Collection and Evaluation of On-Road Vehicle Emission and Activity Data

April 2004

By

Lei Yu, Ph.D., P.E.

Fengxiang Qiao, Ph.D.

Texas Southern University

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Lei Yu, Ph.D., P.E.

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Texas Southern University
3100 Cleburne Avenue
Houston, Texas 77004

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Abstract

In this project, the newly developed on-road emission measurement device OEM-2100 was employed to collect the emission data in Houston area. The device was developed by the Clean Air Technology International, Inc. and is capable of measuring the second-by-second fuel consumption and emissions of NO_x, HC, CO, CO_2, and PM.

Emission data under a total of 170 different test conditions (or called 170 bags) were collected in Houston covering freeways, arterials, intersections and also idling. Testing vehicles included rental cars and trucks, as well as the volunteers' personal cars. GPS data were collected simultaneously when the emission data were collected.

All the collected data were stored in text format (GPS data is in the format of .gps, which can be used as text files.) The large amount of data were processed in EXCEL. Emissions for trucks and for cars were summarized based on different test conditions (arterial road, freeway, feeder, intersection, and idling.) The spatial and temporal distributions of both vehicle speed and emissions were plotted, and the relationships between the emissions and model variables (speed, acceleration, and engine rpm) were drawn. The measured emissions were compared with the

EPA MOBILE6.2 estimates sorted on test conditions, emission factors, and vehicle types; and significant differences were found.

It is recommended that more emission data be collected in Houston for the established data base. Also recommended is to develop a user-friendly EXCEL-based utility for the fast processing of collected data for both general purpose and for specific utilization.

CHAPTER 1

Background and Objectives

1.1 Background of Research

By 2007, the current federal standards for ground-level ozone must be complied with in Houston-Galveston Ozone Non-attainment Region. The city and the region are faced with potential loss of federal transportation funds, increased health costs, and other consequences if the compliance mandates are not meet. The impact of non-compliance for the city and the region is estimated to be as high as 4 billion dollars per year. The research analysis has found that a significant portion of the emissions came from the mobile source. In order to meet the quantitative goals in reducing the mobile source emissions, it is necessary to develop the capability to evaluate the emission impacts of various emission control technologies and strategies, and the air quality improvement projects.

The U.S. Environment Protection Agency (EPA) has developed a computer program MOBILE, which is an abbreviation of Mobile Source Emission Factor Model. The MOBILE (with the newest version MOBILE6), as well as most of the other existing emission models, is based on the emission data collected from the in-laboratory emission testing, using a dynamometer and a sophisticated bank of scientific equipment. The laboratories are expensive to run and the data collected typically do not provide accurate real world information. Moreover, vehicles testing in a traditional laboratory setting do not factor in the effects of aggressive driving, high speed operation, highly transient operation (full-throttle or "leapfrog" acceleration), air conditioning use, and local rod, traffic, and climatic conditions.

Recently, the portable emission measurement systems (PEMS) are invented to measure on-road emissions on a second-by-second basis. Montana OEM2100, which was developed by the Clear Air Technologies, Inc. (CATI), is the most advanced and recent version of the PEMS for real-word on-board emissions monitor. The device is designed to provide HC, CO, CO_2, NO_x, and O_2 readings for gasoline-powered vehicles and NO_x, CO, CO_2, O_2, PM (light scattering) readings for diesel vehicles. Latitude and longitude information of the on-board vehicle testing can be recorded by the GPS system associated with the device, so that the vehicle driving paths can be traced.

1.2 Objectives of Research

The key objectives of this research are to collect real-world vehicle emissions and activity data on freeway, arterials and local streets in Houston using Portable Emission Measurement System (PEMS); to analyze characteristics of the on-road vehicle emissions; and to evaluate and validate the mobile source emission factor model MOBILE6.

1.3 Outline of This Report

The next chapter of this report introduces the equipment that has been used in the emission testing process. Chapter 3 describes how the emission data were collected. Chapter 4 is the analysis and evaluation of the emission testing results. Chapter 5 is the conclusion and recommendations.

CHAPTER 2

Data Collection Equipment

The most advanced and recent version of the portable emission measurement systems (PEMS) is the real-world on-board emissions monitor – Montana OEM-2100, developed by the Clean Air Technologies, Inc. (CATI). This chapter introduces the basic features of this equipment.

2.1 Basic Description of Montana OEM-2100 System

The OEM-2100 System is designed to measure vehicle mass exhaust emissions under actual on-road driving conditions using vehicle and engine operating data and concentrations of pollutants in exhaust gas sampled from the tailpipe. It typically sits in the passenger seat or on the vehicle floor, and provides second-by-second emissions, fuel consumption, vehicle speed, engine rpm and temperature, throttle position, and other parameters.

The OEM-2100 Universal system is designed to work with all internal combustion engines, and equipment ranging in size from chainsaws to marine diesels has been successfully tested. Engine data can be sensed directly using an array of analytical sensors. For vehicles with a supported engine computer diagnostic port, engine and vehicle data is acquired using this interface.

The OEM-2100 unit may be placed in or on the test vehicle. For in-vehicle installation, exhaust sample lines can be routed through a window and secured to the exhaust system using hose clamps. The diagnostic port interface cable is routed to the unit from the port connector. For sensor array installations, sensors are installed on the applicable engine systems and are then routed to the OEM-2100. Power is drawn from a cigarette lighter outlet or from a cable clamped directly onto the battery. The unit is secured by adjustable tie-down straps.

Undiluted exhaust gas is sampled from the tailpipe using repair-grade probes and 20-foot (7-meter) sample lines. The concentrations of HC, CO, CO_2, O_2, and NO_x, in the exhaust gas are determined by a functional equivalent of a repair-grade dual five-gas analyzer subsystem. Particulate Matter (PM) concentration is quantified using a laser light scattering measurement subsystem. At the same time, vehicle speed, engine rpm, intake air mass flow, coolant temperature, and other engine operating parameters are collected using an on-board diagnostics connector or sensor array system. From the intake air mass flow, known composition of intake air, measured composition of exhaust, and user-supplied composition of fuel, a second-by-second exhaust mass flow is calculated. Multiplying the exhaust mass flow by the concentrations of different pollutants yields grams per second emission data.

2.2 OEM-2100 Features and Specifications

The dimensions of a typical OME-2100 are 21in by 17in by 9in (Length by Width by Height). In addition, at least 12in is needed to accommodate the sample bowls and the sample lines. Other cables and the sensor array also occupy space. The weight is less than 38 lbs with the power of 12-14 V DC (12 V nominal), 4-6 Amperes from vehicle electrical system (110V AC adapter included). There is an automatic battery backup. The gas concentrations rate is 1 Hz. The sample flow is 6 liters/minute nominal for each gas analyzer, 3.8 – 4.0 l/min through PM detector. The equipment outputs second by second with 12-second delay. The OBD data rate is 0.6 – 3.5 seconds/frame, depending on the vehicle.

