APPENDIX A

FLEET MAINTENANCE STUDY

I. Introduction

Air Resources Board (ARB) staff conducted a survey to determine the quality of fleet maintenance in California's solid waste collection vehicle (collection vehicle) industry, and to ascertain whether a difference exists in the level of maintenance between three types of fleets: public, large and small private fleets. These fleets differ in that public fleets operate in a non-competitive collection environment, which staff hypothesized to influence the quality of maintenance. Furthermore, larger private and public fleets purchase new vehicles more frequently than smaller private fleets, which appear to purchase used vehicles and maintain them for a much longer time period. Given these differences in fleet types, staff believed a difference might exist in a fleet owner's ability to maintain the vehicles, and subsequently impact the success of implementation of the proposed diesel PM control measure for California's collection vehicle fleet.

Particulate matter (PM) emissions dictate, in part, the ability of a vehicle to be retrofitted using diesel emission control strategies (DECS), especially a passive diesel particulate filter, since the filter can only accommodate a certain maximum amount of PM. While 1994 and newer vehicles have certified emissions of 0.1 grams per brake horsepower-hour (g/bhp-hr), PM from these vehicles can increase with because of engine deterioration, tampering, or poor maintenance. The effectiveness of other DECS may also be impacted by higher PM emissions.

ARB regulations require smoke opacity to be below certain thresholds (55 percent for 1990 and older model year engines; 40 for 1991 and newer model year engines) using a snap-idle test (ARB 1999). While this test is only designed to find gross polluters, the ability of a company's vehicles to pass this test demonstrates the owner's willingness to maintain his fleet in a manner sufficient to comply with regulations. Therefore, the smoke opacity test is a reasonable indicator of the likelihood of a successful retrofit based on maintenance levels. The results from the smoke opacity test illustrate at a minimum the percentage of vehicles likely not to be successfully retrofit. It is possible a greater percentage of vehicles cannot be successfully retrofit based solely on their PM emissions.

Other measures are believed to be good indicators of ability to maintain collection vehicles using DECS. These are mechanic to fleet size ratio, level of training of mechanics, organization of inspection, maintenance and service (IMS) forms, and cleanliness of the shop. The mechanic to number of collection vehicles ratio approximates the amount of time a mechanic can spend inspecting, maintaining and servicing a vehicle. Additionally, the amount of training a mechanic has had illuminates the extent to which a mechanic can diagnose and resolve problems with components of the collection vehicles. This is critical because the DECS will reduce smoke emissions historically used to diagnose problems with the engine. These problems could lead to a spike in PM emissions and to a failure of the device.

Further, usage of IMS schedules and forms (shop organization) illustrates a shop's interest in maintaining well-functioning vehicles. Finally, cleanliness of the shop in the form of visible leaks from vehicles and on the shop floor, as well as visible exhaust from the collection vehicles verifies the extent to which the collection vehicles are well-maintained. Each of these measures plus smoke opacity results is expected to help determine the overall capability of a fleet to successfully maintain DECS, and are thus calculated and discussed below.

II. Methodology

Approximately fifteen percent of the collection vehicle fleets in California, or sixty fleets, were selected to participate in the study. Twenty of each of the following fleets - publicly owned, large privately owned, defined as more than ten vehicles, and small privately owned, defined as five to ten vehicles per fleet – were selected (Table 1). Based on expected variability by fleet type, the simple random sample was chosen by applying a random number generating table to a stratified alphabetized inventory of collection vehicle fleets in California according to ARB's Diesel Retrofit Implementation and Evaluation Database. The sample was proportional by fleet type.

To maximize the sample size of vehicles and the number of companies surveyed, five vehicles from each fleet were smoke opacity tested. With a few exceptions in the small fleets, which did not have all five vehicles available for testing either due to maintenance or long distance routes, staff achieved this goal.

Table 1. Fleet types

Fleet type	Number of fleets
Public	20
Small private (<11 vehicles)	20
Large private (≥11 vehicles)	20
Total	60

Staff visited the collection vehicle yards and collected data regarding fleet maintenance (Figure 1). Using the smoke opacity meter test, ARB staff[1] tested five collection vehicles from each fleet for their emissions and recorded these results (Figure 2). These vehicles were selected by testing the first five to arrive on the site upon beginning the survey.

