

**A Study of the Emissions from Diesel Vehicles
Operating in Sao Paulo, Brazil and in Mexico City,
Mexico**

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Introduction

From March 6 to March 17, 2006 a series of 40 diesel vehicles were tested in Sao Paulo Brazil and from July 13 to July 21 a number of 27 more vehicles were tested in Mexico City, Mexico. All these vehicles were tested under a campaign to measure emissions in Latin America. Tables 1 and 2 indicate the vehicles that were tested in both cities.

Table 1: Diesel Vehicles Tested During the Sao Paulo Study

Test Number	Date	Vehicle Type	Model	Year	Engine Size (cm ³)	Odometer (km)	Load (kg)
1	3/6/2006	Bus (Private)	MB OF1620	1995	5.9	364,385	N/A
2	3/6/2006	Bus (Private)	MB OF1721	1998	5.9	100,996	N/A
3	3/6/2006	Bus (Private)	MB OF1721	2004	5.9	196,110	N/A
4	3/7/2006	Bus (Private)	SCANIA L94	2004	9	106,546	N/A
5	3/7/2006	Bus (Private)	VW 17260 EOT	2004	7.1	61,691	N/A
6	3/7/2006	Bus (Private)	MB OF1620	1997	5.9	765,602	N/A
7	3/7/2006	Bus (Private)	VW 17240OT	2003	6.5	243,551	N/A
8	3/8/2006	Bus (Private)	MB OF1721	1998	6	461	N/A
9	3/8/2006	Bus (Private)	MB OF1620	1996	6	165,717	N/A
10	3/8/2006	Bus (Private)	MB OF1722	2005	N/A	75,506	N/A
11	3/8/2006	Bus (Private)	VW OD17210	2003	N/A	353,926	N/A
12	3/8/2006	Bus (Private)	MB OF1721	2000	4.2	417,506	N/A
13	3/9/2006	Truck	VW 13150	2003	4.3	65,813	N/A
14	3/9/2006	Truck	IVECO 5013	2005	2.8	4,935	N/A
15	3/9/2006	Truck	GM 4HF1	2001	4.3	141,695	N/A
16	3/9/2006	Truck	MB 710	2004	3.9	42,050	N/A
17	3/10/2006	Truck	MB 710	2003	3.9	82,328	N/A
18	3/10/2006	Truck	MB1214	1998	5.9	206,774	N/A
19	3/10/2006	Truck	VW13150	2003	4.3	125,217	N/A
20	3/10/2006	Truck	MB710	2001	3.9	170,227	N/A
21	3/13/2006	Truck	IVECO 5013	2005	2.8	7,166	N/A
22	3/13/2006	Truck	MB 715C	2004	2.7	39,746	N/A
23	3/13/2006	Truck	MB710	2002	3.9	84,643	N/A
24	3/13/2006	Truck	SCANIA93H	1997	8.5	418,030	N/A
25	3/14/2006	Truck	MB1214C	1997	3.9	229,534	N/A
26	3/14/2006	Minibus	ASIA AM715	1995	2.7	108,697	N/A
27	3/14/2006	Truck	MB L1313	1975	5.7	455,000	N/A
28	3/14/2006	Light Duty Truck	FORD	1993	3.9	170,000	N/A
29a	3/14/2006	Minibus	RENAULT DCI120	2005	2.8	41,817	N/A
29b	3/14/2006	Minibus	RENAULT DCI120	2005	2.8	41,817	N/A
30	3/15/2006	Minibus	FIAT DUCATO	2005	2.8	1,215	N/A
31	3/15/2006	Bus (Private)	MB O500M	2003	6.3	109,664	N/A
32	3/15/2006	Truck	MB L1418	1990	5.9	306,000	N/A
33	3/15/2006	Truck	MB 310D	1998	2.5	171,934	N/A
34	3/15/2006	Truck	FIAT DUCATO	1998	2.8	161,820	N/A
35	3/16/2006	Light Duty Truck	CHEVROLET S10	1997	2.5	144,570	N/A

36	3/16/2006	Minibus	MB 311CDI	2003	2.2	84,703	N/A
37a	3/16/2006	Minibus	MB 310D	1997	2.5	360,324	N/A
37b	3/16/2006	Minibus	MB 310D	1997	2.5	360,324	N/A
37c	3/16/2006	Minibus	MB 310D	1997	2.5	360,324	N/A
38	3/16/2006	Minibus	MB 180D	1996	1.8	241,094	N/A
39	3/17/2006	Minibus	MB 312D	2000	2.5	258,000	N/A
40	3/17/2006	Minibus	MB 310D	1998	2.5	82,750	N/A

Table 2: Diesel Vehicles Tested During the Mexico Study

Test Number	Date	Vehicle Type	Model	Year	Engine Size (cm3)	Odometer (km)	Load (Kg)
1	13/07/2006	Truck	Dina Rabon	1977	3.5	N/A	8,000
2	14/07/2006	Light Duty Truck	Nissan frontier	2006	2.5	N/A	1,000
3	14/07/2006	Truck	Ford	1983	4.3	N/A	10,000
4	14/07/2006	Bus	MBZ	1994	6	N/A	2,800
5	14/07/2006	Bus	MBZ	1995	6	N/A	2,800
6	15/07/2006	Bus	International	2004	7.6	N/A	2,800
7	15/07/2006	Light Duty Truck	MBZ	2005	2.7	N/A	1,500
8	15/07/2006	Bus	MBZ	1995	6	N/A	2,800
9	17/07/2006	Truck	Freightliner	2003	6	N/A	8,000
10a	17/07/2006	Truck	MBZ	1992	6	N/A	8,000
10b	17/07/2006	Truck	MBZ	1992	6	N/A	8,000
11	17/07/2006	Light Duty Truck	Nissan frontier	2006	2.5	N/A	1,000
12	18/07/2006	Light Duty Truck	Nissan frontier	2006	2.5	N/A	1,000
13	18/07/2006	Light Duty Truck	MBZ	2004	2.7	N/A	1,500
14	18/07/2006	Truck	Navistar	1998	7.6	N/A	8,000
15	18/07/2006	Bus	MBZ	1992		N/A	3,300
16	19/07/2006	Truck	Freightliner	2004	6	N/A	8,000
17	19/07/2006	Light Duty Truck	MBZ	2005	2.7	N/A	1,500
18	19/07/2006	Truck	MBZ	1992	6	N/A	8,000
19	20/07/2006	Bus	MBZ	1992		N/A	3,375
20	20/07/2006	Truck	Dodge-Cummins	1997	5.9	N/A	8,000
21	20/07/2006	Truck	Perkins	1994	7	N/A	8,000
22	20/07/2006	Truck	MBZ	1994	6	N/A	8,000
23	21/07/2006	Truck	FL60	2003	6	N/A	8,000
24	21/07/2006	Truck	Perkins	1993	6	N/A	8,000
25	21/07/2006	Truck	Ford	1974	6	N/A	8,000
26	21/07/2006	Truck	Cummins	1991	8	N/A	15,000
27	21/07/2006	Truck	MBZ	1992	6	N/A	8,000

This study was a joint effort of Cetesbi (Sao Paulo), Seremi (Mexico) and ISSRC. Cetesbi provided the vehicles and the facilities for the Sao Paulo Study, Seremi provided de vehicles and the facilities for the Mexico Study and ISSRC provided the testing equipment.

Testing Procedure

Vehicles were brought to the test site for test equipment installation. These vehicles were warmed up at the time of the testing. Once emissions testing equipment was installed, the vehicles were operated over a prescribed driving circuit. This circuit was allowed by the city for vehicles to be operated over as wide a range of operating conditions as could be achieved within the city limits. The driving circuit required from 36 to 50 minutes to complete depending upon the traffic situation and included a moderate hill that the vehicles drove over. The typical time to complete the circuit was 30 minutes in Mexico City and 45 minutes in Sao Paulo, approximate.

For emission measurement purposes, Semtech Sensor D gas emissions testing unit was used to measure the emissions of CO, CO₂, total Hydrocarbons (THC), NO_x, and NO₂. The Sensor D unit uses infrared absorption technology to measure CO and CO₂, ultraviolet absorption technology to measure NO_x and NO₂, and a flame ionization detector to measure total hydrocarbon emissions. The Sensor D testing unit is an integrated emissions testing device designed to be used in on-road testing programs. The Sensor D measures emission concentrations and must be provided with exhaust flow rates and ambient temperatures and pressures in order to determine mass emission rates. The Sensor D is equipped with a temperature/pressure sensor. A Semtech manufactured 4 inch (10 cm) exhaust flow measurement device was used to measure the exhaust flow rate from the bus. This device uses standard dynamic and static pressure measurement to calculate exhaust flow. The Sensor D was also equipped with a GPS device to measure location and speed. All data was collected at one second intervals. For further information on the Sensor D test unit and the Semtech exhaust flow device please go to www.sensors-inc.com. The Sensor D test unit was zeroed and spanned at each set of test cycles. The unit was found to be very stable from day to day with the zero and span holding within 1% of the calibration gases.

Particulates were measured on a second by second basis using a Dekati DMM testing unit. This unit uses a particle charging process and six stage impactor setup to determine particle mass. The DMM measures particle concentration. The exhaust flow rates collected by the Sensor D unit must be used with the Dekati measurements to determine particulate mass flow rates. The DMM measures particles in the 0 to 1.5 micron range, which is the size range where virtually all diesel particulates reside. The DMM has been found to produce results comparable to the reference particulate sampling methods for diesel particulates; although, it was found to produce readings about 30% high in some cases. Dekati experts believe that this is due to the fact that the Dekati measurement process can measure volatile particulate matter that is lost in the case of filter based particulate sampling devices. For further information on the DMM, please see www.dekati.com. The DMM was zeroed at the beginning of each testing cycle. The charging and impactor units become covered with particulates and must be cleaned after each 2-3 hours of testing to keep the unit operating properly.

The DMM can not handle the mass concentrations found in uncontrolled diesel units. Thus, the diesel exhaust must be diluted at a controlled rate in order to use the DMM. A field dilution

device was developed by ISSRC to use in on-road emissions testing with the DMM. Figure 1 illustrates the design of the ISSRC field dilution unit.

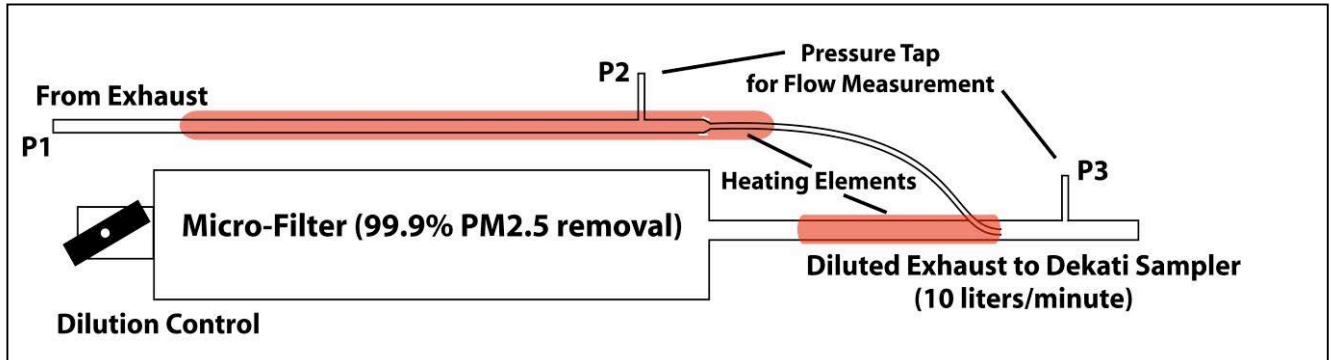


Figure 1: ISSRC Field Dilution Device

The exhaust flow in the dilution device is measured using a Dwyer differential pressure transducer, which is accurate to 0.25% of full scale. The differential pressure gauge is used to measure the pressure difference between P2 and P3 shown in Figure 1. A micro-filter produces particle free air to be diluted with the exhaust sample. The exhaust sample and dilution air are heated to 110 degrees C to avoid water and organic condensation. The dilution control can be adjusted to levels from 20 to 1 to 40 to 1 using the ball valve dilution control at the inlet to the micro-filter. In both campaigns the dilution device had some operational problems, in Sao Paulo the dilution device works for almost 80% of the tests while in Mexico City the dilution operation percentage was below 10%. This problem affects directly the PM results for both campaigns; we will discuss the results later on this report.

