859 | 187,507 | 1,212 | 477,578 |

**All California**

| Flt Size | GVW | Gas | Diesel | Other | *sub-total* |
|---|---|---|---|---|---|
| 1-3 | LH | 227,940 | 35,465 | 48 | *263,453* |
| | MH | 88,435 | 58,292 | 568 | *147,296* |
| | HH | 634 | 26,801 | 180 | *27,616* |
| | SH | 564 | 25,447 | 172 | *26,184* |
| | *Sub-total* | *317,574* | *146,006* | *968* | *464,548* |
| 4-100 | LH | 72,170 | 13,075 | 20 | *85,265* |
| | MH | 34,674 | 58,987 | 593 | *94,254* |
| | HH | 398 | 24,678 | 136 | *25,212* |
| | SH | 356 | 22,981 | 123 | *23,461* |
| | *Sub-total* | *107,597* | *119,721* | *872* | *228,190* |
| over 100 | LH | 30,575 | 3,472 | 2 | *34,049* |
| | MH | 11,668 | 25,569 | 56 | *37,293* |
| | HH | 48 | 7,831 | 7 | *7,886* |
| | SH | 43 | 7,728 | 7 | *7,779* |
| | *Sub-total* | *42,335* | *44,601* | *71* | *87,007* |
| All Flts | LH | 330,685 | 52,012 | 70 | *382,766* |
| | MH | 134,777 | 142,848 | 1,217 | *278,842* |
| | HH | 1,081 | 59,310 | 323 | *60,714* |
| | SH | 964 | 56,157 | 302 | *57,423* |
| | *Total* | *467,506* | *310,327* | *1,911* | *779,745* |

These figures are based on the DMV truck registration data provided by ARB. The data has been adjusted in three ways:

1. The number of LH has been expanded to account for HDTs under 10K lbs, based on statewide EMFAC99 figures
2. The number of HDTs over 33K lbs has been split into HH and SH classes based on our survey data.
3. All figures have been scaled up so that the statewide total matches the total in the EMFAC99 figures.

## 3.2. Areas of Operation – South Coast Air Basin Operation

These population figures are then adjusted to estimate the number of trucks in each sub-population that operate in the Basin. To obtain this estimate, JFA would apply the basin operation fractions from our survey. Note that Basin operation does not reflect the portion of time spent in the Basin by a truck, but rather whether or not a truck travels in the Basin at any time. The basin operation fractions are calculated separately for each of the 24 cells shown in Figure 1. For trucks in small fleets, this calculation can be performed using the survey results directly. Because of the limited number of small fleet heavy-heavy and super-heavy trucks in the survey, JFA combined these two groups to estimate basin operation fractions.

Figure 1: Sample Stratification Scheme to Determine Basin Operation Percentages

| | Small Fleets | | | | Medium Fleets | | | | Large Fleets | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LH | MH | HH | SH | LH | MH | HH | SH | LH | MH | HH | SH |
| Registered IN | % | % | % | % | % | % | % | % | % | % | % | % |
| Registered OUT | % | % | % | % | % | % | % | % | % | % | % | % |

For trucks in medium and large fleets, the analysis is slightly more complex because of the multiple-stage survey process. For medium-sized fleets that do not operate in the Basin, GVW data were collected for all fleets contacted in the Phase I and III surveys. But for medium-sized fleets that do operate in the Basin, GVW data were collected only for a sub-set of the initial sample through follow-up surveys (Phase II and IV). To account for this, JFA calculated the GVW distribution for medium-sized fleets from the Phase II and IV surveys, and applied this distribution to the number of sample trucks that operate in the Basin from the Phase I and III surveys. In doing this, JFA assumes that the GVW distribution does not differ between those fleets that responded in Phase II or IV and those that did not.

For large fleets, JFA's survey data is not extensive enough to determine basin operation fractions by weight class. That leaves JFA with several options. One is to use the basin operation fractions for all large fleet trucks, and assume there is no difference across GVW with respect to basin operation. Another option is to use the basin operation fractions from the medium-sized fleets, and assume that there is no difference between medium and large fleets with respect to basin operation. A third option, and the one JFA employed, is to use large fleet trucks totals for basin operation (sum of all GVWs), and then distribute these across weight class based on the medium fleet GVW distribution. This ensures that the basin-operation fractions by GVW are based on a large sample size, but preserves some of what JFA believes are differences between medium and large fleets. In particular, large fleets registered out of the basin are slightly more likely to operate in the basin than medium-sized fleets. The Basin Operation fractions are shown in Table 3.

Table 3. Number and Percent of Trucks that Operate in Basin (from Survey, 1998*)

| | | Registered In Basin | | | Registered Out Of Basin | | |
|---|---|---|---|---|---|---|---|
| | | Operate In Basin | Do Not Operate In Basin | Percent | Operate In Basin | Do Not Operate In Basin | Percent |
| Small Fleets | LH | 62 | 10 | 86% | 16 | 109 | 13% |
| | MH | 85 | 0 | 100% | 14 | 40 | 26% |
| | HH | 14 | 1 | 93% | 4 | 9 | 31% |
| | SH | 11 | 0 | 100% | 6 | 5 | 55% |
| | *HH+SH* | *25* | *1* | *96%* | *10* | *14* | *42%* |
| | All | 172 | 11 | 94% | 40 | 163 | 20% |
| Medium Fleets | LH | 244 | 58 | 81% | 151 | 945 | 14% |
| | MH | 683 | 119 | 85% | 232 | 1,001 | 19% |
| | HH | 398 | 9 | 98% | 48 | 355 | 12% |
| | SH | 962 | 9 | 99% | 229 | 315 | 42% |
| | All | 2,288 | 195 | 92% | 660 | 2,616 | 20% |
| Large Fleets | LH | 573 | 110 | 84% | 341 | 1,660 | 17% |
| | MH | 1,602 | 224 | 88% | 523 | 1,758 | 23% |
| | HH | 933 | 17 | 98% | 109 | 623 | 15% |
| | SH | 2,256 | 17 | 99% | 517 | 554 | 48% |
| | All | 5,364 | 368 | 94% | 1,490 | 4,595 | 24% |

Note: For small fleets, basin operation fraction was calculated for HH and SH combined.
For large fleets, totals have been allocated to GVW based on the medium fleet distribution.

*Some follow-up to the 1998 survey was done in 1999.

Note that the basin operation fractions (summed across GVW) do not vary much across fleet size. The likelihood of basin operation does appear to increase somewhat with GVW, both for trucks registered In Basin and Out of Basin. For trucks registered Out of Basin, this is intuitive, as larger trucks are more likely to be used for long trips rather than smaller trucks. It is possible that port activities attract heavier trucks registered Out of Basin to operate inside the Basin. For trucks registered In Basin, JFA believes that this trend can be explained by some discrepancies in the registration location information. In our survey efforts, several fleets registered In Basin were found to have trucks garaged elsewhere in the state. Of this small number of fleets, the heavier trucks are more likely to venture into the Basin than lighter trucks. Thus, for trucks registered In Basin, the basin operation fraction increases slightly with GVW.

The basin operation fractions described above are applied to the population figures to produce the control totals. These figures serve as our best estimate of the number of trucks that operate in the basin, by fleet size, GVW and registration location. They will serve as the basis for the analysis of specific operation and maintenance variables. The control totals are shown in Table 4.

Table 4. Control Totals: Number of HDTs Operating In Basin (Basin Operation Fractions Applied to Adjusted 1997 DMV Figures)

| | | Registered In | Registered Out |
|---|---|---|---|
| Small Fleets | LH | 87,367 | 20,735 |
| | MH | 51,300 | 24,888 |
| | HH | 10,152 | 7,107 |
| | SH | 11,625 | 5,873 |
| | *sub-total* | *160,444* | *58,603* |
| Med Fleets | LH | 29,278 | 6,746 |
| | MH | 29,273 | 11,259 |
| | HH | 8,066 | 2,040 |
| | SH | 9,357 | 5,896 |
| | *sub-total* | *75,974* | *25,940* |
| Lrg Fleets | LH | 11,877 | 3,386 |
| | MH | 13,857 | 4,930 |
| | HH | 3,889 | 587 |
| | SH | 4,500 | 1,566 |
| | *sub-total* | *34,124* | *10,469* |
| All Fleets | LH | 128,523 | 30,867 |
| | MH | 94,430 | 41,076 |
| | HH | 22,106 | 9,734 |
| | SH | 25,482 | 13,334 |
| | *sub-total* | *270,541* | *95,012* |

## 3.3. Fuel Types

Once control totals for the number of trucks operating in the Basin are established, the next task is to split the control totals by fuel type. A different process is used to do this depending on registration location. For trucks registered In Basin, apportioning the control totals by fuel type can be done using the DMV registration data. As mentioned, these data include the number of registered trucks by GVW, fleet size and fuel type. For each GVW and fleet size cell, JFA apportions the control total based on the fuel type distribution from the DMV data. Note that this distribution is for all trucks registered In Basin, not just those that are registered In Basin and operate In Basin. However, since well over 90 percent of trucks registered In Basin operate In Basin, this assumption is quite justified.

For trucks registered Out of Basin, JFA cannot rely on DMV data since the fuel distribution for all trucks registered Out of Basin differs from that of trucks registered Outside the Basin, but operating In Basin. (One reason for this is that long-distance trucks are more likely to use diesel fuel, even accounting for GVW.) Therefore, apportioning the control totals among the fuel types is done using survey data. JFA's survey data is not extensive enough to determine these proportions by fleet size as well as GVW, since the number of trucks registered Out of Basin but operating In Basin was relatively small. So in this calculation JFA assumes that for these trucks, fuel type distribution within GVW does not vary across fleet size. The control totals by GVW, fuel, fleet size and registration location are shown in Table 5.

Table 5. Number of HDTs Operating in Basin by GVW, Fuel, Fleet Size and Registration.

| | | Registered In Basin | | | Registered Out of Basin | | |
|---|---|---|---|---|---|---|---|
| | | Gasol | Diesel | Other | Gasol | Diesel | Other |
| Sml Fleets | LH | 76,923 | 10,433 | 12 | 7,488 | 12,960 | 288 |
| | MH | 27,945 | 23,194 | 161 | 10,437 | 14,183 | 268 |
| | HH | 121 | 9,961 | 70 | - | 7,107 | - |
| | SH | 138 | 11,406 | 80 | - | 5,873 | - |
| | *sub-total* | *105,126* | *54,994* | *324* | *17,925* | *40,123* | *556* |
| Med Fleets | LH | 25,412 | 3,860 | 5 | 2,436 | 4,216 | 94 |
| | MH | 10,092 | 18,960 | 220 | 4,722 | 6,416 | 121 |
| | HH | 83 | 7,948 | 34 | - | 2,040 | - |
| | SH | 97 | 9,221 | 40 | - | 5,896 | - |
| | *sub-total* | *35,684* | *39,990* | *300* | *7,157* | *18,568* | *215* |
| Lrg Fleets | LH | 10,728 | 1,149 | - | 1,223 | 2,116 | 47 |
| | MH | 4,203 | 9,636 | 18 | 2,067 | 2,809 | 53 |
| | HH | 11 | 3,875 | 3 | - | 587 | - |
| | SH | 12 | 4,484 | 4 | - | 1,566 | - |
| | *sub-total* | *14,954* | *19,145* | *24* | *3,290* | *7,079* | *100* |
| All Fleets | LH | 113,063 | 15,443 | 17 | 11,146 | 19,292 | 429 |
| | MH | 42,240 | 51,791 | 399 | 17,226 | 23,409 | 442 |
| | HH | 215 | 21,784 | 108 | - | 9,734 | - |
| | SH | 247 | 25,111 | 124 | - | 13,334 | - |
| | *sub-total* | *155,765* | *114,129* | *648* | *28,372* | *65,769* | *870* |

## 3.4. Age of HDTs

JFA used the survey data to estimate HDT populations by model year. The data is not extensive enough to develop a population estimate by individual model years. Rather, the model years have been grouped into the categories commonly used by ARB for emissions analysis: 1994-98, 1991-93, 1988-90 and 1987 & earlier. Table 6 shows the model year distribution by GVW, with the survey data weighted by fleet size.

Table 6. Model Year Distributed by GVW

Data weighted by fleet size

| | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|
| 94-98 | 35% | 25% | 34% | 40% | *32%* |
| 91-93 | 4% | 11% | 16% | 23% | *12%* |
| 88-90 | 21% | 22% | 18% | 17% | *20%* |
| 87&older | 40% | 42% | 32% | 20% | *36%* |
| Total | *100%* | *100%* | *100%* | *100%* | *100%* |
| | | | | | |
| 94-98 | 34% | 33% | 10% | 23% | *100%* |
| 91-93 | 11% | 39% | 14% | 36% | *100%* |
| 88-90 | 32% | 45% | 9% | 15% | *100%* |
| 87&older | 34% | 48% | 9% | 10% | *100%* |
| *Total* | *31%* | *41%* | *10%* | *18%* | *100%* |

JFA explored the influence of fleet size, GVW and usage on truck age. JFA's goal is to identify truck sub-populations that tend to be older than average, as these would be good targets for emission reduction incentives. The survey asked for information on both truck model year and engine model year. An engine may be newer than the truck if the engine has been replaced. Of the 542 trucks for which JFA has information on both the truck and engine model year, only 24 (4.4 percent) have an engine that is newer than the truck. (Three records have anomalous data in which the engine is older than the truck.) JFA included here only cross-tabulations with truck age, since they are very similar to cross-tabulations with engine age. The frequency of engine replacement is analyzed later in this report.

Table 7 shows truck model year by fleet size. Small fleet trucks are considerably older than medium and large fleet trucks. Forty-six percent of small fleet trucks in our survey are model year 1987 or earlier, compared to 20 percent of medium fleet trucks and 35 percent of large fleet trucks.

Table 7. Truck Model Year by Fleet Size

Number of Trucks

| Truck Model Year | Sml Flts | Med Flts | Lrg Flts |
|---|---|---|---|
| pre-1988 | 108 | 144 | 342 |
| 1988-90 | 52 | 133 | 157 |
| 1991-93 | 12 | 179 | 147 |
| 1994-98 | 62 | 279 | 340 |
| Total | 234 | 735 | 986 |
| | | | |
| pre-1988 | 46% | 20% | 35% |
| 1988-90 | 22% | 18% | 16% |
| 1991-93 | 5% | 24% | 15% |
| 1994-98 | 26% | 38% | 34% |
| Total | 100% | 100% | 100% |

Gross vehicle weight is not strongly correlated with truck age, when controlling for fleet size. To explore correlation between truck usage and age, JFA combined small and medium fleets. (Data on large fleet trucks tends to grossly skew any cross-tabulations here.) Table 8 shows usage by truck model year, weighted by fleet size. Trucks used for daily rental are much newer than average, while construction, service/utility and waste hauling trucks are considerably older than average.

Table 8. Truck Model Year by Usage

Number of Trucks, Weighted by Fleet Size (Small and Medium Fleets)

| Truck Model Year | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| pre-1988 | 60 | 148 | 77 | 22 | 1 | 33 | 493 | 834 |
| 1988-90 | 47 | 67 | 23 | 9 | 1 | 37 | 292 | 476 |
| 1991-93 | 89 | 4 | 23 | 13 | 5 | 7 | 118 | 259 |
| 1994-98 | 70 | 80 | 49 | 60 | 17 | 7 | 411 | 694 |
| Total | 266 | 299 | 172 | 105 | 24 | 83 | 1315 | 2264 |
| | | | | | | | | |
| pre-1988 | 23% | 49% | 45% | 21% | 4% | 40% | 37% | 37% |
| 1988-90 | 18% | 22% | 13% | 8% | 4% | 44% | 22% | 21% |
| 1991-93 | 33% | 1% | 13% | 13% | 21% | 8% | 9% | 11% |
| 1994-98 | 26% | 27% | 29% | 58% | 71% | 8% | 31% | 31% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

JFA then explored the characteristics of the older trucks in isolation. Variable frequencies and cross-tabulations were created for trucks of model year 1987 and earlier. All analysis must be controlled for fleet size, since large fleets skew any tabulation. Table 9 shows the GVW distribution of older trucks compared to the total population. Older trucks are more likely to be medium-heavy than the population, and less likely to be super-heavy. Table 10 shows the usage distribution of older trucks compared to the total population. While the difference in usage distribution is not striking, the older trucks are more heavily weighted toward construction and service/utility uses, and less toward trucking. Finally, Table 11 compares the average annual mileage of older trucks with the population. Again, older trucks in small fleets look much like the population of small fleet trucks. Among medium fleet trucks, however, the older vehicles are used considerably less than the population average. Only 32 percent of older medium fleet trucks drive over 30,000 miles annually, compared to 65 percent of all medium fleet trucks.