[1] One staff person, Charles Ross, conducted all of the smoke tests. Mr. Ross is certified in visible emissions evaluation.

CONTACT INFORMATION	Date:	ARB Init:
1. Fleet Contact Name:		
2. Fleet Business Name:		
3. Fleet California ID #:		
4. Fleet Terminal #:		
5. Fleet Terminal Address:		

FLEET INFORMATION		
6. How frequently are new collection vehicles (front, side, rear loaders or rolloffs) purchased?:		
7. How many are purchased at that frequency?:		
8. No. side loaders:		Comments:
9. No. front loaders:		
10. No. rear loaders:		
11. No. rolloffs:		

MAINTENANCE INFORMATION			
12. No. of mechanics:		13. What is training/ background of each mechanic (if add'l, write below form):	
1.		5.	
2.		6.	
3.		7.	
4.		8.	
14. What is vehicle inspection schedule?			per
15. What is vehicle maintenance schedule?			per
16. What is vehicle service schedule?			
17. Do you have inspection/maintenance forms?		Y - N	(attach blank, if yes)
18. Do you have service forms outlining what is done at each service?		Y - N	(attach blank, if yes)
19. What is checked during inspection?			
20. What is checked during maintenance?			

FLEET INSPECTION		
21. Any visible leaks?	Y - N	# vehicles=
22. Any visible exhaust?	Y - N	# vehicles=

DATA FROM ARB PROGRAMS			
23. Age range of vehicles:	-	24. Forms & records organized & easily accessed?	Y - N
25. Periodic Smoke Inspection Records	Y - N	(attach copies, if yes)	

FUEL DATA		
26. Where do you buy your diesel fuel?		
27. How frequently do you buy your fuel?		per
28. How much do you buy each time?		Gallons

ADDITIONAL INFORMATION	
40. Where are vehicles kept when not in service:	Maintenance facility parking lot – Offsite location:

Figure 1. Fleet Condition Survey Form.

VEHICLE INFORMATION: Vehicle 1		VIN No.:				
License Plate No.:		Vehicle GVWR:		lbs	Smoke Opacity Test Results:	
Vehicle Application:	☐ Side loader ☐ Rear loader ☐ Front loader ☐ Rolloff	Vehicle Model Year:				
		Estimated mpg:		mpg		
Vehicle Manufacturer:		Vehicle Mileage:		miles	1:	
ENGINE: Manufacturer:		Fuel Injection:	Mechanical - Automatic		2:	
Engine Model:		Aspiration:	Natural - Turbocharged		3:	
Engine Model Year:		Transmission:	Standard - Automatic		4:	
Engine Horsepower:	hp	Cycle:	Two - Four		5:	
Engine Displacement:	in^3/liters	Fuel type:	CARB #2 - 15 ppm		6:	
EXHAUST: Location:	Up - Down	Configuration: Single - Dual	Using DPF?	Y - N		
Exhaust Pipe Diameter:	mm - inches	Underbody Clearance:		Inches		

VEHICLE INFORMATION: Vehicle 2		VIN No.:				
License Plate No.:		Vehicle GVWR:		lbs	Smoke Opacity Test Results:	
Vehicle Application:	☐ Side loader ☐ Rear loader ☐ Front loader ☐ Rolloff	Vehicle Model Year:				
		Estimated mpg:		mpg		
Vehicle Manufacturer:		Vehicle Mileage:		miles	1:	
ENGINE: Manufacturer:		Fuel Injection:	Mechanical - Automatic		2:	
Engine Model:		Aspiration:	Natural - Turbocharged		3:	
Engine Model Year:		Transmission:	Standard - Automatic		4:	
Engine Horsepower:	hp	Cycle:	Two - Four		5:	
Engine Displacement:	in^3/liters	Fuel type:	CARB #2 - 15 ppm		6:	
EXHAUST: Location:	Up - Down	Configuration: Single - Dual	Using DPF?	Y - N		
Exhaust Pipe Diameter:	mm - inches	Underbody Clearance:		Inches		

