ARB Contract No. 01-340

Incidence of Malfunctions and Tampering in Heavy-Duty Diesel Vehicles

Phase I: Proof of Concept
Final Report

Prepared for:

California Air Resources Board

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Abstract

Emissions from on-road heavy-duty diesel (HDD) vehicles represent a disproportionate source of oxides of nitrogen (NOx) and particulate matter (PM). Malfunctions and tampering are important causes of elevated emissions and the incidence rates for nineteen categories are listed in the EMFAC 2000 model. However, the estimates for the incidence rates vary by more than 100% depending on the source of the estimate. In addition, the data are old and incomplete. This report details the work conducted under Phase I of this project, which was to compare the existing factors for tampering and malfunctioning for HDD trucks in the EMFAC model with those arrived at by the use of several new and independent methods and review of about 7,000 HDD truck records.

The approach or design of the new methods followed the life cycle and repair records of a HDD truck. For about 25% or 290,000 miles of its life cycle, the trucks are covered by a warranty and records are kept at ARB and EPA for specific causes of high emissions. From the analysis of 998 warranty incidents, we learned that most malfunctioning rates were in fair agreement with the values in EMFAC, except that the incidence rates of problems were much higher for fuel injectors, turbos and electronics. Being in fair agreement or higher gives cause for concern as the rates in EMFAC reflect the full life cycle and are expected to be low for the first 25% and increase dramatically for the last 25%. These data suggested that EMFAC may be underestimating the contributions from malfunctions. However, the driver survey and independent repair shop survey data, both of which are instantaneous measures of tampering and malfunction, correspond well with the EMFAC data.

Other data sources proved helpful in providing new insight on the remaining 75% of its engine life. For example, the analysis of 5,210 records for trucks that were inspected indicated that tampering was <1%, so tampering is either not visible or is not there to begin with. Based on our observations when working along side the ARB experienced inspectors in the field and as most engines are designed with electronic controls, we do not think that tampering is a major contributor to emissions and, therefore, conclude that dedicating time to enhanced visual inspections would not be fruitful. However, our pilot work of electronic monitoring was the first to be undertaken in the field and the results yielded new insight about what information was available with proprietary download tools and how it could be analyzed, especially the issue of whether a off-cycle NOx chip was installed. Electronic monitoring should be pursued, as knowing if a reflashed chip is installed will become very important as the vehicles are modified to meet the new low-NOx standards.

A random roadside survey of 78 drivers about the problems with their trucks was undertaken with the resulting malfunction rates again in fair agreement with the values in the EMFAC table. The questionnaire for this form of a data collection is very important so that key information is obtained in an unambiguous nature in a short period of time. We suggest obtaining more surveys even thought the data is probably of a lower quality.

Finally, a data set of 500 trucks repaired at an independent shop indicated that the failure rates were similar to those values listed in the current EMFAC, suggesting that the current factors are adequate. This survey method was very useful and should be continued as the data are high quality and deal directly with the issue of repair frequency for the vehicle that is past the warranty period and into its period of high repair frequency.

After an assessment of Phase I results and when comparing results of this study with the current EMFAC factors for tampering and deterioration, it was decided that the current factors provide adequate values to deal with the estimates from the current fleet. Thus we did not believe that the confidence limits would be further improved in Phase II to justify the expenditure of funds in the current tough budgetary environment. While many of the methods employed in Phase I were successful, it could not be determined with certainty that continuation of the work would provide statistically significant results with sufficient accuracy to make the effort worthwhile.

Executive Summary

Emissions inventories calculated with the EMFAC emissions model show that on-road heavy-duty diesel (HDD) vehicles represent a significant source of oxides of nitrogen (NOx) and particulate matter (PM) and that malfunctions and tampering are important causes of elevated emissions. Currently, EMFAC lists the incidence of nineteen categories of malfunctions and tampering. However, these incidence rates are based on incomplete and dated information, and estimates vary by as much as 100% depending on the source of the estimate. Furthermore, the current list of malfunctions and tampering events does not include malfunctions in the electronic engine controls that have been introduced in the past decade. Failure of these controls can directly affect emissions.

Incidence rates in this report are defined as the percent of on-road vehicles having the malfunction at any one time. Some of the data presented in this report are yearly summaries of the percentage of on-road vehicles that exhibited malfunctions during the year. These "yearly incidence" rates differ from those used in EMFAC, so incidence rates were estimated from the yearly rates where appropriate.

Incidence rate (incidence) = the population percent exhibiting a fault at one time.

Yearly incidence = the population percent exhibiting a fault during one year.

The Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside, has completed Phase I of a two-phase project to improve the accuracy of the incidence rates of malfunctions and tampering used in EMFAC 2000. Many of the faults are expected to occur in less than 5% of the on-road truck population at any particular time. Because of the relatively small proportion of the population, sample sizes necessary for accurate statistical estimation are relatively large. For this reason, this project is focused on characterization of the tampering and malfunction rates only for the Heavy-Heavy-Duty diesel truck population across all model years and engine types.

<u>Phase I – Proof of Concept</u>

Phase I was a six-month "proof of concept" phase to demonstrate the feasibility of several new data-gathering approaches.

Potential data sources for Phase I were:

- Literature review.
- ARB databases.
- EPA databases.
- OEM engine recall data.
- Engine rebuilder surveys.
- Fleet operator surveys.

- Non-fleet repair records.
- Roadside inspections.
- Electronic scan tool pilot test.

During Phase I some of the anticipated data sets proved to be unworkable or were unobtainable, while other data sets were available and analyzed. Specifically, we conducted the following activities in this phase to determine their potential usefulness as sources of information on malfunction and tampering:

- Compilation of an annotated bibliography on heavy-duty malfunctions and tampering.
- Review of the ARB data sets for roadside inspections and warranty repair.
- Survey of the original equipment manufacturers (OEMs), Tier 1 suppliers, and OEM-authorized dealers.
- Development of a stratified random sampling plan for a statewide fleet survey.
- Collection of tampering and repair data from an independent repair shop.
- Collection and analysis of warranty repair records from ARB staff.
- 7 vehicles were given roadside inspections in conjunction with ARB staff.
- 58 roadside driver surveys.
- 7 vehicles were sampled in the pilot trials of an electronic scan tool in coordination with ARB staff.
- Compilation, analysis, and reporting of the results of the pilot phase to the RSC.

The results from this proof-of-concept phase of the study are presented in this report. The goal was to estimate all 19 faults (Table 1) for the HDD population across all model years. Table 2 lists which tasks address what portion of a vehicles life cycle are covered by the various tasks.

The majority of HDD vehicles included in this project were from model years 1994-2002. The first two columns of Table 1 provide the EMFAC incidence rates of the 19 faults for the two model year groups that are representative of the vehicles covered in our results. Sample sizes and type of estimate (yearly rate or incidence rate) are also summarized for the four tasks having valid estimates. Details are provided in the report for each of the tasks.

Table ES-1. Malfunction/tampering population percent estimate by task.

Malfunction/Tampering Group	**EMFAC HHDT 94-97 Population%**	**EMFAC HHDT 98-02 Population%**	Warranty Repair Database (Yearly Incidence)	Roadside Inspection Database (Yearly Incidence)	Repair Shop Survey (Incidence Rate)	Roadside Driver Survey (Incidence Rate)
Phase I Task			Task I-2	Task I-2	Task I-7	Task I-8
Number of Vehicles Used in Estimate			998	5,210	500	58
Injection Timing Advanced	**5%**	**2%**	<1%	NA	6%	NA
Injection Timing Retarded	**3%**	**2%**	<1%	NA	4%	NA
Minor Injector Problem	**15%**	**15%**	2%	<1%	16%	8%%
Moderate Injector Problem	**10%**	**10%**	23%	<1%	8%	4%
Severe Injector Problem	**3%**	**3%**	<1%	<1%	4%	4%
Puff Limiter Mis-Set	**4%**	**0%**	NA	NA	0%	NA
Puff Limiter Disabled	**4%**	**0%**	NA	NA	0%	NA
Max Fuel High	**3%**	**0%**	<1%	NA	2%	8%
Clogged Air Filter	**15%**	**15%**	NA	NA	4%	8%
Wrong/Worn Turbo	**5%**	**5%**	8%	NA	2%	4%
Intercooler Clogged	**5%**	**5%**	<1%	NA	3%	4%
Other Air Problems	**8%**	**8%**	<1%	14%	2%	NA
Mech. Failure	**2%**	**2%**	2%	NA	12%	2%
Excess Oil Consumption	**5%**	**3%**	<1%	NA	14%	NA
Electronics Failed	**3%**	**3%**	65%	<1%	11%	NA
Electronics Tampered	**5%**	**5%**	<1%	<1%	2%	NA
Catalytic Converter Removed	**0%**	**0%**	NA	NA	1%	NA
EGR Stuck Open	**0%**	**0%**	<1%	NA	0%	NA
EGR Disabled	**0%**	**0%**	NA	3%	0%	NA

NA = Not Applicable

Table ES-2. Vehicle coverage by task. Task descriptions are included in Section 2.

	Year 1	2	3	4	5	6	7	8	9	10
Average Cumulative Mileage	61K	163K	249K	322K	384K	435K	480K	517K	548K	575
Task I-1: Literature Search	X	X	X	X	X	X	X	X	X	X
Task I-2a: Review of ARB Warranty Data*	X	X	X	X	NA	NA	NA	NA	NA	NA
Task I-2b: Review of ARB HDVIP Data	X	X	X	X	X	X	X	X	X	X
Task I-3: Review of EPA Data	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Task I-4: Review of OEM supplier and engine recalls	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Task I-5: Surveys of manufacturers and rebuilders records	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Task I-6: Sampling of Fleet Operator Records	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Task I-7: Sampling of Non-Fleet Repair Records	ND	X	X	X	X	X	X	X	X	X
Task I-8a: Random Roadside Inspections	X	X	X	X	X	X	X	X	X	X
Task I-8b: Random Roadside Driver Survey	X	X	X	X	X	X	X	X	X	X
Task I-9: Electronic Scan Tool Pilot Test	X	X	X	X	X	X	X	X	NA	NA

* Warranty data reported for component failure rates greater than 1% during first 290,000 miles.
X = Data Available
ND = No Data
NA = Not Applicable

Phase II – Execution of Full Program

After an assessment of Phase I in consultation with ARB staff it was decided that there was insufficient likelihood of improving the inventory contributions of HDD trucks beyond that needed in the current environment. Thus Phase II could not be justified in the current tough budgetary environment. While many of the methods employed in Phase I were successful, it could not be determined with certainty that continuation of the work would provide statistically significant results with sufficient accuracy to make the effort worthwhile.

1. Introduction

1.1 Background on Emissions

The California Air Resources Board (ARB 2002) estimates that heavy-duty diesel (HDD) vehicles account for about 30% of the oxides of nitrogen (NOx) and 65% of the particulate matter (PM) emitted by mobile sources while comprising only 2% of the on-road vehicle fleet. A portion of the emissions is due to malfunctions and tampering; however, estimating these rates have proved difficult for a number of reasons, one being the lack of data from a program for HDD vehicles like “Smog Check.” Regardless of the foregoing, emissions from all sources, including malfunctions and tampering, must be quantified and included in emission inventory models like EMFAC in order to design effective regulatory strategies.

Incidence rates in this report are defined as the percentage of on-road vehicles having the malfunction at any one time. Some of the data presented in this report are yearly summaries of the percentage of on-road vehicles that exhibited malfunctions during the year. These “yearly incidence” rates differ from those used in EMFAC and so incidence rates were estimated from the yearly rates where appropriate.

Incidence rate (incidence) = the population percent exhibiting a fault at one time.

Yearly incidence = the population percent exhibiting a fault during one year.

Current EMFAC estimates of the incidences of malfunctions and tampering were based on roadside programs for excessive smoke and considerable information is found in the regulatory development process (ARB, 1990, 1997, 1998). In one ARB (1990) study, 912 HDD trucks were tested and 69 trucks were repaired. Seventy percent of the high smoke emissions (opacity exceeding regulatory limit) were attributed to improper control of the air/fuel ratio during transient conditions. Smoking was primarily caused by malfunctioning components due to age, wear, malmaintenance, or design defects rather than tampering (which includes missing, modified or disconnected devices).

ARB’s study included a visual inspection program for tampering and the inspectors noted that the time added to inspect for tampering was limiting the number of vehicles that could be tested and categorized as excessive smoking. Furthermore, the study found that tampered parts were difficult to recognize and the tampering did not always correlate with the high smoke emissions. The ARB inspectors concluded that it was better to inspect additional trucks than to spend time on a lengthy inspection for tampering and implemented that finding.

In conjunction with the earlier roadside inspection programs, ARB developed the truck base emission rates for inventory and air quality purposes in 1988. Radian identified 23 specific categories of tampering and component malfunction (Weaver and Klausmeier, 1988). Subsequent review by other contractors revised the Radian estimates for the U.S. Environmental Protection Agency (USEPA) (Weaver et al., 1998). The resultant incidence rates from these two studies often vary by 100% for some categories, and new research is needed to improve the population estimates. The current EMFAC model lists the incidence rates for the 19 categories of malfunctions and tampering. Furthermore, the current list of specific malfunctions and tampering events and their incident rates do not fully reflect the information about the current fleet and the rapid introduction of new technology into the projected fleet.

A list of the current faults in EMFAC is shown below.

1. Timing Advanced
2. Timing Retarded
3. Minor Injector Problem
4. Moderate Injector Problem
5. Severe Injector Problem
6. Puff Limiter Mis-Set
7. Puff Limiter Disabled
8. Max Fuel High
9. Clogged Air Filter
10. Wrong/Worn Turbo
11. Intercooler Clogged
12. Other Air Problem
13. Engine Mech. Failure
14. Excess Oil Consumption
15. Electronics Failed
16. Electronics Tampered
17. Catalyst Removed
18. EGR Removed
19. EGR Disabled

Since the earlier studies were conducted, a new generation of HDD vehicles with electronic engine management systems now dominant the technology used in the truck fleets. Based on the issue that developed around the off-cycle NOx emissions it is well known that these electronic systems provide new opportunities for tampering, since visual inspections are rendered meaningless for all but the most egregious forms of tampering. Thus new manufacturer-based electronic scan tools will be needed and essential to capture these incidences.