Table 9. Distribution of Trucks by GVW and Age

Number of Trucks, Weighed by Fleet Size

| GVW | Pre-1988 Trucks | | All Years | |
|---|---|---|---|---|
| LH | 900 | 29% | 2,670 | 30% |
| MH | 1,537 | 49% | 3,622 | 41% |
| HH | 344 | 11% | 941 | 11% |
| SH | 358 | 11% | 1,659 | 19% |
| Total | 3,139 | 100% | 8,892 | 100% |

Table 10. Distribution of Trucks by Usage and Age

Number of Trucks, Weighed by Fleet Size

| Usage | Pre-1988 Trucks | | All Years | |
|---|---|---|---|---|
| Trucking | 224 | 7% | 1,197 | 13% |
| Constr. | 466 | 14% | 1,117 | 12% |
| Serv/Util | 583 | 18% | 1,231 | 13% |
| Parcel | 73 | 2% | 383 | 4% |
| Rental | 6 | 0% | 174 | 2% |
| Waste | 166 | 5% | 411 | 4% |
| Other | 1,801 | 54% | 4,939 | 52% |
| Total | 3,320 | 100% | 9,452 | 100% |

Table 11. Distribution of Trucks by Fleet Size, Annual Mileage & Age

| | Pre-1988 Trucks | | | | All Trucks | | |
|---|---|---|---|---|---|---|---|
| Ann. Miles | Small Flts | Med Flts | Sub-Total | Ann. Miles | Small Flts | Med Flts | Sub-Total |
| 0 - 15K | 42 | 22 | 64 | 0 - 15K | 91 | 183 | 274 |
| 15K - 30K | 20 | 23 | 43 | 15K - 30K | 49 | 141 | 190 |
| 30K - 60K | 19 | 12 | 31 | 30K - 60K | 41 | 235 | 276 |
| over 60K | 10 | 9 | 19 | over 60K | 25 | 364 | 389 |
| Total | 91 | 66 | 157 | Total | 206 | 923 | 1129 |
| | | | | | | | |
| 0 - 15K | 46% | 33% | 41% | 0 - 15K | 44% | 20% | 24% |
| 15K - 30K | 22% | 35% | 27% | 15K - 30K | 24% | 15% | 17% |
| 30K - 60K | 21% | 18% | 20% | 30K - 60K | 20% | 25% | 24% |
| over 60K | 11% | 14% | 12% | over 60K | 12% | 39% | 34% |
| Total | 100% | 100% | 100% | Total | 100% | 100% | 100% |

One interesting observation is that the number of trucks in the 1991-93 model-year category is less than would be expected. Among small fleets in particular, the portion of trucks in this age group is much lower than trucks of model year 1988-90, the previous three-year time span. One possible reason for this is the economic recession in California during that period. Such a downturn would probably affect the buying patterns of small fleets more than medium and large fleets, since their profit margins are typically lower.

### 3.5. Public Transit Buses

JFA collected preliminary information on the characteristics of public transit buses that operate in the Basin. JFA purchased the American Public Transit Association's *1999 Transit Vehicle Data Book.* This contains a list of all public transit operators, the number of vehicles they operate, and some physical characteristics of those vehicles. Vehicles are classified by a number of factors including fuel type, vehicle type, number of seats, bus length, and year built. 12 bus transit operators are listed in the Basin. The population of buses belonging to these operators by fuel type, year and bus length is shown in Table 12. Note that these figures do not include vehicles owned by private demand-responsive transit operators.

Table 12. Public Transit Buses in Basin

| Fuel | Model Year | 35 Feet & Longer | 28 - 30 Feet | Minibus & Van |
|---|---|---|---|---|
| Diesel | 1994-98 | 452 | 1 | 6 |
| | 1991-93 | 331 | 7 | 30 |
| | 1988-90 | 1045 | 2 | |
| | 1987&older | 1007 | | |
| | Sub-total | 2835 | 10 | 36 |
| Gasoline | 1994-98 | | | 219 |
| | 1991-93 | | | 34 |
| | 1988-90 | | | 3 |
| | 1987&older | | | |
| | Sub-total | 0 | 0 | 256 |
| CNG/LP | 1994-98 | 665 | 5 | 96 |
| | 1991-93 | | | 74 |
| | 1988-90 | | | |
| | 1987&older | | | |
| | Sub-total | 665 | 5 | 170 |
| Electric | 1994-98 | | | 3 |
| | 1991-93 | 85 | | |
| | 1988-90 | 8 | | |
| | 1987&older | | | |
| | Sub-total | 93 | 0 | 3 |

# 4 HEAVY-DUTY TRUCK PATTERNS

This chapter presents discussions on HDT patterns in the South Coast Air Basin. Six key variables are identified to provide better understanding of the HDT population in the Basin. The variables studied in this section are: usage, range of operation, fueling practice, annual mileage, refrigerated trucks and days of week of operation. While some patterns of the HDT population emerge from analyzing these variables, it must be noted that much of information collected is based on a random sample survey of fleets, not trucks themselves. Because of the sampling methodology and surveys targeting HDT fleets in the area, some of the results are not representative of all trucks in the Basin. Rather, it is assumed that the fleet information (on truck usage/operational practice) obtained through the surveys applies to most, if not all trucks in the fleet. For large fleets, the statistics are not as reliable as in smaller fleets because of a small sampling size.

## 4.1. Usage of Trucks

Table 13 shows the usage of trucks by fleet size. As noted in Section 2.2, there are several reasons why the sample may not be representative of the population of trucks operating in the Basin with respect to usage. Small fleet trucking firms are probably underrepresented in the sample as they are difficult to contact by phone. The sample does not include any trucks from large parcel delivery fleets, which are known to be a significant portion of the truck population.

Table 13. Truck Usage by Fleet Size

| Flt Size | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| SmlFlts | 5% | 16% | 11% | 5% | 0% | 1% | 63% | 100% |
| MedFlts | 25% | 8% | 14% | 8% | 5% | 2% | 37% | 100% |
| LrgFlts | 34% | 7% | 26% | 0% | 18% | 6% | 8% | 100% |

With these limitations in mind, the survey data shows some clear differences in usage across fleet size. Nearly 63 percent of small fleet trucks fall in the "Other" usage category, primarily trucks used for deliveries. The usage of medium fleet trucks are spread more evenly, with 37 percent Other, 25 percent Trucking Firms, and 14 percent Service/Utility. Large fleet trucks tend to be used for Trucking (34 percent), Service Utility (26 percent), and Daily Rental (18 percent).

Table 14 shows truck usage by GVW, with data weighted by fleet size. Nearly three-fourths of trucking firm trucks are in the Super-Heavy category. Construction and Service/Utility trucks are primarily Light- and Medium-Heavy. Waste Hauling trucks are primarily Medium- and Heavy-Heavy.

## 4.2. Range of Operation – Local, Short Haul & Long Haul

Truck range of operation is an important determinant of the effectiveness of many incentive options. In our surveys, local operation trucks were defined as those that typically operate within 50 miles of the truck's base. Long-haul trucks typically operate further than 50 miles from base.

Table 14. Truck Usage by GVW

Data Weighted by Fleet Size

| | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|
| Trucking Firm | 5% | 19% | 2% | 73% | 100% |
| Construction | 47% | 40% | 6% | 8% | 100% |
| Service/Util | 46% | 39% | 13% | 2% | 100% |
| Parcel Deliv. | 40% | 28% | 26% | 7% | 100% |
| Daily Rental | 11% | 59% | 5% | 25% | 100% |
| Waste Hauling | 0% | 44% | 42% | 14% | 100% |
| Other | 31% | 48% | 10% | 12% | 100% |
| Total | 30% | 41% | 11% | 18% | 100% |

JFA first developed an estimate of the population of trucks that operate locally within the Basin. To do this, JFA calculated the percentage of locally-operated trucks by fleet size and registration location and applied these fractions to the control totals. These percentages are shown in Tables 15 and 16. Small fleet trucks are more likely to operate locally than larger fleet trucks. For trucks registered In Basin, it can be assumed that all those that operate locally do so within the Basin. For trucks registered Out of Basin, local operation may or may not involve Basin operation. For fleets based more than 50 miles from the Basin, local operation does not involve travel in the Basin. For trucks based out of the Basin, but within 50 miles of the Basin, JFA assumed that local operation includes Basin operation. In exploring the survey data for which JFA have geographic information, JFA found that 5 of 29 fleets (17 percent) that are registered Out of Basin and operate locally are actually registered within 50 miles of the Basin perimeter. Therefore, JFA assumed that this 17 percent applies to all trucks registered Out of Basin and operating locally. The remainder of trucks registered Out of Basin are either long-haul trucks or trucks that operate locally outside of the Basin. These fractions are shown in the last column of Table 17. The fractions in Table 18 are applied to the sub-totals of Table 4 in order to estimate the sub-population of local operation trucks In Basin. This sub-population is shown in Table 18.

Table 15. Range by Fleet Size (Number of Fleets)

| | Small Flts | Med Flts | Large Flts |
|---|---|---|---|
| Local | 138 | 138 | 17 |
| Long-Haul | 24 | 46 | 12 |
| Total | 162 | 184 | 29 |
| | | | |
| Local | 85% | 75% | 59% |
| Long-Haul | 15% | 25% | 41% |
| Total | 100% | 100% | 100% |

Table 16. Range by Fleet Size (Number of Trucks Represented)

| | Small Flts | Med Flts | Large Flts |
|---|---|---|---|
| Local | 207 | 2202 | 3135 |
| Long-Haul | 38 | 741 | 3719 |
| Total | 245 | 2943 | 6854 |
| | | | |
| Local | 84% | 75% | 46% |
| Long-Haul | 16% | 25% | 54% |
| Total | 100% | 100% | 100% |

Table 17. Range by Registration Location and Fleet Size

Number of Trucks

| | | Registered In Basin | | Registered Out of Basin | | | |
|---|---|---|---|---|---|---|---|
| | | | | All | | Local Oper. In Basin | |
| Sml Flts | Local | 178 | 88% | 29 | 69% | 5 | 12% |
| | Long-Haul | 25 | 12% | 13 | 31% | 37 | 88% |
| | Total | 203 | 100% | 42 | 100% | 42 | 100% |
| Med Flts | Local | 1817 | 80% | 385 | 58% | 65 | 10% |
| | Long-Haul | 466 | 20% | 275 | 42% | 595 | 90% |
| | Total | 2283 | 100% | 660 | 100% | 660 | 100% |

Table 18. Estimated Population by Range, Registration Location and Fleet Size

| | | Registered In Basin | Registered Out of Basin |
|---|---|---|---|
| Sml Flts | Local | 140,685 | 6,879 |
| | Long-Haul | 19,759 | 51,724 |
| | *Sub-Total* | *160,444* | *58,603* |
| Med Flts | Local | 60,466 | 2,572 |
| | Long-Haul | 15,508 | 23,367 |
| | *Sub-Total* | *75,974* | *25,940* |
| Lrg Flts | Local | 19,053 | 167 |
| | Long-Haul | 15,071 | 10,301 |
| | *Sub-Total* | *34,124* | *10,469* |
| All Flts | Local | 220,204 | 9,618 |
| | Long-Haul | 50,337 | 85,393 |
| | *Total* | *270,541* | *95,012* |

*Note: In this table, "Local" refers to local operation within the Basin and not local operation elsewhere.*

A primary determinant of truck range is the type of usage. Table 19 shows that, as expected, trucking firms are far more likely to operate long-haul than any other business type. Fleets of trucks making deliveries ("Other") also have a significant portion that operate long-haul trucks, particularly among the medium and large fleets. The other usage categories operate almost exclusively locally.

Table 19. Range by Usage and Fleet Size

Number of Fleets

| | | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other |
|---|---|---|---|---|---|---|---|---|
| Sml Flts | Local | 6 | 24 | 12 | 8 | | 2 | 82 |
| | Long-Haul | 3 | 1 | 1 | | | | 19 |
| | Total | 9 | 25 | 13 | 8 | 0 | 2 | 101 |
| Med+Lrg Flts | Local | 13 | 24 | 37 | 7 | 8 | 7 | 59 |
| | Long-Haul | 22 | 3 | 3 | 1 | 2 | 0 | 27 |
| | Total | 35 | 27 | 40 | 8 | 10 | 7 | 86 |

| | | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other |
|---|---|---|---|---|---|---|---|---|
| Sml Flts | Local | 67% | 96% | 92% | 100% | 0% | 100% | 81% |
| | Long-Haul | 33% | 4% | 8% | 0% | 0% | 0% | 19% |
| | Total | 100% | 100% | 100% | 100% | 0% | 100% | 100% |
| Med+Lrg Flts | Local | 37% | 89% | 93% | 88% | 80% | 100% | 69% |
| | Long-Haul | 63% | 11% | 8% | 13% | 20% | 0% | 31% |
| | Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

## 4.3. Central Fueling

JFA tested the influence of several variables on central fueling tendencies. Trucks that fuel centrally will generally be better candidates for conversion to alternative fuels than those that fuel on the road. As expected, fleet size is the variable most strongly correlated with central fueling, with larger fleets much more likely to fuel centrally than smaller fleets. As shown in Table 20, roughly three-fourths of large fleet trucks fuel centrally, compared to one-fourth of small fleet trucks. Medium fleets are split more evenly. JFA also tested the influence of usage, range and GVW variables on central fueling. These variables were not as strongly correlated as fleet size.

Table 20. Fleets that use Central Fueling (Number and Percent of Trucks Represented)

| Fuel Centrally? | Sml Flts | Med Flts | Lrg Flts |
|---|---|---|---|
| Yes | 50 | 1535 | 5021 |
| No | 185 | 1037 | 967 |
| Both | 10 | 371 | 866 |
| Total | 245 | 2943 | 6854 |

| Fuel Centrally? | Sml Flts | Med Flts | Lrg Flts |
|---|---|---|---|
| Yes | 20% | 52% | 73% |
| No | 76% | 35% | 14% |
| Both | 4% | 13% | 13% |
| Total | 100% | 100% | 100% |

JFA then tested the influence of other variables while controlling for fleet size. Truck usage (business type) has little correlation with central fueling within fleet size groupings. Truck GVW does appear to be correlated with central fueling in medium and large fleets. As shown in Table 21, central fueling increases with GVW among large fleet trucks and to a lesser extent among medium fleet trucks. This becomes more clear by lumping together trucks that fuel centrally all the time (Yes) and part of the time (Both). Also notable is that across all three fleet size categories, heavy-heavy trucks are the most likely to fuel centrally. It seems likely that central fueling tendency increases with GVW, but many super-heavy trucks are used for long-haul trucking and are not able to fuel centrally. Truck age is not strongly correlated with central fueling tendency, when controlling for fleet size.

To estimate the number of trucks that fuel centrally and operate in the Basin, JFA applied the survey percentages in Table 21 to the control totals in Table 4. A small number of fleets that fuel centrally and operate in the Basin are actually registered outside of the Basin. However, the tendency of Basin-operating trucks to fuel centrally does not vary significantly between those trucks registered In Basin and those registered Out of Basin. In examining the data, it appears that many of the central-fueling trucks based Out of Basin are located near the Basin, such as in Ventura County, Kern County or San Diego County. Therefore, the percentages in Table 21 were applied to the control totals for both registration groups. The central fueling percentages for medium and large fleets were combined in this calculation due to the limited number of large fleet responses. The results in Table 22 show an estimate of the number of centrally-fueled trucks that operate in the Basin, by GVW, fleet size and registration location. Note that some fleets responded to the survey question about central fueling by saying that their trucks "both" fuel centrally and on the road. In some cases, this means that all the fleet's trucks fuel centrally part of the time and fuel on the road part of the time. In other cases, a "both" response means that some trucks in the fleet always fuel centrally, and some always fuel on the road. Since JFA cannot distinguish between these two meanings from the survey data, JFA has chosen the former meaning for the purposes of calculating Table 22.

Table 21. Central Fueling by Fleet Size and GVW (Number and Percent of Trucks)

| SmlFlt | Fuel Centrally? | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|---|
| | Yes | 9 | 23 | 7 | 2 | 41 |
| | No | 65 | 72 | 11 | 13 | 161 |
| | Both | 4 | 4 | | 2 | 10 |
| | Total | 78 | 99 | 18 | 17 | 212 |
| | | | | | | |
| | Yes | 12% | 23% | 39% | 12% | 19% |
| | No | 83% | 73% | 61% | 76% | 76% |
| | Both | 5% | 4% | 0% | 12% | 5% |
| | Total | 100% | 100% | 100% | 100% | 100% |

| MedFlt | Fuel Centrally? | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|---|
| | Yes | 72 | 261 | 179 | 185 | 697 |
| | No | 82 | 86 | 23 | 245 | 436 |
| | Both | 15 | 55 | | 100 | 170 |
| | Total | 169 | 402 | 202 | 530 | 1303 |
| | | | | | | |
| | Yes | 43% | 65% | 89% | 35% | 53% |
| | No | 49% | 21% | 11% | 46% | 33% |
| | Both | 9% | 14% | 0% | 19% | 13% |
| | Total | 100% | 100% | 100% | 100% | 100% |

| LrgFlt | Fuel Centrally? | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|---|
| | Yes | 47 | 238 | 84 | 120 | 489 |
| | No | 326 | 98 | 3 | 4 | 431 |
| | Both | 9 | 7 | | 50 | 66 |
| | Total | 382 | 343 | 87 | 174 | 986 |
| | | | | | | |
| | Yes | 12% | 69% | 97% | 69% | 50% |
| | No | 85% | 29% | 3% | 2% | 44% |
| | Both | 2% | 2% | 0% | 29% | 7% |
| | Total | 100% | 100% | 100% | 100% | 100% |

Table 21. Cont.

| Med+Lrg | Fuel Centrally? | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|---|
| | Yes | 119 | 499 | 263 | 30[illegible] | 1186 |
| | No | 408 | 184 | 26 | 249 | 867 |
| | Both | 24 | 62 | 0 | 150 | 236 |
| | Total | 551 | 745 | 289 | 704 | 2289 |
| | | | | | | |
| | Yes | 22% | 67% | 91% | 43% | 52% |
| | No | 74% | 25% | 9% | 35% | 38% |
| | Both | 4% | 8% | 0% | 21% | 10% |
| | Total | 100% | 100% | 100% | 100% | 100% |

Med & Lrg Flts, weighted by fleet size

| | Fuel Centrally? | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|---|
| | Yes | 191 | 760 | 442 | 490 | 1883 |
| | No | 490 | 270 | 49 | 494 | 1303 |
| | Both | 39 | 117 | 0 | 250 | 406 |
| | Total | 720 | 1147 | 491 | 1234 | 3592 |
| | | | | | | |
| | Yes | 27% | 66% | 90% | 40% | 52% |
| | No | 68% | 24% | 10% | 40% | 36% |
| | Both | 5% | 10% | 0% | 20% | 11% |
| | Total | 100% | 100% | 100% | 100% | 100% |

Table 22. Estimated Number of Centrally Fueled HDTs Operating in the Basin

| | Central Fueling: | Registered In | | | Registered Out | | |
|---|---|---|---|---|---|---|---|
| | | Always | Sometimes | Never | Always | Sometimes | Never |
| Sml Fleets | LH | 10,081 | 4,480 | 72,806 | 2,393 | 1,063 | 17,279 |
| | MH | 11,918 | 2,073 | 37,309 | 5,782 | 1,006 | 18,100 |
| | HH | 3,948 | - | 6,204 | 2,764 | - | 4,343 |
| | SH | 1,368 | 1,368 | 8,889 | 691 | 691 | 4,491 |
| | Sub-total | 31,029 | 7,568 | 121,846 | 11,334 | 2,764 | 44,505 |
| Med Fleets | LH | 6,323 | 1,275 | 21,680 | 1,457 | 294 | 4,995 |
| | MH | 19,607 | 2,436 | 7,230 | 7,541 | 937 | 2,781 |
| | HH | 7,340 | - | 726 | 1,856 | - | 183 |
| | SH | 4,054 | 1,994 | 3,309 | 2,554 | 1,256 | 2,085 |
| | Sub-total | 39,364 | 7,833 | 28,776 | 13,440 | 2,674 | 9,825 |
| Lrg Fleets | LH | 2,565 | 517 | 8,795 | 731 | 147 | 2,507 |
| | MH | 9,281 | 1,153 | 3,422 | 3,302 | 410 | 1,218 |
| | HH | 3,539 | - | 350 | 534 | - | 53 |
| | SH | 1,950 | 959 | 1,592 | 679 | 334 | 554 |
| | Sub-total | 17,681 | 3,518 | 12,925 | 5,424 | 1,079 | 3,965 |
| All Fleets | LH | 18,969 | 6,273 | 103,281 | 4,581 | 1,505 | 24,782 |
| | MH | 40,807 | 5,662 | 47,961 | 16,625 | 2,353 | 22,098 |
| | HH | 14,827 | - | 7,279 | 5,154 | - | 4,580 |
| | SH | 7,371 | 4,320 | 13,791 | 3,924 | 2,281 | 7,130 |
| | Total | 88,074 | 18,919 | 163,548 | 30,198 | 6,518 | 58,295 |

## 4.4. Annual Mileage

High annual mileage is an important indicator of emission reduction potential. JFA developed cross-tabulations of truck annual mileage with several variables including fleet size, GVW, usage and age. Fleet size is the most strongly correlated variable – annual mileage increases with fleet size. Table 23 shows the number of trucks by annual mileage and fleet size category. Only 32 percent of small fleet trucks drive over 30,000 miles per year, compared to 65 percent of medium fleet trucks. Annual mileage information was not provided by enough large fleets to draw reliable conclusions.