The system computer is an industrial computer with the data interface of IDE compact flash memory, and the user interface is designed as the touch-screen or keyboard/keypad. All software are included in the computer. Real-time text information is displayed and the ASCII comma-delimited text file will be generated for the late analysis.

The measured parameters include time, vehicle speed, acceleration, engine rpm, engine coolant temperature, engine load, throttle position, intake air mass flow, exhaust mass flow, fuel consumption, grams per second emissions of HC, CO, NO_x, CO_2 and PM.

The operating temperature and humidity are -5 - +40^{o}C or 25-100^{o}F, 0-90% RH, non-condensing (for ambient conditions); and +5 - +35^{o}C or 40-95^{o}F, 0-90% RH, non-condensing (at instrument location).

The operating of the equipment can be in any type of on-road driving in a production vehicle. Instrument is not designed for rough off-road driving or performance driving on a racetrack. However, unit is able to withstand off road conditions typical of those encountered by construction vehicles such as backhoes, bulldozers, locomotives, marine vessels, etc.

The typical installation time is 10 to 20 minutes. The warm-up time of the equipment is limited by the gas analyzer warm-up time. The unit can be moved and installed while running.

Normally, 15 minutes warming-up time are needed for gaseous emissions only, 30 minutes for PM measurements, 60 minutes recommended for optimal accuracy.

Besides, there are several optional equipment including the global positioning system (GPS), the pre-catalyst sampler (requires drilling a hole into exhaust), the heated-sample line, the heavy-duty engine scanner, and the universal sensor array.

2.3 System Installation

Installation of OEM-2100 System included five typical steps. (1) the warm up procedure; (2) safe and convenient placement of the system; (3) establishing an appropriate source of power; (4) routing exhaust sample lines for gas and particulate matter (PM) concentration measurements; and (5) obtaining engine data for emissions flow calculation.

The simplified equation for the flow calculation is given as is illustrated in Figure 1.

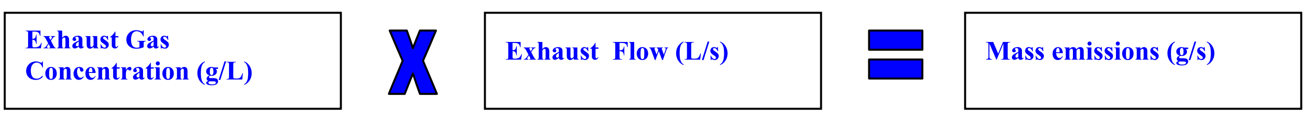

Figure 1. Mass emissions calculation.

The exhaust gas and particulate concentrations are reported by their respective analyzers. The exhaust flow is calculated by using the *instantaneous engine speed*, *intake air temperature*, and *intake air pressure*, combined with known parameters of the engine such as *displacement*. This calculation is proprietary, but generally involves a mass balance equation, whereby the matter coming into the engine must equal that matter coming out of the engine. The system computer uses these engine parameters to calculate instantaneous emissions.

The OEM-2100 has two basic ways of obtaining engine data for the flow calculation – either by obtaining the data from the *vehicle engine computer* or by *sensing the data* directly. When testing vehicles with an engine control unit (ECU) with an available diagnostic port, the system can be equipped with an ECU scanner that will communicate with the ECU and obtain any needed engine parameters. The two most common engine scanners that can be incorporated into the OEM-2100 are a heavy duty engine scanner, and a light-duty engine scanner. Engine scanners supplied with the OEM-2100 include software that allows them to communicate with most U.S vehicles.

The second method that the OEM-2100 can obtain engine data is by sensing the engine parameters directly. This method involves attaching several analog sensors to the engine itself, and is termed a sensor array installation. This type of installation is slower than an ECU scanner installation, but it allows for installation on nearly any internal combustion engine, regardless of whether the vehicle is electronically controlled or mechanically controlled.

The conceptual diagram of system installation is illustrated in Figure 2.

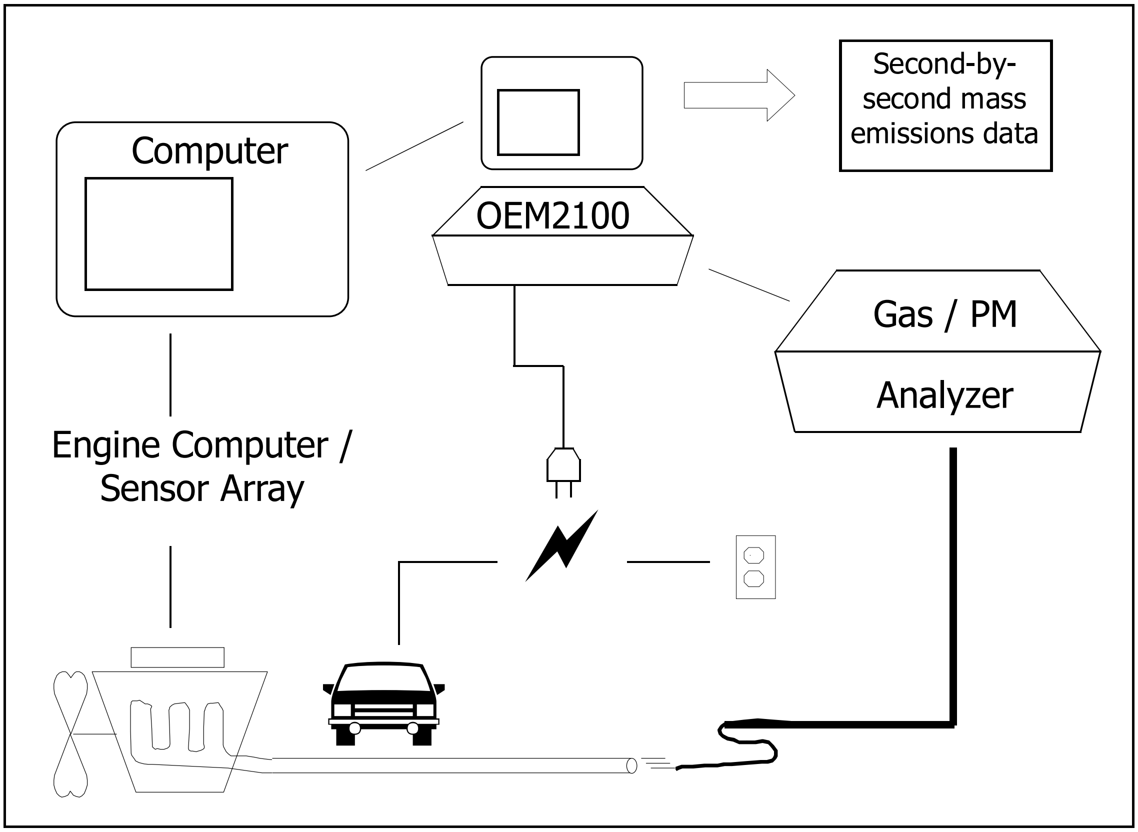

Figure 2. Conceptual diagram of system installation

For cars and trucks, the system is typically installed on the passenger seat of the tested vehicle, such that the screen and the controls are facing the driver, and all the connectors are facing the passenger door. The system can also be installed on the back seat of a car, on the floor of a minivan, in the cargo bay of a hatchback car or a pickup truck, or in any other safe and convenient location in or on a vehicle. When placing the system on a seat, a protective mat or a tarp is recommended to prevent seat damage. When testing heavy-duty vehicles such as diesel trucks, construction equipment, or off road vehicles, the equipment can be placed anywhere deemed safe for vehicle operation and user access. Some examples of system installations are given in Figure 3.