VEHICLE INFORMATION: Vehicle 3		VIN No.:				
License Plate No.:		Vehicle GVWR:		lbs	Smoke Opacity Test Results:	
Vehicle Application:	☐ Side loader ☐ Rear loader ☐ Front loader ☐ Rolloff	Vehicle Model Year:				
		Estimated mpg:		mpg		
Vehicle Manufacturer:		Vehicle Mileage:		miles	1:	
ENGINE: Manufacturer:		Fuel Injection:	Mechanical - Automatic		2:	
Engine Model:		Aspiration:	Natural - Turbocharged		3:	
Engine Model Year:		Transmission:	Standard - Automatic		4:	
Engine Horsepower:	hp	Cycle:	Two - Four		5:	
Engine Displacement:	in^3/liters	Fuel type:	CARB #2 - 15 ppm		6:	
EXHAUST: Location:	Up - Down	Configuration: Single - Dual	Using DPF?	Y - N		
Exhaust Pipe Diameter:	mm - inches	Underbody Clearance:		Inches		

VEHICLE INFORMATION: Vehicle 4		VIN No.:				
License Plate No.:		Vehicle GVWR:		lbs	Smoke Opacity Test Results:	
Vehicle Application:	☐ Side loader ☐ Rear loader ☐ Front loader ☐ Rolloff	Vehicle Model Year:				
		Estimated mpg:		mpg		
Vehicle Manufacturer:		Vehicle Mileage:		miles	1:	
ENGINE: Manufacturer:		Fuel Injection:	Mechanical - Automatic		2:	
Engine Model:		Aspiration:	Natural - Turbocharged		3:	
Engine Model Year:		Transmission:	Standard - Automatic		4:	
Engine Horsepower:	hp	Cycle:	Two - Four		5:	
Engine Displacement:	in^3/liters	Fuel type:	CARB #2 - 15 ppm		6:	
EXHAUST: Location:	Up - Down	Configuration: Single - Dual	Using DPF?	Y - N		
Exhaust Pipe Diameter:	mm - inches	Underbody Clearance:		Inches		

VEHICLE INFORMATION: Vehicle 5		VIN No.:				
License Plate No.:		Vehicle GVWR:		lbs	Smoke Opacity Test Results:	
Vehicle Application:	☐ Side loader ☐ Rear loader ☐ Front loader ☐ Rolloff	Vehicle Model Year:				
		Estimated mpg:		mpg		

Figure 2. Smoke Opacity Results Form.

III. Results and Discussion

As predicted, maintenance quality varied with the type and size of the company, in terms of the number of vehicles. In some private fleets the investigation demonstrated a lack of sufficient maintenance practices. Public fleets appeared to be well-maintained, likely because their vehicles are newer, easier to maintain, and, the lack of competition for contracts. Public fleets typically turn over their vehicle every five to seven years. Large private fleets have a slightly longer turnover timeframe for vehicles of seven to ten years. Small private fleets typically buy used vehicles from both of these fleets and use them for the lifetime of the vehicles. Because private fleets compete for contracts while public fleets do not, private fleets may conduct less complete maintenance to cut costs. Collection vehicles from 1966 are still in-use (ARB 2001) in private fleets.

According to the heavy-duty diesel vehicle industry, lack of maintenance accounts for 50 percent of equipment failures (Dolce 2000). Staff expected this percentage of the fleet would also fail the smoke opacity test, the surrogate used for fleet maintenance. Fortunately, this was not the case for California's collection vehicle fleet. In fact, results were very encouraging, with about 93 percent of the collection vehicles tested passing the smoke opacity test. These and other results from the fleet maintenance study are discussed in-depth in the following sections.

A. Specific Indicators of Fleet Maintenance

Five specific indicators of fleet maintenance were gathered from each fleet. First, five vehicles were smoke opacity tested in each fleet, except for those small private fleets with less than five vehicles available on the day of testing. Second, the number of mechanics per fleet size was calculated. Third, the extent to which the mechanics were trained was determined. Fourth, the organization of shop forms and schedules was captured. Fifth, the shop and fleet cleanliness was observed.

1. Smoke Opacity Testing

Of the 288 vehicles that were smoke opacity tested, 93 percent of the vehicles passed (Figure 3). When calculated by fleet type, government-owned collection vehicles had the greatest success rate (97 percent), followed by large private fleets (94 percent) and then small private fleets (88 percent).