1.2 Background on Emission Contributions

Background information on the emission sources within truck categories is helpful when deciding where to focus the limited resources associated with this research. ARB has categorized a number of truck and bus sectors, including six HDD classes:

- Light heavy-duty trucks 1. Weight 8,501- 10,000 lbs. Population 272,000.
- Light heavy-duty trucks 2. Weight 10,001- 14,000 lbs. Population 84,000.
- Medium heavy- duty trucks. Weight 14,001- 33,000 lbs. Population 266,000.
- Heavy heavy-duty trucks. Weight 33,001+ lbs. Population 175,000.
- School buses. Weight All. Population 30,000.
- Urban buses. Weight All. Population 14,000.

NOx emissions from these categories, calculated with EMFAC 2000, are shown in Figure 1-1a, b, and c. Heavy-heavy-duty trucks dominate the emissions. A comparison with Figures 1b and 1c shows that VMT is a fairly good predictor of NOx by category and that vehicle population is not particularly useful. For example, although the population of medium-duty trucks equals that of the heavy-heavy-duty (HDD) trucks, their NOx emissions are only 25% of those emitted by the HHD by comparison.

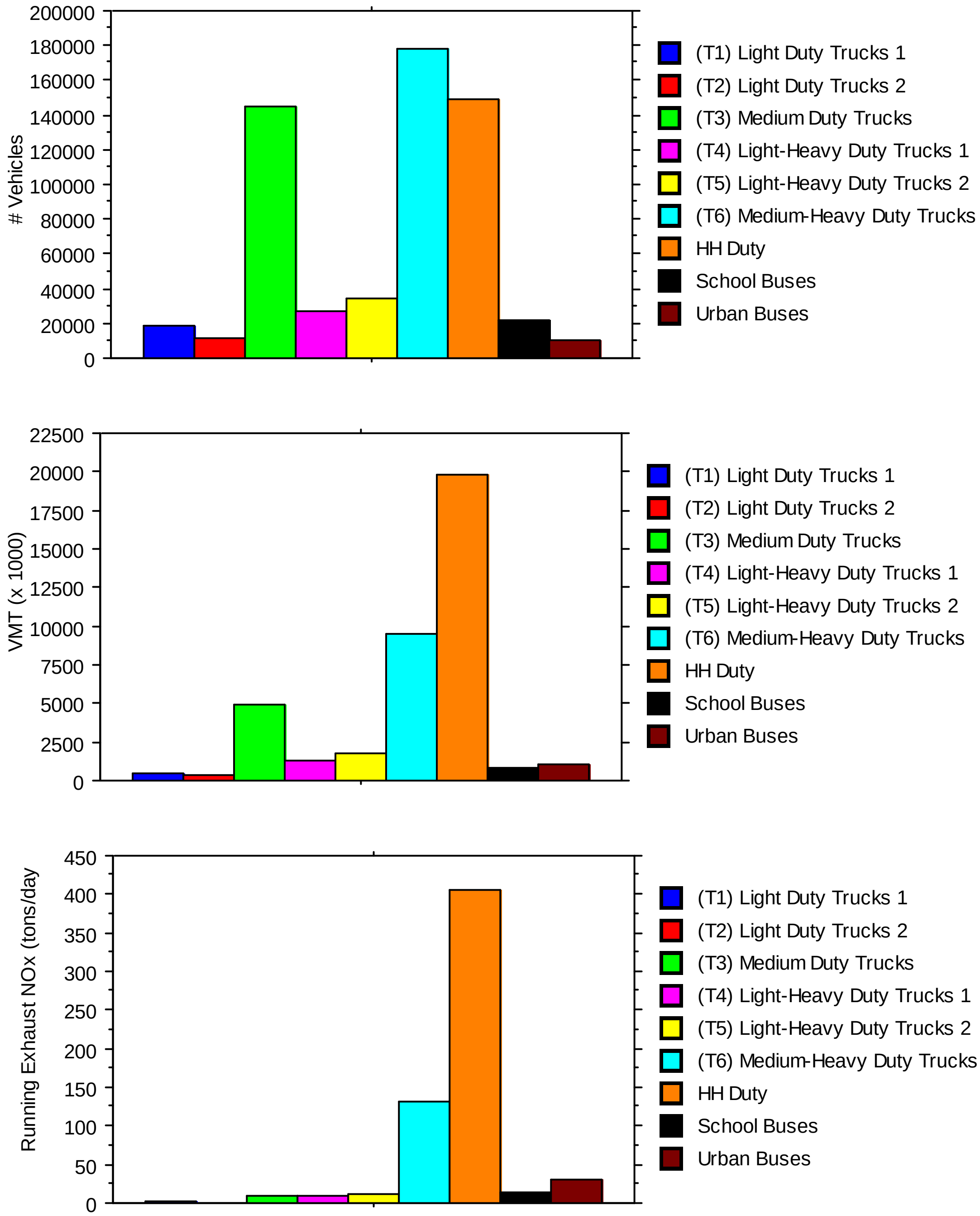

Figure 1-1 a,b,c. Population, vehicle miles traveled, and NOx emissions by class of truck, based on EMFAC. (Source: CE-CERT analysis using EMFAC.)

Another background perspective that is helpful in prioritizing the work effort for the HDD class is the emissions by model year. Since emission standards, vehicle miles traveled and the number of vehicles change with the model year, CE-CERT used EMFAC to calculate the NOx emissions for each model year. Results in Figure 1-2 show that the emissions differed widely by year and that over 80% of the emissions are from trucks that were purchased after 1988. Several years – 1989, 1990 and 1998 – stand out as having high emissions.

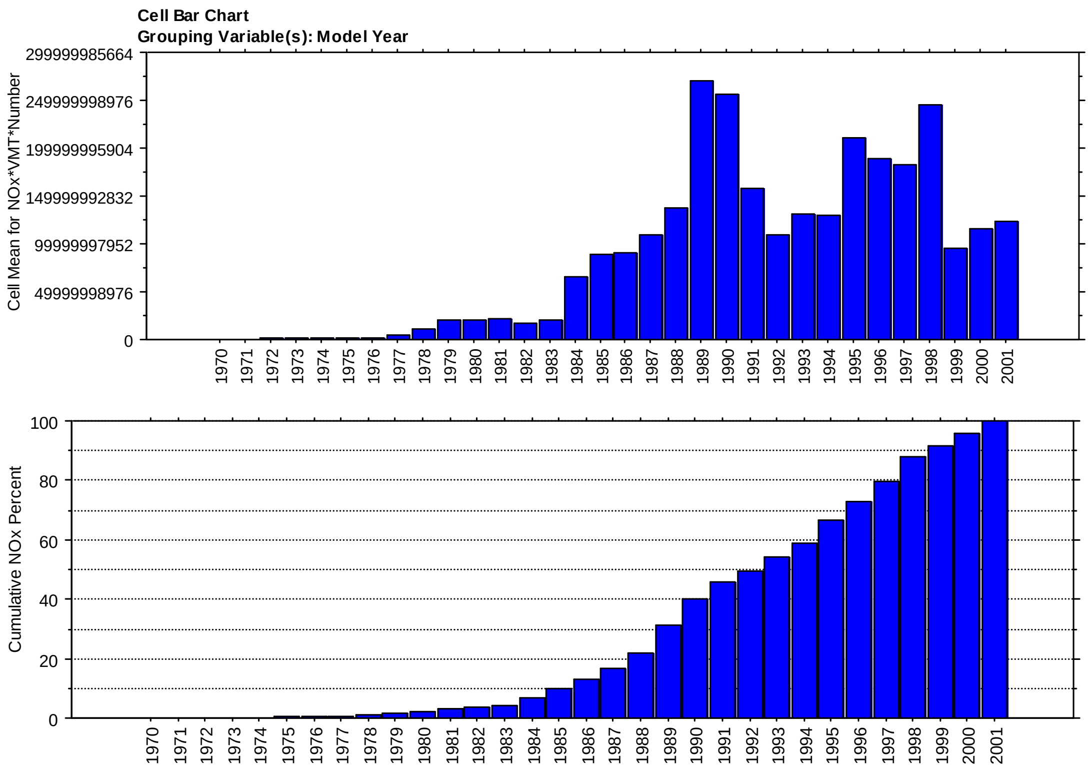

Figure 1-2a, b. (NOx (g/mi) * VMT * number of HDDT and cumulative percent, both by year. (Source: CE-CERT calculations using EMFAC.)

Market share contribution is another background factor in determining where to focus the resources in this research. Some insight is gained in the following figures, whichwere generated using the California Department of Motor Vehicles (DMV) database. As shown in Figure 1-3 and Figure 1-4, some manufacturers clearly have a higher percentage of the market.

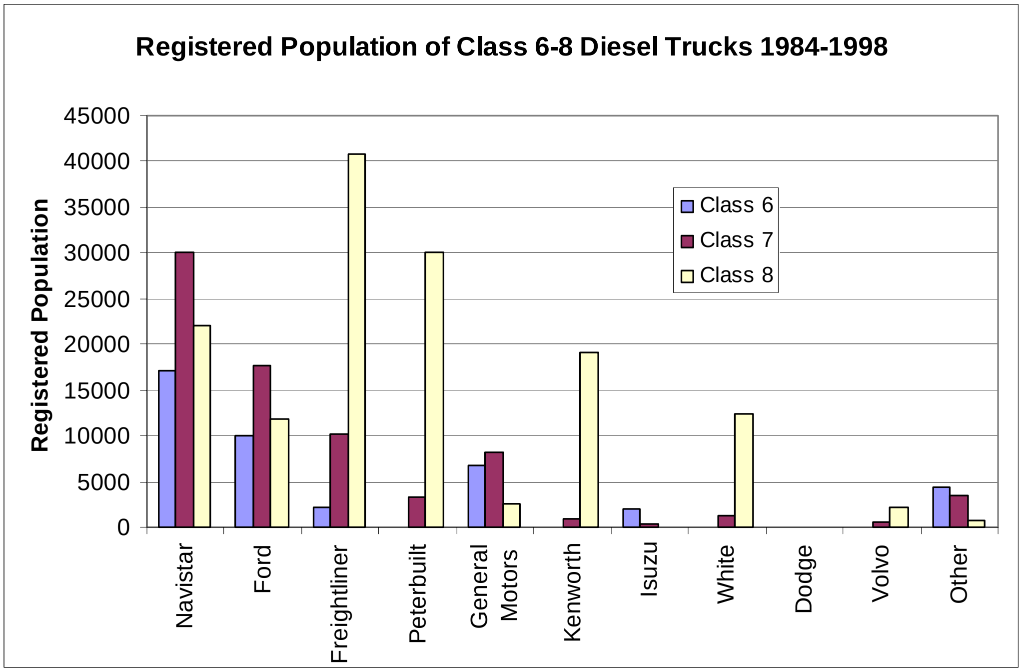

Figure 1-3. Registered population of class 6-8 diesel trucks, 1984-1998 (from Department of Motor Vehicles database).

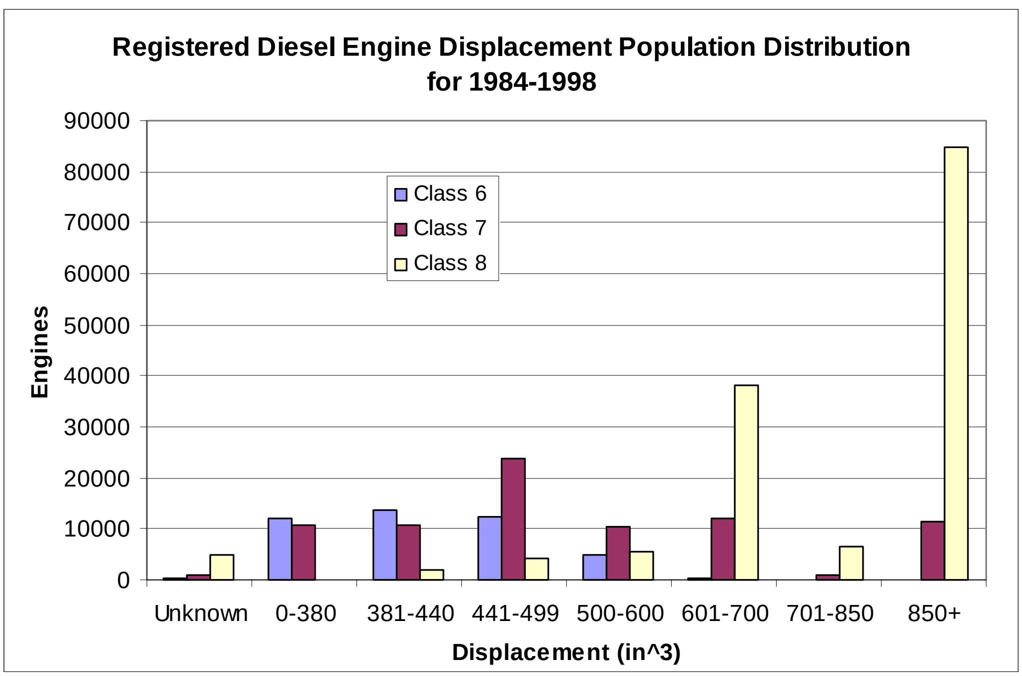

Figure 1-4. Registered diesel engine displacement population distribution, 1984-98 (from Department of Motor Vehicles database).

1.3 Objectives

Many of the faults are expected to occur in less than 5% of the on-road truck population at any particular time (*incidence rate*). Because of the relatively small proportion of the population, sample sizes necessary for accurate statistical estimation are relatively large. For this reason, this project is focused on characterization of the tampering and malfunction rates only for the Heavy-Heavy-Duty diesel truck population across all model years and engine types. For this study, CE-CERT proposed that the objectives of this project be carried out in two phases. The project was divided into two phases because of the unproven nature of many of the possible estimation methods. By conducting the study in two phases, the project could be halted if it was decided that the methods were unlikely to improve greatly the current estimates for tampering and malmaintenance. The main thrust areas were:

- "Proof of concept" trials to verify that task elements without prior experience will meet expectations. The objective of this first phase was to demonstrate that new approaches could be used for this purpose.
- Gather information from commercial and governmental sources to update estimates of the incidence rates of malfunctions and tampering (collectively "faults") in HDD vehicles. Validate some of the incidence rates learned from the repair studies in a limited roadside inspection program and characterize other types of faults to which electronically controlled engines are susceptible. The focus was on developing the estimates for the HDDT class, with engineering judgment to be used to extend the results to all diesel truck classes.