Figure 3. Examples of OEM -2100 installation locations.

2.4. System Operation

While operating the OEM2100, careful attention to detail is critical for obtaining high quality data. Successful operation of the OEM 2100 requires understanding the system, entering correct set up parameters, periodically checking that data are in reasonable ranges during real time operation, periodically calibrating the equipment, observing for leaks, pump failures or flooding, and frequently assuring that the installed hardware has not shifted or been damaged while driving.

There are five major subsystems to the OEM-2100 unit: the computer, the light-duty scanner, the heavy-duty scanner, the PM monitor, and the dual gas analyzers. When using the sensor array, the sensor array signal conditioner is an additional component that is located external to the unit.

During OEM-2100 operation, one screen, the operation screen (Figure 4), is used for instrument control and for displaying real time data output. Information is organized functionally, as described in the figure legend. Most functions can be controlled using the touch screen. To end the testing session, press the green “Press here or <esc> to exit” text at the upper right corner of the screen.

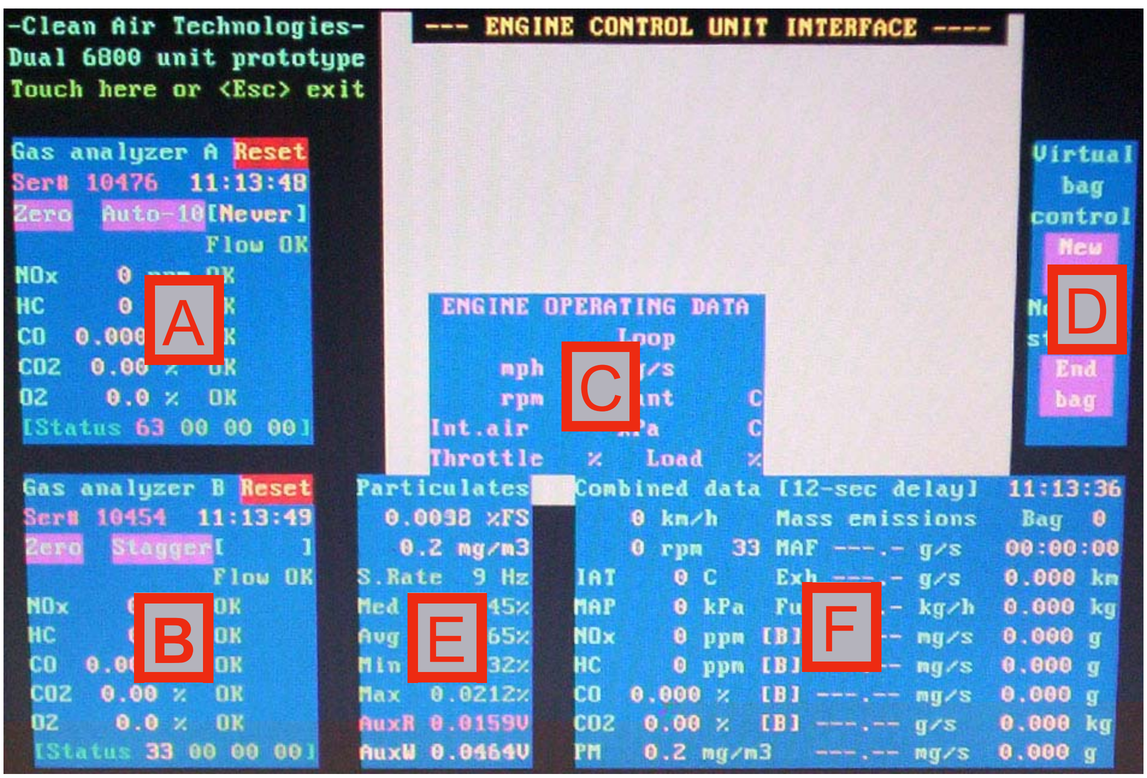

Figure 4. OEM-2100 operation screen.

The letters in Figure 4 represent different displaces. Area A is for analyzer A; area B is for gas analyzer B; area C is for engine interface display; area D is for bag control; area E is for particulate analyzer display; while area F is for combined data display. The middle upper part showing “ENGINE CONTROL UNIT INTERFACE” is called a terminal exactly displaying what are demonstrated in the OBD scanner.

It is important to mention the function of “Bag Control”, which is illustrated as in letter D in Figure 4. In many cases, it is desired to delineate tests into a set of periods of time. The OEM-2100 allows the instrument operator to tag the data output file for particular tests, and to create summary reports for each test. CATI has adopted the term “bag” for these tests. The name was borrowed from the traditional laboratory setting, where the exhaust sample from each test segment is collected in a separate physical bag, and analyzed later to obtain the amount of emissions per test segment. There is no exhaust sample stored in the OEM-2100 system, but the software integrates the distance, fuel use and emissions over the duration of each “bag,” and reports this summary at the end of the test and in the output file.

2.5. System Maintenance

In order to maintain high accuracy of gas concentration measurements, care must be exercised when servicing internal parts of the unit. Advanced training should be provided before conducting maintenance. Periodic maintenance assures that the system will run smoothly, and the data obtained are of highest quality and accuracy. System maintenance includes (1) the cleaning of the sample filtering system; (2) the sample system leak test; (3) the gas analyzer calibration; (4) the replacement of NO and O_2 sensors; (5) the cleaning of NDIR (Non-

Dispersive Infra-Red spectroscopy) sample chamber; and (6) the pump diaphragm inspection/replacement.

Motor vehicle exhaust contains a large amount of water, which needs to be removed prior to entering the analyzers. It also contains soot particles, aerosol droplets and other non-gaseous components that are being introduced into the PM analyzer, but need to be removed before entering the gaseous pollutants analyzers. The external sample filtering system, located on the back of the unit, consists of a water-separating filter bowls for gaseous and particulate measurement systems, and an internal cylindrical paper filter for the gaseous measurement sample inlet. The condition of the filter should be checked daily, and when testing vehicles with high emission levels, every few hours. The filters should be serviced if the internal paper filter looks noticeably dirty, or every 20-30 hours of testing.