Table 23. Annual Miles by Fleet Size (Number of Trucks and Percentage)

| Annual Miles | Sml Flts | Med Flts |
|---|---|---|
| 0 - 15K | 90 | 183 |
| 15K - 30K | 49 | 141 |
| 30K - 60K | 41 | 235 |
| over 60K | 25 | 364 |
| Total | 205 | 923 |

| Annual Miles | | |
|---|---|---|
| 0 - 15K | 44% | 20% |
| 15K - 30K | 24% | 15% |
| 30K - 60K | 20% | 25% |
| over 60K | 12% | 39% |
| Total | 100% | 100% |

Table 24 shows the distribution of truck annual mileage by truck usage. The number of trucks represented has been weighted so that small, medium and large fleet trucks make up 60 percent, 29 percent and 11 percent of the total, respectively. Trucks logging the highest average annual mileage belong to fleets in the trucking business and daily rentals. In trucking fleets, 60 percent of the vehicles average over 60,000 miles per year. Construction, service/utility, parcel delivery and waste hauling fleets exhibit lower than average annual mileage.

Table 24. Annual Miles by Usage
(Percent of Trucks in Each Usage Category, Weighted by Fleet Size)

| Annual Miles | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| 0 - 15K | 6% | 42% | 49% | 35% | 0% | 74% | 33% | 30% |
| 15K - 30K | 14% | 34% | 34% | 54% | 8% | 4% | 18% | 22% |
| 30K - 60K | 20% | 7% | 12% | 0% | 13% | 0% | 31% | 22% |
| over 60K | 60% | 17% | 6% | 11% | 79% | 22% | 18% | 26% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Truck annual mileage increases with gross vehicle weight. Table 25 shows the distribution of annual mileage by GVW, with the number of trucks weighted by fleet size. JFA also developed this cross-tabulation for small and medium fleets separately, and the same trend is evident. Light-heavy trucks are predominantly low-mileage, and super-heavy trucks are predominantly high-mileage. Nearly 60 percent of super-heavy trucks operate over 60,000 miles per year, compared to only 8 percent of light-heavy trucks.

Table 25. Annual Miles by GVW (Number of Trucks, Weighted by Fleet Size)

| Annual Miles | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|
| 0 - 15K | 390 | 512 | 86 | 35 | 1023 |
| 15K - 30K | 249 | 237 | 56 | 34 | 576 |
| 30K - 60K | 109 | 296 | 64 | 146 | 615 |
| over 60K | 67 | 130 | 75 | 312 | 584 |
| Total | 815 | 1175 | 281 | 527 | 2798 |
| | | | | | |
| 0 - 15K | 48% | 44% | 31% | 7% | 37% |
| 15K - 30K | 31% | 20% | 20% | 6% | 21% |
| 30K - 60K | 13% | 25% | 23% | 28% | 22% |
| over 60K | 8% | 11% | 27% | 59% | 21% |
| Total | 100% | 100% | 100% | 100% | 100% |

Annual mileage is also correlated with truck age, though the relationship is not as strong as with GWV or fleet size. Table 26 shows the distribution of annual mileage by truck model year, weighted by fleet size. Annual mileage decline as trucks get older. One-quarter of the trucks of model year 1994 or newer average over 60,000 miles per year, compared to only 11 percent of trucks built in 1987 or earlier.

Table 26. Annual Miles by Truck Model Year
(Number of Trucks, Weighted by Fleet Size)

| | Truck Model Year | | | | |
|---|---|---|---|---|---|
| Annual Miles | pre-1988 | 1988-90 | 1991-93 | 1994-98 | Total |
| 0 - 15K | 190 | 101 | 36 | 113 | 440 |
| 15K - 30K | 103 | 78 | 15 | 107 | 303 |
| 30K - 60K | 88 | 51 | 20 | 84 | 243 |
| over 60K | 49 | 41 | 23 | 100 | 213 |
| Total | 430 | 271 | 94 | 404 | 1199 |
| | | | | | |
| 0 - 15K | 44% | 37% | 38% | 28% | 37% |
| 15K - 30K | 24% | 29% | 16% | 26% | 25% |
| 30K - 60K | 20% | 19% | 21% | 21% | 20% |
| over 60K | 11% | 15% | 24% | 25% | 18% |
| Total | 100% | 100% | 100% | 100% | 100% |

## 4.5. Refrigerated Trucks

Table 27 shows the number and percent of refrigerated trucks in the sample of fleets. Of the large fleet sample total, 4 percent of the trucks are refrigerated. Table 28 shows the fuel and GVW of the refrigerated trucks for which this information was available. Nearly all refrigerated trucks use diesel fuel, and most are in the medium-heavy or super-heavy weight classes.

Table 27. Refrigerated Trucks (Number of Fleets and Trucks)

| | Number of Trucks Represented | |
|---|---|---|
| Refrigerated Trucks? | | |
| Yes | 310 | 4% |
| No | 7703 | 96% |
| Total | 8013 | 100% |

Table 28. Refrigerated Trucks by Fuel and GVW

| | Gasol | Diesel | Other | Total | Percent of Total |
|---|---|---|---|---|---|
| LH | 1 | 3 | 1 | 5 | 5% |
| MH | | 42 | 1 | 43 | 41% |
| HH | | 12 | | 12 | 11% |
| SH | | 45 | | 45 | 43% |
| Total | 1 | 102 | 2 | 105 | 100% |

## 4.6. Days of Week of Operations

Table 29 shows the number of days per week trucks are in use. As with other variables in this section, this is a fleet average applied to all trucks in the fleet. 100 percent of the trucks are used five days per week or more. Medium and large fleet trucks tend to be used more days per week than small fleet trucks. However, as shown in the table, only limited data collection was available from a small number of fleets.

Table 29. Days per Week in Use.

| Days per Week in Use | Number of Fleets | | Number of Trucks Represented | |
|---|---|---|---|---|
| One | 0 | 0% | 0 | 0% |
| Two | 0 | 0% | 0 | 0% |
| Three | 0 | 0% | 0 | 0% |
| Four | 0 | 0% | 0 | 0% |
| Five | 6 | 60% | 1835 | 48% |
| Six | 2 | 20% | 1500 | 39% |
| Seven | 2 | 20% | 500 | 13% |
| Total | 10 | 100% | 3835 | 100% |

# 5 HDT MAINTENANCE INFORMATION

Like truck usage information, maintenance information was generally provided for a truck fleet rather than for individual trucks. (The exception is small fleets, where some maintenance questions were asked of each truck in the fleet.) In our analysis, JFA generally assumed that the maintenance information applies to all trucks in a fleet. The survey percentages described below reflect the number of trucks represented in the survey. The reliability of the results, however, depends on the number of fleets surveyed, not the number of trucks. For each variable below, the number of fleets surveyed is listed along with the estimated sampling error.

For many of the tables presented in this section, several statistical terms were used: They are 'degrees of freedom,' and 'chi-square.' Definitions of these terms from Social Statistics (2nd Ed.) by Hubert M. Blalock, Jr., McGraw Hill are presented below:

> Chi-square: chi-square is obtained by first taking the square of the difference between the observed and expected frequencies in each cell. This figure is divided by the expected number of cases in each cell in order to standardize it, so that the biggest contributions do not always come from the largest cells. The sum of these nonnegative quantities for all cells is the value of chi-square.
>
> Degrees of freedom (df): The number of degrees of freedom is equal to the number of quantities that are unknown minus the number of independent equations linking these unknowns.

Tables presented in the following sections represent tabulated results of the survey questions. In some cases, the tabulated survey results reported herein appear inconsistent. The JFA team recorded and noted some unexpected responses from the survey questionnaire, and attempted to conduct follow-up interviews where applicable and possible. Not all responses that originally appeared anomalous were clarified. Several potential factors for the anomalous responses may be attributed to sampling errors and bias, possible misunderstanding or misinterpretation of the questionnaire on the respondents' part. After the follow-up attempts to clarify unexpected responses, all responses were tabulated and reported as they were received.

## 5.1. Maintenance Frequency

JFA survey collected data on the number of miles that a truck is typically driven between maintenance practices. These practices were defined as Major Service (such as repair or replacement of engine, fuel and/or powertrain components) and Minor Service (such as a tune-up, oil and filter change, etc.). For small fleet trucks, these questions were asked for each individual truck. For medium and large fleets, these questions were asked for each fleet on average.

JFA would expect variations in maintenance frequency to be caused primarily by truck characteristics (like age and GVW) and perhaps usage. It is also possible that smaller fleets could exhibit different maintenance frequencies than larger fleets. Unfortunately, many of those surveyed responded with "Don't Know" for these questions. So the sample size is not large enough to fully explore these relationships by controlling for all variables simultaneously. JFA created separate cross-tabulations of maintenance frequency by fleet size, usage, GVW, and model year.

Table 30 shows the frequency of major service for all trucks in the survey, weighted by fleet size. Nearly half of the trucks represented in the survey reported major service every 10,000 miles or less, while most of the remainder reported major service after more than 30,000 miles. While a general understanding and definition of "major service" was given to the respondents, these responses may indicate that there could be different understandings among the respondents of what "major service" means. (N=181)

Table 30. Frequency of Major Service (miles between major maintenance)

| miles | percent |
|---|---|
| 1-10K | 46% |
| 10K - 20K | 10% |
| 20K - 30K | 5% |
| over 30K | 38% |
| Total | 100% |

Table 31 shows the frequency of minor service for all trucks in the survey, weighted by fleet size. Thirty-eight percent of trucks receive minor service at intervals of 3,000 miles or less, and another 30 percent at intervals of 3,000 – 6,000 miles. (N=275)

Table 31. Frequency of Minor Service (miles between minor maintenance)

| miles | percent |
|---|---|
| 1-3K | 39% |
| 3K - 6K | 31% |
| 6K - 9K | 7% |
| over 9K | 24% |
| Total | 100% |

There are significant differences in minor service frequency across fleet size. (Chi-square=12.8, df=6) Table 32 show that small fleets tend to perform minor maintenance more frequently than medium fleets. Part of this difference is due to the fact that small fleets tend to be made up of older trucks.

Table 32. Minor Service Frequency by Fleet Size (miles between minor maintenance)

Number of Trucks Represented

| | Small Flts | Med Flts |
|---|---|---|
| 1-3K | 91 | 436 |
| 3K - 6K | 67 | 599 |
| 6K - 9K | 16 | 88 |
| over 9K | 27 | 697 |
| Total | 201 | 1820 |
| | | |
| 1-3K | 45% | 24% |
| 3K - 6K | 33% | 33% |
| 6K - 9K | 8% | 5% |
| over 9K | 13% | 38% |
| Total | 100% | 100% |

Tables 33 and 34 illustrate that older trucks do tend to receive more frequent maintenance than newer trucks. Table 33 shows the frequency of major maintenance across truck model year categories, with data weighted by fleet size. (Chi square=16.9, df=9). The relationship between minor maintenance across truck model year is even stronger, as shown in Table 34 (Chi Square=23.6, df=9).

Table 35 shows the frequency of major maintenance by truck usage, with the data weighted by fleet size. In the survey, both of these variables were asked of fleets, not individual trucks. The significant testing has therefore been done based on the number of fleets, and the chi-square test is for this. The percentages below reflect the number of trucks represented in the survey. Service/utility fleets perform major maintenance more frequently than average. Rental, construction and waste hauling fleets perform major maintenance less frequently than average.

Table 33. Major Service Frequency by Model Year (miles between major maintenance)

| | pre-1988 | 1988-90 | 1991-93 | 1994-98 | Total |
|---|---|---|---|---|---|
| 1-10K | 53 | 27 | 11 | 40 | 131 |
| 10K - 20K | 9 | 8 | 8 | 10 | 35 |
| 20K - 30K | 4 | 0 | 1 | 8 | 13 |
| over 30K | 31 | 43 | 27 | 113 | 214 |
| Total | 97 | 78 | 47 | 171 | 393 |
| | | | | | |
| 1-10K | 55% | 35% | 23% | 23% | 33% |
| 10K - 20K | 9% | 10% | 17% | 6% | 9% |
| 20K - 30K | 4% | 0% | 2% | 5% | 3% |
| over 30K | 32% | 55% | 57% | 66% | 54% |
| Total | 100% | 100% | 100% | 100% | 100% |

Table 34. Minor Service Frequency by Model Year (miles between minor maintenance)

| | pre-1988 | 1988-90 | 1991-93 | 1994-98 | Total |
|---|---|---|---|---|---|
| 1-3K | 63 | 42 | 10 | 52 | 167 |
| 3K - 6K | 31 | 26 | 26 | 64 | 147 |
| 6K - 9K | 9 | 18 | 7 | 29 | 63 |
| over 9K | 36 | 42 | 24 | 88 | 190 |
| Total | 139 | 128 | 67 | 233 | 567 |
| | | | | | |
| 1-3K | 45% | 33% | 15% | 22% | 29% |
| 3K - 6K | 22% | 20% | 39% | 27% | 26% |
| 6K - 9K | 6% | 14% | 10% | 12% | 11% |
| over 9K | 26% | 33% | 36% | 38% | 34% |
| Total | 100% | 100% | 100% | 100% | 100% |

Table 35. Major Service Frequency by Usage (miles between major maintenance)
(Percentage of Trucks, Weighted by Fleet Size)

| | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| 1-10K | 31% | 42% | 63% | 59% | 22% | 47% | 51% | 49% |
| 10K - 20K | 27% | 7% | 13% | 0% | 0% | 0% | 7% | 9% |
| 20K - 30K | 0% | 2% | 4% | 0% | 7% | 0% | 6% | 4% |
| over 30K | 42% | 49% | 19% | 41% | 71% | 53% | 37% | 39% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Table 35a. shows the frequency of minor maintenance by truck usage, with the data weighted by fleet size. Trucking firms and truck rental fleets perform minor maintenance less frequently than average.

Table 35a. Minor Service Frequency by Usage (miles between minor maintenance)

| | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| 1-3K | 7% | 64% | 64% | 27% | 15% | 71% | 34% | 38% |
| 3K - 6K | 24% | 15% | 24% | 58% | 9% | 0% | 38% | 30% |
| 6K - 9K | 0% | 14% | 2% | 0% | 1% | 0% | 9% | 6% |
| over 9K | 68% | 7% | 10% | 15% | 75% | 29% | 19% | 25% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

JFA explored the relationship between truck weight class and maintenance frequencies by creating cross tabulations of GVW and maintenance frequency. Tables 36 shows major maintenance frequency by GVW, with data weighted by fleet size. (chi square=53.8, df=9) Table 37 shows minor maintenance by GVW, with data weighted by fleet size. (chi square=380.5, df=9). Both tables show that maintenance is performed the least frequently on super-heavy trucks. Light-heavy and heavy-heavy trucks experience the most frequent maintenance.

JFA also investigated the relationship between annual mileage and maintenance frequency. The frequency of both major and minor maintenance is strongly correlated with annual mileage.

Table 38 shows major maintenance frequency by annual mileage (chi square=104.8, df=9). Table 38a shows minor maintenance frequency by annual mileage (chi square=259.4, df=9). In both tables, maintenance frequency decreases with truck annual mileage. Of low mileage trucks (under 15,000 miles annually), 89 percent receive minor maintenance and 65 percent receive major maintenance at least every 6,000 miles. Of high mileage trucks (over 60,000 miles annually) only 37 percent receive minor maintenance and 28 percent receive major maintenance at least every 6,000 miles.

