A Report on the Evaluation and Comparison of Fuel Economy and Vehicle Emissions of High Performance Clean Diesel (HPCD) as Produced by Eco Chem Alternative Fuels

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Final Report
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Background

The City of Dublin, Ohio (Dublin) is interested in validating the claims that a new diesel fuel produced by Eco Chem Alternative Fuels (EAF) meets its claims of improved fuel performance and reduced vehicle emissions. To that end, Dublin contracted with Resource100 LTD, a tenant in the DEC to manage a fuel performance evaluation and perform certain statistical analysis. The following is the final report prepared by Resource100 LTD.

Experimental Design

The goal of this HPCD validation project is to compare various attributes of two diesel fuels, conventional #2 Ultra Low Sulfur Diesel (ULSD) and High Performance Clean Diesel (HPCD) as produced by EAF. The subjects of the two fuels are school busses owned and operated by the City of Dublin School District. The attributes compared were:

- Fuel economy (MPG)
- NO_X emissions (PPM)
- HC emissions (PPM)

The experiment to compare the two fuels could have been designed in two ways. One way would be to recruit 12 busses and operate 6 busses on the ULSD and the other 6 busses on HPCD. Then, after a suitable length of time measure the various attributes of interest for each bus. This would lead to independent samples for which it is expected to find certain variability among the busses --- they all have different baseline fuel economy and emission profile depending on age, maintenance history and other factors. It was observed that a problem arises if this variability is large in that it could completely hide an important difference in the fuel economy and emissions between the two fuels.

The other method, a paired design, attempts to remove some of this variability from the analysis so it is possible to more clearly see any difference in fuel economy and emissions of the fuels studied. In this case we would start with the same 12 busses, but this time each bus was required to test both fuels.

It was then decided to reduce the number of busses in the experiment to 9 for the purposes of the paired analysis and keep the other 3 busses running on the ULSD to the earlier of the conclusion of the experiment or at a point where any season variation in the fuels could be accounted for and corrected. This is described in the section following.

Subject Vehicles

There were 12 busses owned and operated by the Dublin Ohio School District (DOSD) that were utilized in this evaluation project. The same busses were used throughout. The busses were selected to be representative of the DOSD fleet including low mileage, medium mileage and large mileage busses. The busses all were used to transport students in everyday activities of the DOSD.

Data Management

All data was collected utilizing a strict protocol designed and agreed to in a formal Validation Project Plan (VPP) before the evaluation process began. Important features of the data collection include:

1. All busses were fueled on previously determined days of the week; in most cases Monday, Thursday and Friday.

2. By mutual consent, the busses were fueled by a representative of the City of Dublin, Ohio (Dublin) and not the DOSD.

3. All data was recorded on log sheets by Dublin and forwarded by email to Resource100 LTD for input to database and statistical analysis. A sample log sheet is shown in Appendix A.

4. A similar procedure was followed for the emissions testing. On certain pre-arranged days of the week, early in the morning as the busses were first placed into service emissions testing was performed by Dublin utilizing a 5-gas analyzer.

5. Photographs were taken of each fueling showing the bus and odometer reading so that data could be verified. A sample photograph is shown in Appendix B.

6. All data entry was double checked and verified for accuracy.

The Periods of the Experiment

As indicated previously, with the paired design the evaluation started with 9 busses operating on both fuels. EAF disclosed that in their opinion it was likely that busses would show an increase in vehicle emissions of HC and NO_x and reduced fuel economy for a period of time following the introduction of the HPCD. The theory behind this is that the HPCD does a "scrubbing" of engine parts and during that time frame it is possible that many particles will be released through the fuel, combustion and exhaust system thereby actually reducing performance. The length of this Cleansing phase was estimated to be about 3-4 weeks.

Therefore, the project was broken into 3 distinct periods: Baseline, Cleansing and Validation. In addition to allow for the cleansing period, this approach allowed for the determination of seasonal adjustment factors. This is shown in the table on the following page.