Periodically, the sampling system should be checked for leaks. Leaks degrade the analyzer response time, and are detrimental to the accuracy of the measurement. A leak test is performed using the sample leak test kit. If the analyzer fails the leak test, visually check the entire sampling system – including the sample probe and sample probe cap, the connection between sample line and sample probe, the sample probe (for leaks and scuffs), and the sample inlet, including the water -separating filter bowl. Often the problem is located in one of these areas. It is rare for a leak to occur inside the instrument. If a leak should occur inside the instrument, the repairs should be referred to CATI in order to ensure trained and qualified personnel perform the repairs.

The gas analyzer NDIR subsystem used in the OEM-2100 system is very stable and usually needs to be calibrated only once every three months. Even units not calibrated for over a year tend not to drift from their calibration. The NO and O2 sensors deteriorate with use, and need to be calibrated about once a week to once a month during regular use, or about every 25-50 hours of use. In addition to the regular calibration intervals, the system needs to be calibrated every time a gas analyzer component (especially NO or O2 sensor) is replaced, or if the NDIR sample chamber is cleaned. More frequent calibration is recommended during tests that cannot easily be repeated, or when highest accuracy and repeatability is desired. Also, any time the OEM-2100 system is working in tandem with another system and the correlation between the external and the OEM-2100 data is of importance, both systems should be calibrated with the same calibration gas.

The most universal calibration gas mixture recommended for general testing is a BAR 90 "high" mixture of approximately 12% CO_2, 4% CO, 2000 ppm NO, and 1200 ppm propane. If only clean vehicles are tested, the CO, NO and propane concentrations should be lower, approximately three quarters of the highest concentration measurement that is desired to be accurate. The calibration gas is available from industrial gas suppliers.

NO and O_2 sensors are electrochemical cells that get used up when detecting gases (and to a lesser extent just by sitting on the shelf). The sensors are shown in Figure 5. The gas analyzer keeps track of the life of the NO and O_2 sensors and gives a warning if a sensor is nearing the end of its life. Also, a sensor needs to be replaced when it can no longer be calibrated. At a minimum, NOx and O_2 sensors should be replaced annually, or after approx. 500 hours of testing if the unit is used extensively. The power to the unit must be off before attempting this operation, and the unit must be thoroughly warmed up and calibrated after replacing a sensor.

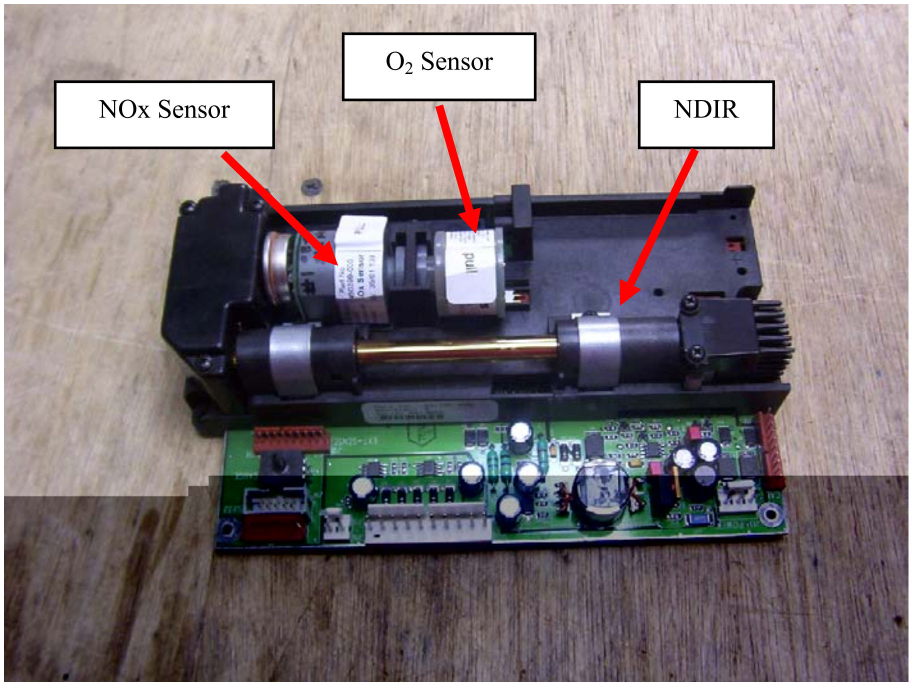

Figure 5. NO_x, O_2 and NDIR sensors.

Every vehicle emits oily substances, as a result of small (on normally functioning vehicle) amount of engine oil in the combustion chamber. Although most of heavy hydrocarbons (oily substances) are captured on the filters, some make it through the filters and condense on the NDIR sample chamber optics. A typical sign of NDIR sample chamber contamination is excessive drift in HC readings while sampling ambient air (even after unit is fully warmed up, drift of ± 5 ppm is normal). This drift is most pronounced shortly after unplugging the sample line from the unit, but may also be caused by dirty filters. Periodically, the sample chamber walls and lenses need to be cleaned with isopropyl alcohol and lint-free fabric to remove any residues from the lenses. The power to the unit must be off before attempting this operation.

As a result of normal unit functioning, a buildup of engine soot can occur on the internal parts of the pumps and will require cleaning. Additionally, the pump diaphragms degrade with use and will eventually fail. This is normal and can be easily repaired by replacing the pump diaphragm(s). Periodically, the pumps should be inspected and cleaned, and the diaphragms replaced as needed. The pump parts can be cleaned with isopropyl alcohol and lint-free fabric to remove any residue. The power to the unit must be off before attempting this operation.

CHAPTER 3

On-Road Emission Data Collection

In this chapter, the way how the emission data were collected will be described. The data collection plan will be introduced first. Then the procedure how the data were collected will be presented. Finally, the encountered problems during the data collection procedures will be listed.

3.1 Data Collection Plan

The data collections were planned to cover different vehicle types with different ages and mileages; different fuel types; different testing routes (freeways, arterial roads, local roads, CBD areas, signalized intersections, frontage roads, etc); different dates, times and weathers (morning, afternoon, sunny, cloudy, raining, different seasons, etc.) The data collected included the emission data (CO, CO_2, HC, NO_X, PM, etc.), activity data (speed, acceleration, rpm), and GPS data.

The main body of the testing vehicles was from the rental car companies. Others were personal cars from volunteers'.

3.2 Data Collection Training

Since the OEM-2100 System is a very sensitive scientific device, the research team was trained by CATI (Clear Air Technologies International, Inc.) technicians. The training was arranged into three rounds: the training in Buffalo, the training in Houston, and the closely communication in testing.