Thus, the dilution rate must be monitored second by second and the dilution rates corrected second by second to produce an accurate particulate mass emissions rate. On occasion when testing a large engine under heavy load, the pressure P1 drops so low as to reduce the exhaust flow in the diluter to near zero. This causes the system to under predict particulate emission rates and must be removed in the data analysis process.

Figure 2 presents a flow diagram for the overall emissions testing system. The data collected by

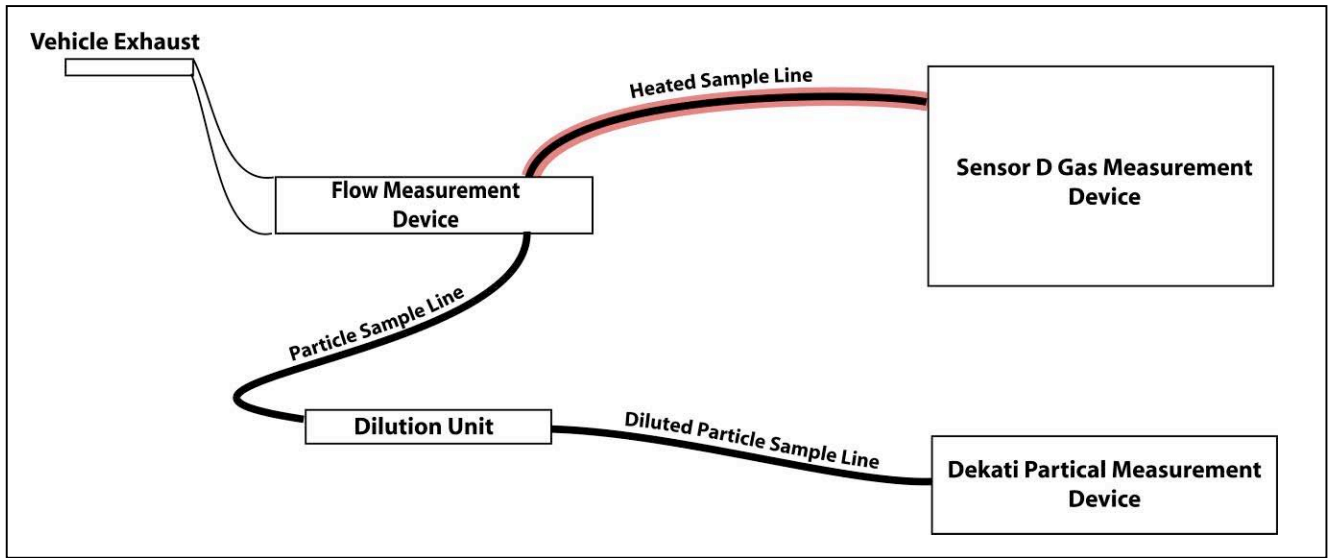


Figure 2: Flow Diagram for the Overall Emissions Testing System

The flow measurement device and the Sensor D are recorded to a flash card on the Sensor D unit. The Dekati information is recorded to a laptop computer that is connected to the Dekati by a serial cable.

Figures 3a and 3b show the exterior and interior of the vehicles outfitted for testing.



Figure 3a: Exterior of Buses Outfitted for Emissions Testing



Figure 3b: Interior of Trucks Outfitted for Emissions Testing

In order to simulate either passenger weight or load weight, sands bags were placed on the vehicle. These containers weighed about 25 kilograms each. Depending upon the size of the vehicle, containers were loaded to simulate a half of the load weight.

Measurement Error

No measurement process is free from measurement and operating error. Referring to Figure 2, there is the potential for measurement error in the flow measurement process, the dilution rate measurement and the gas concentrations measurement.. Table 3 outlines potential error assuming that each process can be held to produce only 2% error to help understand the expected variations in results from the repeated testing.

Table 3: Estimation of Expected Variation in Test Data for Repeated Driving Cycles

Measurement Process	Impact on Gaseous Measurements	Impact on Particle Measurements
Exhaust Volume Flow Measurement	2%	2%
Dilution Measurement	---	2%
Emissions Concentration Measurement	2%	2%
Total Potential Variation	4%	6%

To further complicate the process, data is collected on normal city streets which results in different driving patterns from test to test. Daily variations in traffic flow have a major impact on how the vehicles can be operated. Thus, emissions can vary considerably from test to even using the same vehicle. To correct for this variation, the data is divided into different power demand categories. 60 power demand categories are used for this purpose. These categories are typically referred to as Power Bins and are numbered from 0 to 59. The distribution of driving in the 60 Power Bins is determined. This driving distribution is multiplied by the average emissions measured in the 60 bins to produce a standardized estimate of emissions that would have resulted if the vehicle had been operated on an FTP cycle. This approach was found in a yet to be published study in Brazil to produce estimates of emissions on the actual driving cycle within 6%. While this is good in many respects, it must be added to measurement uncertainty indicated in Table 2, which results in a potential emissions error of 10-12% overall. The error

discussed in the previous paragraphs should be random and thus should average out to some degree over multiple tests.

Finally, the number of vehicles that can be tested in a 2-3 week period is limited. This limited testing further decreases the certainty of how well the tested fleet actually represents the actual urban fleet. Based on ISSRC data collected in similar gasoline emissions studies, the collection of data from a fleet of randomly selected gasoline fueled vehicles resulted in 90% confidence interval of plus or minus 20%.

When all potential errors are combined, it should be anticipated that this study will produce results which are to a 90% probability to within 25-30% of the actual emissions produced by the local fleet. While this potential error is larger than preferred, it is still better than using emission estimates derived from studies in the U.S. and Europe. In the long run, more emissions tests are required in order to reduce the mobile source inventory uncertainty to the 10% range.

Overall Results

Table 3 and 4 presents the average emissions measured for the various vehicles tested in the program. They are listed in the order tested. An average value and 90% confidence limits are also included. The 90% confidence interval in Table 3 and 4 indicates the range of emissions for which there is a 90% probability that the true mean emission rate of the fleet would exist if the tested vehicles were randomly selected from the fleet. The vehicles tested should be somewhat representative of the fleet, thus, the measured values are likely within 10-25% of the true mean of the each city fleet.

Table 3: Overall Emission Measurement Results for the Tested Sao Paulo Diesel Fleet

Test Number	Date Tested	Vehicle Type	Year	Measured Emissions (grams/kilometer)					FTP Normalized Emissions (grams/kilometer)				
				CO2	NOx	PM	CO	THC	CO2	NOx	PM	CO	THC
1	3/6/2006	Bus (Private)	1995	1318	19.04	0.48	4.91	1.82	1019	13.96	0.43	3.70	1.26
2	3/6/2006	Bus (Private)	1998	1245	13.30	0.17	3.42	1.65	940	9.59	0.11	2.21	1.02
3	3/6/2006	Bus (Private)	2004	1454	17.59	0.29	5.66	1.41	1201	13.45	0.24	3.89	0.91
4	3/7/2006	Bus (Private)	2004	2203	18.59	0.28	3.68	1.83	1674	13.35	0.22	2.31	1.23
5	3/7/2006	Bus (Private)	2004	1396	17.26	0.43	8.34	0.91	1096	13.16	0.34	6.81	0.60
6	3/7/2006	Bus (Private)	1997	1165	21.06	0.30	8.86	1.27	955	16.54	0.27	6.88	0.84
7	3/7/2006	Bus (Private)	2003	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	3/8/2006	Bus (Private)	1998	1223	19.55	0.19	4.66	1.36	955	14.61	0.17	2.95	0.84
9	3/8/2006	Bus (Private)	1996	1121	16.93	0.08	3.98	1.52	900	13.60	0.06	2.63	0.97
10	3/8/2006	Bus (Private)	2005	1050	8.61	0.09	4.50	0.58	888	7.20	0.09	4.05	0.37
11	3/8/2006	Bus (Private)	2003	1412	11.56	0.48	6.20	1.04	1219	9.60	0.48	4.08	0.67
12	3/8/2006	Bus (Private)	2000	1148	12.98	0.32	16.21	0.20	958	10.54	0.28	13.91	0.14
13	3/9/2006	Truck	2003	1001	8.27	0.15	3.21	1.00	779	6.17	0.13	1.69	0.55
14	3/9/2006	Truck	2005	453	4.91	0.08	2.44	0.52	326	3.44	0.05	1.51	0.30
15	3/9/2006	Truck	2001	660	5.30	0.43	4.61	2.58	481	3.77	0.33	3.00	1.60
16	3/9/2006	Truck	2004	536	4.83	0.67	2.35	0.91	569	5.12	0.69	2.29	0.89
17	3/10/2006	Truck	2003	414	3.95	0.10	3.47	1.30	344	3.29	0.08	1.84	0.71
18	3/10/2006	Truck	1998	918	10.90	0.43	5.74	1.79	800	9.88	0.37	3.70	1.00

19	3/10/2006	Truck	2003	1085	7.95	0.48	7.21	1.40	761	5.38	0.36	4.06	0.71
20	3/10/2006	Truck	2001	644	5.45	0.67	6.01	2.92	423	3.58	0.37	3.38	1.63
21	3/13/2006	Truck	2005	398	4.57	0.22	2.13	0.50	358	4.19	0.20	1.50	0.32
22	3/13/2006	Truck	2004	556	4.56	0.13	6.16	0.64	469	3.90	0.10	4.00	0.39
23	3/13/2006	Truck	2002	511	5.68	0.10	2.62	0.88	418	4.51	0.09	1.54	0.53
24	3/13/2006	Truck	1997	1594	18.20	0.48	13.50	4.08	1210	12.99	0.36	7.89	2.50
25	3/14/2006	Truck	1997	743	8.79	0.19	3.51	1.45	556	6.71	0.13	2.01	0.84
26	3/14/2006	Minibus	1995	275	1.38	0.13	1.44	0.44	230	1.04	0.14	1.12	0.28
27	3/14/2006	Truck	1975	394	8.31	0.15	2.11	1.12	288	6.20	0.11	1.17	0.62
28	3/14/2006	Light Duty Truck	1993	372	6.87	0.13	2.31	1.53	290	5.40	0.11	1.45	1.03
29a	3/14/2006	Minibus	2005	251	2.26	0.10	3.74	0.36	217	1.83	0.10	3.08	0.25
29b	3/14/2006	Minibus	2005	190	1.63	0.05	1.83	0.21	214	1.78	0.06	1.97	0.20
30	3/15/2006	Minibus	2005	314	4.77	0.05	2.52	0.61	234	3.51	0.05	1.76	0.37
31	3/15/2006	Bus (Private)	2003	1397	17.13	0.30	5.97	1.10	1186	14.08	0.25	4.17	0.65
32	3/15/2006	Truck	1990	1068	17.60	0.80	10.69	4.56	859	14.06	0.71	7.59	2.62
33	3/15/2006	Truck	1998	385	2.82	0.23	1.99	0.85	276	1.96	0.18	1.33	0.53
34	3/15/2006	Truck	1998	384	6.96	0.06	1.32	0.52	282	4.83	0.05	0.66	0.29
35	3/16/2006	Light Duty Truck	1997	296	2.86	0.13	1.08	0.44	208	1.99	0.09	0.67	0.28
36	3/16/2006	Minibus	2003	271	2.34	0.06	1.65	0.17	271	2.34	0.06	1.70	0.17
37a	3/16/2006	Minibus	1997	356	2.79	0.16	2.62	0.20	404	3.23	0.16	3.25	0.21
37b	3/16/2006	Minibus	1997	386	3.16	0.07	2.07	0.17	313	2.61	0.04	1.72	0.14
37c	3/16/2006	Minibus	1997	413	3.26	0.24	2.37	0.18	364	2.89	0.21	2.11	0.15
38	3/16/2006	Minibus	1996	318	1.41	N/A	0.99	0.21	300	1.32	N/A	0.87	0.19
39	3/17/2006	Minibus	2000	347	3.01	N/A	5.25	0.35	324	2.98	N/A	5.03	0.30
40	3/17/2006	Minibus	1998	358	6.15	N/A	2.80	0.16	307	5.33	N/A	2.53	0.14
				CO2	NOx	PM	CO	THC	CO2	NOx	PM	CO	THC
Average Values				762	8.68	0.25	4.43	1.11	616	6.81	0.21	3.19	0.70
90% Confidence Interval				16.1%	18.1%	20.1%	18.6%	22.4%	15.5%	17.4%	20.6%	19.7%	21.0%