Period	Primary Purpose	Calendar	Seasonal Adjustment
Baseline	Baseline performance data	March 8 – April 8	March 8 – April 8
Cleansing	Allow engine cleansing to occur	April 9 – April 29	April 9 – May 10
Validation	Comparative to baseline	April 30 – May 27	Not applicable

As will be explained later in this report, there was a problem when the 5-gas analyzer became damaged and needed to be re-calibrated. As a result, data in the post-calibration near the end of the testing in the validation period was discarded. This “lost” data was replaced by incorporating data from the cleansing period. The experiment still had sufficient data to perform statistical analysis but by including data from the cleansing period there is a recognized bias toward higher emissions (assuming the EAF theory of cleansing is correct).

Data Collected and Calculations

For each and every day that emissions tests were performed and/ or a bus was fueled, data was recorded on a bus-specific log sheet with respect to:

- Date
- Vehicle ID
- Type of fuel pumped
- Gallons of fuel pumped (with a requirement that the tank be topped off)
- Odometer reading

And, where applicable

- NO_x emissions as recorded with a 5-gas analyzer
- HC emissions with the same instrument.

The NO_x and HC were recorded by the test instrument in parts per million (PPM). The busses were taken from a cold start and immediately increased and held engine speed at 1000 RPM. The two tests of interests were then recorded on the log sheet.

Following this test, the busses were then usually taken to the fueling station and the fuel topped off. This data was then recorded on the log sheet.

All of the data was delivered to Resource100 LTD and then entered on a weekly basis into an excel database.

The initial date of the project, March 8, 2011 was used to top off all the bus fuel tanks and record the initial mileage. Thereafter, the miles per gallon statistic (MPG) were calculated by dividing the difference between fuel filling stops by the gallons of fuel pumped.

The descriptive statistics for the raw uncorrected MPG data are shown in Appendix C.

Seasonal Effects and Corrections

There is always a question in an evaluation of fuels if the changed fuel performance or emissions, if any, is due to the fuel itself or due to seasonal or climatic conditions. For example, it is claimed that fuel performance can improve in summer months due in part to better atomization of the fuel and more complete combustion. To account for any such effects, certain busses were used to obtain correction factors for fuel efficiency and vehicle emissions.

The fuel performance validation began at the end of the winter of 2011 and moved through the spring into late spring of 2011. Therefore it was expected to see some improved fuel performance in the last month of the experiment, the Validation period. In order to determine the amount and correct for this seasonal effect, if any, three busses (82, 109 and 127) were operated on solely on ULSD through the BASE (late winter) and CLEANSING (early spring) phases. There is no cleansing that occurs on the ULSD operated busses; but this term is used to identify the period of year that the tests were conducted. The results for fuel performance are shown in the Table 1 below.

BUS	**BASE (MPG)**	**CLEANSING (MPG)**	**DIFFERENCE (MPG)**
82	6.1	5.8	-.3
109	6.2	6.8	+.6
127	7.7	7.9	+.2
Net Difference			+.5
Correction Factor			**+.167**

Table 1 Seasonal Correction for Fuel Economy (MPG)

One bus, 82 had a decrease in fuel efficiency from late winter to early spring; the other two buses had an increase. The net difference was .5 MPG and the average difference was +.167. This average difference is then the Correction Factor which will be applied to all subsequent data for comparison of the effect of the use of HPCD. In other words the first .167 MPG (about 2.5%) improvement in fuel efficiency will be attributed to season effects and not the use of HPCD.

Next to be evaluated was the seasonal affects, if any, that occurred with the testing of HC and NO_X emission. It should be noted that during the testing the equipment became water-damaged and subsequently re-calibrated. The equipment can be used for future evaluations in order to establish baseline conditions for comparative purposes. However, all post-calibration data was discarded from further evaluation due to the distinct possibility from observed data that a shift had occurred between the two datasets (i.e. before and after calibration). The following Table 2 shows the results of HC emissions for the 3 busses during the baseline and cleansing periods.