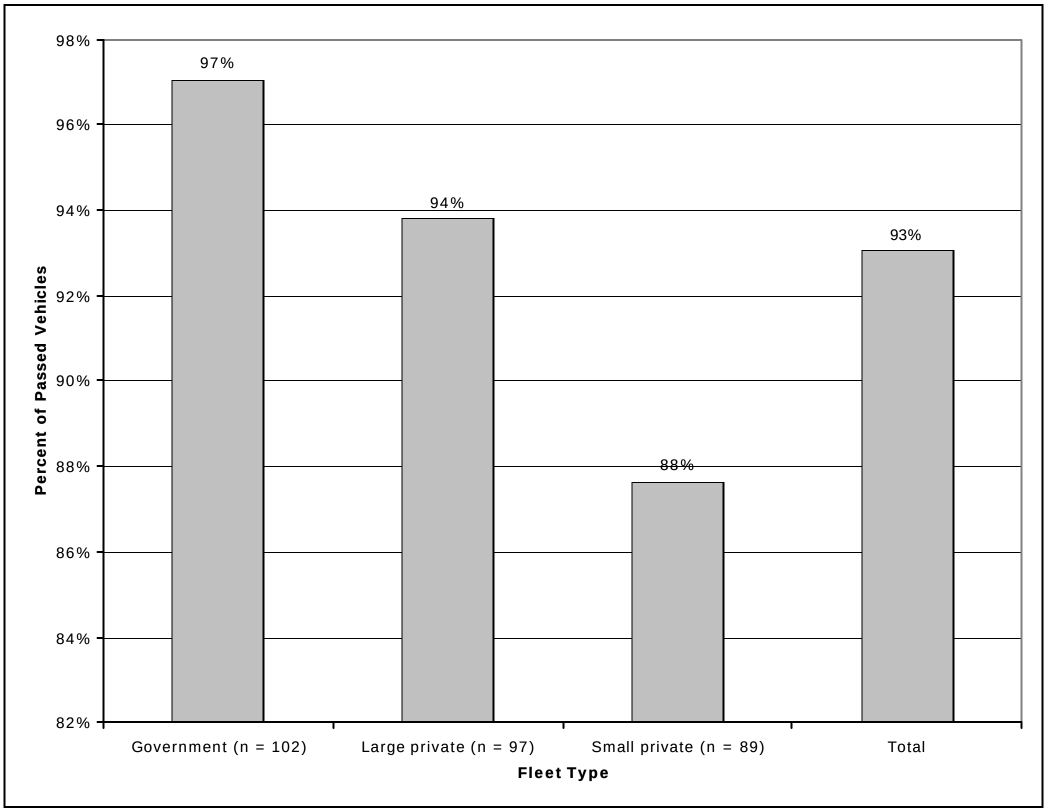

Figure 3. Smoke Opacity Test Results by Fleet Type.

In an effort to determine what segment of the vehicle population contributed most to the success rate, post-1991 and later model year vehicles were compared with pre-1991 and earlier model year vehicles. Regardless of fleet type, 1990 and earlier model year engines met with less success than 1991 and newer model year engines (Figure 4).