Table 4: Overall Emission Measurement Results for the Tested Mexico City Diesel Fleet

Test Number	Date Tested	Vehicle Type	Year	Measured Emissions (grams/kilometer)					FTP Normalized Emissions (grams/kilometer)				
				CO2	NOx	PM	CO	THC	CO2	NOx	PM	CO	THC
1	13/07/2006	Truck	1977	776	8.45	N/A	6.95	3.64	461	5.46	N/A	3.43	1.78
2	14/07/2006	Light Duty Truck	2006	314	3.01	0.04	0.95	0.13	218	2.00	0.01	0.80	0.10
3	14/07/2006	Truck	1983	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	14/07/2006	Bus	1994	1157	11.94	0.48	13.75	1.94	772	7.37	0.32	8.76	1.02
5	14/07/2006	Bus	1995	1375	15.02	N/A	28.23	2.78	776	7.37	N/A	14.48	1.14
6	15/07/2006	Bus	2004	1123	11.95	0.09	6.24	0.43	888	9.27	0.08	4.70	0.25
7	15/07/2006	Truck	2005	509	3.43	0.05	1.59	0.18	413	2.79	0.05	0.76	0.13
8	15/07/2006	Bus	1995	972	13.75	N/A	5.44	1.45	744	10.16	N/A	3.81	1.02
9	17/07/2006	Truck	2003	871	10.99	0.10	7.57	0.77	495	6.22	0.06	3.94	0.38
10a	17/07/2006	Truck	1992	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10b	17/07/2006	Truck	1992	986	9.39	0.41	6.24	2.31	729	6.86	0.28	4.45	1.52
11	17/07/2006	Light Duty Truck	2006	360	3.54	0.04	2.04	0.24	250	2.40	0.03	1.40	0.10
12	18/07/2006	Light Duty Truck	2006	309	3.11	N/A	0.67	0.23	214	2.00	N/A	0.40	0.10
13	18/07/2006	Light Duty Truck	2004	367	3.40	0.02	1.04	0.10	305	2.80	0.00	0.90	0.10

14	18/07/2006	Truck	1998	1306	14.45	0.22	6.11	0.91	883	9.40	0.13	3.94	0.51
15	18/07/2006	Bus	1992	1966	30.68	0.66	73.03	6.93	1147	18.54	0.51	41.28	2.92
16	19/07/2006	Truck	2004	908	9.93	0.11	6.82	0.65	573	6.22	0.13	3.81	0.38
17	19/07/2006	Light Duty Truck	2005	335	2.68	0.02	0.78	0.01	236	1.90	0.00	0.40	0.00
18	19/07/2006	Truck	1992	994	12.66	0.46	7.19	2.20	579	7.24	0.25	3.81	1.27
19	20/07/2006	Bus	1992	1137	14.72	0.22	11.02	2.13	857	8.89	0.13	8.00	1.27
20	20/07/2006	Truck	1997	1554	14.68	4.22	25.13	3.57	937	8.38	2.92	13.97	2.03
21	20/07/2006	Truck	1994	1629	23.60	3.64	26.04	5.60	1017	14.35	2.67	15.24	3.05
22	20/07/2006	Truck	1994	1476	12.29	2.15	40.75	2.22	866	7.11	1.14	21.59	1.14
23	21/07/2006	Truck	2003	899	10.97	0.10	7.29	0.67	530	6.35	0.13	4.19	0.38
24	21/07/2006	Truck	1993	1750	21.42	2.39	42.74	1.44	939	10.54	1.40	21.59	0.64
25	21/07/2006	Truck	1974	1623	21.87	1.10	38.93	6.45	1038	13.46	0.76	24.13	3.43
26	21/07/2006	Truck	1991	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27	21/07/2006	Truck	1992	1154	10.73	0.46	7.70	1.96	724	6.10	0.25	4.32	1.14
				CO2	NOx	PM	CO	THC	CO2	NOx	PM	CO	THC
Average Values				1034	11.95	0.81	14.97	1.96	664	7.33	0.54	8.56	1.03
90% Confidence Interval				15.4%	19.4%	54.6%	39.2%	33.1%	14.0%	18.4%	56.3%	37.9%	31.2%

Figure 4 shows the CO₂, NO_x, and PM emissions from the larger trucks and emissions for groupings of model years. As can be seen, the data for the newer vehicles shows some difference from the older vehicles as expected. In Sao Paulo, the older heavy duty vehicles tend to emit more CO₂ than the news ones, this is logical considering that the advance in technology is looking for more efficient vehicles. Also it shows a reduction in NO_x and PM emissions. In Mexico City (Sao Paulo) there is a tendency to reduce the emissions of heavy duty vehicles by the time; also it can be see a difference between old vehicles and news ones respecting the CO₂ emissions. NO_x shows a reduction similar on percentage to the CO₂ and PM shows a considerable reduction for newer vehicles. The PM reduction can be explained considering that the Mexican truck fleet is following EPA emissions standard as they import their trucks from USA.

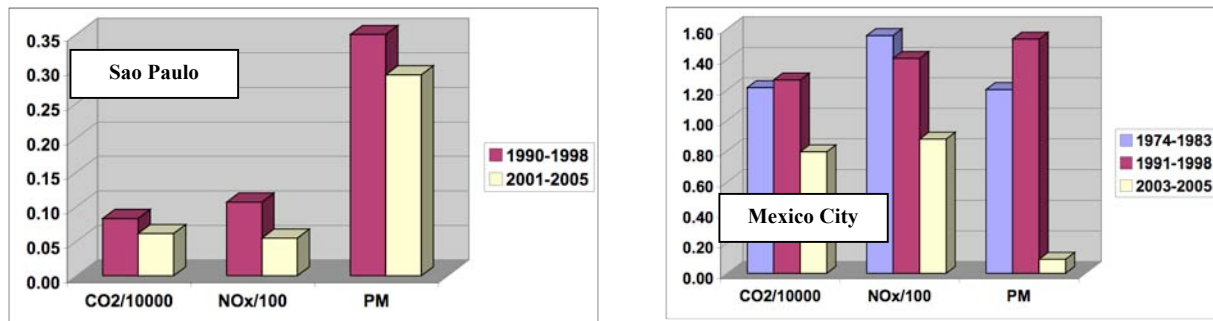


Figure 4: Emissions Averaged Over Selected Model Years for Heavy Duty Vehicles

Figure 5 shows the CO₂, NO_x, and PM emissions from smaller trucks and minibus tested in the study. In Sao Paulo there were more vehicles under test, then there is a better range on vehicles model by year. The results show a slightly difference for CO₂ and NO_x, but the reduction in PM is approximately 50% from the fleet 1993-2000 to the 2003-2005. During the Mexico City campaign the smalls trucks tested where only new ones, divided in tree groups by years. The differences are not relevant for all tree species.

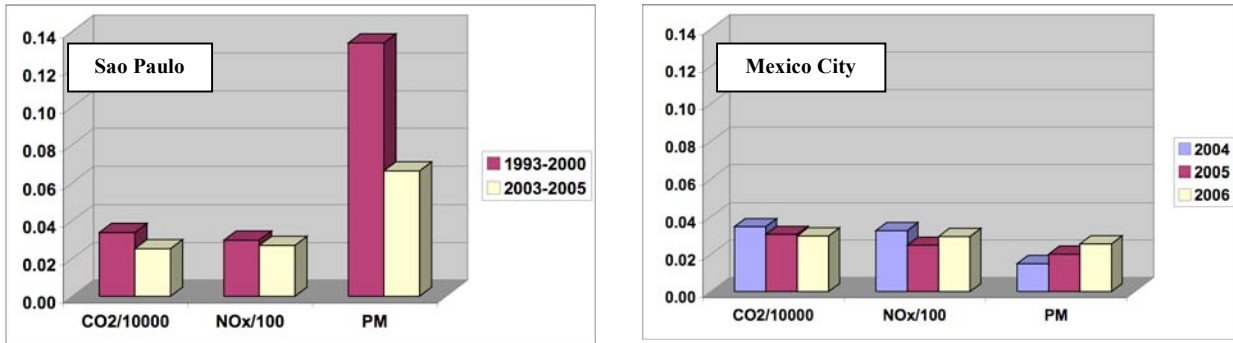


Figure 5: Emissions Averaged Over Selected Model Years for Light Duty Vehicles

Figure 6 shows the CO₂, NO_x, and PM emissions from the buses and emissions for two groupings of model years. As can be seen, the data for the newer vehicles are little difference from the older vehicles. In Sao Paulo there is an increase in CO₂ emission from older buses to the new ones; this can be explained considering that they are using bigger buses in the new fleet. Anyway there is a reduction in NO_x emissions but PM shows a logical increase. In Mexico City, the news buses emit less CO₂ than the old ones, and also they show reduction for NO_x and a considerable reduction for PM. This reduction is around the 80% and can be explained considering that there is a ten year difference between each group.

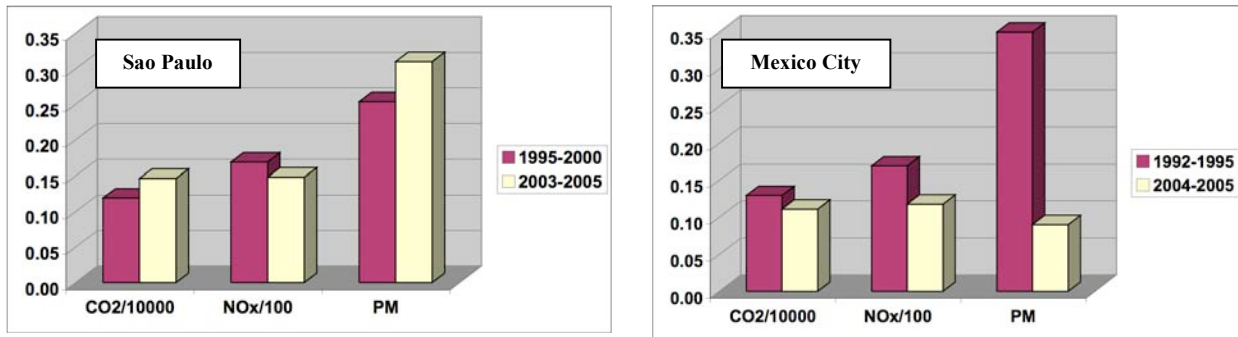


Figure 6: Emissions Averaged Over Selected Model Years for Buses

Vehicle Emissions Under Different Driving Conditions

Another purpose of this study is to determine emissions variation under different driving conditions. These conditions can be represented by the IVE driving bin. The IVE model divides

the range of driving situations into 20 vehicle energy demand situations¹ and 3 engine stress situations². In this section the results are an average between the Sao Paulo and Mexico data. Figure 6a, b, and c present emissions from the large diesel vehicles as a function of IVE driving bin.