BUS	**HC BASE (PPM)**	**CLEANSING (PPM)**	**DIFFERENCE (PPM)**
82	4	6	+2
109	3	5	+2
127	5	5	+0
Net Difference			+4
Correction Factor			**+1.3**

Table 2 Seasonal Correction for HC Emissions (PPM)

As predicted the HC emissions increased with warmer weather. A correction factor of 1.3 PPM of HC emissions was applied to each of the mean data points in the Validation period. In this case the 1.3 PPM was subtracted from the data points in order to compare the Validation period results to the Baseline data.

The final seasonal evaluation applied was for the NO_x emissions. The same procedure and treatment of data was applied as to the HC emissions. The results are shown in Table 3 below.

BUS	**NO_X BASE (PPM)**	**NO_X CLEANSING (PPM)**	**DIFFERENCE (PPM)**
82	165	173	+8
109	140	131	-9
127	228	229	+1
Net Difference			+0
Correction Factor			**+0.0**

Table 3 Seasonal Correction for NO_X Emissions (PPM)

In the case of NOx emissions, there is on the average no detectable seasonal adjustment necessary.

Statistical Analysis and Results

Chart 1 shown below is the average MPG for each bus for each period of the project. These are for the 9 busses that changed from operating on ULSD to HPCD. By inspection it can be seen that for every bus the fuel efficiency as measured by MPG using the HPCD was higher than the ULSD. It should be noted that the data in this chart has been corrected for seasonal variation by adding .167 MPG to each data point in the Validation period.

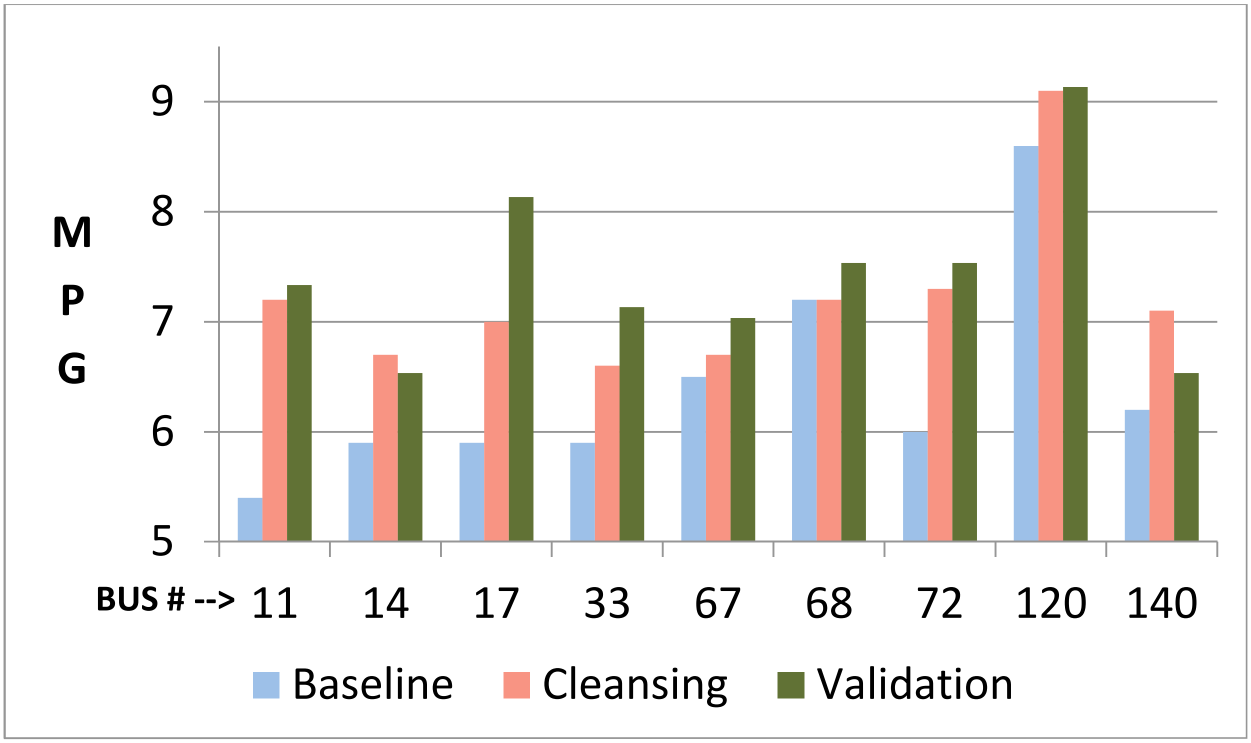

Chart 1 Fuel Economy (MPG) by Bus and Period

The results of the calculated MPG were then subjected to a series of statistical analysis including calculation of descriptive statistics and testing the difference between two means (the ULSD and HPCD) for paired data. The seasonally corrected means of the descriptive statistics were used to create the Table 4 below.