In the first round, the researchers went to the company in Buffalo, New York State from November 12 through 15, 2003, and were trained by all the developers of OEM-2100. Training courses included:

(1) the theories of measuring vehicle exhausted flow;

(2) the operational mechanisms of OEM-2100 Montana System;

(3) the maintenance of the equipment;

(4) the design of field test;

(5) the way to process collected data;

(6) the experiences on testing idling emission;

(7) the coordination of GPS system; and

(8) the processing of some basic hardware problems when testing.

The other activity during the Buffalo training was to practice the field test in Buffalo, NY. A truck and a car were selected as the testing vehicles and the researchers practiced all steps on how to place the equipment in vehicle, how to connect all the cables, how to operate the system, and how to read and manage the on-screen data when testing. After testing, the researchers also learned how to retrieve the generated second-by-second emission data and process them in computer. During the period of the first training, the researchers got to know the basic principles and how to manage the equipment. Figure 6 shows the researches being trained for field test of heavy duty truck in Buffalo, NY.

Figure 6. Field test training in progress in Buffalo, NY

After the Buffalo training, pioneer tests were conducted in November 25, 2003 (a GM Sedan 2002 car), and December 2, 2003 (a Diesel 24 ft 1999 Truck). Data processing was practiced afterwards when analyzing these collected data. Procedures and techniques that were suitable for the data processing of the particular research project were generated, so that the following data processing of the tests can be easily followed.

During the pioneer tests, the NDIR sensor for Analyzer A failed to work. Also it was found that the associated GPS system could not work very well and the researchers felt that more training on applying sensor arrays, system maintenance, and data processing were necessary. So a second round training and problem fixing were conducted at Texas Southern University, Houston, TX by a technician from CATI.

During the second round training in Houston, the CATI technician helped to fix the problem on the GPS system, replaced the NDIR sensor, illustrated the sensor array placement in the engine compartment, and shared their experiences on large number of data processing. Figure 7 is an illustration on the sensor array placement during the Houston training.

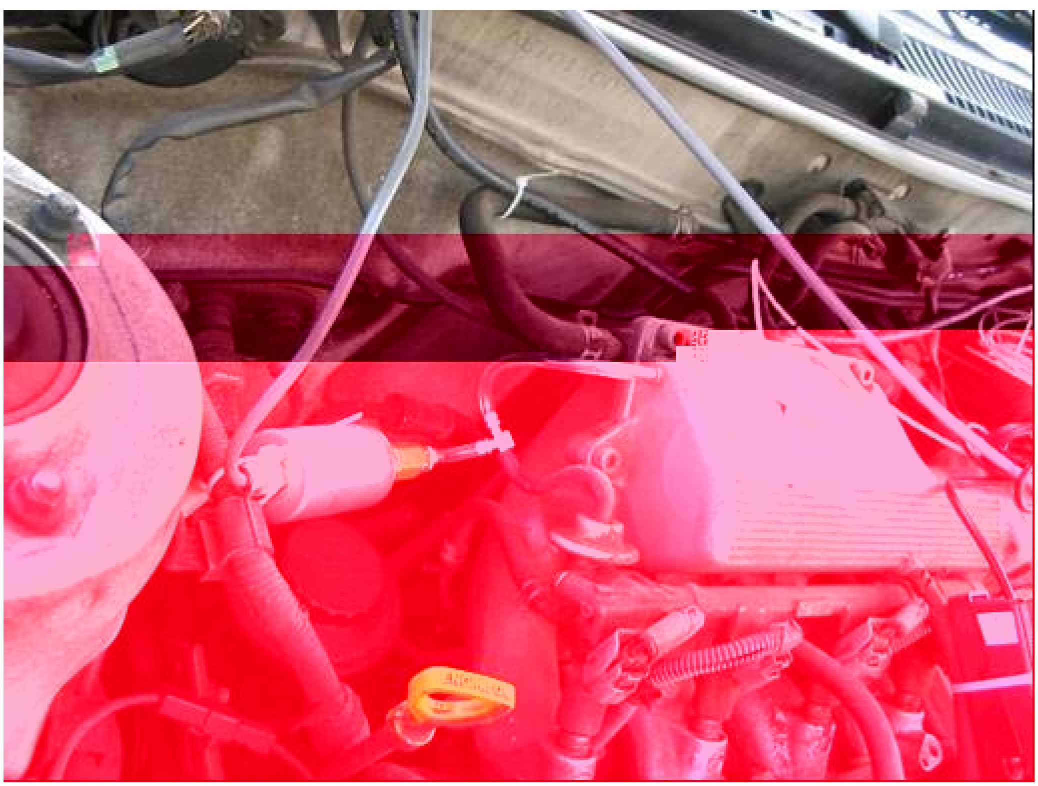

Figure 7. Sensor array placement in the engine compartment during the Houston training

Different from the first two rounds, the third round of training was provided throughout the testing process. Every time when there was a problem, the close communication with the technicians in CATI through phone and e-mail was conducted and ways on how to solve the problems were discussed. The trained techniques during this round included how to handle the problem when the engine information of vehicles could not be uploaded into the channel of the equipment; what countermeasures were needed if there was a warning saying "the system is overheated;" how to transfer the data if the system was shut down improperly; etc.

3.3 Data Collection Procedure

Data collection was conducted in Houston during the first three months of the year 2004. For each of the test, the vehicle information sheet and the test information sheet were filled in order to help tracing the testing conditions for the data processing purpose. Figure 8 is the designed vehicle information sheet, while Figure 9 is the test information sheet.

Vehicle Information

Date	**Engine Make**
Make	**Engine Model**
Model	**Turbo(Y/N)**
Body Type	**Engine displacement (required)**
Color	**Cylinders**
Owner	**Fuel Injected or carbureted**
Mileage at start	**Fuel Type**
License Plate	**Transmission (make/automatic)**
VIN #	

Please note any observations about the vehicle, including mechanical problems.

Figure 8. Sample vehicle information sheet

Test Information Sheet

Date:	Location:
Driver:	OBD/Sensor Array:
Technician:	Air Temperature:
Others Present:	Humidity:
Vehicle:	Weather:

Describe the tests to be performed. Draw map if needed.

Filename	Bag	Time	Test	Notes

Figure 9 Sample test information sheet

There were a total of six vehicles involved in the data collection. Ten full working days were occupied by the tests with some days having two vehicles in testing. Table 1 lists the vehicles and date chosen for testing.