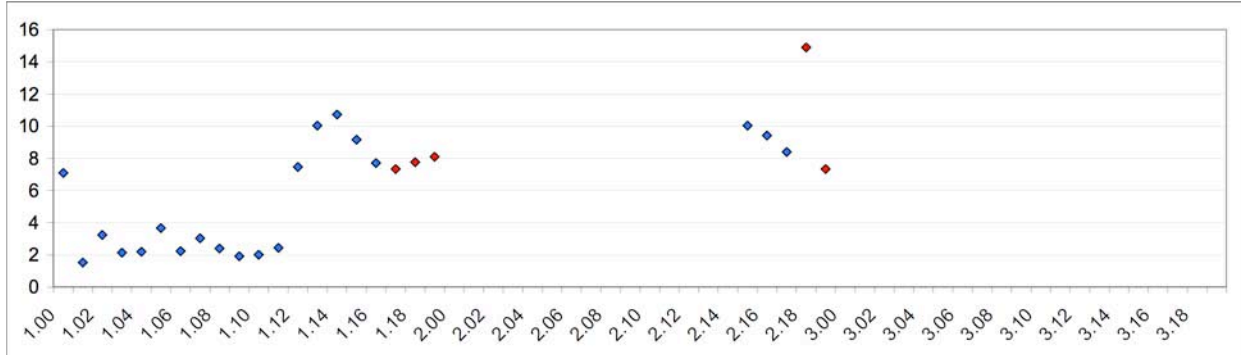


Figure 6a: CO2 Emissions from Heavy Duty Vehicles by IVE Bin

The emissions look typical with the exception of the apparent fall off in emission rate in stress category 1 and bins 16-18 (i.e. 1.16 to 1.18 in Figure 6). These data points are marked in red. Due to traffic congestion in both cities, it is not possible for driving to have occurred in bins 1.17-1.19. Thus, these data points must result from erroneous classification of data into bins. It has been found that the GPS unit will loose signal and freeze and then jump to the correct speed when the signal returns or miscalculation of altitude. This causes an improperly high acceleration or road slope calculation, which results in the emissions being classified into too high bins. Steps are taken to filter these events out of the data; however, a few data points slip by. The data in bins 1.17-1.19 in Figure 6 represent less 0.3% of the collected data (i.e. about 965 seconds out of 9,648,000 seconds of data) and are included only for the sake of completeness.

Figure 6b presents data from the same vehicles but this data is the NOx data from those vehicles.

¹ The energy demand on a vehicle is the result of engine and rolling friction, wind resistance, acceleration energy, and road grade. For a further discussion, the reader is referred to the user’s manual for the IVE model, which can be obtained at www.issrc.org/ive.

² Engine stress relates to engine rpm and the average energy demand on the vehicle in the most recent 15 seconds. The reader is referred to the user’s manual for the IVE model, which can be obtained at www.issrc.org/ive.

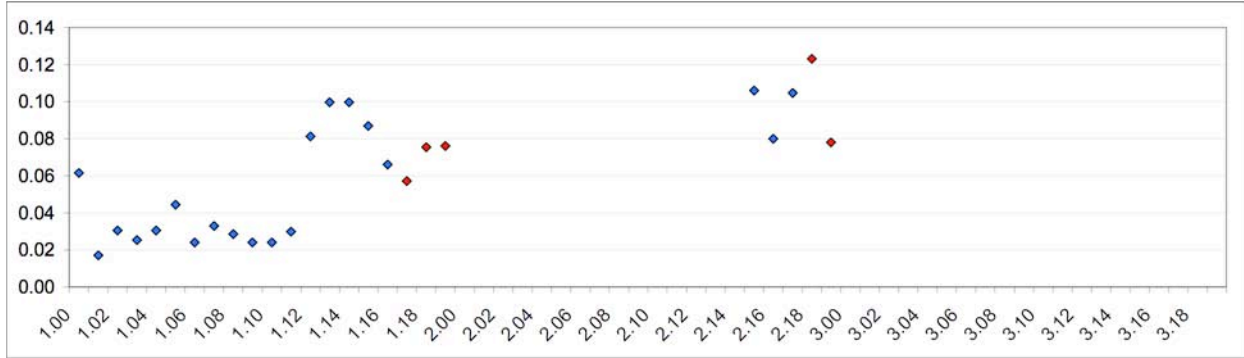


Figure 6b: NOx Emissions from Heavy Duty Vehicles by IVE Bin

There is one interesting aspect of this data set. There is data in bins 1.14 and 1.15 that have dropped off even with significant driving in those bins. Thus, the fall off in NOx emissions in bins 1.14 and 1.15 may be a real phenomenon. This characteristic is seen in gasoline data where the vehicles go into an enrichment mode that reduces the combustion temperatures and thus NOx. These vehicles may be doing the same thing.

Figure 6c presents the binned data for particulate matter from the large diesel vehicles. This data is more discontinuous than the NOx or CO2 data. A part of this discontinuity may be the extra error induced by the requirement to use a diluter and the change in the performance of the Dekati particulate test unit as it becomes dirty. In any case, the general form of the emissions curve can still be seen in the data.

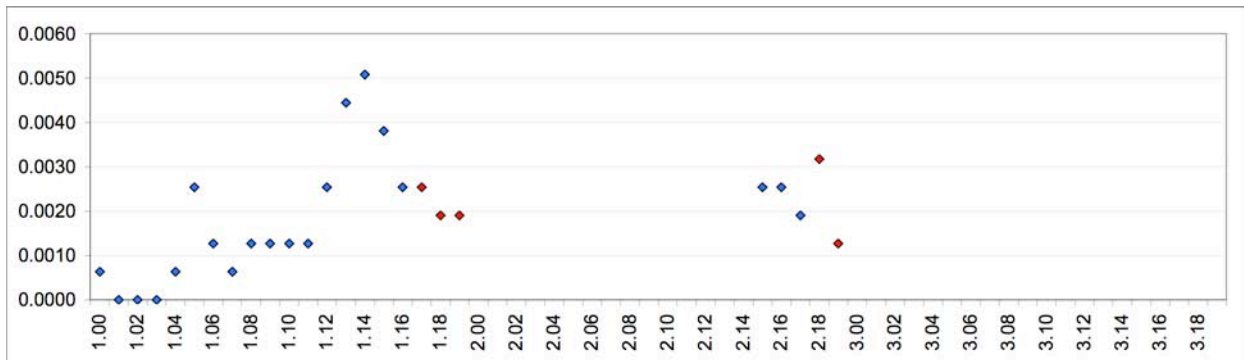


Figure 6c: PM Emissions from Heavy Duty Vehicles by IVE Bin

Figure 7a, b, and c present the same data as Figures 6a, b, c except that it comes from the light duty diesels tested in both cities. The data points marked in red again represent erroneous data points since no driving could have occurred in these bins. Otherwise, the data looks reasonable for these types of vehicles.

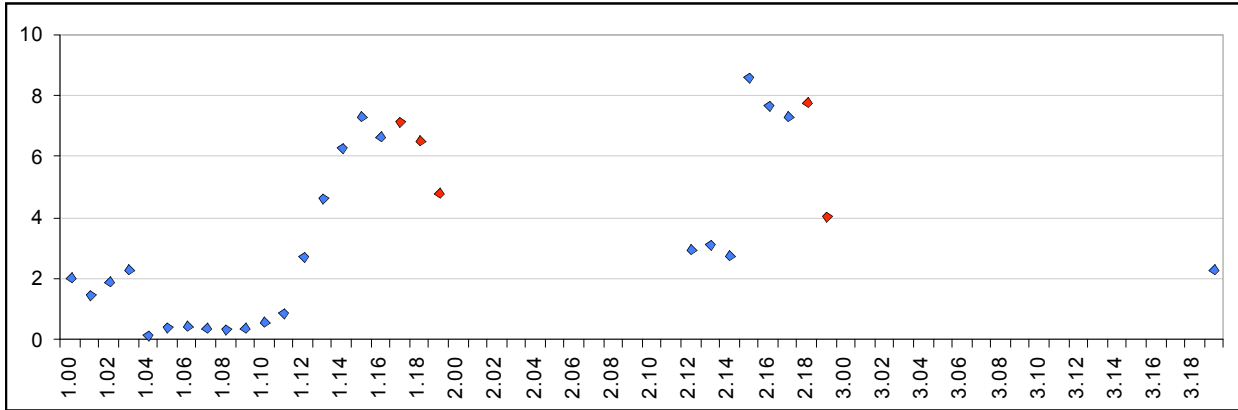


Figure 7a: CO2 Emissions from Light Duty Vehicles by IVE Bin

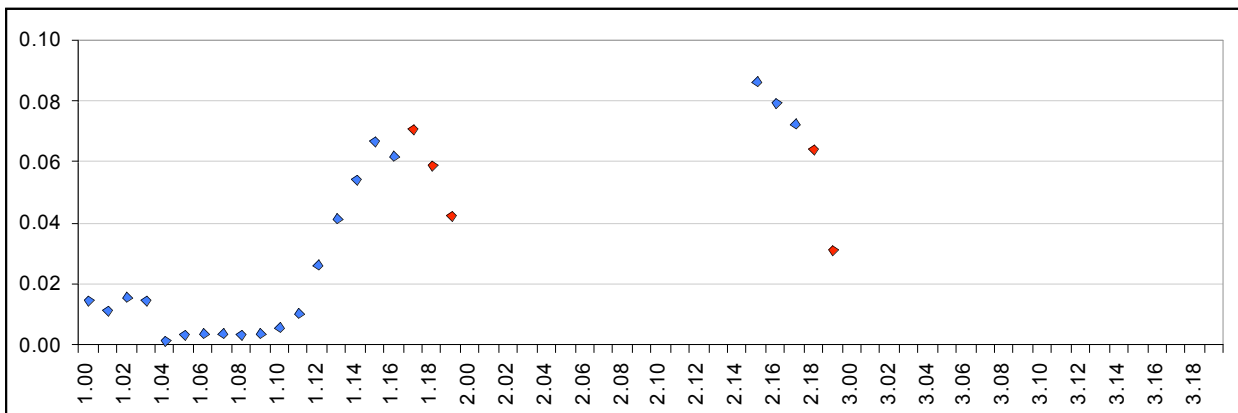


Figure 7b: NOx Emissions from Light Duty Vehicles by IVE Bin

It is difficult to know if there is a similar enrichment in the NOx resulting in emissions reductions in the higher bins in this data set.

Figure 7c presents the binned PM emissions. As was the case with the larger diesel vehicles, the binned emissions are more discontinuous compared to the CO2 and NOx emissions.

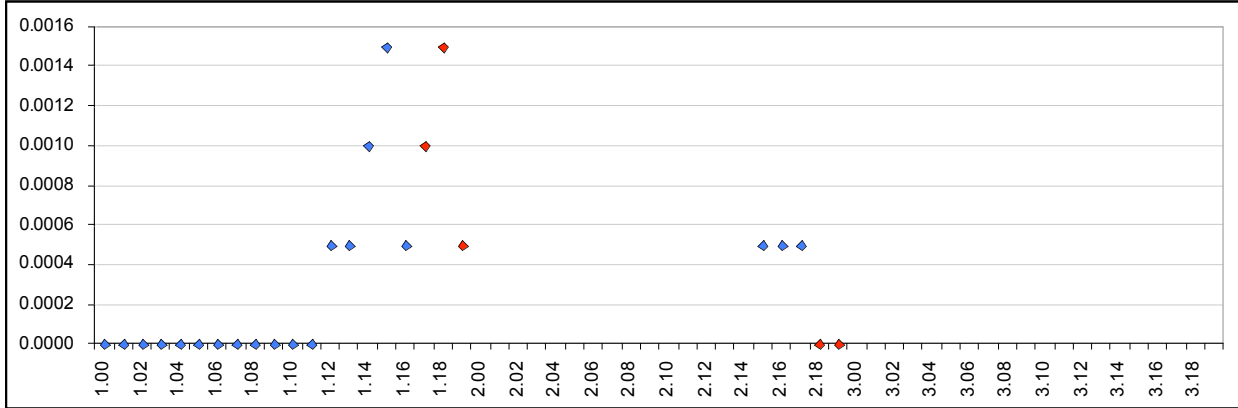


Figure 7c: PM Emissions from Light Duty Vehicles by IVE Bin

The particulate emissions follow the expected pattern on the whole.

Finally in tables 8a, 8b and 8c there are the emissions by bin considering buses results, it can be applied the same logic as the two categories results that are shown before.