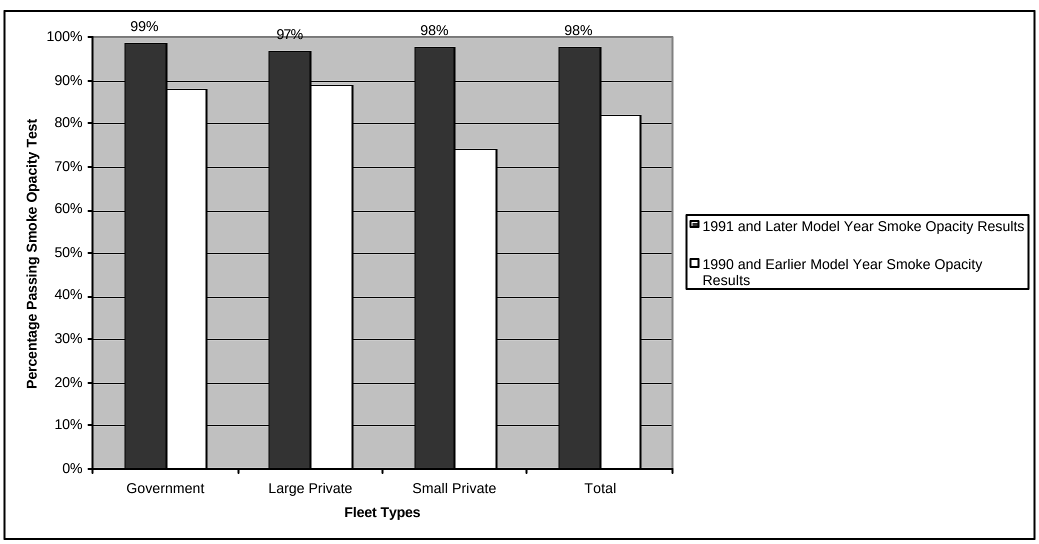

Figure 4. Comparison of 1991 and Later to 1990 and Earlier Model Year Smoke Opacity Results by Collection Vehicle Fleet Type.

In a more in-depth analysis by model year for all of the vehicles tested, average smoke opacity by model year results increased with the age of the vehicle engine (Figure 5). This is as expected with engine deterioration coupled with increasingly stringent diesel PM emissions regulations[2].

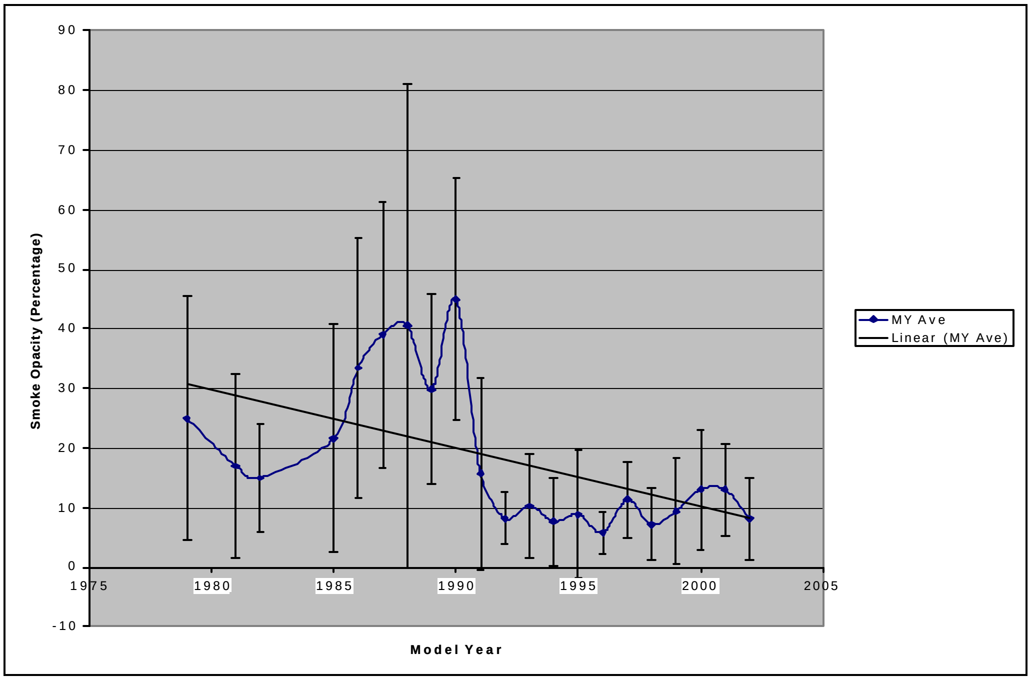

Figure 5. Average Smoke Opacity by Engine Model Year.

2. Number of Mechanics per Fleet Size

One reason for the increase in average collection vehicle smoke opacities from government to private large and then to private small fleet might be because the average number of mechanics to number of collection vehicles decreases accordingly (Figure 6). With fewer mechanics to work on the vehicles, one might predict those vehicles are not as well-maintained. Another potential variable, but which was not captured in this survey, would be number of mechanic-hours per number of vehicles in the fleet. An average work week of 40 hours per week was assumed for the purposes of this study.

[2] Pre-1988 engines were unregulated, 1988 to 1990 engines met 0.6 g/bhp-hr PM emission standard, 1991 to 1993 engines met 0.25 g/bhp-hr PM emission standard, 1994 to 2006 engines met 0.1 g/bhp-hr PM emission standard, 2007 and later engines to meet 0.01 g/bhp-hr PM emission standard.