Table 36. Major Service Frequency by GVW

Number of Trucks, Sml and Med Fleets

| | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|
| 1-10K | 59 | 109 | 63 | 13 | 244 |
| 10K - 20K | 12 | 36 | 0 | 18 | 66 |
| 20K - 30K | 1 | 10 | 1 | 22 | 34 |
| over 30K | 99 | 72 | 12 | 131 | 314 |
| Total | 171 | 227 | 76 | 184 | 658 |
| | | | | | |
| 1-10K | 35% | 48% | 83% | 7% | 37% |
| 10K - 20K | 7% | 16% | 0% | 10% | 10% |
| 20K - 30K | 1% | 4% | 1% | 12% | 5% |
| over 30K | 58% | 32% | 16% | 71% | 48% |
| Total | 100% | 100% | 100% | 100% | 100% |

Table 37. Minor Service Frequency by GVW

Number of Trucks, Sml and Med Fleets

| | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|
| 1-10K | 111 | 102 | 48 | 4 | 265 |
| 10K - 20K | 68 | 104 | 15 | 19 | 206 |
| 20K - 30K | 13 | 44 | 2 | 2 | 61 |
| over 30K | 14 | 54 | 6 | 253 | 327 |
| Total | 206 | 304 | 71 | 278 | 859 |
| | | | | | |
| 1-10K | 54% | 34% | 68% | 1% | 31% |
| 10K - 20K | 33% | 34% | 21% | 7% | 24% |
| 20K - 30K | 6% | 14% | 3% | 1% | 7% |
| over 30K | 7% | 18% | 8% | 91% | 38% |
| Total | 100% | 100% | 100% | 100% | 100% |

Table 38. Major Service Frequency by Annual Mileage

Percentage of Trucks, Weighted by Fleet Size

| | Annual Mileage | | | | |
|---|---|---|---|---|---|
| | 0 - 15K | 15K - 30K | 30K - 60K | over 60K | Total |
| 1-3K | 62% | 36% | 21% | 13% | 33% |
| 3K - 6K | 27% | 44% | 40% | 21% | 32% |
| 6K - 9K | 5% | 12% | 6% | 6% | 7% |
| over 9K | 7% | 8% | 34% | 61% | 28% |
| Total | 100% | 100% | 100% | 100% | 100% |

Table 38a. Minor Service Frequency by Annual Mileage

Percentage of Trucks, Weighted by Fleet Size

| | Annual Miles | | | | |
|---|---|---|---|---|---|
| | 0 - 15K | 15K - 30K | 30K - 60K | over 60K | Total |
| 1-3K | 64% | 37% | 30% | 6% | 38% |
| 3K - 6K | 26% | 40% | 24% | 31% | 30% |
| 6K - 9K | 2% | 16% | 8% | 8% | 8% |
| over 9K | 9% | 7% | 37% | 55% | 24% |
| Total | 100% | 100% | 100% | 100% | 100% |

## 5.2. Maintenance Costs

Fleets were asked to provide the average cost of both major and minor service. Table 39 shows the cost of major service for all fleets surveyed, with data weighted by fleet size. As with service frequency, this question appears to have been subject to differing interpretation. Roughly 32 percent reported the cost of major service as under $500 and another 29 percent reported the cost as over $2,000.

Table 39. Cost of Major Maintenance Service

| Cost Range | Percentage |
|---|---|
| 0 - $500 | 24% |
| $501 - $1000 | 5% |
| $1001 - $1500 | 7% |
| $1501 - $2000 | 42% |
| over $2000 | 21% |
| Total | 100% |

Table 40 shows the cost of minor service for all fleets surveyed, with data weighted by fleet size. Maintenance cost does not vary significantly across either fleet size nor usage category (using all seven usage categories).

Table 40. Cost of Minor Maintenance Service

| Cost Range | Percentage |
|---|---|
| 0 - $50 | 11% |
| $51 - $100 | 17% |
| $101 - $150 | 11% |
| $151 - $200 | 12% |
| over $200 | 49% |
| Total | 100% |

These responses suggest some misunderstanding of the survey questions, with some fleets apparently interpreting "major service" as nearly anything more than an oil change service.

### 5.3. Engine Rebuild and Replacement

The survey also collected information from each fleet on the miles typically driven between engine rebuild and engine replacement. For small fleet trucks, these questions were asked for each individual truck. For medium fleet trucks, these questions were asked for each fleet on average, and then fleets surveyed in Phase II were asked about the miles between engine replacement for individual trucks. Large fleets were surveyed about engine rebuild and replacement during Phase I only. As with maintenance frequency, there appears to be some anomalous survey responses. For example, one in three small fleets reported rebuilding and replacing engines every 100,000 miles or less, which is more frequent than expected.

Table 41 shows the miles between engine rebuild for all fleets and trucks with available information. Table 42 shows the miles between engine replacement.

Table 41. Miles between Engine Rebuild

| Mileage | Trucks | Percent |
|---|---|---|
| 1 - 100K | 1262 | 47% |
| 100K - 200K | 564 | 21% |
| 200K - 300K | 278 | 10% |
| over 300K | 581 | 22% |
| Total | 2685 | 100% |

Table 42. Miles between Engine Replacement

| Mileage | Trucks | Percent |
|---|---|---|
| 1 - 100K | 188 | 11% |
| 100K - 200K | 1133 | 68% |
| 200K - 300K | 162 | 10% |
| over 300K | 190 | 11% |
| Total | 1673 | 100% |

Engine rebuild and replacement frequency do not vary significantly with fleet size. Engine rebuild frequency varies strongly with GVW, as shown in Table 43 (chi square=281.3, df=9). 57

percent of light-heavy trucks reported rebuilding engines every 100,000 miles, while no super-heavy trucks reported rebuilds this frequently. As noted above, this seems somewhat anomalous.

Table 43. Miles between Engine Rebuild, by GVW

Number of Trucks, Small and Med Flts

| | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|
| 1-100K | 22 | 45 | 51 | 1 | 119 |
| 100K - 200K | 53 | 64 | 12 | 26 | 155 |
| 200K - 300K | 40 | 40 | 48 | 25 | 153 |
| over 300K | 0 | 30 | 1 | 89 | 120 |
| Total | 115 | 179 | 112 | 141 | 547 |
| | | | | | |
| 1-100K | 19% | 25% | 46% | 1% | 22% |
| 100K - 200K | 46% | 36% | 11% | 18% | 28% |
| 200K - 300K | 35% | 22% | 43% | 18% | 28% |
| over 300K | 0% | 17% | 1% | 63% | 22% |
| Total | 100% | 100% | 100% | 100% | 100% |

Table 44 shows engine replacement frequency by GVW (chi square=86.9, df=9). Engine replacements occur much more frequently in light-heavy and medium-heavy trucks than in heavy-heavy and super-heavy trucks.

Table 44. Miles Between Engine Replacement, by GVW

Number of Trucks, Small and Med Flts

| | LH | MH | HH | SH | Total |
|---|---|---|---|---|---|
| 1-100K | 13 | 42 | 25 | 0 | 80 |
| 100K - 200K | 21 | 20 | 1 | 10 | 52 |
| 200K - 300K | 44 | 23 | 9 | 3 | 79 |
| over 300K | 26 | 78 | 8 | 14 | 126 |
| Total | 104 | 163 | 43 | 27 | 337 |
| | | | | | |
| 1-100K | 13% | 26% | 58% | 0% | 24% |
| 100K - 200K | 20% | 12% | 2% | 37% | 15% |
| 200K - 300K | 42% | 14% | 21% | 11% | 23% |
| over 300K | 25% | 48% | 19% | 52% | 37% |
| Total | 100% | 100% | 100% | 100% | 100% |

## 5.4. On-site Maintenance

The survey asked whether or not major and minor maintenance was performed at the site of the fleet operator. One would expect that larger fleets would be more likely to perform on-site maintenance than smaller fleets, and the survey bears this out. (For both variables, differences across fleet size are significant at the 5 percent level. Chi square=38.1, df=6. Chi square=14.1, df=6). Table 45 shows that major maintenance is performed on-site by only 21 percent of small fleets, compared to 57 percent of medium fleets and 75 percent of large fleets. This trends holds for minor maintenance as well, as shown in Table 46, though the differences are less striking.

Table 45. On-site Major Maintenance Service by Fleet Size
(Number of trucks represented)

| Major Maint. On-Site? | Sml Flts | Med Flts | Lrg Flts |
|---|---|---|---|
| Yes | 51 | 1672 | 5114 |
| No | 189 | 1271 | 1740 |
| Total | 240 | 2943 | 6854 |
| | | | |
| Yes | 21% | 57% | 75% |
| No | 79% | 43% | 25% |
| Total | 100% | 100% | 100% |

Table 46. On-site Minor Maintenance Service by Fleet Size
(Number of trucks represented)

| Minor Maint. On-Site? | Sml Flts | Med Flts | Lrg Flts |
|---|---|---|---|
| Yes | 144 | 2398 | 5808 |
| No | 98 | 545 | 1046 |
| Total | 242 | 2943 | 6854 |
| | | | |
| Yes | 60% | 81% | 85% |
| No | 40% | 19% | 15% |
| Total | 100% | 100% | 100% |

JFA used cross-tabulations to examine the relationship between truck usage and on-site maintenance. The survey data are not extensive enough to run cross tabulations for each fleet size separately. With the data weighted by fleet size, the likelihood of on-site major maintenance varies significantly across usage category. (chi square=20.5, df=6) Table 47 shows the frequencies for on-site major maintenance for all trucks represented in the survey. On-site major maintenance is much more likely to be performed on rental fleets and waste hauling fleets, and to a lesser extent trucking fleets and service/utility fleets. Delivery, construction and parcel delivery are less likely to perform on-site major maintenance. Table 48 shows the frequencies for on-site minor maintenance for the trucks.

Truck weight class is not strongly correlated with the tendency to perform on-site maintenance, when controlling for fleet size. Similarly, truck age also shows no strong correlation with the tendency to perform maintenance on-site, when controlling for fleet size.

Table 47. On-site Major Maintenance Service by Usage
(Number of Trucks, Medium size Fleets only)

| Major Maint. On-Site? | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| Yes | 354 | 184 | 323 | 64 | 78 | 62 | 607 | 1672 |
| No | 373 | 50 | 98 | 175 | 80 | 4 | 491 | 1271 |
| Total | 727 | 234 | 421 | 239 | 158 | 66 | 1098 | 2943 |
| | | | | | | | | |
| Yes | 49% | 79% | 77% | 27% | 49% | 94% | 55% | 57% |
| No | 51% | 21% | 23% | 73% | 51% | 6% | 45% | 43% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Table 48. On-site Minor Maintenance Service by Usage
Number of Trucks, Medium Fleets Only

| Minor Maint. On-Site? | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| Yes | 580 | 212 | 361 | 169 | 158 | 66 | 852 | 2398 |
| No | 147 | 22 | 60 | 70 | 0 | 0 | 246 | 545 |
| Total | 727 | 234 | 421 | 239 | 158 | 66 | 1098 | 2943 |
| | | | | | | | | |
| Yes | 80% | 91% | 86% | 71% | 100% | 100% | 78% | 81% |
| No | 20% | 9% | 14% | 29% | 0% | 0% | 22% | 19% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

## 5.5. Retired Trucks

Fleets surveyed in Phase I were asked if they have retired any trucks in the last five years. If so, the survey asked for the average age of the retired trucks and whether the trucks were scrapped or sold. As shown in Table 49, 187 of 329 fleets indicated that they had retired trucks in the last five years. The majority of these trucks were sold. Trucks sold are 11.4 years old on average, while trucks scrapped are 18.1 years old on average. The tendency to scrap or sell-off old trucks does not vary significantly with fleet size. Table 50 shows the disposition of retired trucks by usage. All rental fleets sold their trucks, while all waste fleets scrapped their trucks, though the number of respondents was small in both cases. There are no clear relationships between retired truck disposition and the other usage categories.

Table 49. Disposition and Average Age of Retired Trucks
(Number of Fleets)

| | | Number | Mean Age |
|---|---|---|---|
| *Retired Trucks:* | | | |
| | Scrapped | 30 | 18.1 |
| | Sold | 137 | 11.4 |
| | Both | 10 | N/A |
| | Don't Know | 10 | N/A |
| *None Retired:* | | 142 | N/A |
| | Total | 329 | |

Table 50. Disposition and Retired Trucks by Usage
(Number of Fleets)

| | Trucking | Constr. | Serv/Util | Parcel | Rental | Waste | Other | Total |
|---|---|---|---|---|---|---|---|---|
| Scrapped | 3 | 3 | 4 | 2 | | 3 | 15 | 30 |
| Sold | 16 | 16 | 24 | 6 | 9 | | 65 | 136 |
| Both | 5 | 1 | 1 | | | | 3 | 10 |
| Total | 24 | 20 | 29 | 8 | 9 | 3 | 83 | 176 |
| | | | | | | | | |
| Scrapped | 13% | 15% | 14% | 25% | 0% | 100% | 18% | 17% |
| Sold | 67% | 80% | 83% | 75% | 100% | 0% | 78% | 77% |
| Both | 21% | 5% | 3% | 0% | 0% | 0% | 4% | 6% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

# 6 HDT DATA COLLECTION USING GPS

Using global positioning system (GPS) devices, data pertaining to detailed HDT activities and patterns in the SoCAB can be gathered. This section provides discussions on procedures for the data collection using GPS equipment. Also reported in this chapter are summary and analyses of data collected from a number of GPS instrumented trucks.

## 6.1. Review of Methodology

Data collection involving GPS equipment can be broken down into four steps: Recruiting, Scheduling, Instrumentation, and Data Processing/Analysis. The JFA team conducted the first three parts. ARB handled the entire Data Processing/Analysis portion. The following segments briefly describe each of the four parts involved in the GPS data collection.

### 6.1.1. Recruiting

The recruiting portion of the GPS data collection may be the most time consuming element in the process. Many potential participants surfaced after FSC conducted initial telephone surveys for this study. The initial surveys identified fleets that might be responsive to additional data requests including that involving GPS data loggers. JFA conducted follow-up telephone calls targeted to these firms in order to recruit their trucks for the GPS data loggers. Despite their previous stated interest in additional data collection efforts, many firms were reluctant to participate citing various reasons such as unavailability of trucks, proprietary concerns, and lack of time and manpower to aid in the process. Others had general doubts about government agencies and motives behind the study. The success rate in recruiting was quite low. Many calls were made just to identify and locate proper office and/or personnel that would respond to our inquiries. Often a dozen or more calls were made in a period of weeks and even months before it was possible to determine whether fleets would participate or not. JFA also contacted selected large fleets from TTS Directories. In the case of the larger fleets, some of the contacted firms' decision-making process took a long time as internal approval and review processes were lengthy and low in priority for their business operations.

Once a fleet agreed to participate, JFA had to determine if they had trucks that meet the needs of our sampling plan. The sampling plan was based on GVW, fuel and geographic location. If the fleet did not have any trucks that match our sampling plan needs, then the JFA team was unable to use them.

### 6.1.2. Scheduling

Truck operations, regardless of the industries in which trucks operate, are very dynamic, and very time critical. While participating fleet managers were willing to assist, finding suitable time for installations without disrupting the fleets' daily operations was challenging. Some scheduling required weekend appointments. Very early morning installations (5 – 6 am) or late afternoon (after 7 or 8 pm) arrangements were not uncommon. Because of the dynamic nature of the participating trucks, all parties involved had to deal with a very narrow window of available time, which often shifted without warning.

JFA, KARCO (JFA's subcontractor in charge of installation and retrieval of the GPS units) and participating fleets kept in close contacts to minimize delays and missed appointments. However, because truck movements are inherently dependent upon many variables outside drivers' and dispatchers' controls, many scheduled installations had to be moved and rearranged.

### 6.1.3. Instrumentation

Not unlike recruiting and scheduling parts, installing/retrieving of the GPS data loggers experienced many instances of unforeseen changes and irregularities. Under a perfect condition, installing, uninstalling and retrieving of truck activity data would be as follows:

- KARCO technician installs the unit(s). Each installation can take up to 45 minutes.
- KARCO completes the most of the Truck Information Sheet during installation, and faxes this sheet to JFA. This is our confirmation that units have been installed.
- After three (or more) days, the KARCO technician makes a telephone call to the contact person to arrange/confirm time and date to retrieve the GPS data logger unit.
- KARCO technician retrieves the GPS data logger unit and finishes filling out the Truck Information Sheet as necessary.
- KARCO faxes the completed Truck Information Sheet to JFA.
- KARCO mails the GPS flash card with activity data to ARB; the Truck Information Sheet is processed to make identity of participants remain anonymous; then KARCO faxes the sheet to ARB.
- After ARB downloads the activity data from the flash cards, ARB mails the cards back to KARCO.

It was not uncommon for KARCO technicians to find previously agreed and arranged trucks unavailable on the day of installation. Similar changes and delays in retrieving the GPS data loggers after three or more days took place with some frequency. These unplanned changes and delays stem from rather dynamic and unpredictable environments in which truck operations take place.

## 6.2. Sampling Errors

A selected (and recruited) sample is stratified based on physical characteristics of the trucks, including gross vehicle weight (GVW) class, fuel type, truck usage, and area of operation. Therefore, it must be noted that sampling frames and selected participants do not reflect any randomness in sampling. Many fleets that participated in the GPS data logging process are the same fleets that provided valuable information in other previous surveys. In that sense, JFA believes that the survey sample is a representative cross-section of the affected truck population in the SoCAB. However, several factors that may introduce bias in the sample must be noted here. First, due to various factors, the GPS units were installed on only a small number of trucks. The smaller the sample size, the larger would be the potential sampling error. Second, trucks participated were selected in part to fulfill a pre-determined population stratification (based on physical characteristics, GVW, fuel, usage, area of operations, etc). Third, participating fleets helped select available trucks because of scheduling difficulties. These trucks the fleet managers chose to represent may or may not fully represent the population as availability of the trucks in part decided many fleet managers' participation and GPS installation.

### 6.3. Summary of HDT Data using GPS equipment

While this report was being prepared, JFA did not have full access to the data collected using the GPS equipment. It is understood that the ARB would provide detailed information gathered from the GPS data loggers. The ARB staff members conducted summary and analysis of the data and Appendix C presents a brief table containing the results provided by the ARB staff.