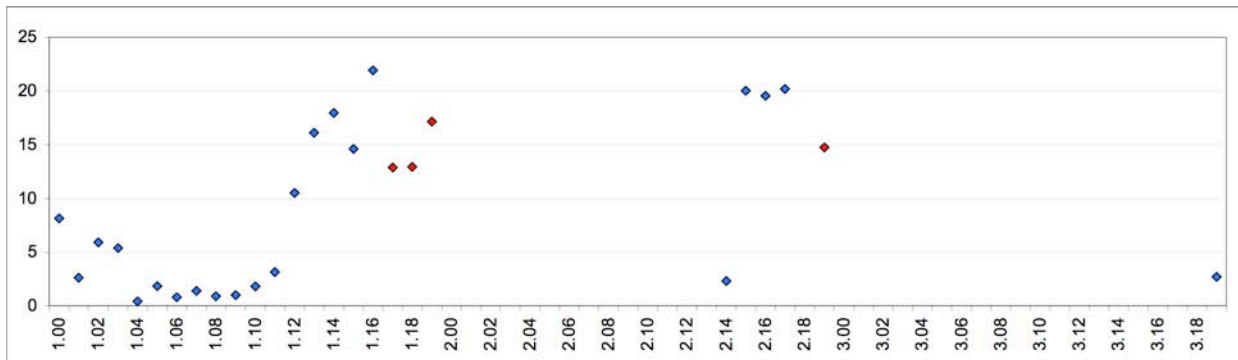


Figure 8a: CO2 Emissions from Buses by IVE Bin

Figure 8b presents data from the same vehicles but this data is the NOx data from those vehicles.

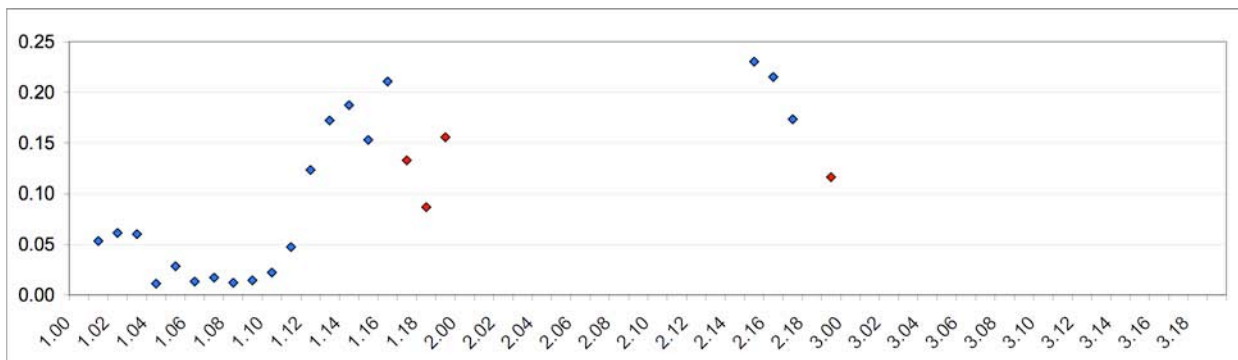


Figure 8b: NOx Emissions from Buses by IVE Bin

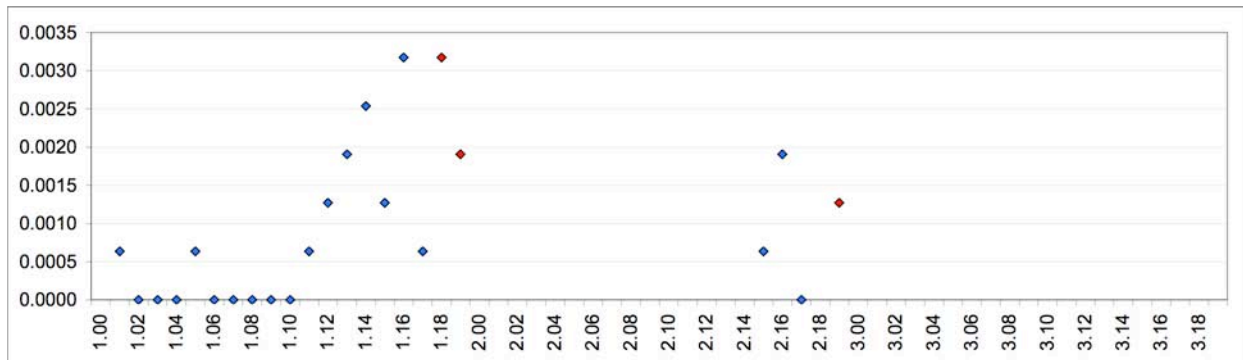


Figure 8c: PM Emissions From Buses by IVE Bin

Emission Comparisons with the IVE Model

As noted earlier, 67 vehicles were tested in Mexico City and Sao Paulo. This limited data does not provide large enough samples of individual technologies to do an analysis of emission comparisons by technology type. Instead, the IVE model was run using an FTP driving pattern, the pattern used to develop base emission factors for the IVE model, using the distribution of vehicles tested. Three vehicle groups were used; the first one was buses, the second was the smaller diesel vehicles and the third one was larger diesel vehicles. The average measured values normalized to FTP driving cycles were divided by the IVE predicted values to evaluate the comparisons. Figure 8 provides the results of this analysis.

As can be seen, the CO2 emission projections were accurate producing a ratio close to 1³. The other predictions, however, showed a wide variance. The greatest difference is with respect to NOx emissions. The measured emissions were 2.5 to 3 times higher than the predicted emissions. These differences were anticipated in the development of the IVE model and provisions are made in the IVE model to add an adjustment file that will adjust the base emission factors to actual measured values. There is a very low comparison of particulate matter emissions with the IVE model factor, this can be the result of the problems with the dilution device readings.

³ There average difference between each categorie for both cities is 7%. These differences are well within the accuracy of the data collection process.

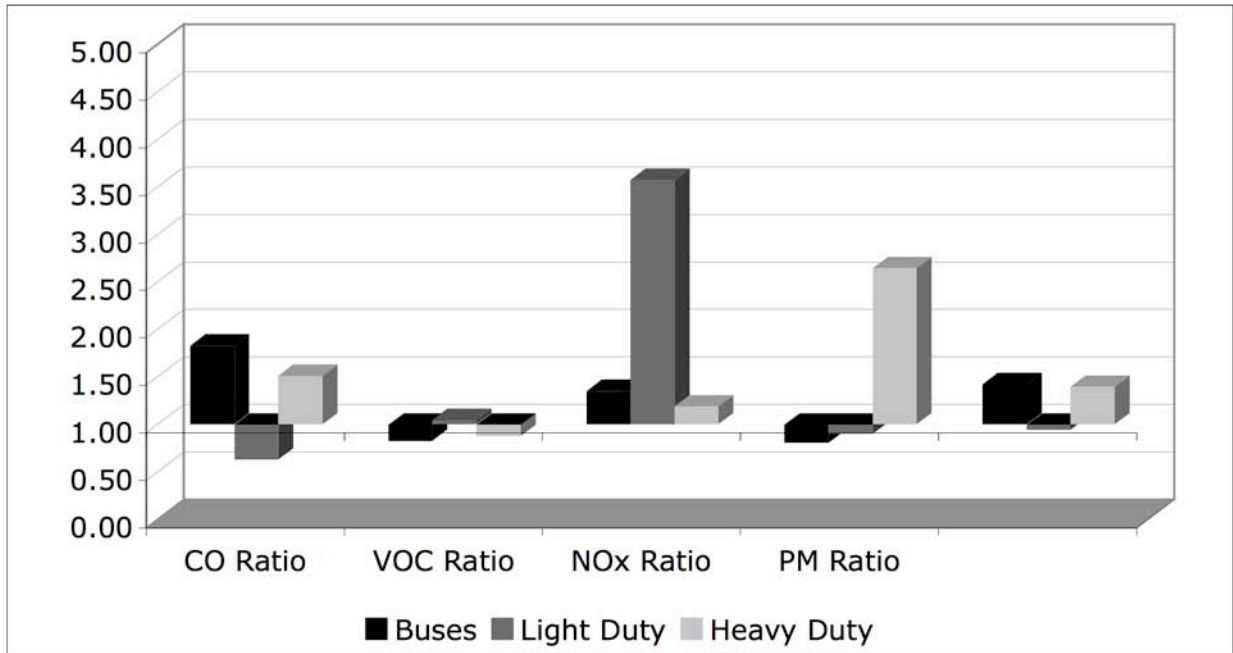


Figure 8a: Comparison of Measured Emission Rates with IVE Predicted Emission Rates (Mexico City)

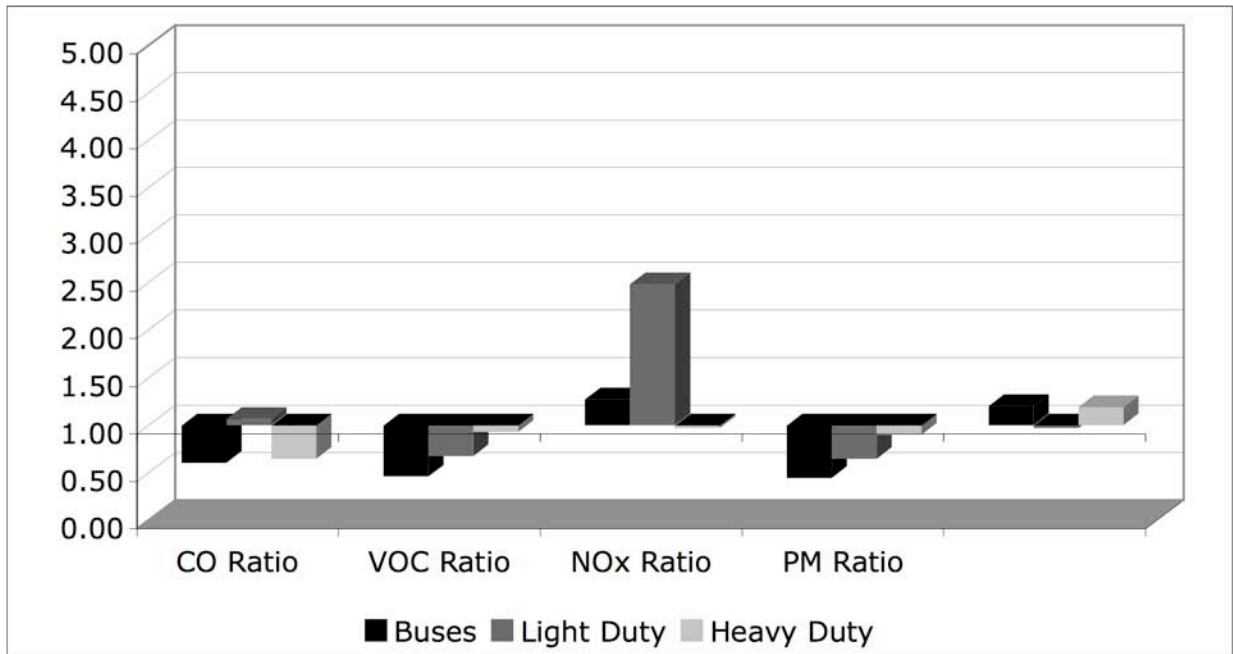


Figure 8b: Comparison of Measured Emission Rates with IVE Predicted Emission Rates (Sao Paulo)

The default base emission factors in the IVE model are based primarily on emission measurements made in the United States and represent test results from thousands of vehicles. It is difficult to know how much weight to give to emission results from only 67 vehicles. However, the confidence limits shown in Table 3 suggest that the results should be in the

ballpark of 30% of the measured values. Table 5 shows the actual ratios and the ratios if the measured emission results were modified to be 30% closer to the IVE projected values.