TABLE 1 Vehicles and dates chosen for testing

Testing Date	Vehicle Types	Model and Make	Year Made	Mileage at start	Source
January 22	Car	Chevy	2003	700	Rent
January 22	Car	Toyota Corola	1994	150,000	Volunteer
January 23	Truck	International	2000	60,000	Rent
February 17	Truck	Ford E-350	2001	54,258	Rent
February 18	Truck	Ford E-350	2001	54,258	Rent
February 18	Car	Ford Taurus	1997	120,000	Volunteer
March 25	Truck	International	2004	300	Rent
March 26	Truck	International	2004	300	Rent
March 27	Truck	International	2004	300	Rent
March 29	Truck	International	2004	300	Rent
March 30	Truck	International	2004	300	Rent
March 31	Truck	International	2004	300	Rent

During the tests, a total of 170 bags were designed. Typically, each bag represented one specific road facility characteristics. Some bags contained two or more roadway facilities. Table 2 lists the number of bags that were set during the tests in terms of the roadway facilities.

TABLE 2 Number of bags set in terms of roadway facilities.

Roadway Type	Code	Number of Bags
Arterial	A	19
Freeway	F	56
Feeder	Fe	5
Intersection	I	49
Idling	Id	38
Intersection + Freeway	I + F	2
Idling + Intersection + Freeway	Id + I + F	1
Total		170

Table 3 provides more detailed information on the bag settings of each testing vehicle for each day. In Table 3, the filename was defined by the system software. The first letter has no special meaning, while the number next to the first letter represents it was in 2004. The following 4 digits stand for the month and the date. The last letter sequences from A to Z chronically. There might be several bags in one file depending on the analytical purposes. In this research, the settings of bags were basically related to the roadway types traveled. The codes of roadway types in Table 3 are the same as in Table 2.

TABLE 3 Data collection information

Name of test	Filename	Bag Number	Road Type	Vehicle Type
Jan2204A	D40122D	2	Id	Car
	D40122D	3	I	
	D40122D	4	I+F	
	D40122D	5	Id	
	D40122D	6	I	
	D40122D	7	F	
	D40122D	8	I	
Jan2204B, Jan2204C	D40122H	1	I	Car
	D40122H	2	F	
	D40122H	3	F	
	D40122H	4	F	
	D40122H	5	A	
Jan2304A	D40123H	1	F	Truck
	D40123H	2	F	
	D40123H	3	F	
	D40123H	4	F	
	D40123H	5	F	
	D40123H	6	I	
Jan2304B	D40123L	1	A	Truck
	D40123L	2	A	
	D40123L	3	A	
	D40123L	4	A	
	D40123L	5	I	
	D40123L	6	I	
Feb1704A	D40217	0	F	Truck
	D40217	1	F	
	D40217	2	F	
	D40217	3	F	

	D40217	4	F	
	D40217	5	I	
Feb1804A	D40218F	1	Id	Car
	D40218F	2	I	
	D40218F	3	F	
	D40218F	4	F	
	D40218F	5	Id	
	D40218F	6	A	
	D40218F	7	I	
	D40218F	8	Id	
Feb1804B	D40218B	1	Id	Truck
	D40218B	2	I	
	D40218B	3	F	
	D40218B	4	A	
	D40218B	5	A	
	D40218B	6	F	
	D40218B	7	I	
	D40218B	8	Id	
Mar2504A	D40325B	1	Id	Truck
	D40325C	0	Id	
	D40325D	1	Id	
	D40325D	2	I	
	D40325E	1	I+F	
	D40325E	2	Id	
Mar2504B	D40325E	3	I	Truck
	D40325E	4	I	
	D40325F	1	A	
	D40325F	2	A	
	D40325G	1	A	
	D40325G	2	A	

	D40325G	3	A	
	D40325G	4	I	
	D40325G	5	I	
Mar2504C	D40325G	6	I	Truck
	D40325G	7	F	
	D40325G	8	F	
	D40325G	9	F	
	D40325G	10	F	
	D40325G	11	I	
	D40325G	12	Id	
Mar2604A	D40326C	1	I	Truck
	D40326C	2	I	
	D40326D	1	I	
	D40326E	1	I	
	D40326F	1	I	
	D40326F	2	I	
	D40326F	3	Id	
Mar2604B	D40326G	1	F	Truck
	D40326G	2	Id	
	D40326H	1	Id	
	D40326H	2	Id	
	D40326H	3	Id	
	D40326H	4	F	
	D40326I	1	F	
Mar2804A	D40328D	1	Id	Truck
	D40328D	2	F	
	D40328D	3	A	
	D40328E	0	F	
	D40328E	1	F	
	D40328F	1	F	

	D40328F	2	F	
	D40328F	3	F	
	D40328G	2	F	
	D40328G	3	I	
	D40328G	4	0	
	D40328G	5	Id	
Mar2804B	D40328G	6	F	Truck
	D40328H	1	F	
	D40328I	1	F	
	D40328I	2	Id+I+F	
	D40328I	3	F	
	D40328J	1	F	
	D40328K	1	F	
	D40328K	2	F	
	D40328K	3	I	
	D40328L	0	Id	
Mar2904A	D40329B	1	Id	Truck
	D40329D	1	I	
	D40329G	1	A	
	D40329G	2	F	
	D40329G	3	Fe	
	D40329H	1	Fe	
	D40329H	2	Fe	
	D40329H	3	F	
	D40329J	1	F	
	D40329J	2	F	
	D40329J	3	I	
Mar2904B	D40329K	1	I	Truck
	D40329L	1	I	
	D40329L	2	I	

	D40329N	1	I	
	D40329O	1	I	
	D40329P	1	I	
	D40329Q	1	I	
	D40329Q	2	Id	
Mar2904C	D40329R	1	Id	Truck
	D40329S	1	Id	
	D40329S	2	I	
	D40329S	3	F	
	D40329T	1	F	
	D40329T	2	F	
	D40329T	3	F	
	D40329T	4	I	
	D40329U	1	Id	
Mar3004A	D40330B	1	Id	Truck
	D40330B	2	Id	
	D40330B	3	I	
	D40330B	4	A	
	D40330C	1	A	
	D40330C	2	A	
	D40330D	1	A	
	D40330D	2	F	
	D40330E	1	F	
	D40330E	2	F	
	D40330F	1	F	
	D40330G	1	F	
	D40330H	1	F	
	D40330I	1	I	
Mar3004B	D40330J	1	I	Truck
	D40330J	2	I	

	D40330K	1	I	
	D40330K	2	F	
	D40330L	1	F	
	D40330L	2	Fe	
	D40330M	1	Fe+F	
	D40330M	2	F	
	D40330M	3	I	
	D40330N	1	Id	
	D40330O	1	Id	
Mar3104A	D40331E	1	Id	Truck
	D40331E	2	I	
	D40331F	1	I	
	D40331G	1	I	
	D40331H	1	I	
	D40331H	2	I	
	D40331H	3	Id	
Mar3104B	D40331B	1	Id	Truck
	D40331C	1	Id	
	D40331C	2	Id	
	D40331D	1	Id	
	D40331D	2	Id	
	D40331D	3	Id	
	D40331D	4	Id	

3.4 Problems Encountered during Data Collection

There were several problems encountered during the data collection process. Generally speaking, the workloads for the data collection and the data processing have been much higher than what were estimated in the research proposal, not only because the equipment that was used is a newly developed and needs a longer time to be learned, but also owing to the fact that there were so many practical factors affecting the data collection process. The following provides some major problems encountered.

