CHAPTER 3
REDIRECTION OF THE HDVIP

3.1 LEGISLATIVE BACKGROUND

The HDVIP was in operation for nearly two years, and, during that period, the test procedure utilized was the focus of much controversy. The trucking industry and the California Trucking Association has argued that the HDVIP's snap-acceleration test is unreliable and incorrectly fails clean trucks. The debate on the test has been ongoing since the program's implementation in 1991, and the issue has been litigated several times.

Due to this debate on the correctness of the test procedure, the Society of Automotive Engineers (SAE) formed a task group in 1991 to develop a recommended smoke test procedure for inspecting in-use heavy-duty diesel vehicles. This task group included representatives from the ARB, engine manufacturers, smokemeter manufacturers, the trucking industry and from other interested parties. The procedure developed by this task group was designated as the SAE J1667 test procedure. After an unanticipated multi-year process by the task group, the final SAE J1667 procedure was issued (after almost five years of deliberation) in February 1996 but one of its appendices is still awaiting completion.

During the 1993/1994 legislative session, Assembly Bill 584 was enacted by the California Legislature that specifically required the ARB to adopt the SAE J1667 procedure as soon as it became available. Due to the delay in the completion of the J1667 test procedure, the HDVIP was suspended in October, 1993. Around the same time, the State Legislature enacted Assembly Bill (AB) 584 which required that the test procedure used in the HDVIP produce "consistent and repeatable" results and states that this requirement is satisfied by the adoption of the SAE J1667 procedure. AB584 further required that the program must

be implemented to cause no false failures, or else ensure that false failure be remedied without penalty to the owner.

In order to satisfy the twin objectives of adopting the SAE J1667 procedure and ensuring that any redirected program be consistent with the requirements of AB 584, the ARB conducted two field studies. The first was called the Random Truck Opacity Survey. As the name implies, HDDVs were randomly sampled from the fleet and tested using the new SAE J1667 procedure. The purpose of this survey was to obtain a detailed understanding of the smoky opacity distribution of the California fleet, so that both the extent for the smoke truck problem and the potential failure rate under a redirected HDVIP (using the J1667 procedure) could be quantified. The second study was the Truck Repair Study, where a sample of in-use trucks with relating high smoke opacity could be recruited and have their engine malperformances (if any) diagnosed and corrected through repair. The purpose of the Truck Repair Study was to develop standards for smoke opacity using the J1667 test that conformed to the legislation intent of AB584.

This chapter provides a brief summary of the new SAE J1667 procedure, focusing on the differences between the new procedure and the procedure previously employed by the HDVIP. This chapter also provides an overview of the two studies conducted by the ARB, the results of which are utilized in the following sections of this TSD.

3.2 THE SAE J1667 PROCEDURE

A key element of the inspection procedure for smoke emissions from HDDVs is the method of smoke measurement used. Historically, the SAE J1243 recommended procedure was the basis for the smoke measurement method, and this method was applicable to any specific test cycle employed. During the "snap-acceleration" test, smoke emissions can be emitted as a relatively short duration puff of smoke, and the response time of the instrument used to measure the opacity of the puff has a major effect on the measured value of peak smoke opacity. The most significant difference between the J1667 procedure and the procedure

employed previously by ARB is in the instrument response time specifications.

The SAE J1667 procedure differs in several key respects from the earlier J1243 procedure, specifically because it is the recommended procedure for assessing smoke emissions from in-use vehicles powered by diesel engines. The SAE J1667 is described is detail in Appendix A and incorporates:

- **A specific method for performing the snap acceleration test.**
- **Correction factors for normalizing measured smoke opacity when measurements are made at alternative optical path lengths and non-standard ambient conditions.**
- **Specifications for the smoke-meter, and especially for overall instrument response time.**

The defined snap acceleration test implementation in SAE J1667 is almost identical to the ARB procedure used previously in the HDVIP. Minor modifications include revisions to the time span spent at governed speed and specifications limiting the amount of idle between successive snap acceleration cycles. The SAE J1667 requires that the throttle be held at the fully open position until the time the engine reaches governed speed, plus an additional 1 to 4 seconds. Upon releasing the throttle, the operator must allow the engine to remain at low idle for at least 5 seconds, but not more than 45 seconds, before initiating the next snap acceleration cycle. These particular time requirements were absent in the previous ARB specification. The J1667 procedure also requires at least three rather than two preconditioning cycles required previously by ARB.