Figure 1-5 summarizes the project's major activities.

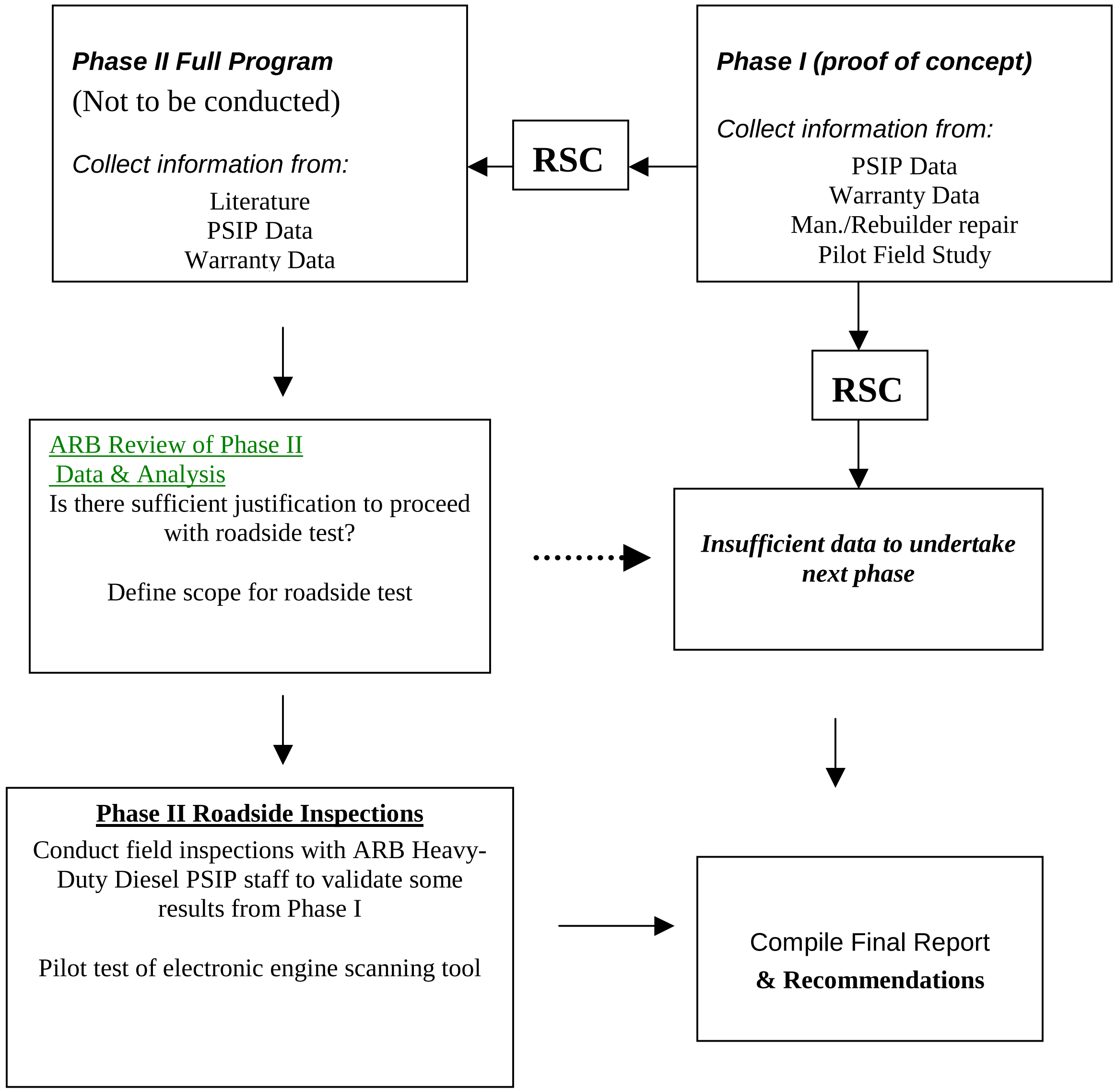

Figure 1-5. Process flow chart for Phases I and II (Phase II not conducted).

2. Phase I Tasks

Phase I was a "proof of concept" activity to demonstrate the feasibility of the new methods based on an analysis of the likely sources of confirming and independent data for repair during the 1,200,000 miles that EMFAC identifies as the useful life of a HDD truck. For the first 290,000 miles, the truck emissions are under a warranty program and the OEM pays for repair while for the remaining 910,000 miles, the owner pays for repair.

Repair Life Cycle of a HDD Truck	
←290,000 miles under warranty→	←910,000 miles under repair paid by owner →

For the warranty portion or approximately 25% of the useful life of a HDD truck, there are a number of Federal and ARB regulations with required reporting provisions. During this period, one would expect very good records, but not too many malfunctioning components, as the manufacturer has to pay for them. As the vehicle ages, owner-operator repairs begin and different scenarios can develop depending on the situation. For example, most new trucks are kept in fleets and will be well maintained, so malfunctions will be quickly repaired. However, those HDD trucks viewed by the fleets as high maintenance are sold to independent operators who may not have the same resources or desire to maintain the trucks to same degree as before. In addition, these older trucks are likely to have continuing deterioration leading to a variety of major repairs, including a major overhaul of the engine components during their remaining 910,000 miles. Data sets covering repair during the more interesting 75% of the HDD truck life are known to be scarce; however, we were going to use some ARB data from the PSIP program.

Based on our understanding of the life cycle of a HDD truck, we designed a number of independent methods to estimate the incident rates of malfunctioning so that we could check the estimates in EMFAC. Our estimation methods were based on database analysis and collection of new data from manufacturers, repair shops, fleet operators, and in limited roadside inspections. These approaches are detailed in the following sections. With the uncertainty associated with so many new estimation methods, the "proof of concept" phase was warranted to ensure success in the subsequent full implementation phase. The Phase I task methodology and results are presented in this section, with the results summarized in the following section. The conclusions for Phase I are presented in Section 3. The recommendations for Phase II are presented in Section 4.

2.1 Task I-1: Literature Review

2.1.1 Literature Methodology

During the proof-of-concept phase, CE-CERT compiled an annotated list of potential sources of existing, open literature. These sources were primarily identified through searches on the internet and through review of relevant EPA and ARB reports.

2.1.2 Literature Results

In their article on diesel emissions, Lloyd and Cackette comment on the scarcity of information on in-use diesel engines: "While the California emission inventory for light-duty gasoline vehicles is based on data from tests performed on over 6000 vehicles, the heavy-duty diesel truck inventory is based on only 70 trucks." Our attempts to uncover new information met the same limited success as Lloyd and Cackette. The completed annotated reference list appears in Appendix A. The Radian (Weaver and Klausmeier, 1988), and EFEE (Weaver et. al, 1988) materials used by the ARB in developing tampering and malfunction rates continue as the only source of data on HDD incidence. Four web sites were found giving information on recalls, including emissions related recalls. These web sites were useful for understanding the types of malfunctions but were not useful for estimation of population rates of the malfunctions. Nine web sites were found with information on tampering in heavy-duty diesel vehicles. One of these sites deals with the EPA Voluntary Diesel Retrofit Program with information on the individual manufacturers models and repair information. The other sites deal primarily with types of tampering and repairs along with general information on fines and inspection programs. The information on types of tampering and malfunctions was useful, particularly for the electronic components but again was not useful for establishing population rates. Two sites were found that related to electronic malfunctions, however neither was useful for estimating population rates.

One site (http://myhome.naver.com/bookitec/diesel%20truck.htm) was for software designed to train users in identification of malfunctions in heavy-duty vehicle electronics and may be a useful tool for training. Six web sites were found that had information on general diesel vehicle engine technology but were lacking in information on population rates.

Thus the two main sources of HDD malfunction and tampering rates are the reports used by the ARB in estimation of the rates in EMFAC. The Radian report and the EFEE rates for HDD 1994-1997 vehicles that make up the majority of the vehicles in our current data collection efforts are summarized in Table 2-1.

Table 2-1. Radian and EFEE HDD 1994-1997 malfunction and tampering rate summary.

Defect	**Radian**	**EFEE**
Injection Timing Advanced		

to be entered into the database from paper records. The two initial data sets are described in Table 2-2.

Table 2-2. Relevant ARB HDD data sets known at beginning of project.

Title	Format	Total Records	Content
Heavy Duty Vehicle Inspection Program	Access database (with paper records)	5,210	200 fields
Periodic Smoke Inspection Program	text file	18,500	10 fields

Discussions were held with ARB staff in the initial part of this task, and several changes were made to the proposed plan for this task.

- Data for all relevant data sets were already in electronic format so time was reallocated from data entry and analysis of 10% of each database to analysis of 100% of each database.
- The Periodic Smoke Inspection Program data set was moved to a lower priority because the program was geared toward making sure that malfunctions and tampering were corrected, not toward tracking specific types of malfunctions and tampering.
- During the project, two additional and relevant data sets were identified.
    - Manufacturer records of warranty repairs.
    - Manufacturer records of recall repairs.
    - CHP Fleet operators database.

Table 2-3 summarizes the data sources for this Task.

Table 2-3. Relevant ARB HDD data sets analyzed.

Title	Format	Total Records	Content
Heavy Duty Vehicle Inspection Program	Access database	5,210	200 fields
Vehicle Warranty Repair Data	Excel file	998	9 fields
CHP Fleet Operators Data	Excel File	27,549	14 fields

The three databases were analyzed with different, but related objectives.

Heavy-Duty Vehicle Inspection Program – This data set focuses on seven of the malfunction and tampering elements from the project objectives. The categories covered were Fuel Injection (3,4,5), Other Air Problem (12), Electronics Tampered (16) and EGR (18, 19). The advantage of the data is that they are collected on-road and throughout the state. While not covering all of the 19 malfunction and tampering categories, the data set does provide a source of information in which both malfunctions and tampering are checked in an in-use setting. We suspected that this data set was likely to provide high estimates of the occurrence rates because the goal of the smoke test program is to identify and check high-emitting trucks, not to conduct a random survey of on-road vehicles. The raw estimates from this data set will serve as high range estimates of the overall population percentages.

The database was obtained from the ARB in MS Access format and converted to MS Excel for analysis. The database contains vehicle and site identification information as well as Snap and Idle test results and visual inspection results. The visual inspections were labeled:

P = Pass
N = Not Applicable to vehicle
S = Missing
D = Disconnected
M = Modified

As an initial step, the data were separated into individual years based on inspection date. Within each year of the database, the data were sorted by model year of the vehicles and tabulated.

Table 2.4. Heavy-duty vehicle inspection database years and vehicle counts.

Database Year	1998	1999	2000	2001	2002
Number of Vehicles	890	1346	1361	1042	775

As discussed earlier a disadvantage of this database for our purposes is that the inspectors on-average do not pull in vehicles on a random basis. The goal of their program is to inspect trucks expected to have emissions problems. This artifact in the data can be seen in the generally older model years of the vehicles inspected when compared to the registration data (Figure 2-1). The 1998 data were used for comparison because CE-CERT has a copy of the California DMV registration database.

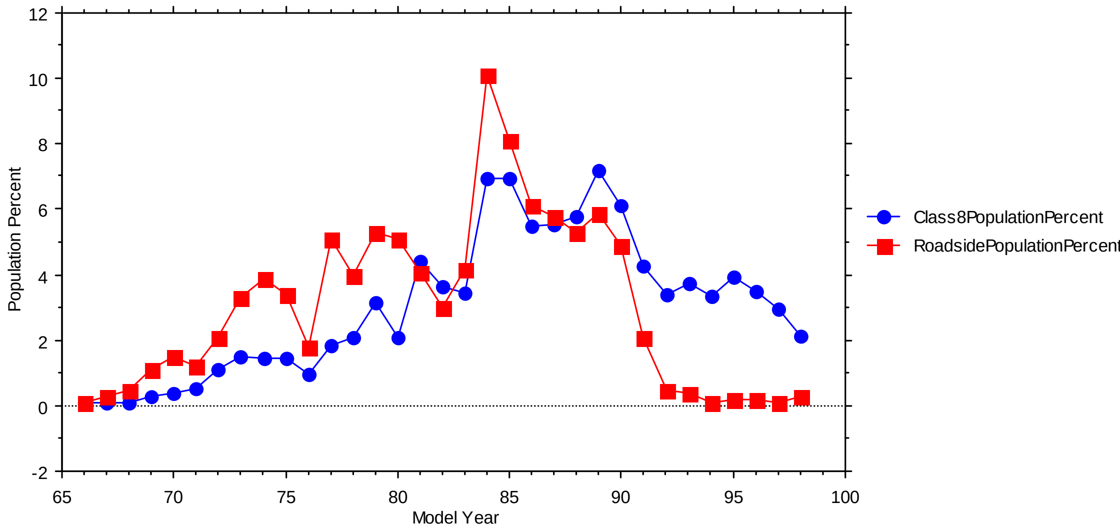

Figure 2-1. DMV class 8 population percent and roadside pullover population percent by model year.

In our analysis, the inspection information was categorized according to ARB inspector groups, and then by the appropriate tampering/malfunction categories. Many of the items checked in the roadside pullovers do not match up with heavy-duty vehicle malfunctions and tampering categories. In addition, many of the malfunction and tampering categories are not covered in the roadside inspections. The relevant roadside observations are listed in Table 2-5, with their corresponding malfunction/tampering categories.

Table 2.5 Heavy-duty vehicle inspection categories and corresponding EMFAC group.