In addition to looking at the original data, a new quantity can be calculated for each bus: the difference between the mean of the two fuels. Both confidence intervals and tests for paired analyses use this difference.

Period →	Baseline	Validation	
Bus No	ULSD (MPG)	Corrected HPCD (MPG)	DIFFERENCE (MPG)
11	5.4	7.33	2.1
14	5.9	6.53	0.63
17	5.9	8.13	2.23
33	5.9	7.13	1.23
67	6.5	7.03	0.53
68	7.2	7.53	0.33
72	6.0	7.53	1.53
120	8.6	9.13	0.53
140	6.2	6.53	0.33
Average	6.4	7.43	1.033

Table 4 Corrected Results of Fuel Economy (MPG)

The mean of the differences is 1.033 MPG. That is, on the average, the HPCD fuel provided an additional 1.0 MPG over the ULSD fuel. To get some idea of the uncertainty in this estimate, we look at the confidence interval which says we are 95% confident that the mean difference in between the two fuels is between 0.6 and 1.8 MPG.

These numbers are a little hard to relate to; so instead, they will be expressed as percentages.

Let K1 = 1.033 / mean (ULSD) = 1.033/6.4 = 16.1%; that is, on the average, the HPCD fuel resulted in over 16% more fuel economy than the ULSD.

Similar calculations were performed on the statistic of HC emissions. The seasonally corrected results are shown in the Table 5 below. It can be seen that the HC emissions were lower after the busses switched from ULSD to the HPCD fuel in all cases but for Bus 33.

Period →	Baseline	Validation	
Bus No	ULSD (PPM)	Corrected HPCD (PPM)	DIFFERENCE (PPM)
11	4.0	3.7	-0.3
14	5.0	4.7	-0.3
17	5.0	4.7	-0.3
33	7.0	7.7	0.7
67	5.0	3.7	-1.3
68	5.0	3.7	-1.3
72	5.0	3.7	-1.3
120	6.0	4.7	-1.3
140	4.0	3.7	-0.3
Average	5.11	4.47	-0.63

Table 5 Corrected Results of HC Emissions (PPM)

The mean of the differences is a negative 0.63 PPM. That is, on the average, the HPCD fuel when combusted produced 0.63 PPM less emissions than the same bus operating on ULSD as a fuel. In order to better understand and relate to the results they will be expressed as percentages.

Let K2 = -0.63/ mean (ULSD) = -0.63/5.11 = 12.3%; that is, <u>on the average, the HPCD fuel resulted in about 12% less HC emissions than while operating on the ULSD.</u>

It should be noted that this dataset included the Cleansing period as well as part of the Validation period, so this estimate may be higher if the EAF claims hold that after the Cleansing period the fuel emissions further reduce. What is not known at this time is how long the Cleansing period actually is. The results of this study and this particular data indicates that engine cleansing begins almost immediately and in turn the beneficial effects of the HPCD fuel in terms of fuel economy and reduced emissions begins quickly as well.

Finally, calculations were performed on the statistic of NO_X emissions. In this case, there was no detected seasonal variation. The results are shown in the Table 6 below. <u>It can be seen that the NO_X emissions were lower after the busses switched from ULSD to the HPCD fuel in all cases.</u>

Period →	**Baseline**	**Validation**	
Bus No	**ULSD (PPM)**	**Corrected HPCD (PPM)**	**DIFFERENCE (PPM)**
11	104	91	-13
14	214	195	-19
17	266	201	-65
33	81	64	-17
67	185	181	-4
68	234	184	-50
72	194	192	-2
120	135	108	-27
140	139	134	-5
Average	172	150	-22

Table 6 Corrected Results of NO_X Emissions (PPM)

The mean of the differences is a negative 22 PPM. That is, on the average, the HPCD fuel when combusted produced 22 PPM less emissions than the same bus operating on ULSD as a fuel. In order to better understand and relate to the results they will be expressed as percentages.