Correction factors have been specified for optical path length variations, and for ambient conditions. The optical path length corrections would be applicable to non-standard exhaust stack diameters (defined as 5 inches for engines in the 301 HP to 500 HP range and as 4 inches for engines in the 201 to 300 HP range). Due to the relative rarity of non-standard exhaust sizes and operational difficulties in determining stack diameter, this correction has not been normally employed in the field. The ambient correction factors were derived for snap-acceleration peak smoke measured for a sample of trucks at various altitudes, and uses a reference dry air density of 1.1567 kg/m^3. The J1667 procedure requires that **this correction be included for altitudes greater than 1500 ft above sea level, and for ambient temperatures over 80° F.**

The smokemeter specifications in SAE J1667 allow the use of either partial flow or full flow smokemeters, and smoke measurement in either opacity or density scales. The SAE J1667 procedures suggest the use of a green Light Emitting Diode (LED) for the light source in the smokemeter. J1667 also specifies a reduced zero drift rate of ± 1 percent opacity per hour, half the previous ARB specification. However, the most significant difference is the use of an electrical filter to adjust total instrument response time to 0.500 ± 0.010 seconds. The SAE procedure requires a second order digital Bessel filter, and defines instrument response time as:

$$t = \mathrm{SQRT}\,(t_p^2 + t_e^2 + t_f^2)$$

where: t_p **is the physical response time of the instrument sampling train**

t_e **is the electrical system response time**

t_f **is the filter response time**

In a full flow end-of-line smokemeter such as the one used historically by ARB, t_p **and** t_e **are much smaller than 0.5 seconds so that almost all of the averaging is achieved by the Bessel filter, in such cases. Historically, ARB has used a low pass filter and strip chart recorder to act as averaging devices but the response times for these devices can be different from those recommended in J1667.**

An SAE J1667 sub-committee is examining a correlation procedure for SAE J1667 "compliant" meters, and this sub-committee had conducted a series of tests on several meters in early 1996. The sub-committee's stated purpose is to assess the correlation of smokemeters that ostensibly meet J1667 specifications based on real world testing, and regulatory agencies are required to establish pass/fail criteria for correlation testing. The procedure is to be described in an Appendix to the J1667 document, but is not yet formally complete. Since ARB has already acquired and tested J1667 compliant smokemeters, this appendix will not directly impact any of the results discussed in this TSD.

3.3. THE RANDOM TRUCK OPACITY SURVEY

Between August and November of 1996, the ARB conducted a random roadside smoke testing program for heavy-duty diesel vehicles. This test program, formally known as the Random Truck Opacity Survey (RTOS)[1], included the application of the SAE J1667 snap-acceleration smoke test procedure to randomly-selected heavy-duty diesel vehicles in an effort to develop a profile of heavy-duty diesel vehicle smoke characteristics in for the California fleet. Through this study, SAE J1667 smoke test results were obtained for a usable sample of 1002 vehicles (as described in Chapter 5.4.2, testing results for 190 vehicles were unusable due to incomplete or erroneous data). Table 3-1 presents a breakdown of the sample test location and by model year group. The RTOS provided a detailed characterization of the smoke opacity distribution of HDDVs for all model year groups of interest to this TSD.

All smoke testing performed under the Random Truck Opacity Survey was conducted in strict accordance with SAE J1667 procedures. As specified under the J1667 test procedure, data other than actual smoke test results are needed in order to make a standardized determination of emitted smoke since both smoke production rates and smoke measurements can be dependent on test conditions. Smoke production rates, which are sensitive to combustion air/fuel ratio, can vary with meteorological conditions affecting air density. Even under identical meteorological conditions, smoke measurement, which relies on a determination of the degree of light absorption and scattering, is sensitive to the distance the transmitted light must pass between its source and a detector (this distance is known as the optical path length). Because of this dependency, two engines with identical

[1] Although formally known as the Random Truck Opacity Survey, the test program measured smoke emissions from all types of in-use heavy-duty diesel vehicles operating on California roadways, including buses.