HDVIP Data Label	EMFAC Tampering/Malfunction Group
EGR	18. EGR Stuck Open or 19. EGR Disabled
CMPTR	16. Electronics Tampered
FUELINJ	3. 4. or 5. Fuel Injector Problems
AAIR	12. Other Air Problem

Vehicle Warranty Repair Data – These data were to be collected as part of Task I-4 from the individual manufacturers during the warranty period or first 290,000 miles. However, it was found that the data already were being collected from the manufacturers by the ARB in accordance with sections within the California Code of Regulations on Procedures for Reporting Failures of Emission-Related Components. Under Section 2144 Emission Warranty Information Report, manufacturers are required to file a emission warranty report for each quarter when the number of unscreened warranty claims for a specific emissions-related component or repair represent at least 1% or twenty five (whichever is greater) of the vehicles or engines of a California-certified engine family. Accordingly, the data at ARB were put into a common database. The advantage of having the data "in-house" at the ARB is that it is in a single, standard format. The warranty data only apply to the vehicles and parts for the useful life of the first 290,000 miles while they are under warranty, and manufacturers are not required to report data until the individual parts reaches the specified threshold. As such, these data covers only the beginning of a truck's life cycle, and does not provide data during the later part of the vehicle life in which the malfunctions presumably are more likely to occur. The raw estimates from this data set will serve as low range estimates of the overall population percentages. The warranty data provided b the ARB covered calendar years 1993 to 1999 by year, and consisted of 998 records with more records in the later years.

For the analysis, the warranty data were coded to match the malfunction and tampering categories used in EMFAC. Assistance in translating the listed repairs into EMFAC categories was provided by a heavy-duty diesel mechanic recruited from a local independent facility.

Table 2-6. Example warranty repair records with corresponding malfunction/tampering group.

MFR	FAMILY	MODEL YEAR	PART DESCRIPTION	RECEIVED	POPUL ATION	CLAIMS	%	Engine size	Mal./Tamp. Group
A	PBfam1	1993	FUEL PUMP ASSEMBLY	1/5/2002	98	27	27.55	6.2L	8
A	PBfam1	1993	CONTROLLER,GLOW PLUG	4/17/2000	59	6	10.17	6.2L	13
A	PBfam1	1993	GLOW PLUGS	4/17/2000	59	2	3.39	6.2L	13
A	PBfam1	1993	FUEL INJECTION HIGH PRESSURE LINE	4/17/2000	59	1	1.69	6.2L	4
A	PBfam1	1993	EXHAUST MANIFOLD - REPLACE L	4/17/2000	59	6	10.17	6.2L	13
A	PBfam1	1993	FUEL TANK - REPLACE - MAIN TANK	4/17/2000	59	9	15.25	6.2L	8
A	PBfam1	1993	CRANKCASE DEPRESSURE REGULATOR	4/17/2000	59	4	6.78	6.2L	NA
A	PBfam1	1993	EXHAUST MANIFOLD, LH	4/17/2000	59	4	6.78	6.2L	13
A	PBfam1	1993	EXHAUST MANIFOLD, RH	4/17/2000	59	2	3.39	6.2L	13
A	PBfam1	1993	GLOW PLUG CONTROLLER MODULE	4/17/2000	59	1	1.69	6.2L	13
A	PBfam1	1993	NOZZLE,FUEL INJECTOR	4/17/2000	59	2	3.39	6.2L	3
A	PBfam1	1993	FUEL INJECTION NOZZLE/SEAL- CLEAN	4/17/2000	59	1	1.69	6.2L	3
A	PBfam1	1993	CROSS OVER EXHAUST PIPE - RE	4/17/2000	59	3	5.08	6.2L	NA
A	PBfam1	1993	GLOW PLUG, {DIESEL} LH BANK	4/17/2000	59	3	5.08	6.2L	13
A	PBfam1	1993	GLOW PLUG, {DIESEL} RH BANK	4/17/2000	59	1	1.69	6.2L	13

Vehicle Recall Repair Data These data were to be collected as part of Task I-4 from the individual manufacturers during the warranty period or first 290,000 miles. However, as with the warranty data, it was found that these data were already were being collected from the manufacturers by the ARB in accordance with sections within the California Code of Regulations on Procedures for Reporting Failures of Emission-Related Components under Section 2143 on Failure Levels Triggering Recall. Engine families shall be subject to a recall when the number of failures of a specific emission-related component exceeds the failure level. For example, if 2% or 50 (whichever is greater) for 1994 and subsequent model-year vehicles or engines fail. Records at ARB, indicated that no recalls had occurred.

CHP Fleet Operators Data – This data set contains a listing of all fleet operators in California and is confidential. The data are not useful for estimation of population rates of the 19 malfunction and tampering categories. However, the data set does provide the data necessary for development of a statistically valid stratified random sample of the fleet operators in California.

The fleet operators data set was reduced to unique ownership, with one record per company. Many of the fleet operations had multiple addresses and were reduced to a single record with the home office address as determined by number of vehicles.

2.2.1 Results

Heavy-Duty Vehicle Inspection Program

Population estimates of the yearly incidence for the relevant categories are presented in Table 2-7. Note that the percentage of modified and disconnected components is very small (<1%) for these mainly older vehicles.

Table 2-7. Roadside inspection summary yearly incidence data (1998-2002).

Roadside Inspection	EMFAC Group	Observation	Percent
EGR	19	Pass	5.3%
	EGR	Not Applicable	91.5%
		Modified	0.4%
		Disconnected	1.4%
		Missing	1.3%
ACI	12	Pass	45.1%
Air Control Indicator	Other Air	Not Applicable	54.4%
		Modified	0.2%
		Disconnected	0.0%
		Missing	0.3%
CMPTR	15 or 16	Pass	5.4%
Computer	Electronics Failed	Not Applicable	93.9%
	Electronics Tampered	Modified	0.1%
		Disconnected	0.1%
		Missing	0.5%
PCV	12	Pass	97.0%
	Other Air	Not Applicable	0.0%
		Modified	0.7%
		Disconnected	1.1%
		Missing	1.1%
TAC	12	Pass	93.4%
Thermostatic Air Cleaner	Other Air	Not Applicable	0.6%
		Modified	0.3%
		Disconnected	0.9%
		Missing	4.8%
AAIR	12	Pass	93.9%
Auxilary Air	Other Air	Not Applicable	1.0%
		Modified	0.5%
		Disconnected	2.0%
		Missing	2.6%
FUELINJ	3,4,5	Pass	93.1%
	Fuel Injection	Not Applicable	6.4%
		Modified	0.4%
		Disconnected	0.0%
		Missing	0.1%

Vehicle Warranty Repair Data

Warranty data from ARB were compiled, sorted according to the categories in the EMFAC model and compared in Table 2-8 to the earlier EFFE results.

Table 2-8. Warranty repair summary yearly incidence averaged across all database years (1993-1999).

Defect	This study	EFFE
1. Injection Timing Advanced	<1%	3%
2. Injection Timing Retarded	<1%	3%
3. Minor Injector Problem	**1.7%**	**20%**
4. Moderate Injector Problem	**22.95%**	**10%**
5. Severe Injector Problem	<1%	3%
6. Puff Limiter Mis-Set	NA	2%
7. Puff Limiter Disabled	NA	4%
8. Max Fuel High	<1%	3%
9. Clogged Air Filter	<1%	16%
10 Wrong/Worn Turbo*	**59.0%**	**8%**
11 Intercooler Clogged	<1%	5%
12 Other Air Problems	<1%	8%
13 Mech. Failure	1.6%	2%
14 Excess Oil Consumption	<1%	2%
15 Electronics Failed	**64.5%**	**5%**
16 Electronics Tampered	<1%	10%
17 Catalytic Converter Removed	NA	0%
18 EGR Stuck Open	<1%	0%
19 EGR Disabled	<1%	0%
* 8% without 1997		

The results presented in Table 2-8 represent the average yearly incidence percentage for each fault across all years of the database. In some years of the database there were more HDD vehicles exhibiting repairs in a particular category than HDD vehicles registered in California. This artifact may in part be due to multiple visits for individual vehicles as well as potential multiple counts of the same repair because it involved more than one part. It is also possible that the warranty data is accumulated by the manufacturers prior to reporting so that the numbers reported for a particular part may have occurred during the year prior to that reported. The interesting finding is that the failure rate for many components are similar to the EFFE results, even though the results in this work would be viewed as low since during the first 25% of the engine life and the EFFE estimates are over the life of the vehicle, including the high repair segment during the high mileage segment. Of particular concern is the high rate of moderate injector problems as these are expected to be a source of significant excess emissions.

Fleet Operators Data

In California, a fleet is defined as having more than two trucks. There were a total of 17,919 fleet operators in the database with a total of 222,429 registered trucks. The average fleet size was 12.41, with the most common fleet having 2 vehicles. The maximum fleet size was 6,650, with a total of 15 fleet operators having over 1,000 trucks. The fleet operators data was summarized (Table 2-9), and the distribution was graphed (Figure 2-2).

Table 2-9. Fleet operator summary data.

Fleet Size	Number of Operators	Percent of operators	Number of Trucks	Percent of Trucks
2	5551	31.0%	11101	5.0%
3-5	6351	35.4%	23669	10.6%
6-10	2966	16.6%	22218	10.0%
11-50	2503	14.0%	52702	23.7%
51-100	312	1.7%	21875	9.8%
101-1000	221	1.2%	53330	24.0%
> 1000	15	0.1%	37534	16.9%
Total	17919		222429	

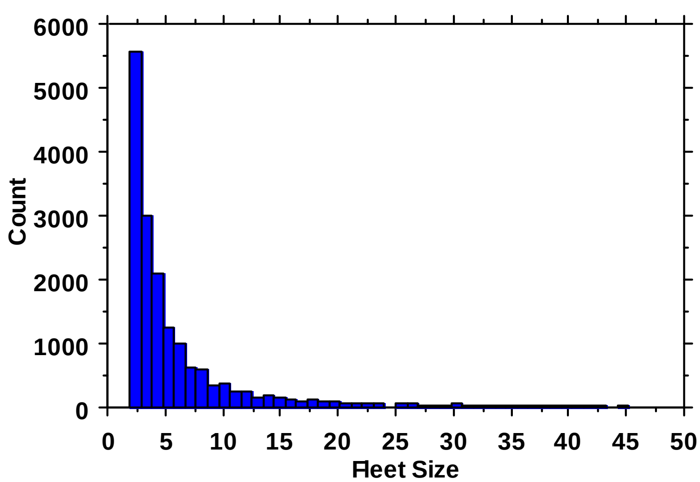

Figure 2-2. Histogram of fleet size distribution.

Stratified Random Sample of Fleet Operators

Sampling of fleet records, either through a general mailing or through site visits, is likely to encounter significant differences in variability and in response rate depending on the size of the fleet. This is likely because of the large differences in the size of the fleets (from 2 to over 6,000 trucks) with differences in record storage media and accuracy. A stratified random sample of the fleet operators, either for a mail survey or for site visits and data collection, would thus be stratified by fleet size. Additional stratification by geographic region may also be required, depending on the uniformity of malfunctions and tampering across the state. The advantage of using a stratified random sample is that it allows for adjustment of sample size by variability as well as allowing for modification of sampling methods as deemed appropriate for the fleets in each group.

2.3 Task I-3: Review of EPA and Other Data Sets

2.3.1 Methodology

When proposed, this task was envisioned as being primarily a data search on EPA web sites until appropriate data were found. After completion of the web search in Task I-1, it was concluded that no obvious relevant data sets were available on-line. For this task, CE-CERT utilized existing contacts within the EPA as well as names identified in the web search for EPA data to locate individuals within the EPA who are responsible for tampering and malfunction data.

2.3.2 Results

Progress on this task was initially slow, with much of the time spent in attempting to locate the right division and personnel within the EPA. During the proof-of-concept phase, CE-CERT has begun to work with the US EPA Certification and Compliance Division, including Bob Montgomery, who is responsible for tampering, and Bob Doyle, a lawyer that works on warranty issues. The Certification and Compliance Division is located in Washington, DC. US EPA staff were contacted by phone, and directly in person by the Principal Investigator while in Washington DC on another project.

Bob Doyle spends time looking for non-compliance with the Not To Exceed (NTE) and the ESC regulations rather than actual in-field tampering investigations. He did provide data on 70 trucks that is being analyzed as part of the questions that exist about the in-use emission rate from trucks in California. During Phase I CE-CERT was also able to talk with Bob Doyle and forwarded him the data in Table 2.8 in hopes that a similar table would be forthcoming from EPA. However, they need to scrub their data to preserve confidentiality and that work has not been completed as of yet. It is important to ntoe that the regulations for the US EPA are different from those in California and are covered in 40 CFR, Part 85: Control of Air Pollution form Mobile Sources, Subpart S (Recall regulation) and Subpart T (Emission Defect Reporting Requirements). Fro example, the manufacturer must file a defect report to the US EPA when a specific emissions-related defect exists in 25 or more vehicles or engines of the same model year.

2.4 Task I-4: Review of OEM Supplier and Engine Manufacturer Recalls

2.4.1 Methodology

HDD warranty and recall data were collected from the ARB as part of Task I-1 rather than from the individual manufacturers.

2.4.2 Results

The results are presented in Task I-2.

2.5 Task I-5: Surveys of Manufacturers' and Rebuilders' Repair Records

2.5.1 Methodology

This goal was based on the recognition that the original equipment manufacturer (OEM) and their decentralized distributor/rebuilder network in the field have detailed records on repair of HDD trucks and engines. Such records enable them to determine the reliability of engines and associated components and the cost of warranty repair.

2.5.2 Results

We approached the Engine Manufacturers Association (EMA) about obtaining records on warranty and other repair from their members. However, the EMA was more interested in learning why we wanted the data and what we were going to do with the data rather than providing the information. Only the initial discussion were held as we decided for Phase 1, it was easier to obtain the warranty data from ARB and EPA. No other results were obtained on this task during Phase I.

We did talk with two major OEM distributors and learned that the OEM must authorize any warranty repair before the work is done and billed to the OEM. The interesting part is that the OEM relies on a download of the information on the ECM chip before it will authorize repair. Some repairs have not been authorized as the information on the chip indicated that the engine was operated outside of the recommended range.