# 7 ANALYSIS OF EMISSION REDUCTION INCENTIVES

This section discusses potential HDV incentive programs that encourage the use of low emission engines or modified truck operations in the SoCAB to achieve emission reductions. In order to estimate the emission reduction impacts of each incentive program, base case emissions levels were first estimated. These estimates were based on data provided by the ARB including Heavy Duty Truck Populations by Weight and Age, daily Vehicle Miles Traveled (VMT) for each group, and the corresponding emissions factors per mile. Penetration levels for each incentive program were then established in order to analyze their emissions impacts.

The level of penetration for each incentive was assumed for discussion to be one percent. Emissions reduction benefits associated with alternative penetration levels of five and 20 percent are provided in an appendix to this chapter. The penetration levels can be interpreted to mean that either a set percentage of the targeted population will change their behavior (*e.g.* convert their vehicle to an alternative-fuel), or the target population will change their behavior by a set percentage (*e.g.* reduce their idle time of operation).

The vehicle population, VMT, and trips were taken from EMFAC2000's year 2010 data. Vehicle ages included range from model years 1966 to 2010. VMT was provided in units of thousands of miles and included all vehicles that fall within each model year and weight class. Trip data also included all vehicles of each model year and weight class. VMT used in later calculations was expressed as average VMT per vehicle per day. Total travel time for each vehicle per day was also estimated based on population, VMT and trips in order to relate emissions factors to time instead of miles.

Much of the emission factors data used in this section came from the EMFAC2000 technical support documentation. Source references in this section will be noted with a reference number and page number if available (Reference #, Page #). The units, unless otherwise stated, are grams per mile (or per vehicle mile traveled). These numbers are converted from brake-specific emission measures such as grams per brake horsepower hour (g/bhp-hr).

Data regarding emission factors in other than baseline operations were either obtained directly or in the form of an emission reduction percentage. Emission reduction percentages represent the improvement in emissions as compared to the baseline condition. Baseline emissions were assumed to be average emissions of diesel-fueled trucks during standard driving cycles in the state of California.

The purpose of this section is to develop an understanding of the relative potential of selected HDV incentive programs to reduce vehicle emissions. The ultimate effectiveness of an incentive program depends on both the reaction of the target decision group (vehicle owners, operators, freight facility operators, etc.) and the effectiveness of the targeted behavior change on reducing emissions. This study collected data through surveys of the trucking industry and the instrumentation of HDVs. This information coupled with a literature review led to the selection of the set of incentive programs to be evaluated for their emissions reduction potential.

The effectiveness of an incentive program in changing the targeted behavior is related to:

- The availability of alternative behavior
- The cost of alternative behavior
- The acceptability of alternative behavior
- Size of the incentive
- Selection of appropriate decision maker

To evaluate the impact of incentive programs, reductions in pollutants are measured against the baseline emissions. It must be noted that units of the emission inventory used in this analysis calculated were grams per day. JFA later converted emission reductions expressed in grams per day into a unit of measurement represented in grams per mile.

In this chapter, it is assumed that the incentives program is correctly targeted and that appropriate alternatives are available. It is further assumed that the cost of the alternative and the level of the incentive result in certain percent changes in the targeted behavior. With these assumptions, it is possible to estimate the change in HDV emissions that could result. It is worthwhile to note that these estimates are speculative, as no actual experiments with behavior changes have been conducted. However, data collected from the trucking industry and available evidence suggest that the targeted behavior can be changed.[1]

The potential penetration of these incentives is unknown, but will certainly vary across programs. For example, a one to five percent penetration rate for alternative fueled vehicles may be reasonable while much greater changes in vehicle idle time may be possible. As mentioned earlier, this analysis estimates the change in emissions of the four subject pollutants that result from a one percent change in the target activity. These estimates indicate which incentive programs have the best potential among each group to change the emissions of a specific pollutant. Those programs with the greatest potential can then be selected for additional study to determine their potential.

The incentive programs were categorized in three broad groupings:

- Low-Emission Technologies Group
  - Alternative Fuels Programs (AF*x*)
  - Conventional Fuels Programs (CF*x*)
- Operations & Practices Group (OP*x*)
- Infrastructure Improvements Group (II*x*)

Under each group and sub-group, various incentive programs were studied. Table 51 outlines these programs, the variables used, their units and sources, as well as the formula that calculates the emission reduction for each of the incentive programs. The four pollutants included in this analysis are oxides of nitrogen (NOx), particulate matter (PM), total hydrocarbon/hydrocarbon

[1] For example, one HDV operator reported a 20 percent drop in average idle time when idle time measurement and driver incentives/disincentives were employed.

(THC/HC), and carbon monoxide (CO). Specific methodologies and concerns are introduced as needed throughout the chapter.

Table 51. HDV Emissions Reduction Incentive Programs, Variable List

| Incentive Programs | Variables | Units | Sources | Formula w/ 1% Penetration |
|---|---|---|---|---|
| **Low-Emission Technologies** | | | | |
| *Alternative fuels programs* | | | | |
| AF1: New Vehicle Purchase AND Vehicle Conversion | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D |
| | B Daily VMT for each group | Mile | 2 | |
| | C Emission factors for each group (conventional fuel) | G/Mile | 3 | |
| | D Emission reduction % for each group w/ alternative fuel | % | 7 | |
| AF2: Fuel Purchase | A Central Fuel Tendency for each group | % | 10 | 1%*A*B*C*D*E |
| | B HDT populations by weight class and age group | Vehicle | 2 | |
| | C Daily VMT for each group | Mile | 2 | |
| | D Emission factors for each group (conventional fuel) | G/Mile | 3 | |
| | E Emission reduction % for each group w/ alternative fuel | % | 7 | |
| *Conventional fuels programs* | | | | |
| CF1: New Vehicle Purchase | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D |
| | B Daily VMT for each group | Mile | 2 | |
| | C Emission factors for each group (conventional fuel) | G/Mile | 3 | |
| | D Emission reduction % for each group w/ better device | % | 8 | |
| CF2: Vehicle Retirement | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*(Cnew-Cold)*(1-D)*E |
| | B Daily VMT for each group | Mile | 2 | |
| | C Emission factors for each group (conventional fuel) | G/Mile | 3 | |
| | D Estimated survival rate for each group | | 5 | |
| | E Adjustment factor (Replacement by Used Vehicles) | | 0 | |
| CF3: Replacing Engines | A Replacing probability for each group | % | 0/7/10 | 1%*A*B*C*(Dnew-Dold) |
| | B HDT populations by weight class and age group | Vehicle | 2 | |
| | C Daily VMT for each group | Mile | 2 | |
| | D Emission factors for each group (conventional fuel) | G/Mile | 3 | |
| CF4: Emission Control | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D |
| | B Daily VMT for each group | Mile | 2 | |
| | C Emission factors for each group (conventional fuel) | G/Mile | 3 | |
| | D Emission reduction % for each group w/ better device | % | 8 | |
| CF5: Fuel/Additives Purchase | A Central Fuel Tendency for each group | % | 10 | 1%*A*B*C*D*E |
| | B HDT populations by weight class and age group | Vehicle | 2 | |
| | C Daily VMT for each group | Mile | 2 | |
| | D Emission factors for each group (conventional fuel) | G/Mile | 3 | |
| | E Emission reduction % for each group w/ better fuel | % | 4 | |
| **Operations & Practice** | | | | |
| OP1: Idle Time Modification | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D |
| | B Daily travel time for each group | Hour | 2 | |
| | C % of idle time | % | 10 | |
| | D Emission factors for idle time | G/Hour | 3 | |
| OP2: Shifting Operating Hours | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C |
| | B Daily VMT for each group | Mile | 2 | |
| | C Emission changes in congested/non-congested roads | G/Mile | 3/6 | |

Table 51 Cont.

| | | | | |
|---|---|---|---|---|
| **Operations & Practice** | | | | |
| OP1: Idle Time Modification | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D |
| | B Daily travel time for each group | Hour | 2 | |
| | C % of idle time | % | 10 | |
| | D Emission factors for idle time | G/Hour | 3 | |
| OP2: Shifting Operating Hours | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C |
| | B Daily VMT for each group | Mile | 2 | |
| | C Emission changes in congested/non-congested roads | G/Mile | 3/6 | |
| **Infrastructure Improvements** | | | | |
| II1: Intermodal Improvements | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D*E*F |
| | B Daily travel time for each group | Hour | 2 | |
| | C % of idle time | % | 10 | |
| | D Emission factors for idle time | G/Hour | 3 | |
| | E % of idle time spent on terminals | % | 0 | |
| | F % of affected HDT population w.r.t. weight class | % | 10 | |
| II2: Truck Terminals/ Freight Centers | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D*E*F |
| | B Daily travel time for each group | Hour | 2 | |
| | C % of idle time | % | 10 | |
| | D Emission factors for idle time | G/Hour | 3 | |
| | E % of idle time spent on terminals | % | 0 | |
| | F % of affected HDT population w.r.t. weight class | % | 10 | |
| II3: Truck Stops/ Parking Area | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D*E*F |
| | B Daily travel time for each group | Hour | 2 | |
| | C % of idle time | % | 10 | |
| | D Emission factors for idle time | G/Hour | 3 | |
| | E % of idle time spent on terminals | % | 0 | |
| | F % of affected HDT population w.r.t. weight class | % | 10 | |
| II4: Trucks-Only Roadways/ Truck Lanes | A HDT populations by weight class and age group | Vehicle | 2 | 1%*A*B*C*D |
| | B Daily VMT for each group | Mile | 2 | |
| | C Emission changes in congested/non-congested roads | G/Mile | 3/6 | |
| | D % of affected HDT population w.r.t. weight class | % | 10 | |

Source References:

0 Assumed
1 ARB - Derivation of Emission and Correction Factors for EMFAC7G
2 ARB - EMFAC 2010 Output
3 ARB - EMFAC 2000 Technical Support Documentation
4 ARB - Fuels Report: Appendix IV to the Diesel Risk Reduction Plan
5 ARB - Other
6 DOT - Evaluation of MOBILE Vehicle Emission Model
7 EPA - Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines
8 EPA - Verified Technology List
9 FHA - Heavy-Duty Truck Activity Data
10 JFA - HDV Fleet Characterization in the SoCAB

## 7.1. Low Emission Technologies

Most incentive programs that JFA evaluated involve promoting the use of cleaner vehicle technologies. While there are various ways to structure these programs, they can be organized into two major low emission technology groups - alternative fuel technologies and cleaner conventional fuel technologies.

### 7.1.1 Alternative Fuels (AF)

Some of the potential alternative sources of power for the HDT population are methanol, ethanol, natural gas including liquefied and compressed natural gas (CNG & LNG), propane, and electricity. Feasibility of alternative fuels in HDTs depends on a number of variables such as fleet characteristics, truck characteristics, and activity patterns.

Incentives that have been proposed to encourage the conversion of trucks to low-emission alternative fuel engines include cash grants, tax subsidies, and low-cost financing. Alternative incentives could include restrictive lanes for alternative fueled vehicles (AVFs) or the right to operate during time periods when conventional vehicles are restricted. Certain vehicle/fleet characteristics make a vehicle a good candidate for these incentives. These include:

- High annual mileage (for natural gas fuels with low fuel cost relative to diesel)
- Centrally fueled
- On-site maintenance
- Short range (local)
- No significant payload constraints

The types of trucks/fleets that meet each of these criteria are listed below.

High Annual Mileage

- Medium and large fleets
- Trucking, daily rental, and other private delivery fleets
- Heavy-heavy and super-heavy trucks (possibly some medium-heavy trucks)
- Post-1990 trucks

Central Fueling

- Large and medium fleets
- Medium-heavy and heavy-heavy trucks

Local Area of Operation

- Small and medium fleets (although almost 50 percent of large fleets have high local range)
- All usage categories except trucking firms (small trucking fleets have local range)

On-site Maintenance

- Medium and large fleets

Limited Payload Constraints

- Construction, service/utility, some local delivery and daily rental

Based on the analysis above, the highest priority candidates for alternative fuels applications would likely be private delivery fleets and medium to large fleets operating medium and heavy-heavy trucks.

JFA examined two incentive programs related to alternative fuels applications. The following discussion focuses on programs that either directly promote the purchase of new alternative fueled vehicles and/or the conversion of existing conventional fuel vehicles to alternative fueled engines, or indirectly promote the purchase of alternative fuels by central fueling candidates.

New Vehicle Purchase and Vehicle Conversion (AF1)

This program provides incentives for truck operators to purchase new alternative fuel vehicles (AFV) or convert existing conventional vehicles to AFVs. Possible incentives for the program include but are not limited to cash incentives, tax and/or fee reductions, and access to low-rate financing.

The emissions reduction under this incentive program were estimated as the product of HDV population by weight class and age group, penetration percentage, daily VMT for each group, emission factor for each group with conventional fuel, and the emission reduction percentage for each group with alternative fuel.

JFA estimated alternative fueled engines' emissions in order to assess benefits of the program. The emission factors of alternative fueled engines used were 0.07 g/bhp-hr HC, 0.15 g/bhp-hr CO, 0.75 g/bhp-hr NOx, and 0.04 g/bhp-hr PM (8, p.70). Conversion factors of around 1.6, 2.3, and 2.7, respectively were used for light, medium, and heavy heavy-duty diesel vehicles as multipliers. These were applied to brake-specific emission levels in order to estimate emissions on a gram-per-mile basis (11, table1). Based on these inputs, the resulting emissions reductions were estimated to be:

- NOx 0.078341 grams per mile
- PM 0.004012 grams per mile
- HC 0.002354 grams per mile
- CO 0.023410 grams per mile

In relative terms, this program at the assumed 1 percent penetration rate, may result in emissions reduction of:

- NOx 0.81 percent
- PM 0.81 percent
- HC 0.58 percent
- CO 0.87 percent

The alternative fuel used for analysis of this program was assumed to be CNG. Various studies of CNG vehicles have showed significant emission reductions compared to Gasoline powered vehicles (6, 9). However, those studies are more comprehensive in light-duty vehicles.

Therefore, applying these numbers to HDVs that are heavier and older may not necessarily result in the significant emission reductions noted in the available studies. It also must be noted here that while the information sources JFA used only dealt with CNG, the overall results in this section (AF1) and the following section (AF2) may apply to LNG as well.

Fuel Purchase (AF2)

This program is meant to provide a cash incentive to HDT operators for the purchase of alternative fuels (i.e. CNG and/or LNG).

The emission reductions calculation under this program was similar to that used for vehicle purchase/conversion. The population that is centrally fueled, however, is especially targeted to improve the effectiveness of the impacts. The estimate is therefore the product of the penetration percentage, the central fueling tendency (%) for each weight class, HDV population by weight class and age group, daily VMT for each group, emission factors for each group with conventional fuel, and emission reduction percentage for each group with alternative fuel.

JFA surveyed many of the fleets operating in the SoCAB, and collected information on the fleets' tendency to fuel at central locations. The central fueling tendency used in calculating the emission benefits of this program is thus derived from the data JFA collected data, weighted by sub-populations of three different weight classes. The centrally fueled percentages for each weight class were estimated to be 22.34 percent 52.54 percent, and 52.81 percent, respectively, for light, medium, and heavy heavy-duty diesel vehicles. Based on these percentages, the emission reductions for this incentive program were estimated to be:

- NOx 0.040911 grams per mile
- PM 0.002107 grams per mile
- HC 0.001237 grams per mile
- CO 0.011956 grams per mile

This program at a 1 percent penetration rate, would result in emissions reduction of:

- NOx 0.42 percent
- PM 0.42 percent
- HC 0.31 percent
- CO 0.44 percent

### 7.1.2 Conventional Fuels (CF)

Promoting cleaner conventional fuel technologies involves three major methods. The first method is purchasing new vehicles to replace older ones. Another is to repower old vehicles with a newer powertrain. The third method is to retrofit old vehicles using up-to-date emission control technologies. Alternative to encouraging new vehicle purchases, incentives can also be oriented towards retirement of HDV with inferior emissions control. In addition, centrally fueled candidates can be especially targeted to use cleaner fuels or fuel additives that improve emissions characteristics.

Through various mechanisms such as tax credits, financing, grants and other incentives, firms and operators of older HDVs could convert from older conventional fueled trucks to cleaner trucks with newer technologies. However, not all of the HDV population in the SoCAB could easily carry out such options. Many determining factors must be considered.

Data from EMFAC 2000 suggest that older trucks without the benefit of modern engine management and emissions control technologies may contribute disproportionately to the emissions from heavy-duty vehicles. If there are sub-populations that tend to keep these trucks/engines on the road longer because they cannot afford new vehicles, and these fleets tend also to lack the technical and operational resources to deal with alternative fuel conversions, they may be good candidates for conventional fuel re-power/retrofit options. Characteristics of these fleets/trucks include:

- Older trucks
- Frequent major service intervals
- Older engines
- Shorter intervals between engine rebuilds.

The types of trucks/fleets that meet each of these criteria are listed below.

Older Trucks

- Small fleets
- Light-heavy and medium-heavy trucks
- Construction trucks followed by service/utility followed by waste hauling followed by private delivery trucks

Frequent Major Maintenance

- Small fleets
- Older trucks
- Heavy-heavy and medium-heavy

Shorter Engine Rebuild Intervals

- Light-heavy, medium-heavy, heavy-heavy
- Small fleets

The high potential candidates for conventional fuel re-powering seem less clearly defined than those for alternative fuel conversions. However, incentives could be targeted at small fleets that do not operate super-heavy trucks, most likely to be found in construction and service/utility applications.

The following discussion provides methodologies in estimating emission reductions through conventional fuel programs such as new vehicle purchase, vehicle retirement and scrapping, repowering engines, emission control device retrofit, and fuel or fuel additives purchase.

New Vehicle Purchase (CF1)

This program provides cash incentives for truck operators to purchase new trucks with superior emission control. Similar to the case under alternative fuel incentives, penetration percentage, HDV population by weight class for new vehicles, daily VMT for each group, emissions factors for each group with conventional fuel, and the emission reduction percentage for each group with the better device were applied to estimate the emission reduction under this program.