smoke generation rates but different diameter exhaust stacks will generate different opacity readings (using full flow end-of-line smokemeters). The SAE J1667 test

TABLE 3-1 DISTRIBUTION OF RTOS TEST LOCATIONS

Test Location	Model Year Group					Total Tested	Percent Tested
	Pre-1980	1980-83	1984-87	1988-90	1991+		
Northern California Locations							
Antelope	15	8	29	16	30	98	9.8
Cordelia	10	6	19	15	24	74	7.4
Los Banos	0	3	9	2	7	21	2.1
Northern Total	25	17	57	33	61	193	19.3
Southern California Locations							
Cache Creek	0	0	0	0	5	5	0.5
Castaic	5	7	22	26	46	106	10.6
Desert Hills	5	7	12	9	18	51	5.1
Grapevine	0	5	15	7	14	41	4.1
Rainbow	16	17	44	34	70	181	18.1

San Onofre	29	35	96	61	120	341	34.0
Temecula	2	6	5	9	8	30	3.0
Winterhaven	4	7	11	11	21	54	5.4
Southern Total	61	84	205	157	302	809	80.7
All Locations							
Sample Total	86	101	262	190	363	1,002	100.0

procedure includes corrections to address both phenomena and produce standardized smoke measurements. Data required to perform the necessary J1667 smoke measurement corrections include the effective optical path length to correct for different exhaust stack sizes and meteor-ological parameters to correct for differences in ambient air density. For full flow end-of-line type smokemeters, the effective optical path length is generally equivalent to exhaust stack diameter. For partial flow sampling smokemeters, the effective optical path length for smoke measurement is a function of the meter's internal sampling chamber. However, partial flow sampling smokemeters require the user to input the stack diameter for the test vehicle and actual smoke measurements are internally corrected to this input "path length" prior to reporting. As a result, both end-of-line and partial flow smokemeters report smoke measurements based on the stack diameter of the test vehicle. To correct for differences in ambient air density, parameters such as dry and wet bulb temperatures and barometric pressure must be measured at the time of testing.

The Random Truck Opacity Survey included collection of all such required data as well as additional data to classify the subject test vehicle and engine population according to gross vehicle weight rating (GVWR) class and model year. These data were utilized after data cleaning and applying the optical path and ambient corrections, to develop estimates of future failure rates.

3.4 TRUCK REPAIR STUDY

The requirement in AB584 to prevent false failures is based on the concept that an engine in good operating condition and set to manufacturers specifications should meet applicable standards. Since the components of in-use engines are subject to wear and deterioration, deriving a precise definition of an engine in" good" operating condition is difficult. Even if such a definition were available, it would be time consuming and expensive to check if all components in any given engine meet this definition. From an emissions perspective, ARB

has previously utilized the concept of identifying gross polluters in the fleet in an inspection/maintenance program, and subjecting these gross polluters to repair. Hence, ARB's focus is on engines where the emission control system is malperforming, which certainly implies that the engine is not in good operating condition.

In order to set a standard that relates "good operating condition" to the absence of malperformance in engines, two hypotheses were developed to test any selected smoke opacity standard. The hypotheses are:

1) **Any vehicle whose measured smoke emissions on the J1667 test exceeded standard, x, would have one or more malperformances in the engine or emission control system.**

2) **If the malperformance or malperformances are repaired and the engine's adjustable parameters are set to manufacturers' specifications, the measured smoke emissions on the J1667 standard would be below the standard.**

Such a standard, x, could be derived from data on a sample of engines whose measured smoke opacity, on the J1667 test spanned a wide range of opacities. If these engines were subsequently diagnosed for malperformances, and any detected malperformances repaired, the post-repair smoke opacity and pre-repair smoke opacity data serve as the basis for selecting a standard.

The ARB conducted the Truck Repair Study to determine the appropriate standard by procuring and repairing a sample of heavy-duty diesel vehicles spanning a range of smoke opacities. The distribution of post-repair smoke opacity levels as measured on the J1667 procedure is utilized to select a standard that would result in no false failures per the legislative requirement of AB584. In order to determine whether any false failures would result through the imposition of a standard, it is ideal to have a sample with as wide a representation of different engine designs, (characterized by the make, model type and model year designation) as possible. However, the resource and time constraints obviously limited total repair sample size. Initially, ARB had expected to test 100 engines and have these repaired to manufacturer specification; hence, the study was initially termed as the "Hundred Vehicle Study" (HVS). Due to time and resource constraints, 71 engines were recruited and the study was renamed as the Truck Repair Study.