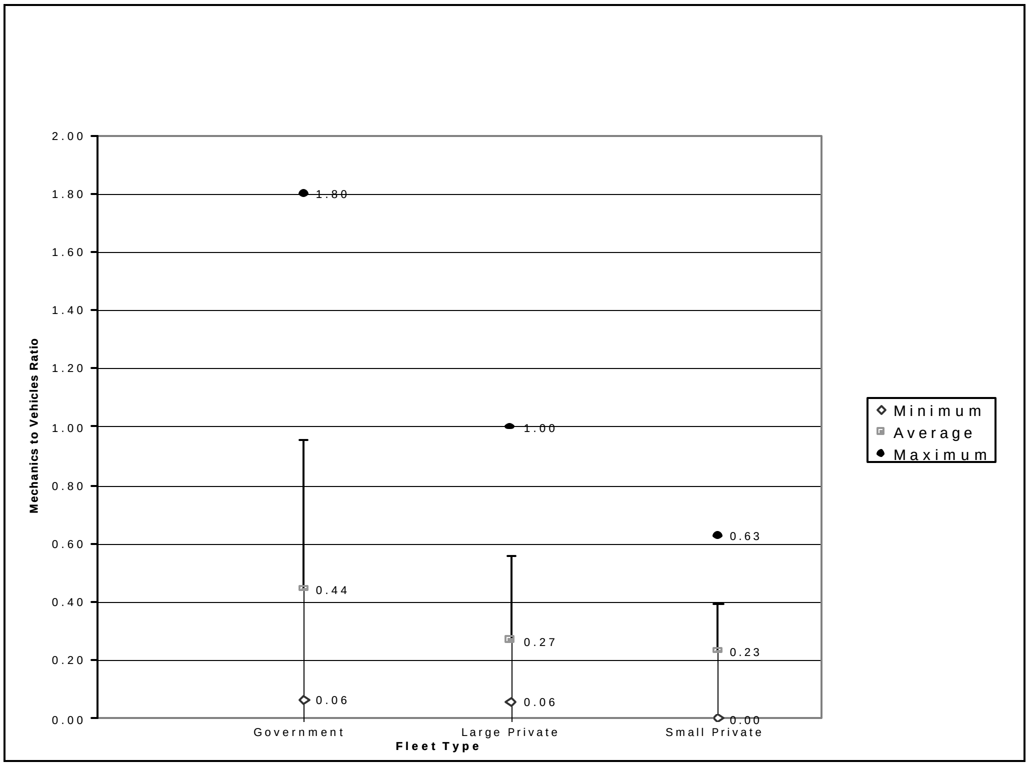

Figure 6. Number of Mechanics to Collection Vehicles Ratio for California's Solid Waste Collection Vehicle Fleets.

3. Training of Mechanics

Fifty-eight out of 60 shops had on-site mechanics, and two fleets (one government and one small private fleet) contract out for maintenance. ARB staff quantitatively ranked the training of the mechanics on a scale of one to four, one being the least amount of training and four being the most amount of training. A rank of (1) meant the mechanics had taken no classes or certification work and were not mechanics for extended periods of time. A rank of (2) was assigned to those who have been mechanics for a long time were considered to be journey level, but were not certified or did not have specific training courses. Mechanics received a rank of (3) if they had training in specific courses, such as hydraulics or alternative-fueled vehicles maintenance, or were ASE certified. Those mechanics with the most training were class A mechanics or had taken extensive coursework were assigned a rank of (4).

The ranking for each company was based on the highest ranked mechanic in the fleet. Staff reasoned that the highest ranked mechanic would be in charge of the others and their training, thus raising the general level of competency for the entire group of mechanics.

This parameter similarly supports the conclusions drawn from the smoke opacity tests. Government fleets have the most training and small private fleets have the least amount of training (Figure 7). The more training the mechanics have had, the better they are able to maintain their fleets. Better training may also correlate to more time and money for training, which smaller fleets often do not have.