The emission reduction percentages used in the calculation were 60 percent for PM, CO and HC, zero percent for NOx. These percentages were based on the Continuously Regenerating Technology (CRT) in the verified technology list in EPA's voluntary diesel retrofit program (2). The emission reductions were estimated to be:

- PM 0.002259 grams per mile
- HC 0.001590 grams per mile
- CO 0.013203 grams per mile
- NOx None

This represents a percent reduction relative to the baseline of:

- PM 0.04 percent
- HC 0.04 percent
- CO 0.05 percent
- NOx 0.00 percent

Most vehicles that have been certified to produce lower emissions are either alternative-fueled or dual-fueled. In addition, those dual-fueled heavy-duty engines soon will not be able to meet planned new emission requirements. Thus, a new purchase of a conventional fueled HDV is assumed to be a baseline vehicle with a better device retrofit. The resulting emissions reduction from this program is thus a fraction of that of the emission control device retrofit program as this program only affects the current year (year 2010) vehicles. Additional information regarding device retrofit is provided in later sections of the conventional fuels programs discussion.

Vehicle Retirement and Scrapping (CF2)

This program provides cash incentives to truck operators to retire HDVs with inferior emissions control. It is assumed that newer, cleaner HDVs are to be added to the fleet to meet the requirements once older HDVs are removed from the fleet. In estimating this program's emission reductions, the level of penetration percentage is multiplied by the HDV population by weight class and age group, daily VMT for each group, the difference in emissions factors for each group between conventional fuel and a brand new vehicle, one minus the estimated survival rate for each group, and an adjustment factor of 0.5.

The estimated survival rate for each age group was taken from the EPA (8, p.117). The rates were expected to vary among different weight classes - light heavy-duty vehicles are expected to retire sooner, while heavy and super heavy-duty vehicles are expected to last longer. The mileage traveled by retired vehicles, if replaced by brand new vehicles, would produce the maximum effect for this program. However, only about half of the purchases were expected to be brand new vehicles. This is the basis for the adjustment factor of 0.5 when calculating the effect of the emissions reduction. Therefore, the emission reductions stemming from replacing older, retired vehicles by newer vehicles was approximated by replacing all the retired vehicles with brand new ones, and dividing by two. The estimated reductions from this program were:

- NOx 0.006629 grams per mile
- PM 0.000396 grams per mile
- HC 0.000343 grams per mile
- CO 0.001718 grams per mile

These figures represent a percentage reduction over the baseline of:

- NOx 0.07 percent
- PM 0.08 percent
- HC 0.08 percent
- CO 0.06 percent

Replacing Engines (CF3)

This program is designed to encourage fleet operators to repower/replace older engines sooner than would otherwise occur. This is expected to result in improved emissions characteristics for those replaced engines.

For the purpose of estimating the emissions reductions, the frequency of engine replacement was used to estimate the probability of engine replacement for each HDV group. This estimated replacement percentage was then multiplied by the penetration percentage, HDV population for weight class and age group, daily VMT for each group, and the difference in emission factors with the older engine running a conventional fuel as compared to a new engine running a conventional fuel.

The frequency of engine replacement was assumed to be approximately every 229.0 thousand miles for light, 283.6 thousand miles for medium, and 339.2 thousand miles for heavy heavy-duty vehicles. These frequency assumptions were developed considering the 1995 average mileage to overhaul numbers of 297,654, 411,300, and 511,119 for class 6-8 heavy-duty diesel trucks found in an EPA report (8, p.33), and the much more frequent replacements shown in the data in this report for the SoCAB region. Based on the expected life spans of the light, medium and heavy HDV populations in this study, the assumed replacement frequencies mean that engines will be replaced once, one and a half, and three times, respectively. In general, lighter trucks are not designed for rebuilds and have a much shorter useful life, while heavy heavy and super heavy classes of HDVs are more suitable for rebuilds and sustain a much longer service mileage.

In order to determine the expected vehicle life spans for the study's HDV population, JFA constructed a database of accumulated mileage for each model year. The vehicle model year that captures the suggested engine replacement mileage, was given the most weight in the statistical distribution. Other vehicle model years were assigned less weight in the distribution. It is reasonable to expect multiple engine replacement in a vehicle's life cycle. Therefore, the distribution process, when applicable, was repeated to ensure full distribution. Older vehicles clearly face a higher likelihood of engine replacements than the newer vehicles.

The emissions reductions based on these assigned probabilities of engine replacements were estimated to be:

- NOx 0.002921 grams per mile
- PM 0.000060 grams per mile
- HC 0.000131 grams per mile
- CO 0.000228 grams per mile

Assuming 1 percent of the affected sub-populations adopt this program, it would result in emissions reductions of:

- NOx 0.03 percent
- HC 0.03 percent
- PM 0.01 percent
- CO 0.01 percent

The sub-populations expected to be most affected by this program are middle-aged vehicles that are still in active service.

Emission Control Device Retrofit (CF4)

This program is designed to encourage fleet operators to retrofit existing engines that use conventional fuels. The program would result in HDVs with improved emission characteristics compared with the original engines. To estimate the emission reductions under this program, the level of penetration percentage was multiplied by the HDV population by weight class, daily VMT for each group, emissions factors for each group with conventional fuel, and the emission reduction percentage for each group with a better emission control device.

The emission reduction percentage used in the calculation was 60 percent for PM, CO and HC, and zero percent for NOx, which are the same as the program of new vehicle purchase. These percentages were based on the percentages of emission reduction suggested by EPA (2) when installing Continuously Regenerating Technology (CRT) filter system, a particulate filter patented by Johnson Matthey System. The emission reductions were estimated to be:

- PM 0.002922 grams per mile

- HC 0.002428 grams per mile
- CO 0.016222 grams per mile

These figures the represent percentage reductions over the baseline of:

- PM 0.59 percent
- HC 0.60 percent
- CO 0.60 percent

These reduction percentage estimates are conservative compared to the results of the regulated emissions test of the New York City Transit Authority (1). This demonstration program combined the effects of Ultra Low Sulfur Fuel and CRT systems and resulted in a reduction in average emissions of 92 percent for THC, 94 percent for THC, and 88 percent for PM, compared to baseline conventional fuel and catalyst systems.

A variety of technologies can be applied to reduce pollutant emissions from heavy-duty diesel vehicles. The following paragraphs were taken from EPA's 1997 *Final Regulatory Impact Analysis* (8, p.47-48):

> Simultaneous control of NOx and PM presents a particular challenge. PM results from the incomplete evaporation and combustion of fine fuel droplets. High combustion temperatures cause nitrogen in the intake air (and to a lesser degree in the fuel) to combine with available oxygen to form NOx. NOx emissions are controlled primarily by lowering peak combustion chamber temperatures. However, simply lowering combustion temperatures can lead to an increase in PM formation because PM is less thoroughly oxidized at lower temperatures. NOx control strategies such as retarding fuel injection timing by themselves are limited because they cause an increase in PM. Engine manufacturers have had to devise more sophisticated emission control strategies due to this trade-off. Engine manufacturers have used a variety of technologies, often balancing their effects and optimizing among them to achieve the emission standards.
>
> Lowering both NOx and PM has been accomplished primarily through improvements to combustion chamber, intake air system, fuel injection system, and the use of electronic controls. NOx has been controlled substantially through charge air cooling, i.e., cooling the intake air by passing it through a heat exchanger. The key to PM control has been improved mixing of the fuel and air within the cylinder through the use of higher fuel injection pressures to better atomize the fuel and through better combustion chamber design. Improved turbocharger control and cylinder ring design for decreased oil consumption have also been important. Fuel injection control has been critical for both PM and NOx reduction. It is very important to ensure that the appropriate amount of fuel is injected at the appropriate time. Many engines are now equipped with electronically controlled fuel injection, lowering emissions and providing better fuel economy. Some engines are also equipped with oxidation catalysts for additional PM control.

In addition to implemented strategies, EPA expects the utilization of exhaust re-circulation (EGR), fuel injection rate shaping, and possibly exhaust after-treatment. The potential and feasibility of these technologies remain to be studied. Overall, assumptions regarding emission reduction percentages are expected to be very limited regardless of the combination of technologies to be used.

Fuel and Fuel Additives Purchase (CF5)

This program encourages the use of cleaner fuels or fuel additives to improve HDV emissions characteristics. Similar to the fuel purchase program with alternative fuels, centrally fueled fleets are especially targeted sub-populations of the program. The emissions reduction estimate is thus the product of the level of penetration percentage, HDV population by weight class and age group, central fuel tendency applied to each group, daily VMT for each group, emission factor for each group with conventional fuel, and emission reduction percentage for each group with better fuel.

The percentages of emissions reductions from using cleaner fuels are the following: three percent for NOx, 13 percent for PM, 13 percent for HC, and six percent for CO, taken from ARB 2000 Fuels Report (3, p.15+). These figures are based on certified ARCO fuel. Using the ARB figures and other data available for this study, the emissions reductions from the fuel/fuel additives program is estimated to be:

- NOx 0.001505 grams per mile
- PM 0.000338 grams per mile
- HC 0.000273 grams per mile
- CO 0.000828 grams per mile

These reductions represent percentages below the baseline emissions of:

- NOx 0.02 percent
- PM 0.07 percent
- HC 0.07 percent
- CO 0.03 percent

Alternatively, Fischer-Tropsch fuel would provide emissions reductions of four percent for NOx, 26 percent for PM, 20 percent for HC, and 36 percent for CO (3, p.17). PuriNOx fuel would provide emissions reductions of 15 percent for NOx, 51 percent for PM, 14 percent for HC, and 51 percent for CO (3, p.19). Ethanol-Diesel fuel emissions reductions would be 15 percent for NOx, 35 percent for PM, -35 percent for HC, and 10 percent for CO (3, p.21).

Although the adopted percentages seem relatively conservative compared to some other studies, these alternative diesel fuels might require particular combinations of technologies to ensure consistent performance of HDVs. Studies indicate generally that reducing sulfur, aromatic, and PAH (polycyclic aromatic hydrocarbon) contents, increasing cetane number and back-end volatility; and decreasing the density of diesel fuel cause reductions in diesel PM and NOx emissions. Overall, the fuel property effects on heavy heavy-duty diesel truck emissions are expected to be more pronounced relative to other HDVs because of their higher-emitting engines.

### 7.2 Operational Characteristics and Practices (OP)

Truck activity patterns collected from the GPS data loggers provided data on idle time, number of stops, VMT, speed profiles, average speed, time of the day, and other activity. This information was used to help identify HDV sub-populations that could take advantage of shifting activities from peak hours to off-peak hours in order to reduce missions.

Sub-populations of HDVs may be able to shift shipping and receiving activities from peak hours to off-peak hours. Changing truck activities from peak to off-peak hours might only apply to firms based locally as it may be too difficult for non-local companies to arrange shipping schedules to fit off-peak travel hours from outside the region.

Another area of modified operational practices is reducing idle time for trucks. Different types of trucks spend varying average amounts of time idling. From the activity data collected, appropriate sub-populations of trucks to which idle time restrictions could be applied, can be identified.

Two incentive programs have been developed to reduce idle time and shift operations away from congested periods.

Idle Time Modification (OP1)

This program is designed to demonstrate the effects on emissions from reducing idle time. HDV drivers are encouraged to turn their engines off instead of keeping them running at idle. Daily miles traveled and trips data provided by CARB were transformed to be travel hours per day. These travel hours per day were multiplied by the penetration percentage, HDT population by weight class and age group, percentage of idle time, and emission factors for idle time (g/hr) to estimate the emissions reduction.

According to the GPS data collected by JFA, idle time percentages were 42.5 percent for heavy heavy-duty diesel vehicles and 61.2 percent for light and medium heavy-duty vehicles. Corresponding idle emission rates are 44 for HC, 247 for CO, and 396 for NOx (4, p.36). The emission rates for PM range from 5.37 to 1.004 grams per hour. The calculated estimates of emission reduction from the idle time modification program at the 1 percent penetration level were:

- NOx 0.139041 grams per mile
- PM 0.000430 grams per mile
- HC 0.000059 grams per mile
- CO 0.000694 grams per mile

These figures represent relative emissions reductions of:

- NOx 1.44 percent
- PM 0.09 percent

- HC 0.01 percent
- CO 0.03 percent

While the program appears to have a sizeable emission reduction for NOx, it must be noted that the idle time percentage used in the calculation differs from those found in other available studies. According to ARB, the idle emission rates are obtained from emissions testing of light heavy-duty trucks conducted by U.S. EPA. These emission rates are general and do not take account of different weight classes and age groups. Also, idle trips are assumed to be five percent for light and medium heavy-duty diesel trucks and 26 percent for heavy heavy-duty diesel trucks (4, p.36). If these percentages were applied instead of those derived from the JFA data, the emission reduction numbers from this program would be significantly smaller.

Shifting Operating Hours (OP2)

Operating in congested road conditions increases certain emission characteristics from HDVs in SoCAB. This program would provide incentives for shifting operations from congested periods.

In order to estimate changes in emissions from HDVs under this program, different emissions characteristics were examined under varying speed profiles. It is assumed that by shifting operations from congested hours to non-congested hours, the HDVs participating in this program would have a higher average speed.

Emission profiles were obtained to compare different emission characteristics under two speed profiles – congested periods and normal operation. The emission reduction estimates were the product of the penetration percentages, HDT population by weight class and age group, daily VMT for each group, and changes in emissions owing to higher speed.

The speed profiles by rush and non-rush hours were obtained by charting the HDV activity analysis (5, Table 11.4-25 to 11.4-27). The profiles were estimated to be 20, 35, and 40 mph in congested hours and 40, 55, and 50 mph in non-congested hours for light, medium, and heavy heavy-duty trucks, respectively. The corresponding changes in emissions were estimated from MOBILE5a from the U.S. Department of Transportation (10, p.121-22). The changes in emissions were -0.1 to -0.5 for NOx, 0.2 to 0.9 for HC, and 2 to 12 for CO.

Estimated changes in emissions show an increase in NOx emissions while the other pollutants are expected to have emission reductions:

- NOx –0.002243 grams per mile
- HC 0.003576 grams per mile
- CO 0.038516 grams per mile

This represents relative emissions reductions of:

- NOx –0.02 percent
- HC 0.88 percent
- CO 1.42 percent

The speed profiles of HDVs vary among combinations of function roads, time of day, and geographical area. Different weight classes usually spend different portions of time on urban/rural roads and travel at different speeds. According to *Heavy-Duty Truck Activity Data* from the Federal Highway Administration (7, p.23-44), heavier trucks tend to spend less time on local roads and travel with longer distance. The SoCAB region showed relatively slower speeds compared to those of other regions. The emissions changes based on these speed profiles would be very different from estimates provided here.

### 7.3. Infrastructure Improvements (IT)

Improved intermodal connections in the region could help reduce emissions from many HDVs. More efficient transfers for trucks at ports or rail yards could translate to less idle time. Also, such improvements could increase rail use over truck use in certain areas. However, these changes could only apply to trucks that serve intermodal connections.

Other infrastructure improvements like relocation and/or consolidation of terminals and freight centers may help reduce emissions from those trucks that serve such facilities. Truck-only facilities such as truckways can also reduce truck emissions by reducing congestion associated with passenger traffic. More specific truck activity data may be required.

<u>Intermodal Improvements (II1)</u>

This program is intended to reduce idle time for HDV sub-populations that transfer cargo between truck and rail. The emission reduction of this and the following two programs are similar to the idle time modification program (OP1) except for the JFA assumption that the affected sub-populations and portion of idle time are expected to be limited when analyzing the Intermodal Improvement program. The emission reduction was estimated to be equal to the penetration percentage multiplied by HDV population, percentage of affected HDV population with respect to weight class, daily travel time for each group, percentage of idle time, the expected percentage of idle time spent on terminals, and emission factors for idle time.

JFA assumed that the affected group would be heavy heavy-duty trucks that belong to trucking companies. According to the data JFA collected for this report, this group comprises about 18.86 percent of the heavy heavy-duty truck population. These trucks were assumed to spend about five percent of their idle time at the rail terminals. At the 1 percent penetration level, the estimated emission reductions were relatively small:

- NOx 0.000490 grams per mile
- PM 0.000002 grams per mile
- HC 0.000000 grams per mile
- CO 0.000002 grams per mile

<u>Truck Terminals and Freight Centers (II2)</u>

This program improves operations at terminals in order to reduce high emissions behaviors such as the idle time. The emission reduction estimation procedure was similar to the previous program and was calculated as the penetration percentage multiplied by HDV population, percentage of affected HDV population with respect to weight class, daily travel time for each group, percentage of idle time, the expected percentage of idle time spent on terminals, and emission factors for idle time.

The program's affected population was assumed to be all heavy-duty trucks that serve the trucking firms and parcel pickup/delivery companies. According to the data JFA collected for this report, this composed about 3.85, 6.59, and 21.00 percent, respectively, of light, medium, and heavy HDVs. These trucks were assumed to spend about five percent of their idle time at truck terminals and freight centers. The estimated emission reductions at the 1 percent penetration level were about one and half times that of the intermodal improvements program, but were still relatively small:

- NOx 0.000806 grams per mile
- PM 0.000003 grams per mile
- HC 0.000000 grams per mile
- CO 0.000004 grams per mile

Truck Stops and Parking Area (II3)

This program also improves operations at truck stops and parking areas in order to reduce emissions behavior. The emission reduction was estimated to be the penetration percentage multiplied by HDV population, percentage of affected HDV population with respect to weight class, daily travel time for each group, percentage of idle time, the expected percentage of idle time spent on truck stops, and emission factors for idle time. The difference between this and the previous two programs was expected to be the applicable population.

It was assumed that only heavy heavy-duty trucks deployed in long-haul operations that serve the trucking firms would be targeted by this incentive program. According to the data JFA collected for this report, this segment represents about 5.60 percent of the heavy heavy-duty truck population. These trucks were assumed to spend about five percent of their idle time at truck stops or parking areas. The estimated emissions reductions were proportionally smaller than those of the previous two programs as shown below.