This section describes the established protocol during the conduct of the study for the HVS; deviations from this protocol are detailed in the next chapter.

3.4.1 Sample Design

The sample of trucks to be recruited was stratified by model year groups, where each group of model years are homogenous or approximately homogenous in terms of certification emission standard stringency. Emission standards for heavy-duty diesels in California are shown in Table 3-2. Although the numerical emission standards show variations in the 1980-1987 time frame, it is because of changes to the test procedure between 1984 and 1985; NO_x was the limiting factor in emission stringency, and the emissions standards over the entire period were approximately constant at 6 g/BHP-hr for NO_x as measured on the steady state test. As a result, all engines certified over the 1980-1987 period met standards of approximately equal stringency. Trucks older than model year 1980 were also considered as one group largely because they comprise a small and diminishing share of the total heavy-duty diesel truck population. (A survey indicated that pre-1980 vehicles account for 7 to 9 percent of the total heavy-duty vehicle population). Hence the sample was divided into four model year group categories: pre-1980, 1981-1987, 1988-1990 and 1991-1993. Vehicles newer than model year 1993 could not be recruited for the study partly because of the rarity of finding such new trucks having significant or excessive smoke opacity levels, and partly because many are still under factory warranty, limiting owner interest in participating in this program.

Within each model year stratum, the intent was to represent as wide a range of makes and models as possible. Engines were further stratified into medium-heavy and heavy-heavy-duty types as per certification definitions. In each of these sub-strata, four engine manufacturers account for over 90 percent of all sales. The manufacturers are Cummins, Caterpillar, Detroit Diesel and Mack in the heavy-heavy-duty segment and International

(Navistar), Caterpillar, GM (until 1990) and Ford in the medium-heavy segment. There are a limited number of other makes and models in each segment but resource constraints prevented testing all possible designs. The sample was to be focused on the different models offered by the manufacturers named above.

Table 3-2
CALIFORNIA EXHAUST EMISSION STANDARDS FOR HEAVY-DUTY DIESEL ENGINES
(grams per brake horsepower-hour)

Model Year[1]	Total Hydrocarbons	Non-Methane Hydrocarbons[2]	Carbon Monoxide	Oxides of Nitrogen	Oxides of HC + NO_x[3]	Particulates
1973-74	--	--	40	--	16	--
1975-76	--	--	30	--	10	--
1977-79	--	--	25	--	5	--
	1.0	--	25	7.5	--	--
1980-83	1.0	--	25	--	6.0	--
	--	--	25	--	5.0	--
1984	0.5	--	25	--	4.5	--
1985-87	1.3	--	15.5	5.1	--	--
1988-89	1.3	--	15.5	6.0	--	0.6
1990	1.3	1.2	15.5	6.0	--	0.6
1991-93	1.3	1.2	15.5	5.0	--	0.25[4]
1994-47	1.3	1.2	15.5	5.0	--	0.1
1998-2003	1.3	1.2	15.5	4.0	--	0.1
2004+	--	0.5	15.5	2.0	2.5	0.1/0.05

[1] The steady-state procedure was used through 1984 and the transient procedure has been used since 1985.

[2] Manufacturers may choose to certify to the total HC or the non-methane HC standard.

[3] Manufacturers has the option of certifying to separate HC and NO_x standards or to a combined HC + NO_x standard in 1977-79.

The third dimension to the sample stratification is the range of opacities of the vehicles to be selected for repair. The HDVIP had originally used 55 percent as the standard for pre-1991 vehicles and 40 percent opacity as the standard for 1991 and later vehicles. These standards were relative to the smoke measurement method used earlier. Comparative testing of the same sample of trucks using the previous ARB method and J1667 method revealed that, on average, the J1667 measured opacity values were approximately 4 percent lower for pre-1991 vehicles and 12 to 13 percent lower for 1991+ and later vehicles, relative to the smoke opacity measured using the previous ARB method. It should be noted that these comparisons between the two measurement methods were not used to select standards for the J1667 procedure but simply to indicate an appropriate range for examination. Hence, the region of interest for setting standards was expected to lie in the 40 to 100 percent opacity range for pre-1991 vehicles and 25 to 100 percent opacity range for 1991+ vehicles.