Several distributors raised the issue of the huge reduction in the cost of warranty repair over the past ten years and the impact on their repair business. For one company, the warranty repair ten years ago amounted to over $2,000 per engine per year, but today the reliability is so high that the warranty repair is about 20% of what it was formerly. Another distributor mentioned that their repair business is down so they were creating opportunities for an extended warranty if the owner would bring their trucks in at 600,000 miles instead of waiting until the approximate 800,000 miles that tucks experience before coming in for their in-frame repair. Clearly, the EMFAC factors need to reflect the improved reliability of engine and engine-components.

2.6 Task I-6: Sampling of Fleet Operators' Records

2.6.1 Methodology

A stratified random sample of the fleet operators records, with strata based on region within the state and fleet size, would provide a good unbiased estimate of the incidence rates within the statewide fleet. The sampling could be accomplished either with a large mail survey, or with a more limited set of on-site data collection efforts.

2.6.2 Results

During Phase I, no fleet operators' records were collected. However, the ARB fleet operators database was used to develop stratified random sample plan for implementation in Phase II of this project. In previous research, CE-CERT was able to obtain cooperation from 4 out of 5 waste hauling fleet operators. The fleet operators in that study varied in the level of cooperation provided, ranging from full access to computer records and drivers to removing CE-CERT staff from the property. It is anticipated that the responses of the fleet operators in general will lie within a similar range. As long as non-compliant fleet operators are randomly distributed across the fleet the study results will be valid.

The fleet operator data will provide an overview of the instantaneous tamper and malfunctions on a statewide basis with statistically measured accuracy. With good sample design and sampling methods, these data will provide unbiased estimates of the malfunction rates. These data are not likely to provide estimates of the tampering rates because of the nature of tampering.

For a mail survey it is recommended that a simple one-page survey similar to the driver or repair facility survey be used to maximize responses. If site visits for collection of repair records is to be used a smaller sample would be recommended, with 200 to 400 site visits proportional to truck population (Table 2-10).

Table 2-10. Sample allocation for a mail survey (n=1000) of fleet operators.

1,000 Mailing Sample Fleet Size	Allocated by Truck Population Number of Surveys	Allocated by Fleet Population Number of Surveys
2	59	310
3-5	126	354
6-10	118	166
11-50	281	140
51-100	117	17

contacted by telephone. The responses ranged from uninterested to openly hostile, with a general concern that providing data could lead potential problems without providing any opportunity for additional revenue. The results of the telephone solicitations are summarized in Table 2-11.

Table 2-11. Types of response to repair records data collection by county.

County	Friendly but Uninterested	Time Seen as Unprofitable	Distrustful/Skeptical
Riverside	2	1	2
Orange	1	3	1
San Bernardino	1	2	2
Los Angeles	1	1	0

For most of the repair shops that were not distrustful or skeptical, two phone calls were attempted. An initial phone call during the day gave a brief description of the project, followed by a call towards the end of the day to offer further information and attempt to set up a meeting. No meetings were scheduled, with lack of interest at the present time given as the reason.

Future data collection efforts from repair shops could likely be accomplished with a financial incentive. Since about 70% cited an interest in profits as a reason for not participating, it is likely that a cash incentive would produce a good response rate.

A final attempt was made on this task with a short one-page survey with a small incentive. The survey was expected to take about 5 minutes, with $10 in donut gift coupons to be provided upon completion and return of the survey. To keep the survey as short as possible, repair facilities were asked to provide data on the last month of operation and were told that estimates were sufficient if they did not have exact records available. The primary goal was to obtain cooperation in completing the survey so that the repair shop rates, even if they were less exact than an exact count, would be available for comparison with the other methods.

2.7.2 Results

Out of 6 shops contacted, three agreed to complete the survey. Only one returned the survey after assurances that all answers would remain confidential. The survey form is included in the Appendix. The results of the survey (based on one response) are presented in Table 2-12.

Table 2-12. Repair shop tampering and malfunction incidence rate estimates.

Defect	Number	This study	EFEE
1. Injection Timing Advanced	30	6%	3%
2. Injection Timing Retarded	20	4%	3%
3. Minor Injector Problem	80	16%	20%
4. Moderate Injector Problem	40	8%	10%
5. Severe Injector Problem	20	4%	3%
6. Puff Limiter Mis-Set		0%	4%
7. Puff limiter disabled		0%	
8. Max Fuel High	10	2%	3%
9. Clogged Air Filter	**20**	**4%**	**16%**
10. Wrong/Worn Turbo	10	2%	8%
11. Intercooler Clogged	15	3%	5%
12. Other Air/fuel Problems	10	2%	8%
13. Mech. Failure/	**60**	**12%**	**2%**
14. Excess oil consumption	**70**	**14%**	
15. Electronics Failed	**55**	**11%**	**5%**
16. Electronics Tampered	10	2%	10%
17.Catalytic Converter Removed	5	1%	0%
18. EGR Stuck Open		0%	0%
19. EGR Disabled		0%	0%

These numbers are compiled for an entire month, and represent a mix of vehicles brought in for problems as well as for routine maintenance. Thus, these numbers are likely to be biased high in the tampering and repair categories where the vehicle is likely to be brought in for repair. These would include severe injector problems, mechanical and electronic failure, and excess oil consumption.

2.8 Task I-8: Random Roadside Inspections

2.8.1 Methodology

Random Roadside Inspections

The Phase I roadside inspections were conducted as a proof-of-concept to evaluate their effectiveness in identification of tampering and malfunction rates. The roadside inspection portion of Phase II is provisional; it depends on the results from the Phase I inspections and ARB's approval as shown in Figure 2-3. CE-CERT anticipates roadside inspections of about 125 trucks would be necessary to validate some of the results from the earlier tasks. The most cost effective solution would be run these inspections in conjunction with existing programs on the ARB Enforcement Division and involve a visual inspection for all trucks and an electronic inspection for some smaller sub-set of the 125 trucks. While Phase II of this project has been cancelled, it is recommended that ARB consider conducting these roadside inspections anyway. The roadside inspection provides the most unbiased in-use estimate of the incidence of tampering and malfunction.

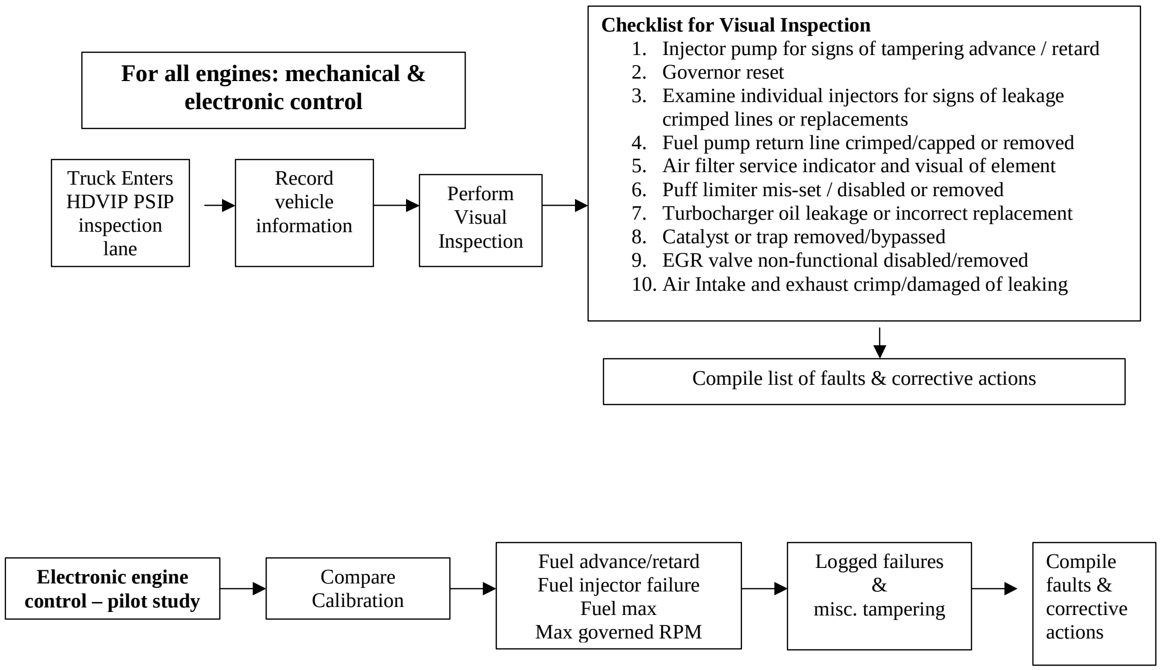

Figure 2-3. Process flow chart for roadside inspection study.

The survey site selected was located in the CHP weigh station on northbound Interstate 15, south of Temecula, CA. The site was staffed by two members of the ARB southern division of the heavy duty diesel periodic smoke inspection program and two CE-CERT employees. The ARB staff members were responsible for directing candidate vehicles into an inspection lane where they were asked to participate in the voluntary survey. Drivers were apprised by the ARB and CE-CERT staff, in English or Spanish, of the nature of the survey, that the survey was entirely voluntary and that no enforcement action would result from their participation. Drivers were informed that the nature of the electronic inquiry and reassured the ET diagnostic scan would not affect any engine parameters or vehicle performance. As an inducement for participation, drivers were informed that a copy of the diagnostic scan would be provided to them at no charge, if they so desired.

Participant drivers were asked to fill out a brief survey detailing their vehicle operation and any recent maintenance or performance problems. Concurrent with this activity, a CE-CERT staff member would connect the ET interface cable to the vehicle’s diagnostic port located below the dash on the driver side of the vehicle. The information download typically required less than 5 minutes to complete. ARB inspectors examined the engine for any visible signs of tampering. This information was recorded on each survey as well as the license and test vehicle number. Upon completion of the survey and scan the vehicle was returned to service, typically within 15 minutes of the initial stop.

Roadside Driver Survey

In addition to the inspection and electronic data downloads planned in the proposal, it was decided to also collect a survey of the drivers. The surveys were added to the roadside plans because of their low cost and ability to obtain data from a different source than the inspections and limited number of electronic downloads. Drivers were not surveyed about tampering incidence because of the lack of confidence in the honesty of the answers and the likely reduction in the number of willing participants.

2.8.2 Results

Roadside Inspection Activity

Prior to working at the Temecula site, two researchers from CE-CERT spent a day working with the full North and South ARB smoke inspection teams near Tulare. The main objectives were to observe how the various smoke teams work, their rationale for which trucks were pulled over, how they did the visual inspections for tampering and how long each of the inspections took. One key observation was the difference in style used by the inspectors. Some inspectors waited for trucks that were smoking while others kept pulling over trucks. Clearly the sample of trucks that was puller over was not representative of what was on the road. We also participated in a demonstration of a suite of analytical instruments that were clipped onto the tailpipe and measured emissions as the truck drove down the road. The owners of the analytical equipment have published their results from the Tulare testing.

Working with ARB's Heavy-Duty Vehicle Inspection staff, CE-CERT conducted a random roadside inspection of 7 vehicles in the Temecula area to determine whether visual inspections can identify target faults and, to the extent possible, to validate the incidence rates or trends identified from other sources. It was determined that identification of malfunctioning and tampered vehicles was difficult without either obvious malfunctions such as leaking fuel injectors or with highly trained staff. This experience matched what we learned from the Tulare experience.

In Phase II this task would be easily accomplished with either the hiring of an outside consultant for the data collection days, or with the assistance of ARB roadside inspection staff. The ARB roadside inspection crewmembers are highly trained and knowledgeable about diesel engines, but were focused on the actual pullovers and assisting the CE-CERT staff in conducting the electronic downloads and driver surveys.

Roadside Driver Survey

A survey was given to a total of 51 heavy-duty diesel truck drivers on September 23, 2002, chosen at random, at the weigh station in Temecula on northbound Interstate 215. The ARB assisted us with pulling over trucks after they came through the scales. Drivers were given free sodas and donuts for their participation in our survey. The voluntary nature of the survey was stressed in the initial contact, with less than 5% of the drivers declining to participate. The model year, make and engine manufacturer were obtained, as well as what malfunctions their trucks had experienced within the last year. A second survey of 7 drivers regarding malfunctions was conducted in conjunction with the field electronic data collection on October 3. In the second survey the drivers were all selected from vehicle having Caterpillar engines. This was done because the primary goal of the second roadside pullover operation was to obtain the electronic data. Because of the theft of a laptop computer, CE-CERT at that time only had the ability to download data from Caterpillar engines. A total of 58 drivers participated in the two roadside surveys.

Drivers were asked whether they had experienced any of the malfunctions on the list within the past year, as well as some vehicle identification information. A space for "Other" malfunctions was included in case they had problems that they were not sure of the correct category. All of the "other" responses in this small dataset were non-emissions related items such as water pumps. Slight modifications were made to the survey form for the second roadside survey to better identify the ownership of the vehicle. This was done to allow for testing of the results for differences between owner/operators and drivers who have no ownership involvement. A copy of each of the survey forms is included in Appendix C. Summarized results are presented in Table 2-13 and shows reasonable agreement with the EMFAC factors. Fuel injector problems are less in the survey.

Table 2-13. Random roadside driver survey incidence rate results (% experiencing the problem in the last 12 months).

Defect	This study	EFEE
1. Injection Timing Advanced		3%
2. Injection Timing Retarded		3%
3. Minor Injector Problem	7.8%	20%
4. Moderate Injector Problem	3.9%	10%
5. Severe Injector Problem	3.9%	3%
6. Puff Limiter Mis-Set	0%	4%
7. Induction problems	2.0%	
8. Max Fuel High		3%
9. Clogged Air Filter	7.8%	16%
10. Wrong/Worn Turbo	3.9%	8%
11. Intercooler Clogged	3.9%	5%
12. Other Air/fuel Problems	7.8%	8%
13. Mech. Failure/	2.0%	2%
14. Valve lash	3.9%	
15. Electronics Failed	0%	5%
16. Electronics Tampered		10%
17.Catalytic Converter Removed		0%
18. EGR Stuck Open		0%
19. EGR Disabled		0%
Throttle delay	2.0%	
Other	9.8%	

Some problems were experienced in coordination of staff for the roadside pullovers. The roadside part of the project required coordination between multiple agencies and multiple groups within the agencies. These problems were addressed with the drafting of a formal field protocol for future roadside work. The draft protocol is included in Appendix D.