- NOx 0.000146 grams per mile
- PM 0.000000 grams per mile
- HC 0.000000 grams per mile
- CO 0.000001 grams per mile

Trucks-Only Roadways and Truck Lanes (II4)

This program would attract HDVs from mixed-flow lanes to trucks-only roadways and/or truck lanes in order to improve trip emissions characteristics. Similar to the shifting operating hours program, many of the affected HDVs are expected to increase their average speeds. The emission reduction estimates were the product of the penetration percentages, HDT population by weight class and age group, daily VMT for each group, and changes in emissions owing to higher speed.

It was assumed that the program's targeted sub-populations would include all HDVs that travel on urban roads. According to the data JFA collected for this report, this represents about 88.63, 84.50, and 48.50 percent, respectively, of the light, medium, and heavy heavy-duty truck population. Not unlike the shifting operating hours program, the trucks-only roadways/truck lanes program is expected to result in a NOx emission increase. JFA had no available data for estimating PM emissions. The estimated emission reductions were a fraction of those of the shifting operating hours programs and were:

- NOx -0.001684 grams per mile
- HC 0.002626 grams per mile
- CO 0.028701 grams per mile

This represents relative emissions reductions of:

- NOx - 0.30 percent
- HC 0.65 percent
- CO 1.06 percent

**7.4 Summary**

In this section, JFA estimated the emissions associated with relevant sub-populations of trucks and developed the most promising incentive programs to achieve emission reductions inside the SoCAB.

First, JFA examined various incentive programs and concepts for low-emission heavy-duty vehicles. The programs were categorized in three broad groupings: Low-Emission Technologies group, which was divided into two sub-groups (alternative fuels programs and conventional fuels programs); Operations & Practices; and Infrastructure Improvements. Under each group and sub-group, various incentive programs were studied.

Second, JFA estimated a baseline emission as well as different emissions reductions associated with relevant sub-populations under each of the incentive programs. It must be noted here that different programs could affect different sub-populations of trucks. Because the emission estimates were calculated by sub-populations, activity patters and with adjusted emission factors, a side-by-side comparison of the incentive programs would not always result in an equitable evaluation of the programs. Nonetheless, it is worthwhile to note that the various incentive programs designed to reduce emissions seem to have differing impacts on the four pollutants considered by JFA. No single program appears to be an apparent panacea for reducing emissions in SoCAB. Each program has its strengths and weaknesses, and further studies may be warranted to consider the incentives' feasibility and practical applications.

JFA considered four major pollutants (NOx, PM, HC and CO) when calculating emissions. A summary of the major findings with respect to the incentive programs follows:

- For reducing NOx emission levels, modifying idle time appears to be the most promising incentive program.

- For reducing PM, purchasing new AFVs or converting conventional HDVs to AFVs seems to have the greatest effects on reducing PM emissions.
- For reducing HC and CO emission levels, the most promising incentive program appears to be that of shifting the operating hours of HDVs in the Basin.

Table 52 provides detailed emission reduction as well as baseline figures by pollutants and incentive programs. The table also shows the emission information in terms of percentage.

Table 52. Potential HDV Emissions and Percentage Reductions in the South Coast Air Basin, 2010 with and without Incentive Programs (grams/mile with 1 percent incentive penetration)

| | | NOX | | PM | | HC | | CO | |
|---|---|---|---|---|---|---|---|---|---|
| BC | Base Case Emission | 9.647031 | 100.00% | 0.497895 | 100.00% | 0.404625 | 100.00% | 2.703605 | 100.00% |
| | ***Alternative Fuels*** | | | | | | | | |
| AF1 | New Vehicle Purchase & Vehicle Conversion | ***0.078341*** | ***0.81%*** | ***0.004012*** | ***0.81%*** | ***0.002354*** | ***0.58%*** | ***0.023410*** | ***0.87%*** |
| AF2 | Fuel Pruchase | ***0.040911*** | ***0.42%*** | ***0.002107*** | ***0.42%*** | 0.001237 | 0.31% | 0.011956 | 0.44% |
| | ***Conventional Fuels*** | | | | | | | | |
| CF1 | New Vehicle Purchase | N/A | N/A | 0.002259 | 0.45% | 0.001590 | 0.39% | 0.013203 | 0.49% |
| CF2 | Vehicle Retirement | 0.006629 | 0.07% | 0.000396 | 0.08% | 0.000343 | 0.08% | 0.001718 | 0.06% |
| CF3 | Replacing Engines | 0.002921 | 0.03% | 0.000060 | 0.01% | 0.000131 | 0.03% | 0.000228 | 0.01% |
| CF4 | Emission Control | N/A | N/A | 0.002922 | 0.59% | 0.002428 | 0.60% | 0.016222 | 0.60% |
| CF5 | Fuel Addictive Purchase | 0.001505 | 0.02% | 0.000338 | 0.07% | 0.000273 | 0.07% | 0.000828 | 0.03% |
| | ***Operations & Practice*** | | | | | | | | |
| OP1 | Idle Time Modification | ***0.139041*** | ***1.44%*** | 0.000430 | 0.09% | 0.000059 | 0.01% | 0.000694 | 0.03% |
| OP2 | Shifting Operating Hours | (0.002243) | -0.02% | N/A | N/A | 0.003576 | 0.88% | 0.038516 | ***1.42%*** |
| | ***Infrastructure Improvements*** | | | | | | | | |
| II1 | Intermodal Improvements | 0.000490 | 0.01% | 0.000002 | 0.00% | 0.000000 | 0.00% | 0.000002 | 0.00% |
| II2 | Truck Terminals/Freight Centers | 0.000806 | 0.01% | 0.000003 | 0.00% | 0.000000 | 0.00% | 0.000004 | 0.00% |
| II3 | Truck Stops/Parking Area | 0.000146 | 0.00% | 0.000000 | 0.00% | 0.000000 | 0.00% | 0.000001 | 0.00% |
| II4 | Trucks-Only Roadways/Truck Lanes | (0.001684) | -0.02% | N/A | N/A | 0.002626 | 0.65% | 0.028701 | ***1.06%*** |

N/A - Data Not Available

**Document References**

1. "NYCTA Interim Report: Emission Results from Clean Diesel Demonstration Program with CRT$^{TM}$ Particulate Filter at New York City Transit," by New York City Transit Authority, 2001 <http://www.epa.gov/otaq/retrofit/retronyc.htm>.

2. Verified Technology List, Voluntary Diesel Retrofit Program by U.S. EPA Office of Transportation & Air Quality, December 2000 <http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm>.

3. "Fuel Report: Appendix (IV) to the Diesel Reduction Plan," by California Resources Board, October 2000. <http://www.arb.ca.gov/diesel/documents/rrpapp4.pdf>.

4. "Heavy-Duty Trucks Emission Factors Development," Section 10 of Technical Support Documentation by California Air Resources Board, May 2000 <http://www.arb.ca.gov/msei/doctabletest/documents/HDT_Emissions_New.doc>.

5. "Heavy-Duty Truck Activity Analysis," Section 11 of Technical Support Documentation by California Air Resources Board, May 2000 <http://www.arb.ca.gov/msei/doctabletest/documents/HDT_Activity_New.doc>.

6. "Topical Reports: Alternative Fuels for Fleet Vehicles," by Pacific Northwest Pollution Prevention Resource Center, May 1999 <http://www.pprc.org/pprc/pubs/topics/altfuels.html>.

7. "Heavy-Duty Truck Activity Data," prepared for Office of Highway Information Management, Office of Technology Applications, Federal Highway Administration by Battelle, April 1999 <http://www.fhwa.dot.gov/ohim//tvtw/final.pdf>.

8. "Final Regulatory Impact analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines," U.S. EPA, Office of Air and Radiation, Office of Mobile Resources, Engine Programs and Compliance Division, September 1997 <http://www.epa.gov/otaq/regs/hd-hwy/1997frm/hwy-ria.pdf>.

9. "Round 1 Emission Results from Compressed Natural Gas Vans and Gasoline Controls Operating in the U.S. Federal Fleet," Kelly et al., Presentation at Society for Automotive Engineers' International Spring Fuels and Lubricants Meeting, May 1996 <http://www.afdc.nrel.gov/pdfs/sae_cng.pdf>.

10. "Evaluation of MOBILE Vehicle Emission Model," prepared for J.A. Volpe National Transportation Systems Center, U.S. Department of Transportation by Sierra Research, Inc., June 1994 <http://ntl.bts.gov/DOCS/mob.html>.

11. "Derivation of Emission and Correction Factors for EMFAC7G," Mobile Source Division, Motor Vehicle Analysis Branch, California Air Resources Board.

## Attachment to Chapter 7

### Table 53. Potential HDV Emissions and Percentage Reductions in the South Coast Air Basin, 2010 from Selected Incentive Programs (grams/mile with 5 percent incentive penetration)

| | 5% Incentive Penetration | NOX | | PM | | HC | | CO | |
|---|---|---|---|---|---|---|---|---|---|
| BC | Base Case Emission | 9.647031 | 100% | 0.497895 | 100.00% | 0.404625 | 100.00% | 2.703605 | 100.00% |
| | ***Alternative Fuels*** | | | | | | | | |
| AF1 | New Vehicle Purchase & Vehicle Conversion | 0.391703 | 4.06% | 0.020060 | 4.03% | 0.011771 | 2.91% | 0.117050 | 4.33% |
| AF2 | Fuel Pruchase | 0.204554 | 2.12% | 0.010534 | 2.12% | 0.006184 | 1.53% | 0.059781 | 2.21% |
| | ***Conventional Fuels*** | | | | | | | | |
| CF1 | New Vehicle Purchase | N/A | N/A | 0.011295 | 2.27% | 0.007948 | 1.96% | 0.066016 | 2.44% |
| CF2 | Vehicle Retirement | 0.033143 | 0.34% | 0.001982 | 0.40% | 0.001715 | 0.42% | 0.008591 | 0.32% |
| CF3 | Replacing Engines | 0.014607 | 0.15% | 0.000299 | 0.06% | 0.000654 | 0.16% | 0.001142 | 0.04% |
| CF4 | Emission Control | N/A | N/A | 0.014609 | 2.93% | 0.012139 | 3.00% | 0.081108 | 3.00% |
| CF5 | Fuel Addictive Purchase | 0.007523 | 0.08% | 0.001690 | 0.34% | 0.001365 | 0.34% | 0.004141 | 0.15% |
| | ***Operations & Practice*** | | | | | | | | |
| OP1 | Idle Time Modification | 0.695207 | 7.21% | 0.002148 | 0.43% | 0.000293 | 0.07% | 0.003470 | 0.13% |
| OP2 | Shifting Operating Hours | (0.011216) | -0.12% | N/A | N/A | 0.017879 | 4.42% | 0.192579 | 7.12% |
| | ***Infrastructure Improvements*** | | | | | | | | |
| II1 | Intermodal Improvements | 0.002450 | 0.03% | 0.000008 | 0.00% | 0.000001 | 0.00% | 0.000012 | 0.00% |
| II2 | Truck Terminals/Freight Centers | 0.004028 | 0.04% | 0.000013 | 0.00% | 0.000002 | 0.00% | 0.000020 | 0.00% |
| II3 | Truck Stops/Parking Area | 0.000728 | 0.01% | 0.000002 | 0.00% | 0.000000 | 0.00% | 0.000004 | 0.00% |
| II4 | Trucks-Only Roadways/Truck Lanes | (0.008421) | -0.09% | N/A | N/A | 0.013128 | 3.24% | 0.143503 | 5.31% |

N/A - Data Not Available

### Table 54. Potential HDV Emissions and Percentage Reductions in the South Coast Air Basin, 2010 from Selected Incentive Programs (grams/mile with 20 percent incentive penetration)

| | 20% Incentive Penetration | NOX | | PM | | HC | | CO | |
|---|---|---|---|---|---|---|---|---|---|
| BC | Base Case Emission | 9.647031 | 100.00% | 0.497895 | 100.00% | 0.404625 | 100.00% | 2.703605 | 100.00% |
| | ***Alternative Fuels*** | | | | | | | | |
| AF1 | New Vehicle Purchase & Vehicle Conversion | 1.566811 | 16.24% | 0.080241 | 16.12% | 0.047083 | 11.64% | 0.468202 | 17.32% |
| AF2 | Fuel Pruchase | 0.818216 | 8.48% | 0.042134 | 8.46% | 0.024735 | 6.11% | 0.239125 | 8.84% |
| | ***Conventional Fuels*** | | | | | | | | |
| CF1 | New Vehicle Purchase | N/A | N/A | 0.045180 | 9.07% | 0.031790 | 7.86% | 0.264065 | 9.77% |
| CF2 | Vehicle Retirement | 0.132571 | 1.37% | 0.007929 | 1.59% | 0.006860 | 1.70% | 0.034365 | 1.27% |
| CF3 | Replacing Engines | 0.058427 | 0.61% | 0.001196 | 0.24% | 0.002615 | 0.65% | 0.004570 | 0.17% |
| CF4 | Emission Control | N/A | N/A | 0.058435 | 11.74% | 0.048555 | 12.00% | 0.324433 | 12.00% |
| CF5 | Fuel Addictive Purchase | 0.030092 | 0.31% | 0.006759 | 1.36% | 0.005459 | 1.35% | 0.016566 | 0.61% |
| | ***Operations & Practice*** | | | | | | | | |
| OP1 | Idle Time Modification | 2.780827 | 28.83% | 0.008591 | 1.73% | 0.001171 | 0.29% | 0.013882 | 0.51% |
| OP2 | Shifting Operating Hours | (0.044864) | -0.47% | N/A | N/A | 0.071517 | 17.67% | 0.770318 | 28.49% |
| | ***Infrastructure Improvements*** | | | | | | | | |
| II1 | Intermodal Improvements | 0.009801 | 0.10% | 0.000032 | 0.01% | 0.000005 | 0.00% | 0.000049 | 0.00% |
| II2 | Truck Terminals/Freight Centers | 0.016112 | 0.17% | 0.000051 | 0.01% | 0.000007 | 0.00% | 0.000081 | 0.00% |
| II3 | Truck Stops/Parking Area | 0.002912 | 0.03% | 0.000009 | 0.00% | 0.000001 | 0.00% | 0.000015 | 0.00% |
| II4 | Trucks-Only Roadways/Truck Lanes | (0.033686) | N/A | N/A | N/A | 0.052513 | 12.98% | 0.574010 | 21.23% |

N/A - Data Not Available

# Appendix A – Survey Responses

| Fleets Operating In Basin | | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|---|
| | Registration | Fleets | Trucks | Fleets | Trucks | Fleets | Trucks |
| **Phase I** | In Basin | 131 | 197 | 128 | 1828 (1) | 6 | 2975 |
| | Out Basin | 30 | 42 | 39 | 717 (1) | 4 | 2523 (1) |
| **Phase II** | In Basin | | | 48 | 748 | | |
| (details of Phase I trucks) | Out Basin | | | 18 | 219 | | |
| **Phase III** | In Basin | | | 10 | 568 | 10 | 2757 |
| | Out Basin | | | 8 | 303 (1) | 9 | 2510 (1) |
| **Phase IV** | In Basin | | | 5 | 310 | 4 | 835 |
| (details of Phase III trucks) | Out Basin | | | 2 | 31 | 3 | 151 |
| **Total for Analysis** | In Basin | 131 | 197 | 138 (2) | 1058 (3) | 16 (2) | 835 |
| | Out Basin | 30 | 42 | 47 (2) | 250 (3) | 13 (2) | 151 |
| | All | 161 | 239 | 185 | 1308 | 29 | 986 |
| **Sampling Error** (at 95% confidence level) | | 7.7% | 6.3% | 7.2% | 2.7% | 18.2% | 3.1% |

| Fleets Not Operating In Basin | | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|---|
| | Registration | Fleets | Trucks | Fleets | Trucks | Fleets | Trucks |
| **Phase I** | In Basin | 13 | 16 | 7 | 87 | 0 | 0 |
| | Out Basin | 99 | 165 | 129 | 1752 | 5 | 1423 |
| **Phase III** | In Basin | | | 0 | 0 | 0 | 0 |
| | Out Basin | | | 16 | 518 | 4 | 1052 |
| **Total for Analysis** | In Basin | 13 | 16 | 7 | 87 | 0 | 0 |
| | Out Basin | 99 | 165 | 145 | 2270 | 9 | 2475 |
| | All | 112 | 181 | 152 | 2357 | 9 | 2475 |

Notes:
(1) Includes some trucks that do not operate In Basin, but belong to Basin-operating fleets.
(2) Sum of Phase I and III
(3) Sum of Phase II and IV