Table 5: Potential Adjustment Values to Be Used in IVE Model (Mexico)

Class	CO Ratio	VOC Ratio	NOx Ratio	PM Ratio
Buses	1.82	0.82	1.35	0.80
Buses Adjusted 30% in direction of default values	1.28	1.00	1.00	1.00
Overall Auto (Light Duty Vehicles)	0.63	1.04	3.57	0.90
Overall Auto Adjusted 30% in the direction of default values	0.81	1.00	2.50	1.00
Overall Truck (Heavy Duty Vehicles)	1.51	0.88	1.19	2.64
Overall Truck Adjusted 30% in direction of default values	1.00	1.00	1.00	1.85

Table 6: Potential Adjustment Values to Be Used in IVE Model (Sao Paulo)

Class	CO Ratio	VOC Ratio	NOx Ratio	PM Ratio
Buses	0.61	0.46	1.27	0.44
Buses Adjusted 30% in direction of default values	0.79	0.60	1.00	0.58
Overall Auto (Light Duty Vehicles)	1.06	0.68	2.48	0.64
Overall Auto Adjusted 30% in the direction of default values	1.00	0.88	1.74	0.84
Overall Truck (Heavy Duty Vehicles)	0.65	0.93	0.97	0.90
Overall Truck Adjusted 30% in direction of default values	0.84	1.00	1.00	1.00

Because of the limited number of tests, it is suggested that the values closer to the IVE default values (the 30% adjusted values) be used until more in-use emissions data is collected. A value of 1 is used in the cases where the 30% adjustment takes the values from less than 1 to greater than 1.

Table 6 presents the recommended adjustment values for diesel vehicles as an average of both cities. These values should, of course, be improved as more data is collected.

Table 6: Recommended Adjustment Values for Use in the IVE model

Class	CO Ratio	VOC Ratio	NOx Ratio	PM Ratio
Buses Adjusted 30% in direction of default values	1.03	0.80	1.00	0.79
Overall Auto Adjusted 30% in the direction of default values	0.91	0.94	2.12	0.92
Overall Truck Adjusted 30% in direction of default values	0.92	1.00	1.00	1.42

Appendix A

Field Manual For Diesel Vehicle Testing

IVE In-Use Vehicle Emissions Study for Diesel Vehicles

I. Introduction:

Diesel emissions are important contributors to air quality degradation in urban areas. Diesel particulates are considered to be carcinogenic or likely carcinogens in the United States, and diesels are often the prime source of nitrogen oxide emissions. It is thus important that diesel emissions be well understood and that air quality planners be able to predict the impact of diesels in the present time and at times in the future based on specific control scenarios. To support these efforts, a process of on-road measurement of diesel emissions has been devised and the International Vehicle Emissions (IVE) model was developed to estimate emissions from diesel vehicles under different driving and control scenarios.

The IVE model is designed to make estimates of in-use vehicle emissions in the full range of global urban areas. At the point in time of IVE model development, data to establish base emission factors and driving pattern adjustments were, of necessity, based on vehicle studies carried out primarily in the United States. This has raised questions as to the applicability of the base emission rates and driving pattern adjustments used in the model to developing countries. The IVE in-use vehicle emissions study is designed to test the hypothesis that similar vehicle technologies will produce equivalent emission results in a given location and to provide some rudimentary data for creating improved emission factors.

The IVE modeling framework provides the user with the ability to enter adjustments to the base emission factors that are specific to a location in case the supplied factors are found to be in error. This capability was built into the model to support emission measurement studies that would be made in developing countries as local capacity increases. The IVE In-Use vehicle emissions study is not designed to fully develop correction factors for the IVE model. The original data base used to develop the IVE model correction factors was based on more than 500 vehicle tests each involving three driving cycles carried out at the University of California CE-CERT research facility. This information was combined with summarizations of thousands of in-use vehicle tests provided by the United States Environmental Protection Agency. The IVE In-Use emissions study discussed in the following section results in emissions data for 40 diesel fueled vehicles. Information from 40 vehicles, while significant, does not provide the range of data for the development of a full range of new emission factors and adjustments. Nonetheless, the IVE In-Use emissions study can be used to make rudimentary adjustments to the IVE model that will certainly improve its performance for developing countries.

The actual IVE In-Use vehicle emissions study makes use of recently developed emissions measurement technology that can be carried on-board vehicles while they are driven on urban streets. This technology allows emission mass per unit distance to be determined in real driving situations. To date, this on-board emissions measurement technology can be used to measure carbon monoxide (CO), carbon dioxide (CO₂), total hydrocarbons (THC), and nitrogen oxides (NO_x). A different testing device to measure particulate emissions is also used during the study to establish real-time particulate emissions from the tested diesel vehicles.

The IVE in-use vehicle emissions study is built around a two week study period where on-road vehicle emissions data is collected.

II. Equipment Needed to Complete Study

A wide range of equipment is required to carry out the diesel emissions study. The key pieces of equipment will be shipped from the United States. However, a significant amount of equipment and supplies must be provided locally. An Excel spreadsheet program is provided with this write-up that indicates the equipment that will be sent from the United States and the equipment that must be procured locally.

III. Sample Size and Impact on Emissions Measurement Reliability:

Unfortunately for the researcher studying the emissions from on-road vehicles, the variance in emissions among vehicles with similar technologies is quite large. This means that multiple tests on different vehicles are required to accurately establish the true fleet wide average for a given technology. Equation II.1 indicates the 70% confidence interval for data in a Gaussian distribution.

$$I_{70\%} = \pm \sigma / \sqrt{(n-1)} \quad \text{II.1}$$

where,
 $I_{70\%}$ = 70% confidence interval
 σ = standard deviation
 n = sample size

In the case of vehicular emissions, σ is often close to the sample mean; although diesel vehicles show a little less variation than do gasoline fueled vehicles. In this case, Equation II.1 becomes:

$$I_{70\%} = \pm [M / \sqrt{(n-1)}] \quad \text{II.2}$$

where M = measured sample mean

In this special case, to insure that the measured mean has a 70% probability of being within 15% of the actual mean requires a sample size of 44 vehicles. The actual variation in emissions from similar technologies is unknown but based on the previous discussion it is clear that a relatively large number of vehicles of a given technology class should be tested. For purposes of this study, at least 10 vehicles of each important technology should be measured to insure even a moderate level of confidence in the results. Once the data is collected, the variance in the data of similar vehicles will establish the true confidence that can be placed in the results of the tests.

With present vehicle testing technology, about 1.5 hours are required to remove the equipment from one vehicle and install the sampling equipment in a second vehicle. To collect data for $\frac{3}{4}$ of an hour for a given vehicle will thus require a total of 2.25 hours per vehicle. In a 9 hour day, about 4 vehicles can be sampled. In a two week sampling period (10 sampling days), about 40 vehicles can be studied. Thus, based on the preceding discussion, only four general vehicle technology groups should be studied over the two week sampling period in order to insure at

least 10 vehicles per technology class are studied. The variety of diesel engine technologies operating in most urban areas today are relatively small and the study of the four most predominate vehicle technologies in an area will provide useful data for understanding the overall diesel emissions in an urban area.

IV. Sampling Program:

Based on Section II, it is desired to study four vehicle technology classes during the two week study. The vehicle technology classes that should be studied are those groups which dominate the local diesel fleet being studied and which will continue to be important in the next 5 years. The vehicles selected may vary from location to location, but based on previous experience, it is suggested that the following four technology classes be considered:

1. Euro 1 type technologies
2. Euro 2 type technologies
3. Euro 3 type technologies
4. Euro 4 type technologies if available or extend testing of most common of the three previous groups.

The previous suggested technology classes should not be rigidly adhered to in cases where the local fleet does not contain significant numbers of vehicles in any of the vehicle classes listed. It is best to tailor the study to the makeup of the local fleet. For this paper, the four suggested classes will be used for discussion purposes.

Start emissions are important for gasoline vehicles but are not considered as important for diesel vehicles. Thus the testing program that will be used will not collect diesel vehicle start emissions. Vehicles will be scheduled to be brought to the testing area at 2.25 hour intervals beginning at 08:00. Thus a second vehicle will be due at 10:15. (On the first day only two tests should be scheduled to allow for proper on-site training.) It is critical that vehicles not arrive late. It is best to schedule them to arrive a little early. The new vehicles will be parked in the test area leaving room for the returning vehicle to be parked. Once the vehicle being tested arrives at the test setup facility, the equipment is moved from the tested vehicle and installed in the new vehicle that has arrived for testing. Buses are expected to arrive with only a driver. Sand bags will be loaded onto the bus to simulate passenger weight. Trucks should arrive with a half to a full load for purposes of testing. The truck or bus will be at the facility for about 3 hours for equipment installation, testing, and equipment removal. It can then be returned to its owner.



Figure 1: Truck and Bus with Flow Measurement Devices Connected to the Exhaust

V. Vehicle Driving Procedure:

Table IV.1 indicates the approach that will be used to test the vehicle. The driving roads selected for the study should provide for convenient stopping locations that will occur at the desired time intervals and return the vehicle to the starting point at the desired time. The roads selected should also allow for as great a variety of driving as feasible for the location.

It is critical that vehicles arrive on time. A testing facilitator should be in touch with the vehicle suppliers to insure that the vehicles will arrive on schedule.

Table IV.1: Vehicle Driving Procedure

Step	Procedure	Time Interval
1	A vehicle arrives at the test setup facility at the designated appointment time while previous vehicle is being tested.	----
2	Vehicle will be parked in the next vehicle test setup location	5 minutes
3	Vehicle will be studied and a decision will be made as to the best way to attach testing equipment to the just arrived vehicle. Sand bags are loaded onto vehicle to be tested.	20 minutes
4	Tested vehicle returns to the test setup location and parks near the next vehicle setup location.	5 minutes
5	Download data from the just tested vehicle	5 minutes
6	Test equipment is removed from tested vehicle and transferred to new vehicle and tested vehicle released for return to the owner.	30 minutes
7	Equipment installed on new vehicle.	25 minutes
8	Data collection initiated and vehicle started and driven over the designated one-hour test route.	45 minutes
9	Total time to test one vehicle	135 minutes

Traffic will of course impact the distances that will be covered during the driving phase. Thus, the test route should be designed so that there are alternate routes to be taken so that the vehicle can complete its test run in the 45 minutes that are allocated. Since traffic will flow better at various times of the day, the test may be completed in 30 minutes in one case and in 60 minutes in another case. The test route should be selected so that the vehicle can complete the test run in 60 minutes in the worst traffic. It is also critical that the driving course selected contain street sections where higher speeds and accelerations can be achieved as well as slower speeds and lower accelerations. The driver should operate the vehicle in a manner typical of the traffic that

is occurring at the time of testing and in the manner that the vehicle is normally used (i.e., a bus will stop at bus stops even though it does not pick up or discharge passengers). Buses and trucks should be marked with signs taped to the vehicle indicating that the vehicle is participating in a testing program.

VI. Vehicle Procurement:

Procuring 40 large diesel vehicles for testing with a driver and, in the case of trucks, can be a challenge. Bus companies must be contacted as well as trucking companies to find the desired vehicles.

In both Mexico City and Sao Paulo, a \$US50 per vehicle fee was paid for gasoline fueled vehicle. This fee plus the use of contacts at the partnering agencies provided all of the needed vehicles in Sao Paulo. In the case of buses and trucks a higher fee may be necessary unless representative buses can be obtained from government sources supportive of the testing program.

It is recommended that \$200-\$300 be set aside for payment to bus/truck owners for providing a vehicle and driver for the approximate 3 hour testing program. However, this is a local decision that should be made.