1. It is hard to find the old rental vehicles (some tested old vehicles were personal vehicles from the volunteers.) Owing to the limitation of the rental vehicles, the vehicle age and mileage could not be chosen subjectively.
2. Restricted by the field conditions, it was necessary to spend a considerable amount of time on fixing the hardware problems of the instrument. Although the equipment is newly developed and advanced, it crashed time by time during the testing (this would increase the workload of data processing.) Sometimes the tests had to be terminated waiting for CATI technicians to come.
3. The setting of bags in the field tests may not match what had been designed exactly. This could be corrected in the data processing process. However, the workload might also increase.

CHAPTER 4

Analysis and Evaluations

This chapter deals with the analysis and evaluations of the collected emission data. The data processing procedures will be provided first. Then, measured emissions for trucks and for cars will be summarized based on different test conditions. Besides, the temporal and spatial distributions of emissions will be analyzed. After that, the relations between emissions and model variables (speed, accelerations, rpm, etc.) will be presented. Subsequently, the measured emissions are compared with MOBILE6.2 factors. Finally, other opportunities for using the measured emission data will be provided.

4.1 Procedures on Data Analysis and Evaluations

The generated emission data and GPS data were second-by-second data. Special data processing procedures were needed in order to analyze and evaluate the data. After the pioneer tests in late November, 2003 and early December, 2003, the procedures on data analysis and evaluations were initially produced and further improved when analyzing the collected data.

The following is the general description of the data processing procedure.

Step 1. Controlling data quality

Data quality control included interpreting and eliminating the error and missing data. For example, for some reasons, the vehicle speed increased 200 mi/hr in one second, which is obviously impossible. This kind of speed would be smoothed by the speed before and after that particular temporal point.

Step 2. Summarizing data for each bag

Summarized data analysis included the summary of the total / average emissions for each bag in terms of mileage and/or time spent. This provided the comparable emissions for different tests and for different bags. The summarized results could also be used for the comparisons with other model estimates. The step repeated for each of the 170 bags.

Step 3. Plotting speed diagrams

Speed is one of the important factors in vehicle traveling. In step 3, the temporal and spatial speed diagrams for each test were plotted. The temporal speed diagrams would come from either the emission data base or the GPS data base. However, the spatial speed diagram would employ the longitude and latitude coordinates from the GPS data base. If the speed data in GPS file was good enough, all speed diagrams could be plotted by using GPS data.

Step 4. Plotting temporal and spatial distribution of emissions and fuel consumptions

Temporal distribution of emissions and fuel consumptions could be conducted by analyzing the emission data base directly. In analyzing the spatial distribution of emissions and fuel consumptions, it is important to relate the emission data and their corresponding GPS data. Since emission data and GPS data came from two different sources, time is the only factor that could connect them together. However, due to the different settings, the time line on emission data base may not be matched with the GPS time. Time alignment is very important here. After correctly synchronized time, the spatial analysis could be conducted. The emissions that were taken into account in data analysis are HC, CO, CO_2, NO_x, and PM.

Step 5. Plotting the relationships between emissions / fuel and Model Variables (Speed, Accelerations, rpm)

Since both the emissions and the model variables were generated with time, it is natural to observe their relationships by plotting their temporal distributions in one figure. For example, if the relationships between HC and acceleration are compared, the temporal distributions of both HC and acceleration can appear in a single figure. In this way, it would be easy to identify how the emission of HC varied with acceleration along time.

Step 6. Comparing the measured emissions with that were calculated by models (e.g. MOBILE6.2)

After analyzing the collected emission data, the measured emissions could be generated. Considering the fact that, the emission factor model MOBILE6.2 is employed nationwide, it would be interesting and important to compare the measured emissions with the MOBILE emission factors.

4.2 Bag-based Emission Analysis

After controlling the data quality, the original bags that were set during the tests were re-calibrated to better meet the research needs. The total / average emissions for each bag in terms of mileage and/or time spent were calculated for the newly set bags. This work repeated for all the 170 bags.

The bag-based summary of emissions can present the general information regarding different testing conditions such as vehicle type, roadway facilities, etc. The analysis was conducted for trucks and for cars, respectively. The trucks involved in this research correspond to the MOBILE6.2 defined HDGV3 and HDDV6; while the cars involved to LDGV.

Table 4 listed the truck emissions by summarizing the collected data. The emission indexes measured include NO_x, HC, CO, CO_2, and PM. Besides, fuel consumption was also measured and compared in Table 4. In Table 4, the comparisons were based on gram per mile (g/mi) for roadway type "Arterial," "Freeway," "Feeder," and "Intersection;" and on gram per minute (g/min) for idling tests.

TABLE 4 Truck emissions by summarizing collected data

Road Type	**NO_x [g/mi]**	**HC [g/mi]**	**CO [g/mi]**	**CO_2 [g/mi]**	**PM [g/mi]**	**Fuel [Gal/mi]**
Arterial	7.3801	0.6701	1.7616	977.4	24.9490	0.1003
Freeway	8.1155	0.9047	**3.1242**	**1223.7**	37.8218	**0.1271**
Feeder	6.9246	0.6114	1.9456	1077.5	0.1255	0.1076
Intersection	**10.3603**	**1.4340**	3.0398	1149.1	**169.5120**	0.1175
All Roads	8.5126	0.9874	2.8229	1156.8	67.5718	0.1193
Condition	**NO_x [g/min]**	**HC [g/min]**	**CO [g/min]**	**CO_2 [g/min]**	**PM [g/min]**	**Fuel [Gal/min]**
Idling	0.0319	0.0948	35.3420	0.4557	0.0219	0.8517

From Table 4, it is shown that the emissions for different tests are quite different, implying the fact that the on-road emission tests are very important for correctly understanding the emission characteristics in Houston area. For example, the measured emission NO_x varies from 6.9246 to 10.3603 when driving on different types of road. It should be noticed that the PM value for "Feeders" is extremely smaller than the others. This phenomenon could be further identified via more tests.

Figure 10 through 15 illustrated the emissions and fuel consumptions for trucks under different locations. From theses figures it is obvious that basically emissions were very high when the trucks drove around intersections, especially for NOx, HC and PM, and also for CO. This is probably because it is hard for trucks to make turning when driving on small roads around intersections. So the extra accelerations and deceleration when turning caused higher emissions.