# Appendix B – Survey Frequencies

| Trucks That Operate In Basin | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|
| | No. of Trucks (unless noted) | Valid Percent | No. of Trucks (unless noted) | Valid Percent | No. of Trucks (unless noted) | Valid Percent |
| | | | | Individual Truck Information | | |
| **GVW** | | | | | | |
| Light-Heavy | 78 | 37.0% | 169 | 13.0% | 382 | 38.7% |
| Medium-Heavy | 98 | 46.4% | 402 | 30.9% | 343 | 34.8% |
| Heavy-Heavy | 18 | 8.5% | 202 | 15.5% | 87 | 8.8% |
| Super-Heavy | 17 | 8.1% | 530 | 40.7% | 174 | 17.6% |
| *Sub-Total* | *211* | *100%* | *1303* | *100%* | *986* | *100%* |
| Don't Know/Refused | 28 | | 5 | | 0 | |
| **Fuel** | | | | | | |
| Gasoline | 66 | 27.6% | 145 | 11.1% | 497 | 50.4% |
| Diesel | 171 | 71.5% | 1150 | 87.9% | 478 | 48.5% |
| Other | 2 | 0.8% | 13 | 1.0% | 11 | 1.1% |
| *Sub-Total* | *239* | *100%* | *1308* | *100%* | *986* | *100%* |
| Don't Know/Refused | 0 | | 0 | | 0 | |
| **Truck Model Year** | | | | | | |
| 1994 - 1998 | 62 | 26.6% | 279 | 38.0% | 340 | 34.5% |
| 1991 - 1993 | 12 | 5.2% | 179 | 24.4% | 147 | 14.9% |
| 1988 - 1990 | 52 | 22.3% | 133 | 18.1% | 157 | 15.9% |
| 1987 & older | 107 | 45.9% | 144 | 19.6% | 342 | 34.7% |
| *Sub-Total* | *233* | *100%* | *735* | *100%* | *986* | *100%* |
| Don't Know/Refused | 6 | | 573 | | 0 | |
| **Bought New?** | | | | | | |
| Yes | 128 | 54.9% | 435 | 73.9% | | |
| No | 105 | 45.1% | 154 | 26.1% | | |
| *Sub-Total* | *233* | *100%* | *589* | *100%* | | |
| Don't Know/Refused | 6 | | 719 | | | |
| **Engine Model Year** | | | | | | |
| 1994 - 1998 | 64 | 32.2% | 157 | 44.2% | | |
| 1991 - 1993 | 13 | 6.5% | 51 | 14.4% | | |
| 1988 - 1990 | 42 | 21.1% | 71 | 20.0% | | |
| 1987 & older | 80 | 40.2% | 76 | 21.4% | | |
| *Sub-Total* | *199* | *100%* | *355* | *100%* | | |
| Don't Know/Refused | 40 | | 953 | | | |
| **Original Engine?** | | | | | | |
| Yes | 194 | 84.3% | 479 | 95.6% | | |
| No | 36 | 15.7% | 22 | 4.4% | | |
| *Sub-Total* | *230* | *100%* | *501* | *100%* | | |
| Don't Know/Refused | 9 | | 807 | | | |

| | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|
| **Annual Miles (individual truck data)** | | | | | | |
| 0 - 15K | 90 | 43.9% | 183 | 19.8% | | |
| 15K - 30K | 49 | 23.9% | 141 | 15.3% | | |
| 30K - 60K | 41 | 20.0% | 235 | 25.5% | | |
| over 60K | 25 | 12.2% | 364 | 39.4% | | |
| *Sub-Total* | *205* | *100%* | *923* | *100%* | | |
| Don't Know/Refused | 34 | | *385* | | | |
| **Percent of Miles in So. Cal.** | | | | | | |
| 100% | 190 | 83.3% | 615 | 63.6% | | |
| 95% - 99% | 3 | 1.3% | 41 | 4.2% | | |
| 90% - 94% | 5 | 2.2% | 30 | 3.1% | | |
| 50% - 89% | 15 | 6.6% | 224 | 23.2% | | |
| 1 - 50% | 15 | 6.6% | 57 | 5.9% | | |
| *Sub-Total* | *228* | *100%* | *967* | *100%* | | |
| Don't Know/Refused | 11 | | 341 | | | |

**General Fleet Information**
**(Number of trucks represented, unless noted)**

| | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|
| **Miles Between Engine Rebuild** | | | | | | |
| 1 - 100K | 11 | 33.3% | 251 | 20.6% | 1000 | 69.7% |
| 100K - 200K | 11 | 33.3% | 378 | 31.1% | 175 | 12.2% |
| 200K - 300K | 4 | 12.1% | 264 | 21.7% | 10 | 0.7% |
| over 300K | 7 | 21.2% | 324 | 26.6% | 250 | 17.4% |
| *Sub-Total* | *33* | *100%* | *1217* | *100%* | *1435* | *100%* |
| Don't Know/Refused | *206* | | 1731 | | *5419* | |
| **Miles b/t Engine Replacement** | | | | | | |
| 1 - 100K | 10 | 32.3% | 178 | 28.2% | 0 | 0.0% |
| 100K - 200K | 12 | 38.7% | 121 | 19.1% | 1000 | 99.0% |
| 200K - 300K | 2 | 6.5% | 160 | 25.3% | 0 | 0.0% |
| over 300K | 7 | 22.6% | 173 | 27.4% | 10 | 1.0% |
| *Sub-Total* | *31* | *100%* | *632* | *100%* | *1010* | *100%* |
| Don't Know/Refused | *208* | | 2316 | | *5844* | |
| **Miles Between Major Service** | | | | | | |
| 1 - 10K | 64 | 55.2% | 480 | 33.2% | 1725 | 54.2% |
| 10K - 20K | 10 | 8.6% | 126 | 8.7% | 250 | 7.8% |
| 20K - 30K | 6 | 5.2% | 50 | 3.5% | 0 | 0.0% |
| over 30K | 36 | 31.0% | 789 | 54.6% | 1210 | 38.0% |
| *Sub-Total* | *116* | *100%* | *1445* | *100%* | *3185* | *100%* |
| Don't Know/Refused | *123* | | 1503 | | *3669* | |
| **Cost of Major Service** | | | | | | |
| 0 - $500 | 47 | 37.0% | 300 | 23.6% | 500 | 24.0% |
| $501 - $1000 | 22 | 17.3% | 148 | 11.7% | 0 | 0.0% |
| $1001 - $1500 | 12 | 9.4% | 49 | 3.9% | 200 | 9.6% |
| $1501 - $2000 | 12 | 9.4% | 253 | 19.9% | 1200 | 57.6% |
| over $2000 | 34 | 26.8% | 520 | 40.9% | 185 | 8.9% |
| *Sub-Total* | *127* | *100%* | *1270* | *100%* | *2085* | *100%* |
| Don't Know/Refused | *112* | | 1678 | | *4769* | |

| | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|
| **Miles Between Minor Service** | | | | | | |
| 1 - 3K | 90 | 45.0% | 436 | 24.0% | 1175 | 38.1% |
| 3K - 6K | 67 | 33.5% | 599 | 32.9% | 300 | 9.7% |
| 6K - 9K | 16 | 8.0% | 88 | 4.8% | 10 | 0.3% |
| over 9K | 27 | 13.5% | 697 | 38.3% | 1600 | 51.9% |
| *Sub-Total* | *200* | *100%* | *1820* | *100%* | *3085* | *100%* |
| Don't Know/Refused | *39* | | 1128 | | *3769* | |
| **Cost of Minor Service** | | | | | | |
| 0 - $50 | 18 | 9.4% | 263 | 14.1% | 300 | 8.7% |
| $51 - $100 | 52 | 27.2% | 421 | 22.6% | 475 | 13.8% |
| $101 - $150 | 40 | 20.9% | 370 | 19.9% | 200 | 5.8% |
| $151 - $200 | 43 | 22.5% | 342 | 18.4% | 250 | 7.3% |
| over $200 | 38 | 19.9% | 465 | 25.0% | 2210 | 64.3% |
| *Sub-Total* | *191* | *100%* | *1861* | *100%* | *3435* | *100%* |
| Don't Know/Refused | *48* | | 1087 | | *3419* | |
| **Minor Maintenance On Site?** | | | | | | |
| Yes | 143 | 60.6% | 2398 | 81.5% | 5808 | 84.7% |
| No | 93 | 39.4% | 545 | 18.5% | 1046 | 15.3% |
| *Sub-Total* | *236* | *100%* | *2943* | *100%* | *6854* | *100%* |
| Don't Know/Refused | 3 | | 5 | | 0 | |
| **Major Maintenance On Site?** | | | | | | |
| Yes | 51 | 21.8% | 1672 | 56.8% | 5114 | 74.6% |
| No | 183 | 78.2% | 1271 | 43.2% | 1740 | 25.4% |
| *Sub-Total* | *234* | *100%* | *2943* | *100%* | *6854* | *100%* |
| Don't Know/Refused | 5 | | 5 | | 0 | |
| **Any Trucks Retired in Last 5 yrs?** | | | | | | |
| Yes | 60 flts | 38.5% | 118 flts | 72.4% | 9 flts | 90.0% |
| No | 96 flts | 61.5% | 45 flts | 27.6% | 1 flts | 10.0% |
| *Sub-Total* | *156 flts* | *100%* | *163 flts* | *100%* | *10 flts* | *100%* |
| Don't Know/Refused | 5 flts | | 22 flts | | 19 flts | |
| ***If "Yes", Were Trucks*** | | | | | | |
| Scrapped? | 10 flts | 17.2% | 20 flts | 18.2% | 0 flts | 0.0% |
| Sold? | 47 flts | 81.0% | 83 flts | 75.5% | 7 flts | 77.8% |
| Both | 1 flts | 1.7% | 7 flts | 6.4% | 2 flts | 22.2% |
| *Sub-Total* | *58 flts* | *100%* | *110 flts* | *100%* | *9 flts* | *100%* |
| Don't Know/Refused | 2 flts | | 8 flts | | 0 flts | |
| **Fuel Centrally?** | | | | | | |
| Yes | 50 | 20.9% | 1535 | 52.2% | 5021 | 73.3% |
| No | 179 | 74.9% | 1037 | 35.2% | 967 | 14.1% |
| Both | 10 | 4.2% | 371 | 12.6% | 866 | 12.6% |
| *Sub-Total* | *239* | *100%* | *2943* | *100%* | *6854* | *100%* |
| Both/Don't Know/Refused | 0 | | 5 | | 0 | |

| | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|
| **Refrigerated Truck** | | | | | | |
| Yes | 15 | 6.3% | 330 | 11.2% | 207 | 3.5% |
| No | 224 | 93.7% | 2618 | 88.8% | 5647 | 96.5% |
| *Sub-Total* | *239* | *100%* | *2948* | *100%* | *5854* | *100%* |
| Don't Know/Refused | 0 | | 0 | | 1000 | |

| | Small Fleets | | Medium Fleets | | Large Fleets | |
|---|---|---|---|---|---|---|
| **Days per Week in Use** | | | | | | |
| One | 17 | 7.1% | 4 | 0.2% | 0 | 0.0% |
| Two | 11 | 4.6% | 23 | 1.0% | 0 | 0.0% |
| Three | 42 | 17.6% | 48 | 2.1% | 0 | 0.0% |
| Four | 49 | 20.5% | 216 | 9.4% | 0 | 0.0% |
| Five | 103 | 43.1% | 1401 | 60.9% | 1835 | 47.8% |
| Six | 14 | 5.9% | 387 | 16.8% | 1500 | 39.1% |
| Seven | 3 | 1.3% | 223 | 9.7% | 500 | 13.0% |
| *Sub-Total* | *239* | *100%* | *2302* | *100%* | *3835* | *100%* |
| Don't Know/Refused | 0 | | 646 | | *3019* | |
| **Business Type** | | | | | | |
| Trucking Firm | 12 | 5.0% | 727 | 24.7% | 2339 | 34.1% |
| Construction | 38 | 16.0% | 234 | 8.0% | 495 | 7.2% |
| Service/Utility | 25 | 10.5% | 421 | 14.3% | 1812 | 26.4% |
| Parcel Pickup/Delivery | 12 | 5.0% | 239 | 8.1% | 0 | 0.0% |
| Daily Rental | 0 | 0.0% | 158 | 5.4% | 1210 | 17.7% |
| Waste Hauling | 2 | 0.8% | 66 | 2.2% | 430 | 6.3% |
| Other | 149 | 62.6% | 1098 | 37.3% | 568 | 8.3% |
| *Sub-Total* | *238* | *100%* | *2943* | *100%* | *6854* | *100%* |
| Don't Know/Refused | 1 | | 5 | | 0 | |
| ***of Trucking Firms*** | | | | | | |
| TL | 4 | 40.0% | 330 | 78.8% | 500 | 45.5% |
| LTL | 6 | 60.0% | 89 | 21.2% | 600 | 54.5% |
| *Sub-Total* | *10* | *100%* | *419* | *100%* | *1100* | *100%* |
| Don't Know/Refused | 2 | | 308 | | 1239 | |
| ***of Non-trucking Firms*** | | | | | | |
| Make Deliveries | 143 | 63.3% | 1742 | 78.6% | 4189 | 92.8% |
| Do Not Make Deliveries | 83 | 36.7% | 474 | 21.4% | 326 | 7.2% |
| *Sub-Total* | *226* | *100%* | *2216* | *100%* | *4515* | *100%* |
| Don't Know/Refused | *0* | | *0* | | *0* | |
| **Range** | | | | | | |
| Local | 202 | 84.5% | 2202 | 74.8% | 3135 | 45.7% |
| Long-Haul | 37 | 15.5% | 741 | 25.2% | 3719 | 54.3% |
| *Sub-Total* | *239* | *100%* | *2943* | *100%* | *6854* | *100%* |
| Don't Know/Refused | 0 | | 5 | | 0 | |

# Appendix C – GPS Datalogger Information Summary
# (Furnished and provided by ARB)

**Summary of GPS Datalogger Data of JFA Truck Study**

| | | | | | | VMT Distribution by Speed Bin (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Truck ID | # of Days | # of Trip | # of Idle Trip | Idle Trip Time (min) | Avg Trip VMT | 0 - <10 mph | 10 - <20 mph | 20 - <30 mph | 30 - <40 mph | 40 - <50 mph | 50 - <60 mph | 60 - <70 mph | 70 - <80 mph | >80 mph | # of Air Basin | % SCAB VMT |
| 101 | 4 | 16 | 3 | 33.1 | 158 | 0 | 1 | 2 | 5 | 13 | 44 | 34 | 0 | 0 | 2 | 50 |
| 103 | 5 | 25 | 5 | 84.7 | 179 | 0 | 1 | 2 | 3 | 4 | 14 | 75 | 2 | 0 | 4 | 26 |
| 104 | 8 | 17 | 0 | | 76 | 1 | 2 | 4 | 5 | 6 | 64 | 17 | 0 | 0 | 3 | 81 |
| 105 | 6 | 11 | 0 | | 125 | 2 | 4 | 6 | 9 | 10 | 44 | 25 | 0 | 0 | 3 | 82 |
| 106 | 6 | 10 | 0 | | 115 | 2 | 5 | 9 | 12 | 11 | 25 | 34 | 3 | 0 | 3 | 89 |
| 107 | 4 | 12 | 0 | | 84 | 3 | 7 | 9 | 14 | 14 | 46 | 7 | 0 | 0 | 3 | 85 |
| 109 | 4 | 16 | 1 | 15.4 | 21 | 2 | 5 | 6 | 8 | 12 | 52 | 15 | 0 | 0 | 1 | 100 |
| 112 | 7 | 38 | 2 | 11.5 | 10 | 4 | 14 | 32 | 28 | 11 | 8 | 1 | 0 | 0 | 1 | 100 |
| 113 | 11 | 22 | 3 | 200 | 27 | 4 | 12 | 21 | 19 | 12 | 20 | 12 | 0 | 0 | 1 | 100 |
| 114 | 6 | 26 | 0 | | 42 | 3 | 9 | 21 | 19 | 16 | 22 | 10 | 0 | 0 | 1 | 100 |
| 115 | 1 | 7 | 0 | | 37 | 1 | 4 | 4 | 7 | 12 | 36 | 36 | 0 | 0 | 1 | 100 |
| 116 | 8 | 39 | 2 | 6.1 | 28 | 3 | 11 | 18 | 25 | 18 | 20 | 4 | 0 | 0 | 1 | 100 |
| 117 | 4 | 55 | 1 | 3.4 | 38 | 1 | 3 | 5 | 9 | 10 | 71 | 0 | 0 | 0 | 2 | 97 |
| 120 | 7 | 28 | 3 | 24.8 | 97 | 1 | 3 | 3 | 4 | 9 | 63 | 17 | 0 | 0 | 3 | 47 |
| 123 | 5 | 18 | 1 | 2.0 | 87 | 1 | 3 | 5 | 6 | 9 | 37 | 37 | 2 | 0 | 2 | 54 |
| 128 | 5 | 54 | 0 | | 88 | 2 | 3 | 5 | 7 | 7 | 75 | 0 | 0 | 0 | 2 | 96 |
| 129 | 4 | 25 | 0 | | 34 | 2 | 5 | 7 | 12 | 11 | 12 | 33 | 17 | 2 | 1 | 100 |
| 130 | 5 | 26 | 0 | | 47 | 1 | 4 | 6 | 8 | 11 | 52 | 17 | 0 | 0 | 2 | 93 |
| 141 | 7 | 53 | 0 | | 21 | 4 | 9 | 12 | 12 | 11 | 44 | 8 | 0 | 0 | 1 | 100 |
| 142 | 4 | 29 | 0 | | 19 | 5 | 13 | 14 | 12 | 7 | 34 | 16 | 0 | 0 | 1 | 100 |
| 144 | 3 | 9 | 1 | 2.1 | 5.9 | 8 | 24 | 35 | 32 | 1 | 0 | 0 | 0 | 0 | 1 | 100 |
| 145 | 4 | 24 | 6 | 26.7 | 27 | 3 | 6 | 10 | 11 | 12 | 53 | 4 | 0 | 0 | 1 | 100 |
| 146 | 4 | 16 | 1 | 3.2 | 64 | 2 | 7 | 13 | 16 | 12 | 39 | 11 | 0 | 0 | 1 | 100 |
| 147 | 3 | 19 | 0 | | 22 | 2 | 4 | 6 | 9 | 12 | 25 | 43 | 0 | 0 | 1 | 100 |
| 148 | 6 | 37 | 1 | 1.2 | 40 | 2 | 4 | 7 | 13 | 14 | 10 | 49 | 0 | 0 | 1 | 100 |
| 151 | 5 | 16 | 1 | 2.0 | 278 | 0 | 1 | 1 | 2 | 3 | 22 | 65 | 6 | 0 | 3 | 51 |
| 152 | 4 | 22 | 1 | 10.3 | 64 | 1 | 1 | 2 | 2 | 4 | 18 | 71 | 0 | 0 | 2 | 15 |
| 159 | 5 | 14 | 0 | | 76 | 1 | 5 | 8 | 11 | 12 | 37 | 26 | 0 | 0 | 1 | 100 |
| 160 | 4 | 23 | 0 | | 28 | 2 | 4 | 7 | 14 | 19 | 20 | 22 | 12 | 0 | 1 | 100 |
| 163 | 6 | 34 | 0 | | 199 | 0 | 1 | 3 | 4 | 5 | 26 | 60 | 1 | 0 | 2 | 30 |