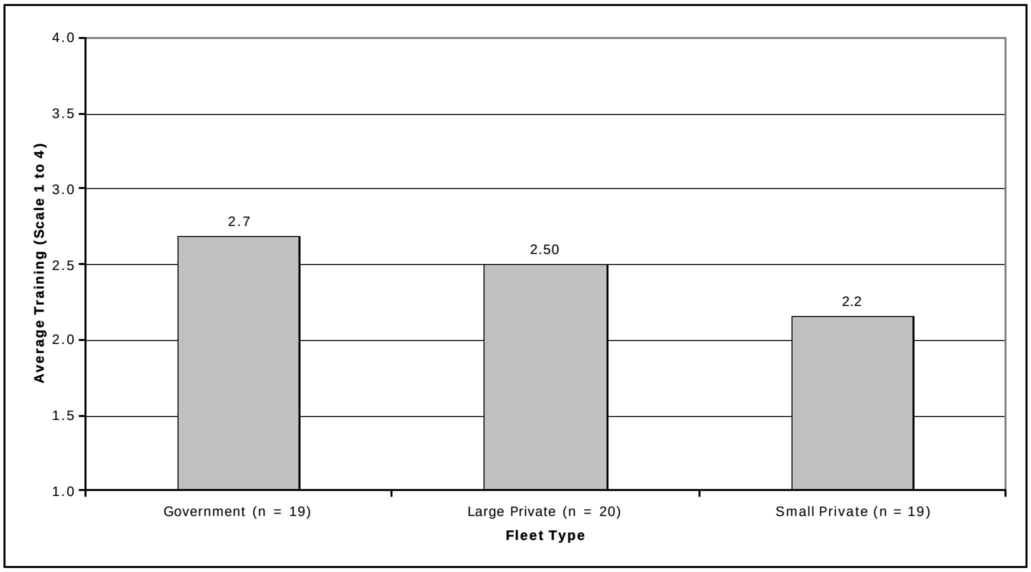

Figure 7. Training of Mechanics in California's Solid Waste Collection Vehicle Fleets.

4. Organization of Shop

In general, the companies were well-organized in terms of having forms and schedules for IMS. For this category, ARB staff quantified shop organization by assigning a “yes” response as a (1), and a “no” response as a (0) to the two questions of whether the owner had (1) forms and (2) schedules for IMS. These ranks were summed and normalized to arrive at average shop organization by fleet type. The government and large privately-owned fleets were slightly more organized than smaller fleets receiving a ranking of 100 percent organization and 82 percent organization, respectively.

5. Cleanliness of Shop and Fleet

The measure of cleanliness also supports the previous results with the government fleets having the fewest visible leaks and exhaust (Figure 8). In order to arrive at the measurements, those fleets with leaking vehicles or spills on the floors received a score of (0). Those with visible exhaust received an additional score of (0). Those without leaks received a score of (1) as well as those without visible exhaust received a score of (1). Therefore, the cleanest fleets received scores of (2) and the dirtiest fleets, scores of (0).

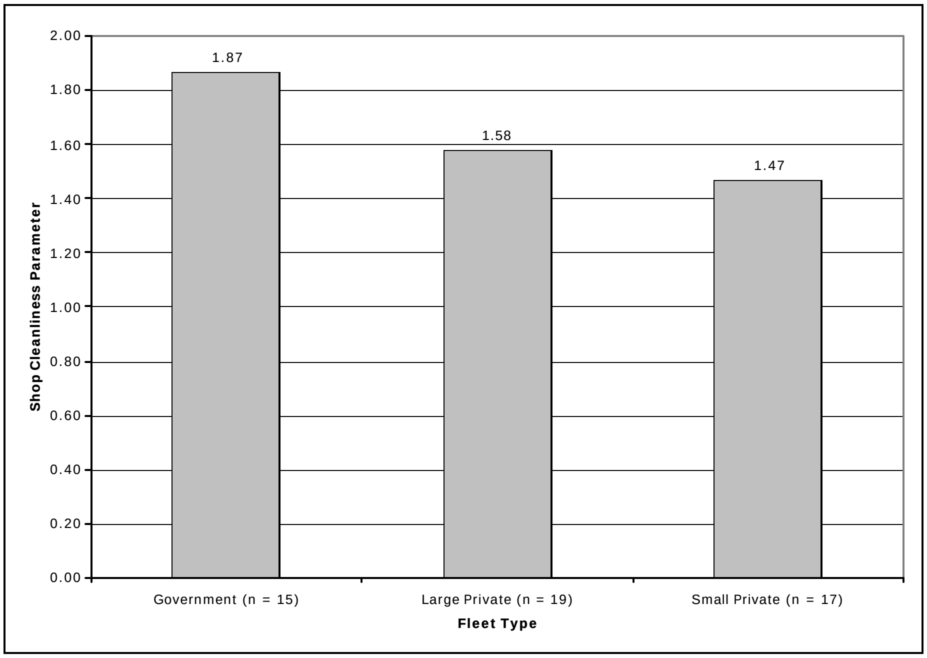

Figure 8. Shop Cleanliness of California's Solid Waste Collection Vehicle Fleets.