Let K3 = -22/ mean (ULSD) = -22/172 = 12.8%; that is, <u>on the average, the HPCD fuel resulted in about 13% less HC emissions than while operating on the ULSD.</u>

Once again, note that this dataset included the Cleansing period as well as part of the Validation period, so this estimate may be higher. For this reason, it is recommended that to the extent possible, additional spot checks be made of the fuel economy and emissions for the busses as they continue to operate on the HPCD. It will be important to learn where the fuel performance peaks and determine if continued cleansing and further reduced emissions occurs.

Conclusions and Recommendation

- When corrected for seasonal variations of .167 MPG, the HPCD fueled busses showed an average 1.2 - .167 or 1.033 MPG net improvement in fuel economy. On a percentage basis, this equates to 1.033/6.4 or 16.1%. The expected average increase in MPG by using HPCD rather than conventional ULSD is 16.1%. These results are show graphically in Chart 2 below. The bottom section of each bar is the average MPG for each bus operating with ULSD. The top section is the incremental boost in MPG on average by the change to using exclusively HPCD.

  Although individual busses varied, in every case, the HPCD showed an improvement in fuel economy.

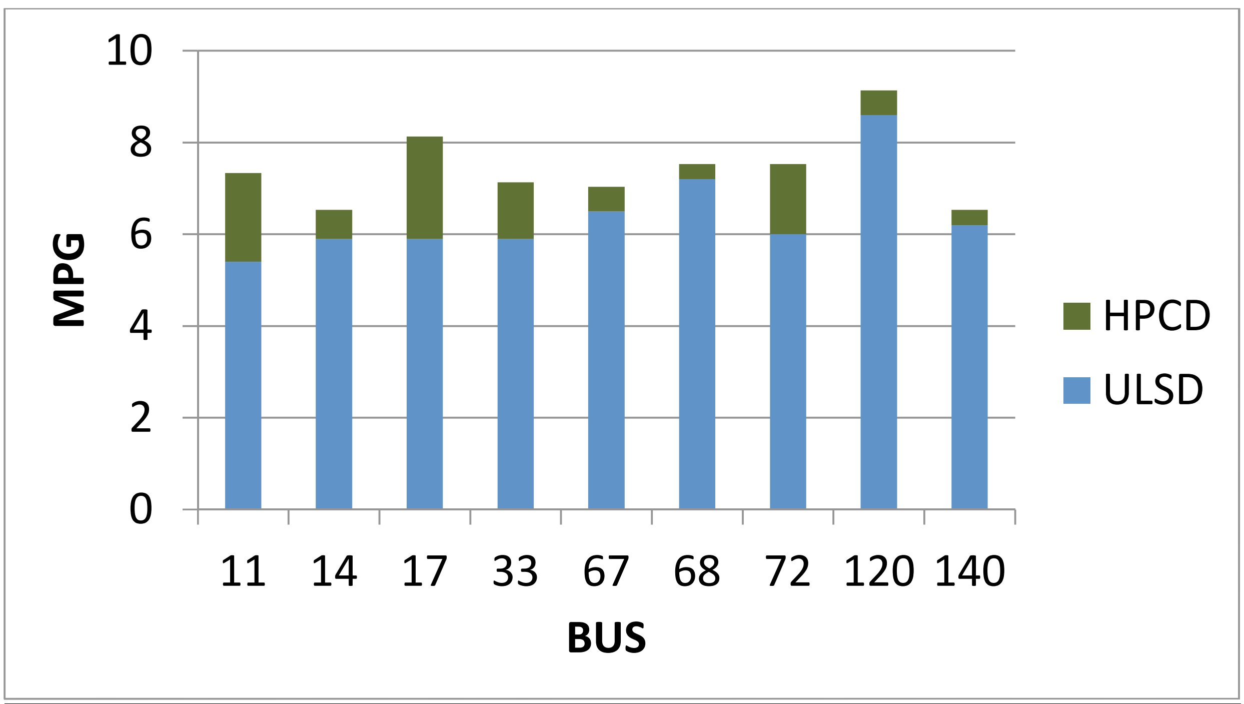

Chart 2 Impact on Fuel Economy of Switch from ULSD to HPCDF

- When corrected for seasonal variations, the HPCD fueled busses produced on average 12% less HC emissions than while operating on the ULSD.