2.9 Task I- 9: Pilot Test of an Electronic Scan Tool within the Existing Roadside PSIP

2.9.1 Methodology

The field electronic inspections were designed to sample from a representative cross-section of three major engine manufacturers: Caterpillar, Cummins and Detroit Diesel. At the time of the original field inspections, computer interface compatibility issues prevented the use of both the Cummins and Detroit Diesel software. The Caterpillar Electronic Technician (ET) software was used exclusively for this preliminary work. The ET program permits access to a range of diagnostic and archived engine and vehicle activity data. An example of the comprehensive download is provided for CE-CERT's Caterpillar equipped class 8 truck in Appendix D. The software is intended for fleet operators and repair shops in order to monitor driver activity and customize or limit engine operation to meet specific owner requirements. In the current program only certification information was obtained from the survey candidates.

2.9.2 Results

A large number of variables are available on the engine downloads. The engine setting variables available on the Caterpillar engine downloads are presented in Table 2-14.

Comparison of engine download data with factory setting can provide information on vehicles that have been "re-flashed" to a non-standard personality. In the roadside test of the electronic downloads, 7 vehicles were completed. The results of the roadside downloads regarding tampering are summarized in Table 2-15. All three indicators of tampering with the electronic controls were negative for six vehicles. On one vehicle the system parameters had been changed, but it indicated that it was a factory reflash by a CAT dealer. More experience is necessary to identify the full range of responses, however, it appears that all of the vehicles examined in this project did not have electronic tampering.

Table 2.14. Caterpillar engine variables available on downloads.

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

Table 2.15. Electronic download summary for seven vehicles .

Last Tool To Change System Parameters = 0	ECM ID VIN Matches Vehicle VIN	Personality Module Release Date Matches Truck
7/6	7/7	7/6

In addition to the ECM data, vehicle operational data are also available on the engine downloads. These data cover engine RPM bins by vehicle speed.

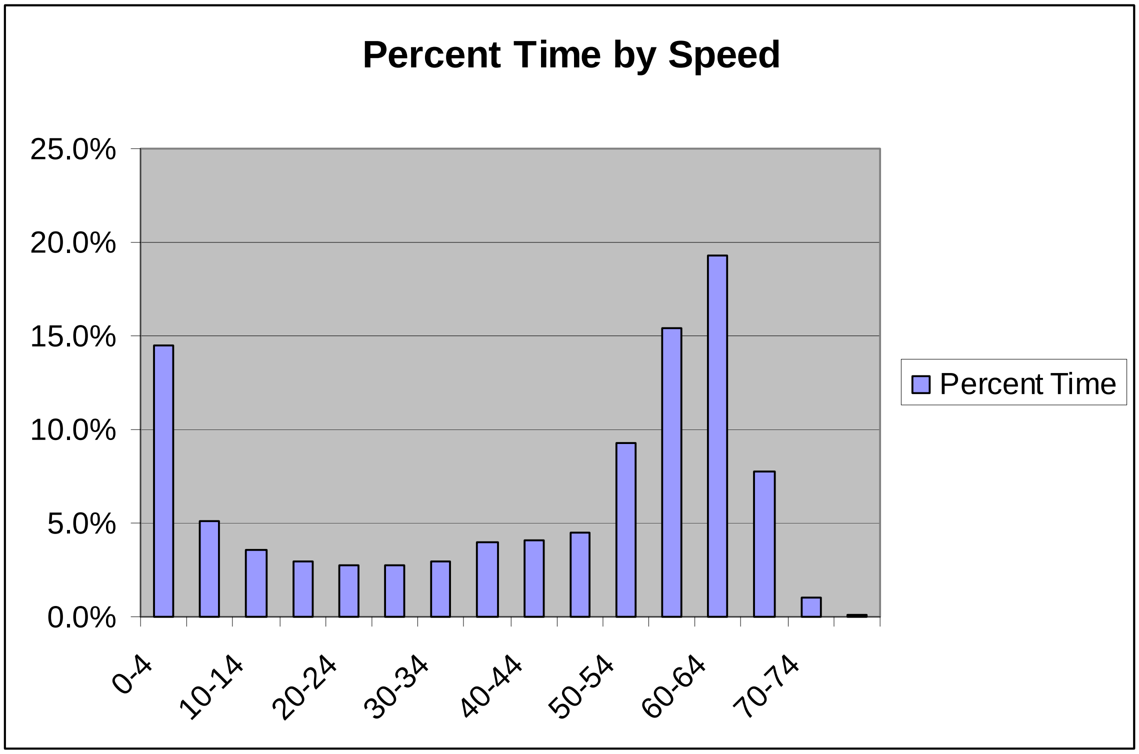

Figure 2-4. Example of percent time by speed for 1999 Caterpillar.

While the speed and RPM data available from the vehicle downloads are not likely to identify malfunctions and tampering, they will be valuable in testing for differences in driving behavior for malfunctioning and tampered vehicles. A dataset that contains both malfunction and tampering information correlated with operational data would be very valuable for emissions inventory work.

2.10 Task I-10: Compilation and Analysis of Results

2.10.1 Methodology

The metric of estimates produced in this project must be, for a given malfunction, the count of all vehicles running with that malfunction (at a given time) expressed as a fraction of all vehicles. We will call a statistic in that metric an "instantaneous rate". However, most of the various direct results in the datasets produced in the previous tasks in Phase 1 produce estimates that can generally be characterized as "yearly" on how many vehicles had a problem during a given calendar year, with no information in the data on the duration of the condition. We will call such a statistic a "yearly rate." Yearly results need to be adjusted to provide estimates of the percent of the on-road fleet that have a given problem at any particular time.

The estimation of the adjustment factors is critical in translating yearly summary data into instantaneous rates for use in EMFAC. With the tampering conditions, it is assumed that (since it they are intentional) they remain in effect until discovered. Since the number of vehicles captured in roadside inspections is relatively low compared to the number of trucks in use in California, it will be assumed that all tampering conditions are in effect for the full 12 months. That is, the adjustment factor is 1.00. The tampering and malfunction categories are listed in Table 2-16 along with three criteria that were used to estimate the time till correction. Estimates were based on engineering judgment, and further research is recommended for refining of these important factors if the yearly data is to be used to improve the EMFAC rates.

Table 2-16. Tampering and malfunction factors affecting rate of detection and repair.

Tamper/Malfunction	Existence apparent to driver?	Effect on driver	Detectable?	Time till discovery
1 Timing Advanced	Possible	Varies	With proper equipment	3 months
2 Timing Retarded	Possible	Varies	With proper equipment	3 months
3 Minor Injector Problem	No	No	With proper equipment	6 months
4 Moderate Injector Problem	Possible	Yes	Yes	3 months
5 Severe Injector Problem	Yes	Yes	Yes	1 Month
6 Puff Limiter Misset	Possible	No	Yes	3 months
7 Puff Limiter Disabled	Possible	No	Yes	6 months
8 Max Fuel High	Possible	Yes	With proper equipment	3 months
9 Clogged Air Filter	Possible	No	Yes	3 months
10 Wrong/Worn Turbo	Possible	Yes	Yes	1 Month
11 Intercooler Clogged	Possible	Yes	Yes	3 months
12 Other Air Problem	Possible	Varies	With proper equipment	3 months
13 Engine Mechanical Failure	Immediate	Large	Yes	1 day
14 Excess Oil Consumption	Possible	No	Yes	3 months
15 Electronics Failed	Immediate	Large	Yes	1 day
16 Electronics Tampered	Possible	Yes	With proper equipment	6 months
17 Catalyst Removed	NA	NA	NA	6 months
18 EGR Stuck Open	No	No	With proper equipment	6 months
19 EGR Disabled	No	No	With proper equipment	6 months

2.10.2 Results

Using the time estimates in Table 2-16, the yearly Warranty database data was adjusted to provide instantaneous results. The adjusted results are presented in Table 2-17.

Table 2-17. Adjusted warranty fleet average tamper and malfunction rates.

Tamper/Malfunction	Fleet Average (Year)	Fleet Average (Instantaneous)
1 Timing Advanced	<1%	<0.1%
2 Timing Retarded	<1%	<0.1%
3 Minor Injector Problem	1.73%	0.87%
4 Moderate Injector Problem	22.95%	5.74%
5 Severe Injector Problem	<1%	<0.1%
6 Puff Limiter Misset	Not Applicable	Not Applicable
7 Puff Limiter Disabled	Not Applicable	Not Applicable
8 Max Fuel High	<1%	<0.1%
9 Clogged Air Filter	Not Applicable	Not Applicable
10 Wrong/Worn Turbo *	59.03%	4.92%
11 Intercooler Clogged	<1%	<0.1%
12 Other Air Problem	<1%	<0.1%
13 Engine Mechanical Failure	1.59%	<0.1%
14 Excess Oil Consumption	<1%	<0.1%
15 Electronics Failed	64.52%	0.18%
16 Electronics Tampered	<1%	<0.1%
17 Catalyst Removed	Not Applicable	Not Applicable
18 EGR Stuck Open	<1%	<0.1%
19 EGR Disabled	Not Applicable	Not Applicable

*(8.01% Without 1997)

3. Summary

Task I-1: Literature Review

The literature review was moderately successful in Phase I, with some general information about repairs and malfunctions, but little new information that was sufficiently specific on incidence in the on-road fleet.

Task I-2: Review of ARB Data Sets

- Roadside Inspection database.
    - Readily available.
    - Large sample.
    - Collected statewide.
    - Instantaneous estimates.
    - Non-random recruitment likely to bias results high.
    - Seven tamper and malfunctions covered.

      .
- Warranty database.
    - Readily available.
    - Large sample.
    - Collected statewide.
    - Yearly fault count data.
    - Restricted to warranty period only.
    - Some questions about data accuracy because of large numbers reported in some years for some malfunctions.
- CHP Fleet operators database.
    - Statewide listing.
    - Comprehensive listing.
    - Lists number of vehicles, no malfunction or tamper information.
    - Names and addresses make it very useful for survey design and implementation.

Task I-3: Review of EPA and Other Data Sets

- Contacts were made with US EPA Certification and Compliance Division.
- Data exchange discussed, completion was expected in Phase II.

Task I-4: Review of OEM Supplier and Engine Manufacturer Recalls

- Not successfully completed in Phase I.

Task I-5: Surveys of Manufacturers' and Rebuilders' Repair Records

- Not successfully completed in Phase I.

Task I-6: Sampling of Fleet Operators' Records

- Stratified random sample designed. On-site or mail survey planned for Phase II.

Task I-7: Sampling of Non-Fleet Repair Facilities' Records

- No success without incentives.

- Small percent very unfavorable.
- Majority of those contacted friendly but unwilling to take time away from business.
- Small incentives produced 1 response from a large independent repair facility.
- Larger incentives likely to bring better response, however the incentives would need to be conducted by a non-state entity.

Task I-8: Random Roadside Inspections

- Scheduled and conducted 2 roadside inspection days.
- 7 vehicles inspected, no faults found.
- 58 driver surveys conducted.
- Sampling protocol developed and presented in Table 2.13.

Task I- 9: Pilot Test of an Electronic Scan Tool within the Existing Roadside PSIP

- Equipment purchased.
- Software installed on computer.
- 7 vehicles successfully sampled on the roadside for the first time.
- Data downloaded and analyzed.

Task I-10: Compilation and Analysis of Results

- Incidence rates estimated for yearly data and instantaneous data.

4. Conclusions

Emissions from vehicles with diesel engines, especially heavy-duty diesel trucks, contribute in a grossly disproportional manner to their number on the road. Compounding the issue is scarcity of data for HDD trucks, either for the base in-use emission rates or for the deterioration rate. While Mobile 6 includes a deterioration rate, EMFAC uses factors for tampering and malfunctioning to address deterioration. This project was about comparing the existing factors for tampering and malfunctioning in the EMFAC model with those arrived at by the use of several new and independent methods.

The basis for the new methods was to follow the life cycle and repair records of a HDD truck. For about 25% or 290,000 miles of its life cycle, the trucks are covered by a warranty, and records are kept at ARB and EPA for specific causes of high emissions. From the analysis of 998 warranty incidents, we learned that most malfunctioning rates were in fair agreement, except that the incidence rates of problems were much higher for fuel injectors, turbos and electronics. Being in fair agreement or higher gives cause for concern as the rates in EMFAC reflect the full life cycle and are expected to be low for the first 25% and increase dramatically for the last 25%. These data suggest that EMFAC may be underestimating the contributions from malfunctions.

Other data sources proved helpful in providing new insight or the remaining 75% of its engine life. For example, the analysis of 5,210 records for trucks that were inspected indicated that tampering was <1%, so tampering is either not visible or is not there to begin with. Based on our observations when working along side the ARB experienced inspectors in the field and as most engines are designed with electronic controls, we do not think that tampering is a major contributor to emissions and, therefore, conclude that dedicating time to enhanced visual inspections would not be fruitful. However, our pilot work of electronic monitoring was the first to be undertaken in the field and the results yielded new insight about what information was available with proprietary download tools and how it could be analyzed, especially the issue of whether a off-cycle NOx chip was installed. Electronic monitoring should be pursued, as knowing if a reflashed chip is installed will become very important as the vehicles are modified to meet the new low-NOx standards.

A random roadside survey of 78 drivers about the problems with their trucks was undertaken with the resulting malfunction rates again in fair agreement with the values in the EMFAC table. The questionnaire for this form of a data collection is very important so that key information is obtained in an unambiguous nature in a short period of time. We suggest obtaining more surveys even thought the data is probably of a lower quality.

Finally a data set of 500 trucks repaired at an independent shop indicated that the failure rates were similar to those values listed in the current EMFAC, suggesting that the current factors are adequate. This survey method was very useful and should be continued as the data are high quality and deal directly with the issue of repair frequency for the vehicle that is past the warranty period and into its period of high repair frequency.

After review of the results of Phase I with ARB staff, it seemed as though the work was validating the results in the current EMFAC and it was not clear that any big surprises would be uncovered. Accordingly, it was decided that Phase II would not be conducted. However, CE-CERT recommends the following activities for future projects for refining the estimates of the tampering and malfunction rates:

- Random sampling of fleet operator repair records, either through on-site inspections of through an anonymous survey.
- Random roadside pullover electronic inspections with careful inspection of the vehicles by experienced mechanics or ARB staff.