B. Issues with Data Collection

A number of issues arose during data collection that may bias the results. These are discussed below.

1. Companies Bought Out

Many of the smaller companies are being purchased by the larger companies. These companies may, therefore, have a better ability to maintain their fleets, because of additional resources brought to them when they are bought. For the purpose of this study, staff categorized them as small companies, however, because staff determined they still tend to function as they did before purchase (i.e., have similar number of vehicles, same mechanics and staff, etc.).

2. Companies Gone Out of Business

Some companies that were on the initial randomly selected list went out of business in the time after the list was created. Therefore, additional companies had to be selected. While this was another random selection, bias may have a occurred as a result.

3. Potential Bias of Non-random Selection by Fleet Owners

ARB staff selected the first five vehicles to enter the maintenance facility to smoke opacity test. Owners of larger fleets may have ordered their collection vehicles as have the dirtiest vehicles enter the facility after the testing was complete and staff had left the premises. This would lead to a potential bias to overestimate the success of the fleets. Staff believes this would be minimal, given that all of the other measurements reveal similar results.

C. Overall Fleet Maintenance Indicator

Assuming all indicators are of equivalent weight, turning each measurement into a percentage and summing the five measurements of fleet maintenance, the rankings remained as they had for each individual measure (Table 2). Public fleets were the best maintained with an overall score of 4.01 out of five. Large private fleets were next with an overall score of 3.63 out of five. Small private fleets were the least well-maintained with a score of 3.21 out of five.

Table 2. Overall Fleet Ranking of Fleet Maintenance

	Measurement (in percentage)					
Fleet Type	Smoke Opacity	Mechanics per Vehicles	Training	Forms	Shop Cleanliness	Overall
Public	0.97	0.44	0.67	1.00	0.93	4.01
Large Private	0.94	0.27	0.63	1.00	0.79	3.63
Small Private	0.88	0.23	0.54	0.82	0.74	3.21

Even if only the two true numerical ranked parameters, the smoke opacity and the mechanics per vehicles, were analyzed, the same conclusion would be arrived at as when the qualitative data were quantified. As such, ARB staff feels this ranking strategy is a valid indication of the overall fleet maintenance by fleet type.

IV. Implications for Solid Waste Collection Vehicle Fleet Retrofit Feasibility

Based on this study, ARB predicts that, on average, the best maintained DECS will be with those companies that have the most well-trained mechanics with the fewest amount of collection vehicles per mechanic. The government fleets will likely have a slightly higher success rate with retrofitting than the large private fleets, followed by the small private fleets. This study, however, is not truly a predictor of future practices, but only an observational study of past or current practices. Companies that invest in new technology may be more likely to concurrently invest in training and improve their maintenance practices to maintain their investments in the DECS technology.

ARB believes DECS manufacturers and dealerships should invest in training the mechanics on proper maintenance of these DECS. Operator training in the appropriate response to warning lights will also be a critical factor not explored in this study, but experienced in the demonstrations (See Technical Support

Document). If the vehicle operators are communicative to the mechanics of any backpressure monitor lights that go on, or issues that may arrive while driving, then the possibility of failure of a DECS should decrease.

Staff expects poor fleet maintenance to only adversely impact the success of certain type of DECS, such as the diesel particulate filter. Other DECS, such as a diesel oxidation catalyst or fuel-based strategy, may be unaffected by maintenance practices. Staff can use the results of this study to focus outreach and education based on fleet type and size, and also the type of DECS the owner plans to implement.

V. References

Air Resources Board (ARB). April 1999. Information Package for the Heavy-Duty Vehicle Inspection Program, Periodic Smoke Inspection Program. Mobile Source Operations Division, Mobile Source Enforcement Branch.

Dolce, J. May 2000. The X’s and O’s of Warranties: How to Create a Winning Warranty Program. Utility & Telephone Fleets.