- When corrected for seasonal variations, the HPCD fueled busses produced on average 13% less NO_X emissions than while operating on the ULSD.

- As stated previously, it is recommended that some if not all of the busses be monitored for long-term changes in fuel economy and especially emissions. This is due to the fact that some data from the cleansing period needed to be incorporated into the dataset in order to perform the statistical analysis. Therefore, for the comparison of vehicle emissions only, there was a merging of the data from the Cleansing and Validation periods. It is possible that further reduced emissions will be found primarily because of the previously mentioned bias toward higher emissions (see Page 4, Periods of the Experiment).

- It is the opinion of Resource100 LTD that the for the subject vehicles HPCD fuel produced statistically significant results of improved vehicle fuel economy and reduced vehicle emissions over conventional # 2 ULSD fuel.

The above results are summarized in the table below:

Parameter	HPCD Percent Change over ULSD	Units measured
Fuel Economy	+ 16.1%	MPG
HC Emissions	- 12 %	PPM
NO_X Emissions	- 13%	PPM

Disclaimers

- The results and conclusions contained herein are the opinions of Resource100 LTD and not necessarily the City of Dublin, Ohio or The City of Dublin Ohio School District.
- All work was performed independently by Resource100 LTD under contract to the City of Dublin.

Appendix A

Sample Log Sheet

#2 HPCD FUEL VALIDATION PROJECT

Vehicle Fueling & Exhaust Test Log

ALL FUELING MUST BE TOPPED OFF! **Type of Fuel Pumped: #2 HPCD**

Operating Entity

DUBLIN CITY SCHOOLS

Date	Vehicle ID No.	Odometer Reading	Fuel Pumped	Exhaust Testing Results HC's	NOx	OP	Other
4/5/11	67						
4/7/11	67						
4/8/11	67						
4/12/11	67	74637	24.9	4	217		
4/14/11	67	74796	25.7	6	187		
4/15/11	67	74876	11.1	7	187		
4/26/11 (19)	67	75035	24.1	3	159		
4/28/11	67	75194	23.5	5	185		
4/29/11 (26)	67	75338	19.6	6	187		
5/3/11 (4-28-11)	67	75497	23.3	5	170		
5/5/11 (4-29-11)	67	75,586	13.7	6	162		
5/6/11	67						
5/10/11	67						
5/12/11	67						

Fueling Technician **Test Technician**

Signature and date **Signature and date**

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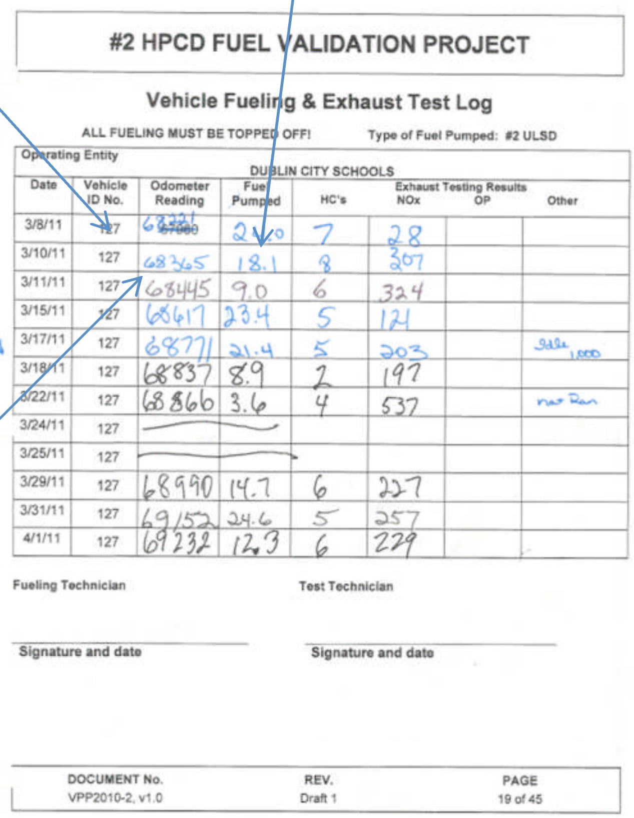
Appendix B