These two tasks, if conducted concurrently with assistance from ARB staff or other knowledgeable inspectors for the vehicles will provide an unbiased estimate of the on-road rates of tampering and malfunctions. The data, with the electronic engine downloads, will also provide a linked activity database along with the malfunction and tampering data that will be very valuable for estimation of the statewide inventory.

The results of this project from the repair shop survey were consistent with the current estimates of HDD tampering and malfunction rates.

5. References

ARB, *Technical Support Document for Public Meeting to Consider Proposed Roadside Smoke Test Procedures and Opacity Standards for Heavy-Duty Vehicles*, August 1990

ARB, *Technical Support Document to Public Meeting to Consider Approval of Revisions to the State's On-Road Motor Vehicle Emissions Inventory*, May 2000.

California Code of Regulations, Title 13, Chapter 2. Enforcement of Vehicle Emission Standards and Surveillance Testing, Article 2.4, Procedures for Reporting Failures of Emission-Related Components

On-Road Emissions EMFAC2002 Release
http://www.arb.ca.gov/msei/on-road/emfac2002_output_table.htm

Lloyd, A C. and Cackette, T. A. (2001) *Diesel Engines: Environmental Impact and Control* J. Air & Waste Manage. Assoc. **51**:809-847

Weaver, C.S., and Klausmeier, R.F. (1988) *Heavy-Duty Diesel Vehicle Inspection and Maintenance Study - Volume II - Quantifying the Problem*. Prepared by Radian Corporation for ARB under contract No. A4-151-32.

Weaver, C.S., Balam A., and C.J. Brodrick, *Modeling Deterioration in Heavy Duty Diesel Particulate Emissions*, EFEE, Inc., Final Report to EPA, Contract 8C-S112-NTSX, 1998.

Appendix A

Annotated Bibliography

Literature

ARB (2000) *Technical Support Document to Public Meeting to Consider Approval of Revisions to the State's On-Road Motor Vehicle Emissions Inventory*, May.

ARB documentation from the public meeting to consider approval of the EMFAC model version released in May of 2000.

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Good summary.

Weaver, C.S., and R.F. Klausmeier (1988) *Heavy-Duty Diesel Vehicle Inspection and Maintenance Study - Volume II - Quantifying the Problem*. Prepared by Radian Corporation for ARB under contract No. A4-151-32.

This report, prepared by Radian Corporation for the California Air Resources Board, details the current estimates of the HDD malfunction rates. This report is useful, but possibly out of date at this time because of the advances in electronic control of emissions as well as improvements in combustion chamber design and fuel control.

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Good.

Weaver, C.S., A. Balam, and C.J. Brodrick (1998) *Modeling Deterioration in Heavy Duty Diesel Particulate Emissions*, EFEE, Inc., Final Report to EPA, Contract 8C-S112-NTSX.

This report describes the modeling of deterioration in emission controls of particulates in heavy-duty vehicles. While focused on particulates, this report does provide useful information on the types of malfunctions that lead to increases in particulate emissions.

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Good.

Web Sites

I. Recalls

http://www.thedieselstop.com/faq/1999faq/Trouble-Recall.htm?

Ford-diesel general information, maintenance, trouble spots. This site also lists recalls for Ford diesel vehicles. The majority of the recalls and technical service bulletins are not emission-related. The site was not particularly useful because of the small number of emissions related items, however this site is updated as new recalls occur.

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Not useful.

http://www.nhtsa.dot.gov/cars/problems/recalls/Index.cfm

Office of Defects Investigation, Recall Campaigns Database. This database is searchable by manufacturer and includes heavy-duty truck manufacturers. Search results did include specific information on the problems and the solutions for fixing the problem. However, the search was general and did not allow for emissions-specific searches. Useful for understanding malfunctions but not useful for estimating population rates.

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Not useful.

http://www.consumeraffairs.com

Automobile Recalls – Official Government Database. This database has been offline with no forwarding link. Search engines still find it, but no connection has been made as of 11/16/02.

Utility Malfunction and Tampering general information: Not useful.
Malfunction and Tampering rates: Not useful.

http://www.epa.gov/otaq/cert/recall/

Index of emission related recalls from 1991 to 1999. From the EPA Office of Air and Radiation, Office of Transportation and Air Quality. This site contains information on light-duty as well as heavy duty vehicles with brief descriptions of the emissions problem leading to the recall and the applicable models of vehicles. This site contains consent decree information in plain text form.

Utility Malfunction and Tampering general information: Somewhat useful.
Malfunction and Tampering rates: Not useful.

II. Tampering

http://www.epa.gov/otaq/retrofit/retrotamper.htm

Voluntary Diesel Retrofit Program – Application of Memo 1A. VDRP and EPA Tampering concerns. This EPA site provides general background information on the consent decree issues as well as more specific information on the retrofit program and information on replacing and converting existing engines. This site has links to additional information on the retrofit program and the consent decree.

Utility Malfunction and Tampering general information: Somewhat useful for electronic items.
Malfunction and Tampering rates: Not useful.

http://www.arb.ca.gov/newsrel/nr121197.htm

This site is the 1997 ARB news release announcing the diesel truck and bus inspection program. "ARB research has shown that excessive smoke from diesel vehicles generally results from not properly maintaining the engine's fuel system or because of deliberate tampering with the engine." This site gives background information on the emissions inventory in California due to trucks and busses.

Utility Malfunction and Tampering general information: Somewhat useful.
Malfunction and Tampering rates: Not useful.

http://www.greentruck.com/air_emissions/1410.html

This site is sponsored by the American Trucking Association. It has some general truck emissions information as well as driving tips and a warning of the fines that result from tampering. The focus is primarily on smoke emissions and the related malfunctions and tampering. The tampering section lists several common types of tampering that can result in a fine of up to $25,000.

Utility Malfunction and Tampering general information: Somewhat useful.
Malfunction and Tampering rates: Not useful.

http://www.arb.ca.gov/msei/doctabletest/documents/Table_of_Contents.doc

ARB Public Meeting to Consider Approval of Revisions to the State's On-Road Motor Vehicle Emissions Inventory, Technical Support Document.
10.7 Effect of Tampering and Malfunctions on Heavy-Duty Diesel Truck Emissions - Deterioration Rates.

Utility Malfunction and Tampering general information: Somewhat useful.
Malfunction and Tampering rates: Not useful.

http://www.state.me.us/dep/air/mobile/dieseltest.htm

This site is the Maine diesel testing web site and has general information on the Maine roadside snap and idle test program. This site lists possible causes of smoking vehicles as well as discussion of the consequences of engine tampering and several types of tampering. "Common misunderstanding about smoke and power are often the cause of tampering with engine emission controls."

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Not useful.

http://www.epa.gov/OMS/models/mobile5/mob5ug.pdf

This site is a link to an Acrobat version of the Mobile 5 Users guide. (Mobile Source Emission Factor Model). Sec.2.2.1 Tampering Rates (description, options, required information, anti-tampering programs). This site gives a good description of the issues regarding Tampering in the Mobile 5 model, as well as some background information on tampering and malfunctions.

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Not useful.

http://www.epa.gov/OMS/models/ap42/ap42-h0.txt

Text description of the highway mobile source emissions tables that can be found in http://www.epa.gov/OMS/models/ap42. This text file lists the various table numbers including the tampering related sites.

Utility Malfunction and Tampering general information: Good.
Malfunction and Tampering rates: Not useful.

http://www.epa.gov/OMS/models/ap42/h-tables/a42402b1.txt

Tampering Offsets for Total Crankcase Emissions for Low Altitude Heavy Duty Gasoline Powered Vehicles. This site is a small table giving the tampering offsets for several mileage categories.

Utility Malfunction and Tampering general information: Somewhat useful for emissions.
Malfunction and Tampering rates: Not useful.

http://www.epa.gov/otaq/consumer/contacts.pdf

USEPA – Office of Transportation and Air Quality Contacts by Topic. (Includes contact numbers for emissions, tampering issues, etc for heavy-duty highway engines and vehicles)

Utility Malfunction and Tampering general information: Good contact information.
Malfunction and Tampering rates: Not useful.

III. Malfunctions

http://myhome.naver.com/bookitec/diesel%20truck.htm

This site is a private company site for Boo-ki Scientific Company in Korea. The company produces training software for heavy-duty truck electrical systems. This software trains the user in identification of malfunctions and tampering in the electrical systems.

Utility Malfunction and Tampering general information: Possible source of additional information on electronic tampering and malfunctions.
Malfunction and Tampering rates: Not useful.

http://www.epa.gov/OMS/url-fr/fr22de98.pdf

This web site is a pdf document of the Federal Register from December 1998 listing the changes to 40 CFR Part 86. SUMMARY: Today's action finalizes modifications to the federal on-board diagnostics regulations, including: harmonizing the emission levels above which a component or system is considered malfunctioning. These regulations are for light-duty cars and trucks having OBD II systems.

Utility Malfunction and Tampering general information: Good, but not applicable for HDD vehicles.
Malfunction and Tampering rates: Not useful.

IV. Other Diesel Engine Information

http://www.epa.gov/OMSWWW/hd-hwy.htm

This EPA web site contains general information about heavy-duty engines such as trucks and buses, and their emissions. There is also information regarding EPA's diesel programs, regulations, and retrofit/rebuild programs. This site has numerous links and is well documented. There are many emission related links including In-Use Smoke Testing and 2004 diesel emissions rule making.

Utility Malfunction and Tampering general information: Good source of links.
Malfunction and Tampering rates: Not useful.

http://www.arb.ca.gov/newsrel/nr1109298.htm

This site is a pdf file of the ARB News Release - Workshop to replace heavy-duty diesel engines. This gives some details of the ARB program to spend $25 million to replace diesel engines in 1998. The workshop was held in El Monte, California.

Utility Malfunction and Tampering general information: Limited use.
Malfunction and Tampering rates: Not useful.

http://www.pirg.org/reports/enviro/dangerousdiesel/

This web site is run by the U.S. Public Interest Research Group, established in 1983 to help protect consumers from special interests. The report in this link is Dangers of Diesel – A report documenting the health benefits from cleaning up diesel vehicles. This report provides the PIRG perspective on the dangers of diesel emissions.

Utility Malfunction and Tampering general information: Not useful.
Malfunction and Tampering rates: Not useful.

http://www.dieselforum.org/news/april_21_2000.html

This site is intended to provide a forum for the discussion and dissemination of information on diesel engine technology. The Diesel Technology Forum was created by leading companies in the diesel technology, engine, vehicle and fuel systems manufacturing, and petroleum refining to create a new dialogue and encourage the full exchange of information and views on a full range of issues concerning today's diesels and tomorrow's diesel technologies.

Utility Malfunction and Tampering general information: Somewhat useful.
Malfunction and Tampering rates: Not useful.

http://www.truckline.com/infocenter/topics/tech/122299_four.html

This site is produced by the American Trucking Association and has numerous links to information on all aspects of trucking including environmental considerations. Trucking, Technology & The Four R's: Reliability, Risk, Research, and Recording. This site includes a short discussion of manufacturer recalls.

Utility Malfunction and Tampering general information: Somewhat useful.
Malfunction and Tampering rates: Not useful.

Appendix B Letters and Surveys

CE-CERT Letter to Independent Repair Facility

Dear Mr. XXXXXX,

The Bourns College of Engineering-Center for Environmental Research and Technology (CE-CERT) is preparing a list of the frequency of diesel truck malfunctions for the Air Resource Board (ARB). We are researching the different types of malfunctions that are known to occur in diesel engines with the goal of estimating what percentage of the on-road fleet have the malfunctions. For this particular study, we would like to find out what percentages of heavy-duty trucks have had these problems that could contribute to higher emission rates. The types of malfunctions we are looking for are:

1. Timing Advanced
2. Timing Retarded
3. Minor Injector Problem
4. Moderate Injector Problem
5. Severe Injector Problem
6. Puff Limiter Mis-Set
7. Puff Limiter Disabled
8. Max Fuel High
9. Clogged Air Filter
10. Wrong/Worn Turbo
11. Intercooler Clogged
12. Other Air Problem
13. Engine Mech. Failure
14. Excess Oil Consumption
15. Electronics Failed
16. Electronics Tampered
17. Catalyst Removed
18. Trap Removed/Disabled
19. EGR Disabled

Due to the nature of our study, manufacturer names are irrelevant. We are only interested in the data about the engines in general and how often these problems occur, not who made them. We are happy to come down to obtain the information in person, and work around your schedule. Any data you could give us access to, without the manufacturer information would be quite helpful and greatly appreciated. If you have data available that summarizes the number of vehicles checked and the number of vehicles with each of the problems that would be sufficient for our purposes. If this data is not currently summarized we would be glad to do the data entry and provide you with the summary data for use in running your business. We know that this is a potential problem with confidentiality and certainly understand your reluctance in providing assistance on this project. What I would propose is that we come up with a method of entering the data that removes all identification from the records as they are entered so that we only obtain the counts and can then maintain total confidentiality.

Sincerely,

Theodore Younglove
Principal Statistician
CE-CERT
(909)781-5047

ARB Letter to Independent Repair Facility

Dear XXXXX,

CE-CERT of the University of California, Riverside, is working on a contract for the Research Division of the Air Resources Board (ARB). The purpose for CE-CERT's work is to estimate the fractions of heavy-duty trucks on the road that have various faults in the engine that can increase emissions of particulate matter or oxides of nitrogen. In part, the estimates will be based on repair records from companies in your line of business.

CE-CERT is seeking data from you solely for statistical purposes. CE-CERT will not retain, transfer to ARB, or transfer to another party any data that can be traced to its source.

I hope that you can provide the data that CE-CERT is requesting. If you have questions, you may call me at 916-323-5774.

Thank you.

Richard Vincent
Contract Manager
Research Division

Roadside Driver Survey

Heavy-Duty Diesel Malfunction Survey

University of California, Riverside

Participation in this survey is voluntary. All responses will be confidential and survey forms will not be identified for individual vehicles.

Model Year ________

During the past year, which of the following malfunctions have you had on your truck? (Check all that apply).