The resultant sampling plan provided a detailed definition of the make/model/model year group/opacity range of the desired sample.

3.4.2 Test Protocol Design

A brief summary of the test protocol is provided here as a guide. The plan was to recruit and repair a sample of 100 heavy-duty diesel vehicles, subject to time and resource constraints of the project. It should be noted that the test protocol had to be relaxed during the study, and the differences between the established and actual protocol are discussed in Chapter 4.

Vehicle Recruitment was to be accomplished by ARB field staff employed at weigh stations and roadside locations. Vehicles potentially exceeding the smoke opacity levels set as minimum criteria (40 percent for pre-1991 vehicles and 25 percent for 1991 + vehicles) were to be tested using the SAE J1667 procedure, by ARB staff based on voluntary driver cooperation. A vehicle owner/operator whose truck had a smoke opacity that exceeded the

minimum criteria was to be provided a flyer offering free repairs if their vehicle met the sampling plan requirements. The vehicle owner/operator was to be provided a toll free number to call the recruiting contractor.

A vehicle meeting the sampling plan requirements was to be directed to an authorized dealership repair facility following a detailed conversation between the owner and the recruiting contractor (in this case, Parsons Engineering-Science) to verify vehicle eligibility.

<u>Vehicle Qualification</u> was to be performed by Engineering-Science and the repair facility. The first phase in the process was to insure that the vehicle engine model, model year and measured smoke opacity met the criteria of the sampling plan, and to obtain information on the engine maintenance history. The second phase of the qualification procedure was to occur at the dealership and included the following steps:

- **A safety check to ensure that the engine did not cause any legal risk.**
- **A tampering and wear check, where mechanics would inspect trucks to identify extensive tampering or very worn engines that are rebuild candidates. Such engines were not accepted for repair.**
- **A pre-repair opacity check that insured that the measured opacity was not significantly different (±5 opacity points) than the measured opacity value at the time of initial recruitment**

A vehicle meeting all three criteria was to be repaired under the study plan, or else the owner was paid a cash incentive for participation if the vehicle was rejected from the repair program.

<u>Vehicle Repairs</u> were conducted at selected authorized dealerships only. These dealership had fully qualified mechanics and also had access to manufacturer technical representatives. Through the auspices of the Engine Manufacturer's Association, all major heavy-duty engine manufacturers participated in this program by providing technical and monetary assistance to the dealers performing repairs. Prior to conducting repairs, the dealership mechanics received a briefing from the contractor and ARB staff on record keeping requirements as well as the <u>sequence</u> of repairs to be conducted. The repair sequence recommended was essentially to have mechanics check out the lowest cost repairs first and progress to higher cost repairs as a possible means to examining incremental cost-

effectiveness of repairs. However, the recommended sequence was not intended to guide the mechanic to perform any repair outside

manufacturer's recommendations or to recommend any setting of timing or other adjustable parameters outside manufacturers specifications. Mechanics could (optionally) perform SAE J1667 smoke opacity tests at interim repair stages, and were required to perform a final post-repair SAE J1667 opacity check. ARB personnel were to validate this final opacity retest by performing a SAE J1667 test prior to vehicle release to the owner.

A cost ceiling of $750 was set for repairs, and if estimated cost requirements were higher, the repair shop was required to obtain special authorization to proceed. On a case-by-case basis, both ARB and EMA were to provide additional funding, if required, to complete repairs; the vehicle owner could also be solicited for funding beyond the additional EMA/ARB contributions. Repair records were required to be as complete as possible. Special cases of expensive repairs were to be examined on an as-required basis for approval. This was necessary to maintain total repair costs incurred under the study cost ceiling.

When the Truck Repair Study was conducted, it became necessary to relax some of the vehicle qualification requirements due to difficulty in obtaining the required sample. These deviations from the study design and the results of the study are discussed in Chapter 4.