Sample Photographs



#2 HPCD FUEL VALIDATION PROJECT

Vehicle Fueling & Exhaust Test Log

ALL FUELING MUST BE TOPPED OFF! Type of Fuel Pumped: #2 ULSD

Operating Entity: DUBLIN CITY SCHOOLS

Date	Vehicle ID No.	Odometer Reading	Fuel Pumped	HC's	Exhaust Testing Results NOx	OP	Other
3/8/11	127	68321	[illegible]	7	28		
3/10/11	127	68365	18.1	8	307		
3/11/11	127	68445	9.0	6	324		
3/15/11	127	68617	23.4	5	124		
3/17/11	127	68771	21.4	5	203		Idle 1,000
3/18/11	127	68837	8.9	2	197		
3/22/11	127	68866	3.6	4	537		not Ran
3/24/11	127						
3/25/11	127						
3/29/11	127	68990	14.7	6	227		
3/31/11	127	69152	24.6	5	257		
4/1/11	127	69232	12.3	6	229		

Fueling Technician

Signature and date

Test Technician

Signature and date

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5 Gas Analyzer

Appendix C
Descriptive Statistics: MPG

The following tables show the descriptive statistics from all the collected data. A separate table is displayed for each Bus. For each of the three evaluation periods (Base, Cleansing and Validation) the sample size (N), Mean, Standard Error of the Mean (SE) and Standard Deviation (StDev) are shown. The sample size relates to the number of distinct fueling dates for each period throughout the evaluation. There were between 30 and 32 data points for each bus. A scatterplot of the uncorrected means of the data is also shown below.

Bus 11

Period	N	Mean	SE Mean	StDev
Base	12	5.412	0.407	1.409
Cleansing	8	7.181	0.533	1.506
Validation	12	7.506	0.604	2.092

Bus 14

Period	N	Mean	SE Mean	StDev
Base	12	5.937	0.401	1.389
Cleansing	8	6.689	0.552	1.562
Validation	10	6.667	0.354	1.118

Bus 17

Period	N	Mean	SE Mean	StDev
Base	11	5.893	0.344	1.140
Cleansing	8	7.011	0.120	0.339
Validation	12	8.33	1.06	3.67

Bus 33

Period	N	Mean	SE Mean	StDev
Base	11	5.916	0.324	1.076
Cleansing	8	6.60	1.01	2.86
Validation	12	7.280	0.571	1.977

Bus 67

Period	N	Mean	SE Mean	StDev
Base	11	6.484	0.336	1.113
Cleansing	8	6.726	0.140	0.397
Validation	12	7.162	0.326	1.129

Bus 68

Period	N	Mean	SE Mean	StDev
Base	12	7.172	0.843	2.920
Cleansing	8	7.208	0.476	1.346
Validation	12	7.711	0.805	2.787

Bus 72

Period	N	Mean	SE Mean	StDev
Base	12	6.001	0.486	1.685
Cleansing	8	7.252	0.459	1.298
Validation	12	7.665	0.617	2.136

Bus 120

Period	N	Mean	SE Mean	StDev
Base	12	8.566	0.532	1.844
Cleansing	8	9.083	0.451	1.274
Validation	10	9.309	0.426	1.348

Bus 140

Period	N	Mean	SE Mean	StDev
Base	12	6.156	0.428	1.482
Cleansing	8	7.075	0.466	1.317
Validation	12	6.679	0.307	1.062