Fuel Injection Problems Mild_____ Medium _____ Severe _____

Clogged Air Filter _____

Other Induction Problems _____

Engine Failure _____

Electronic Failure _____

Turbocharger Problems _____

Intercooler Problems _____

Valve Lash Clearance _____

Governor Misadjusted _____

Air/Fuel Ratio Control _____

Throttle Delay _____

Other ____

____

Independent Repair Facility Quick Survey

The University of California, Riverside is doing a quick survey in order to find out some general information on heavy-duty truck malfunction and tampering rates. These results are for modeling purposes and all answers are confidential.

During the last month, how many heavy-duty trucks have you examined in your shop? _____________________ examined.

About how many trucks had each of the following problems?

1. Timing Advanced _______________
2. Timing Retarded _______________
3. Minor Injector Problem _______________
4. Moderate Injector Problem _______________
5. Severe Injector Problem _______________
6. Puff Limiter Mis-Set _______________
7. Puff Limiter Disabled _______________
8. Max Fuel High _______________
9. Clogged Air Filter _______________
10. Wrong/Worn Turbo _______________
11. Intercooler Clogged _______________
12. Other Air Problem _______________
13. Engine Mech. Failure _______________
14. Excess Oil Consumption _______________
15. Electronics Failed _______________
16. Electronics Tampered _______________
17. Catalyst Removed _______________
18. Trap Removed/Disabled _______________
19. EGR Disabled _______________

Sincerely,

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Appendix C: Protocol For Field Operations

Protocol for Field Operations

October 28, 2002

The execution of a field study requires a much higher level of communication and coordination among the team members than in more routine office or laboratory work. Since most people spend only a small fraction of their time in the field, it is easy to forget that when a field operation is scheduled, it is necessary to initiate different modes of communication. This protocol is intended to assist those who must schedule and execute a field operation lasting one or more days. It presents general guidelines only, and it does not cover every conceivable situation.

Lead Person. One person should be designated as the lead for the operation. This person will not necessarily be the Project Manager or Principal Investigator. However, it is the responsibility of this person to have a clear and comprehensive understanding of the objectives, logistics, and mechanics of the field operation. It is recommended that the objectives and procedures be documented, such as in a Standard Operating Procedure. It should include goals, tasks, responsibilities, procedures, equipment, sample custody, and any other key elements of the operation. The lead person initiates the operation and defines its team, and is the principal point of contact from its planning through its execution.

Identification and Listing of Key Personnel. The lead person shall identify all key personnel who will participate in the operation. These persons may or may not be present at the field location. A list in electronic format should be developed that identifies each person, their organization and its location, office telephone number, e-mail addresses, cell phone number, responsibility within the operation, and descriptions of any equipment or expendables for which the person is responsible. Backup personnel should also be identified. This list must be sent to all members of the team.

Planning for Schedule. The lead person is responsible for scheduling the operation. Well in advance of the determination of a firm date and time for the operation, the lead person must contact each team member and present a provisional date, time, and location of the field operation. This will provide time to resolve and preclude any scheduling conflicts, and assure that all essential tasks within the operation are properly staffed. In addition, it will help each team member understand the task he or she is to perform in the operation, and how that task interacts with the tasks of the other members.

Final Schedule. After the date, time, and location for the field operation have been fixed, the lead person must then send to each team member an e-mail with this information. This communication must be sent in sufficient advance of the date of the operation. The amount of advanced time needed is determined by envisioning each person's scenario in traveling to the field location. The longest scenario and/or necessary travel reservations determine this amount of advance time, and is usually no more than 48 hours.

The e-mail must contain all personnel information described above, plus the location, date, and time that the field work will begin. This e-mail should also identify a backup lead person, in the event that the lead person becomes unavailable. The success of a field operation may depend on personnel traveling from different locations all arriving at the field location on schedule. In this case it must be verified by the lead person that all personnel traveling to the field location have a cell phone, know the route to the field location, and know how long their particular journey will require.

It is essential that each person on the team confirm receipt and understanding of the "marching order" e-mail. In addition, this e-mail should also indicate that any further communications between the team members and lead person past a defined point in time must occur by cell phone only. This may be the point in time that the first team member who will be on travel status to the field location, and thus will no longer have access to e-mail communications before the rendezvous. After this point in time, all personnel must keep their fully charged cell phones turned on and within easy access.

Communications. If any team member encounters a problem that will affect arriving fully prepared and on time at the field location, it is that member's responsibility to promptly contact the lead person and fully explain the situation. It is the sole responsibility of the lead person to assess the situation and take the appropriate corrective actions as necessary, including contacting the other team members. All communication within the team regarding such matters must be in parallel and not in series, unless more than one team member is at the same location, and all such communication must include the lead person.

Appendix D Example Engine Computer Download

Drivers were promised confidentiality in exchange for allowing the electronic download of the ECU data. Some of the data is vehicle specific and for that reason the complete download provided here is from CE-CERT's 1999 C-15 equipped Caterpillar Tractor.

Cat Electronic Technician Cat ET2002A
Configuration

10/3/2002 3:56 PM

C-15 Truck (6NZ21712)

Parameter	Value
Vehicle ID	1FUJAHAV61PH09465
Engine Serial Number	6NZ21712
ECM Serial Number	12800042KA
Personality Module Part Number	1779200-00
Personality Module Release Date	nov99
Personality Module Code	6
ECM Date/Time	10/3/2002 5:58:40 PM

Description	Value	Unit	TT
Selected Engine Rating			
Rating Number	2		1
Rating Type	Standard		
Multi-Torque Ratio	Unavailable		
Advertised Power	475 HP		
Governed Speed	2100 RPM		
Rated Peak Torque	1650 lb-ft @ 1200 RPM		
Top Engine Speed Range	2120 - 2120 RPM		
Test Spec	0K1088-00		
Test Spec with BrakeSaver			
ECM Identification Parameters			
Vehicle ID	1FUJAHAV61PH0946		1
Engine Serial Number	6NZ21712		
ECM Serial Number	12800042KA		
Personality Module Part Number	1779200-00		
Personality Module Release Date	nov99		
Security Access Parameters			
Total Tattletale	48		
Last Tool to change Customer Parameters	ET059700		
Last Tool to change System Parameters	0		
ECM Wireless Communications Enable	No		0
Vehicle Speed Parameters			
Vehicle Speed Calibration	29840	PPM	1
Vehicle Speed Limit	127	MPH	0
VSL Protection	2120	RPM	0
Tachometer Calibration	12	PPR	1
Soft Vehicle Speed Limit	No		1
Low Speed Range Axle Ratio	Unavailable		
High Speed Range Axle Ratio	Unavailable		
Cruise Control Parameters			
Low Cruise Control Speed Set Limit	20	MPH	2
High Cruise Control Speed Set Limit	90	MPH	2
Engine Retarder Mode	Coast		1
Engine Retarder Minimum VSL Type	Hard Limit		0
Engine Retarder Minimum Vehicle Speed	0	MPH	1
Auto Retarder in Cruise (0 = Off)	0	MPH	1
Auto Retarder in Cruise Increment	0	MPH	1
Cruise/Idle/PTO Switch Configuration	Set/Accel-Res/Decel		1
SoftCruise Control	Yes		1
Idle Parameters (Old PTO)			
Idle Vehicle Speed Limit	1	MPH	1
Idle RPM Limit	2120	RPM	1
Idle/PTO RPM Ramp Rate	50	RPM/s	1
Idle/PTO Bump RPM	20	RPM	1
Dedicated PTO Parameters			
PTO Configuration	Off		1
PTO Top Engine Limit	Unavailabl	RPM	
PTO Engine RPM Set Speed (0 = Off)	Unavailabl	RPM	
PTO Engine RPM Set Speed A	Unavailabl	RPM	
PTO Engine RPM Set Speed B	Unavailabl	RPM	
PTO to Set Speed	Unavailable		
PTO Cab Controls RPM Limit	Unavailable		
PTO Kickout Vehicle Speed Limit	Unavailabl	MPH	
Torque Limit	Unavailabl	lb-ft	
PTO Shutdown Time (0 = Off)	Unavailabl	min	
PTO Shutdown Timer Maximum RPM	Unavailabl	RPM	

PTO Activates Cooling Fan	Unavailable		
Engine/Gear Parameters			
Lower Gears Engine RPM Limit	2120	RPM	0
Lower Gears Turn Off Speed	3	MPH	0
Intermediate Gears Engine RPM Limit	2120	RPM	0
Intermediate Gears Turn Off Speed	5	MPH	0
Gear Down Protection RPM Limit	2120	RPM	0
Gear Down Protection Turn On Speed	127	MPH	0
Top Engine Limit	2120	RPM	0
Top Engine Limit with Droop	No		0
Low Idle Engine RPM	700	RPM	1
Transmission Style	Manual Option 1		1
Eaton Top 2 Override with Cruise Switch	Unavailable		
Top Gear Ratio	0.73		1
Top Gear Minus One Ratio	0.86		1
Top Gear Minus Two Ratio	0		0
Timer Parameters			
Idle Shutdown Time (0 = Off)	0	min	0
Idle Shutdown Timer Maximum RPM	2120	RPM	0
Allow Idle Shutdown Override	Yes		1
Minimum Idle Shutdown Outside Temp	Not Installe	Deg F	
Maximum Idle Shutdown Outside Temp	Not Installe	Deg F	
A/C Switch Fan On-Time (0 = Off)	180	Sec	1

Powertrain Data Link	J1922	1
System Parameters		
Personality Module Code	6	0
FLS	-12	0
FTS	17	0

Cat Electronic Technician Cat ET2002A
Total Time vs Engine Speed And Vehicle Speed (hours)

10/3/2002 3:57 PM

C-15 Truck (6NZ21712)

Parameter	Value
Vehicle ID	1FUJAHAV61PH09465
Engine Serial Number	6NZ21712
ECM Serial Number	12800042KA
Personality Module Part Number	1779200-00
Personality Module Release Date	nov99
Personality Module Code	6
ECM Date/Time	10/3/2002 5:59:15 PM

Total Time vs Engine Speed And Vehicle Speed (hours)

RPM	0-599	600-699	700-799	800-899	900-999
MPH					
0-4	1.2	6	8.9	2.05	1.5
5-9	0	1.35	1.95	0.7	0.9
10-14	0	0.85	1.1	0.25	0.3
15-19	0	0.55	0.7	0.2	0.2
20-24	0	0.35	0.55	0.2	0.05
25-29	0	0.25	0.45	0.05	0.35
30-34	0	0.1	0.2	0.2	0.1
35-39	0	0.05	0.1	0.05	0.25
40-44	0	0.05	0.05	0	0.05
45-49	0	0.05	0.05	0	0
50-54	0	0	0	0	0
55-59	0	0	0	0	0
60-64	0	0	0	0	0
65-69	0	0	0	0	0
70-74	0	0	0	0	0
75-79	0	0	0	0	0
Total	1.2	9.6	14.05	3.7	3.7

RPM	1000-1099	1100-1199	1200-1299	1300-1399	1400-1499
MPH					
0-4	1.05	0.7	0.55	0.25	0.05
5-9	0.85	1	1.05	1.05	0.75
10-14	0.55	0.5	0.5	0.65	0.95
15-19	0.2	0.4	0.45	0.6	0.2
20-24	0.3	0.45	0.4	0.1	0.65
25-29	0.45	0.05	0.35	0.8	1.5
30-34	0.1	0.8	0.95	0.05	0.15
35-39	0.3	0.05	0.4	1.95	3.75
40-44	0.25	0.95	0.05	1.7	1.45
45-49	0.1	0.15	2.75	1.85	0.35
50-54	0	0.45	1.1	5.1	10.3
55-59	0	0	2.7	6.45	6.3
60-64	0	0	0	4.45	12.25
65-69	0	0	0	0	2.75
70-74	0	0	0	0	0
75-79	0	0	0	0	0
Total	4.15	5.5	11.25	25	41.4

RPM	1500-1599	1600-1699	1700-1799	1800-1899	1900-1999
MPH					
0-4	0.05	0.05	10.9	0.1	0
5-9	0.65	0.55	0.4	0.3	0.15
10-14	0.55	0.45	0.4	0.3	0.3
15-19	0.5	0.6	0.55	0.65	0.55
20-24	0.85	1	0.65	0.05	0.05
25-29	0.2	0.05	0.2	0.55	0.5
30-34	1.45	1.55	0.85	0	0
35-39	0.1	0.1	0.4	0.9	0.7
40-44	2.75	1.25	0	0	0
45-49	0.4	1.45	2.7	0.5	0
50-54	1.2	0.35	0	1.4	1.45
55-59	16	0.1	1.75	0.4	0
60-64	0.8	21.15	5.4	0.1	0.15
65-69	4.9	0	7.7	2.1	0
70-74	0.3	1.4	0	0.35	0.3
75-79	0	0	0.15	0	0
Total	30.7	30.05	32.05	7.7	4.15

RPM	2000-2099	2100-2199	2200-2299	2300-2399	2400-2499
MPH					
0-4	0	0.05	0	0	0
5-9	0.05	0.15	0	0	0
10-14	0.3	0.25	0	0	0
15-19	0.15	0.3	0.1	0	0
20-24	0.25	0.5	0.05	0	0
25-29	0.45	0.1	0	0	0
30-34	0	0.25	0	0	0
35-39	0.05	0	0	0	0
40-44	0.4	0.4	0	0	0
45-49	0	0	0	0	0
50-54	0.05	0	0	0	0
55-59	0.9	0.85	0	0	0
60-64	0	0	0	0	0
65-69	0.05	0.25	0	0	0
70-74	0	0	0	0	0
75-79	0.15	0.05	0	0	0
Total	2.8	3.15	0.15	0	0

RPM	2500-2599	2600-2699	Total
MPH			
0-4	0	0	33.4
5-9	0	0	11.85
10-14	0	0	8.2
15-19	0	0	6.9
20-24	0	0	6.45
25-29	0	0	6.3
30-34	0	0	6.75
35-39	0	0	9.15
40-44	0	0	9.35
45-49	0	0	10.35
50-54	0	0	21.4
55-59	0	0	35.45
60-64	0	0	44.3
65-69	0	0	17.75
70-74	0	0	2.35
75-79	0	0	0.35
Total	0	0	230.3