VII. Vehicle Sampling Equipment:

For purposes of these studies a SEMTECH-D portable emissions monitor (PEM), manufactured by Sensors, Inc., will be used for gaseous emissions. This unit employs a flame ionization detector (FID) to measure THC, a Non-Dispersive Ultraviolet (NDUV) analyzer to measure NO and NO₂, a Non-Dispersive Infrared (NDIR) analyzer to measure CO and CO₂, and an Electrochemical sensor to measure O₂. Fuel for the FID is provided via a high-pressure canister mounted within the PEM. For measuring particulate emissions, a Finnish Dekati testing unit will be used to collect second by second particulate emissions data. The Dekati test unit makes use of technology that ionizes the particulates and collects them by size. A whole-exhaust, mass flow measurement device will measure the exhaust flow rate based on static and dynamic pressure differentials. A partial stream of the exhaust, taken from within the mass flow measurement device, is routed through the analyzer system at a constant rate of 10 liters per minute. The concentration and flow rate data is input to the onboard data logger on a second by second basis. Internal filters, carbon absorbers, and chillers are strategically located in the sample stream to minimize interferences. A temperature and humidity measurement device also provides second by second data on the temperature and humidity of the engine intake air. Algorithms in the processing software provide the necessary adjustment to the NO and NO₂ results from the NDUV based upon the humidity of the intake air. Data, also collected on a 1 hertz cycle, from an onboard GPS unit allows the measured mass of each pollutant to be matched up with the driving activities of the vehicle.

The PEM, including protruding knobs and connectors, measures 404 mm in height by 516 mm in width by 622 mm in depth. It weighs approximately 35 kg. The ID of the mass flow measurement device will have a diameter of 10.2cm.



Figure 2: A Bus and Truck with Equipment and Sandbags Loaded

Except during actual testing, the internal temperatures of the PEM will be maintained using a line-serviced 12-volt DC power supply. A Y-connector allows the PEM to be simultaneously connected to the line-serviced power supply as well as a deep-cycle 12-volt battery. Prior to starting the first test each day, the PEM will undergo a leak test as well as a zero, span, and, if necessary, calibration test. The proper size mass flow measurement device will be selected based upon the engine size of the test vehicle. This will insure that a backpressure of less than ten inches of water column is maintained during the testing. The mass flow measurement device will then be attached to the rear of the vehicle using high vacuum suction cups. A high-temperature silicone sleeve, sized to match the OD of the tailpipe, will be attached to the tailpipe with a hose clamp. The silicone sleeve will be attached to flexible silicone transport tubing. A second silicone sleeve will be used to attach the other end of the transport tubing to the mass flow measurement device. The PEM will be disconnected from the line-serviced 12-volt power supply and placed in the trunk or back seat of the test vehicle along with the deep-cycle 12-volt battery. A 18-foot sample line will be used to connect the mass flow measurement device to the sample input system of the PEM. The GPS unit will be magnetically attached to the roof of the vehicle and connected to the PEM. The temperature and humidity probe will be located near the front of the vehicle and connected to the PEM. If the PEM is placed in the trunk, a special piece of hardware will be used to allow the lid of the trunk to be latched but still allow space for the sample line and other lines to be connected to the external devices. At this point, the PEM will be switched to the measurement mode and the engine of the test vehicle will be started. Following completion of the vehicle driving procedure described earlier in Table IV.1, the installation process will be reversed to remove the PEM from the vehicle. The data collected will be downloaded to a laptop computer at the end of each vehicle test. At the end of each day, a span check will be conducted to observe the sustained linearity of the system.

Calibration gases are a critical component of insuring that the measurements by the Semtech-D are correct. The following table recommends gas concentrations for calibrating and auditing the Semtech-D unit. The audit gases may be skipped if it is difficult to get gases or if the cost is beyond that budgeted for the project.

Gas	For Unit Calibration	For Unit Auditing
CO ₂	12%	6%
CO	1200 ppmv	200 ppmv
NO	1500 ppmv	300 ppmv

Total Hydrocarbons (as Propane)	200 ppmv	50 ppmv
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VIII. Local Support Requirements:

The most difficult job for the local partnering agencies is the procurement of the needed 40 vehicles. This procedure needs to be started one month or more before the beginning of testing. Each vehicle owner is required to bring their vehicle for testing at least exactly at the scheduled time. In addition, a secure location must be found where two large vehicles can be parked and sampling equipment removed from one and installed on another.

Once the testing is begun, a person is needed to insure that the next vehicle will arrive on time and to help with installation of equipment and data downloading. An experienced driver is needed to drive the vehicle. This should be supplied by the vehicle owner. An experienced mechanic is needed to help install the test equipment and to identify the engine type and technology. Necessary ladders to enable the installers to reach the exhaust for connection will be required. In the case of buses, sand bags representing a the weight of a 2/3 full bus must be available along with two persons to load the bags onto the bus. The ISSRC team will supply one person to work with the group to carry out the testing. The local partner must also arrange for a zero gas and a calibration gas that is guaranteed to be within a 2% tolerance of specified values.

The testing program is begun at 06:30 when all personnel must arrive at the testing location and typically continues until 18:00; although, on good days the testing may finish by 17:00 and on bad days the testing may take until 19:00. The daily work crew must be prepared to stay until testing is completed.

IX. Analysis of Emissions Data:

Once collected, the data needs to be divided into the appropriate 60 driving bins required by the IVE model based on the GPS data collected along with the emissions data. The GPS evaluation program contains the necessary algorithms to estimate average emissions in each power bin to look at the relative emissions in the various power bins. The binned GPS data can also be entered into the IVE model and emissions predicted for that driving pattern and vehicle technology. These two comparisons will then indicate how well the IVE model is performing when averaged over the vehicles tested. Based on the results, emission adjustment files can be generated for the IVE model for the location of interest.

A. Viewing GPS and Emissions Output

The SEMTECH system outputs mass emissions second by second into a spreadsheet that can be opened in excel. There is a template made called ‘Raw Emissions Data.xls’ that can be opened and the data post processed to create the proper emissions files from the SEMTECH unit. Also in this worksheet, there are some graphs to view the emissions data in some common formats.

B. Binning GPS and Emissions Output

After processing the data in excel, the file should be saved as a text file and used in the GPSEvaluate program. This program will take all of the data files and compile them to create the emissions correction for each of the 60 bins, as well as the driving fraction for each of the 60 bins. The output file will be a text file that can be used in the IVE model.

The text files that are to be processed should be placed in the **'Data' folder** in the same folder with the GPSEvaluate program. The program should then be started (Figure VI.1). The program will list all files found in the **'Data' folder** at the time of program start. These appear in the upper left hand window. Clicking in the box to the left of the file names will cause the checked file to be evaluated when the **'Calculate'** button is clicked. For each group, all data associated with that group is usually selected for the calculation.

The screenshot shows the 'EVALUATE GPS DATA' application window. It features a menu bar with 'File' and 'Edit'. The main interface is divided into several sections:

- Select Files to Evaluate:** A list box containing 'All', 'flash gps data sample1 155554.log', and 'flash gps data sample2 155570.log'. A callout box explains: 'Lists the files found in the 'data' folder that might be processed.'
- Settings Panel:** A grid of dropdown menus for configuring data columns and options. A callout box explains: 'Dropdown menus indicating the columns for the time and speed data, start rows to skip, columns for each pollutant, and other user options.'
- Buttons:** 'CALCULATE', 'SaveSettings', 'LoadSettings', and 'SAVE RESULTS'.
- Display Power in Bins:** A dropdown menu currently set to '0.0'. A callout box explains: 'Indicates what information will be displayed in lower portion of program. Options are Driving fractions, CO, CO2, PM, VOC, or NOx. The display does not impact the output files, all data is always provided in the output files.'
- Calculation Results (%):** A table showing results for 'Low Stress', 'Med Stress', and 'High Stress' across 60 bins. A callout box explains: 'Displays results, including percentage in each bin, emissions in each bin, overall number of data points processed, and average speed.'
- Average Speed:** A field at the bottom right showing the calculated average speed.

Figure VIII.1. GPSEvaluate Program

The upper right portion of the program displays the current settings for the program. A description of each setting is described in the Table VI.1 below.

Table VIII.1. Description of the Options in the GPSEvaluate Program

Parameter	Default Value	Units	Description
Time column	1	hh:mm:ss	Indicates which column the hour, min and second is in the GPS text files. The GPS units report this information in the column 1 when counting from 0 (see Table 1 in the section above).
Max Time Jump	1	seconds	When there is a time gap of more than the entry in this column, it will discard the data during that time period and pick up when the time gap is over.
Speed column	9	Mph	Indicates which column the velocity is in the GPS text files. The GPS units report this information in the column 9 when counting from 0 (see Table 1 in the section above).
Min Time Jump	1	seconds	When there is a time gap of less than the entry in this column, it will ignore the data during that time period. This is to protect against data that is collected at a faster resolution than the GPS reports. For example, if the GPS is 1 Hz (1 measurement per second), but the data is collected at every half second, the output file will report a line of data every half second, with the information only changing every second). In this situation you would want to make sure the Min Time Jump is set to 1 second.
Altitude column	7	Meters above sea level	Indicates which column the altitude is in the GPS text files. The GPS units report this information in the column 7 when counting from 0 (see Table 1 in the section above).
Start Rows to Skip	3	integer	This is the number of rows after the data starts that is not used in the analysis. Usually, once the recording begins, there are several seconds that do not represent the usual driving pattern.
Start hour	0	n/a	Indicates which hour of the day to start the processing, according to the time column, or if calculations for each hour should be performed.
End hour	23	n/a	Indicates which hour of the day to end the data processing, according to the time in the time column. This does not apply if 'hourly calculation' has been selected in the start hour column.
CO column	n/a	Mass/sec	Indicates which column the CO emissions are in, if they exist.
CO2 column	n/a	Mass/sec	Indicates which column the CO2 emissions are in, if they exist.
NOx column	n/a	Mass/sec	Indicates which column the NOx emissions are in, if they exist.
VOC column	n/a	Mass/sec	Indicates which column the VOC emissions are in, if they exist.
PM column	n/a	Mass/sec	Indicates which column the PM emissions are in, if they exist.
No Limit on Idle	No Limit	minutes	Indicates the maximum time to allow for idling in the program. If this is set to 10 minutes, the program would set any idle time (defined as a velocity of less than .5m/s) of longer than 10 minutes to 10 minutes.
Satellite column	n/a	Integer through 14	Indicates the column that contains the number of satellites. This column is optional and is not used in the default configuration. If this option is selected, program will ignore data that has less than 3 satellites.
Straight Speed	Straight	n/a	Indicates whether to average the current row of data and the previous row (average speed) or to use each data point separately (straight speed).
Save Settings Button	n/a	n/a	This button will save the current settings. Settings should be saved in the Settings Folder as a txt file.
Load Settings Button	n/a	n/a	This button will load the file named "GPSEvaluateSettings.txt" that is located in the Settings Folder.
Time Offset Button	0.0	hours	This is to enter the time difference from UTC (GMT) time reported in the GPS data to local time. (If location is +6 hours from GMT, enter 6. If location is -6 hours from GMT, enter 18)

Once the appropriate settings have been selected or loaded, and the files to process have been checked in the boxes, the user is ready to process the data by pressing '*Calculate*'. The bar above the '*Calculate*' button will show you the status of the calculation. The calculation may take a few minutes, especially with many data files or long data files. Once the calculation has been finished, the results will be displayed in the bottom half of the program. There will be the percentage of travel in each of the 60 bins along with the total number of rows processed and the average speed over all the files.

It is also possible to save the output of the file analysis. Click on the '*Save Output*' button and a text file with the information contained in the '*Results*' box can be saved. All data on the driving and emissions will be saved in a text file.

C. Applying Base Correction Factors in the IVE model

You can use the emissions data collected in the field study to derive base (or emission) correction factors in the IVE model. These emission factors will apply a correction to the IVE emission rates already used in the model. To calculate the change in emissions from the IVE default emissions to the new measured emissions, emissions will need to be predicted on the same driving trace as the emissions measurements were made on. This means a driving trace for the overall driving conducted during the emission measurement test procedure will need to be created and input into the IVE model. The GPSEvaluate Program has already made a composite set of data with fractions of driving in each bin that add up to 100%. This data can be entered into the IVE model in one of two ways. The data can simply be entered into the IVE model directly into the location page (Figure VI.2). While this is a simple option for entering in data for a single file, this can be time consuming for many data files or many hours of the day. For multiple files, the import function in the Location File Template may be used (Figure VI.3). To use the Location File Template, follow the instructions on the first spreadsheet in the workbook or refer to the GPS Operating Instructions document.

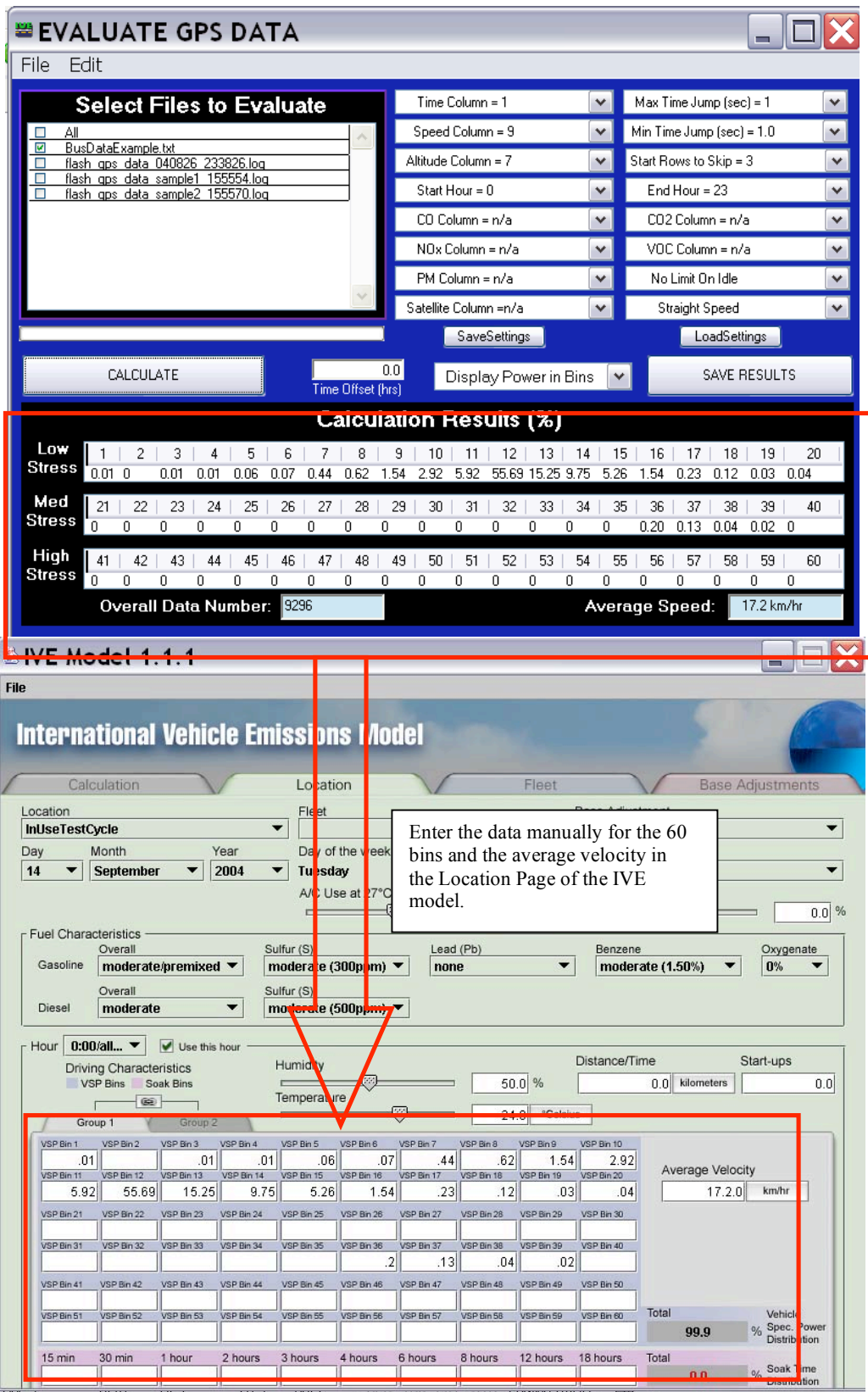


Figure VIII.2. IVE Model User Interface for Entering in Driving Pattern Data

Location:	Various Input	Latitude	Longitude	Altitude	Units				
Location Info:	Template			500	m	m=meters, ft=feet			
Date:	MM/DD/YYYY 8/28/2002								
Road Grade:		Units	positive value is uphill,negative number is downhill						
I/M Class:			enter text for one of five options						
Percent AC In Use at 80 F (27 C):			percent of public with AC on vehicle using AC at 80F (27C) ambient temperature						
Fleet File to Use:									
Interpolation File to Use:		A blank will be interpreted to use a linear fit for missing hours							
	Overall	Lead(Pb)	Sulfur(S)	Benzene	Oxygenate				
Gasoline:							Enter gasoline related data.		
Diesel:							Enter diesel related data.		
Description:		Units	Driving Style Distribution (Facility Cycle Distribution)--Group 1 Vehicles						
Time Period:		hr	VSP Bin 1	VSP Bin 2	VSP Bin 3	VSP Bin 4	VSP Bin 5	VSP Bin 6	VSP Bin 7
Total Distance (or Time) Driven:		km							
Number of Statuses:		S							
Temperature:		C							
Relative Humidity:		%							
Average Velocity for Group 1 Vehicles:		km/hr	15 min	30 min	1 hour	2 hour	3 hours	4 hours	6 hours
Average Velocity for Group 2 Vehicles:		km/hr	Driving Style Distribution (Facility Cycle Distribution)--Group 2 Vehicles						
Units			VSP Bin 1	VSP Bin 2	VSP Bin 3	VSP Bin 4	VSP Bin 5	VSP Bin 6	VSP Bin 7
sec=seconds, min=minutes, hr=hours, Mhr=1000's of hours									
km=kilometers,Mkm=1000's of kilometers,mi=miles,Mmi=thousands of miles									
S=single units, M=1000's									
C=degrees Centigrade,F=degrees Fahrenheit									
m/s= meters/second, mph= miles per hour, km/hr=kilometers/hour									
Description:		Units	Driving Style Distribution (Facility Cycle Distribution)--Group 1 Vehicles						
Time Period:		hr	VSP Bin 1	VSP Bin 2	VSP Bin 3	VSP Bin 4	VSP Bin 5	VSP Bin 6	VSP Bin 7
Total Distance (or Time) Driven:		km							
Number of Statuses:		S							
Temperature:		C							
Relative Humidity:		%							
Average Velocity for Group 1 Vehicles:		km/hr	15 min	30 min	1 hour	2 hour	3 hours	4 hours	6 hours
Average Velocity for Group 2 Vehicles:		km/hr	Driving Style Distribution (Facility Cycle Distribution)--Group 2 Vehicles						
Units			VSP Bin 1	VSP Bin 2	VSP Bin 3	VSP Bin 4	VSP Bin 5	VSP Bin 6	VSP Bin 7
sec=seconds, min=minutes, hr=hours, Mhr=1000's of hours									
km=kilometers,Mkm=1000's of kilometers,mi=miles,Mmi=thousands of miles									
S=single units, M=1000's									
C=degrees Centigrade,F=degrees Fahrenheit									
m/s= meters/second, mph= miles per hour, km/hr=kilometers/hour									

Figure VIII.3. Location File Template in Excel

Once the driving fractions have been entered, select all other information as close as possible to match the emissions testing conditions in the Location Page. This includes selecting the ambient temperature and humidity, fuel specifications, and fleet. The user will have to create a fleet file to represent the type of vehicle tested in this study. For deriving correction factors, only one technology should be used at a time. To more information on how to fill out the location file and creating a fleet file, please refer to the IVE user's manual. Once the fleet and location file have been properly filled out, the user can run the model and record the emission rate per distance for each pollutant.

Once the emissions values have been predicted by the IVE model, these values can then be compared with the actual emissions values that were collected in the study. To derive the correction factors, simply divide the measured emission value over the predicted value to get the correction factor for that specific technology. Then in the IVE model, this correction should be entered and used when predicting emissions from this area. For example, if the IVE model predicts a CO emission rate of 10 g/mi and the emissions measurements indicated on average an emission rate of 13 g/mi of CO, the correction factor for this technology would be 1.3. This information is entered in the base correction factor worksheet (Figure VI.4). Any time this base correction factor file is used, it will correct the emissions predicted by a factor of 1.3 for CO for this specific technology.

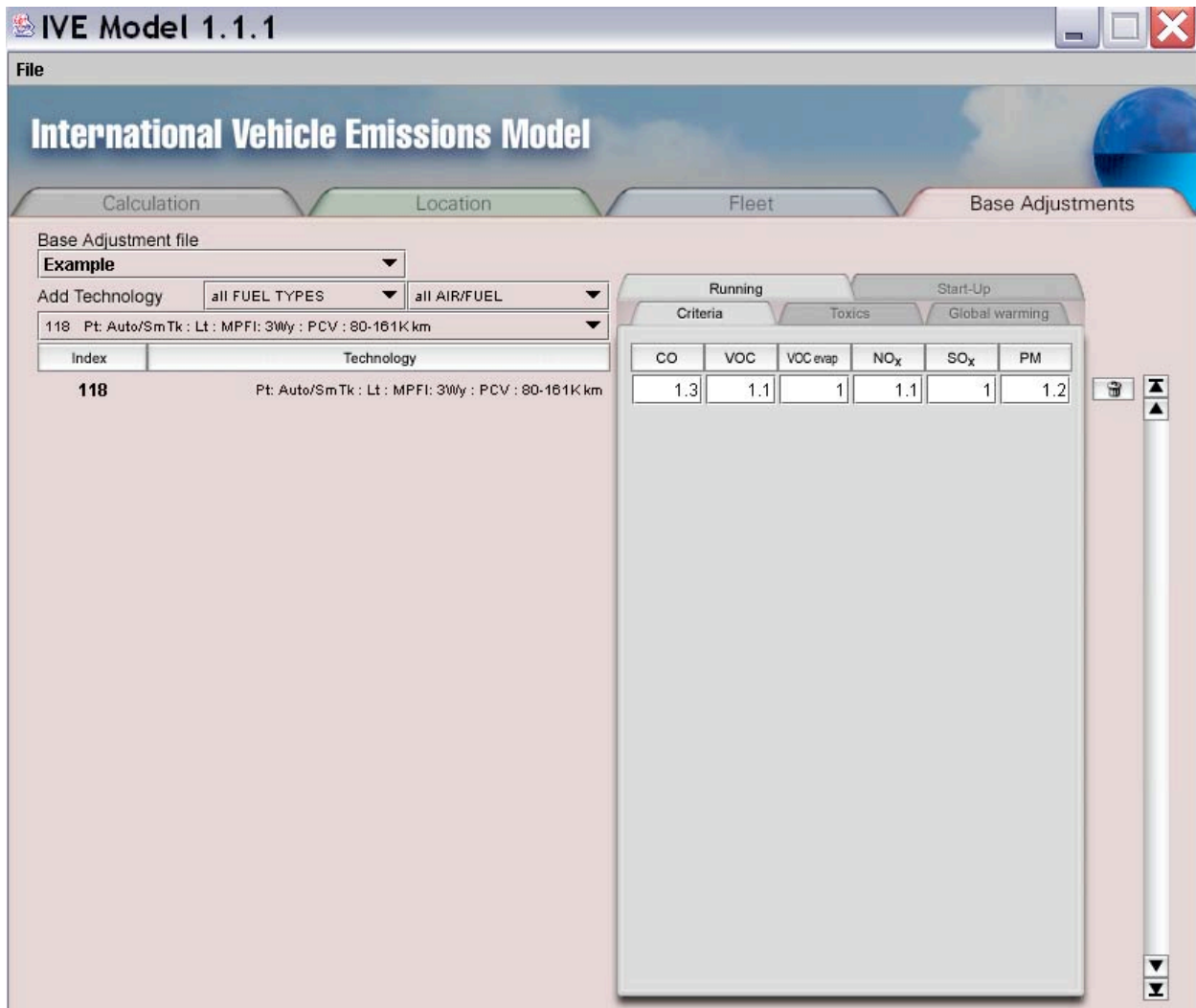


Figure VIII.4. Applying Location Emission Correction Factors in the IVE model.