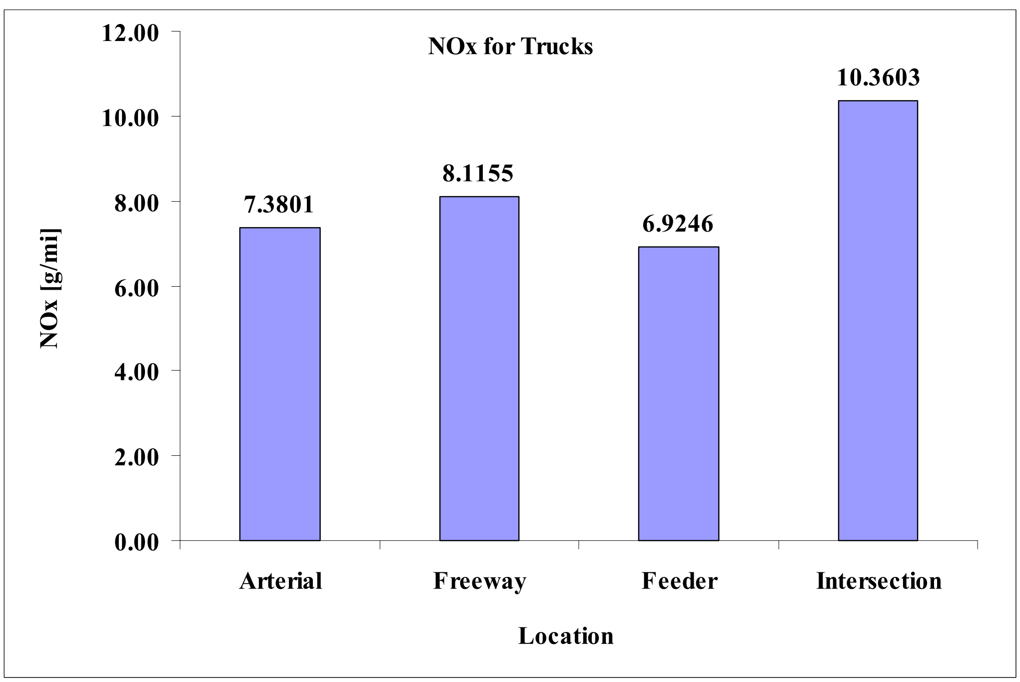

Figure 10. NO_x for trucks

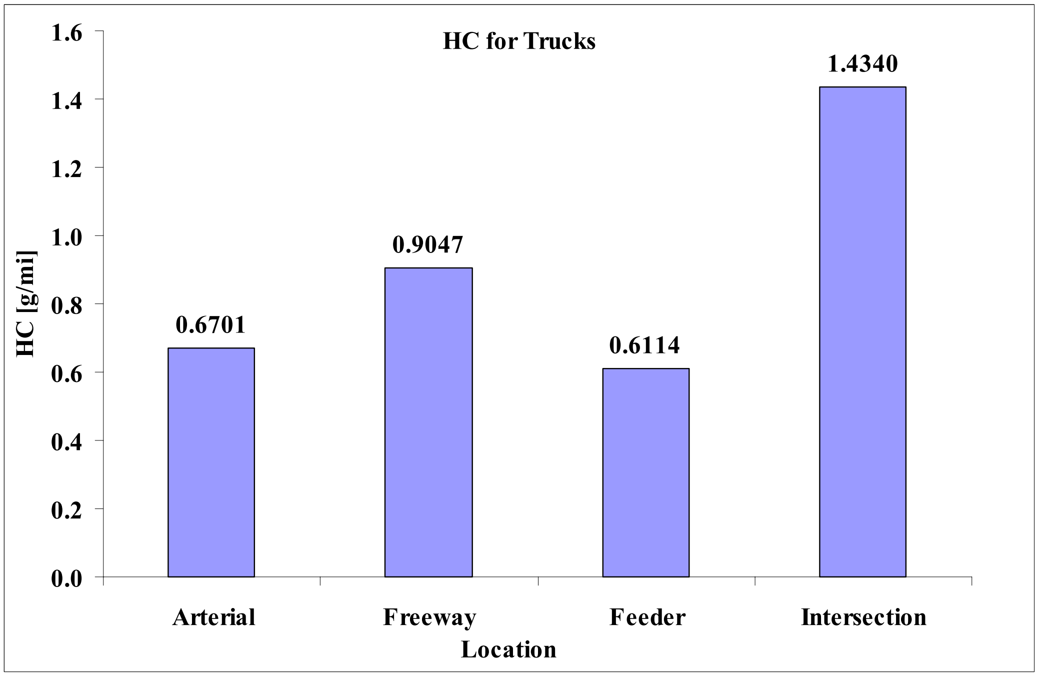

Figure 11. HC for trucks

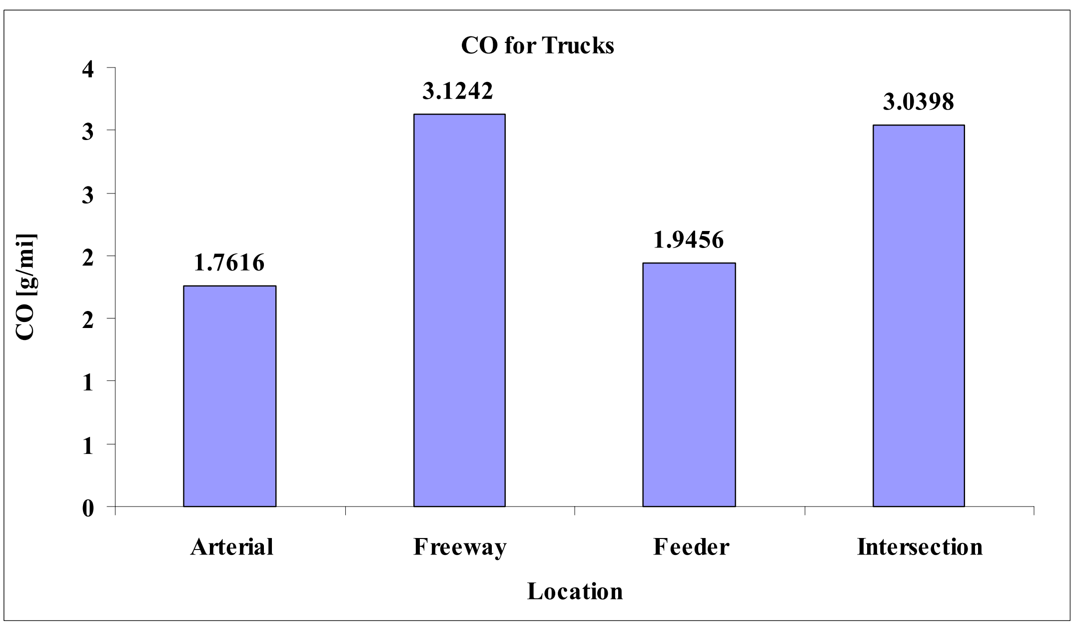

Figure 12. CO for trucks

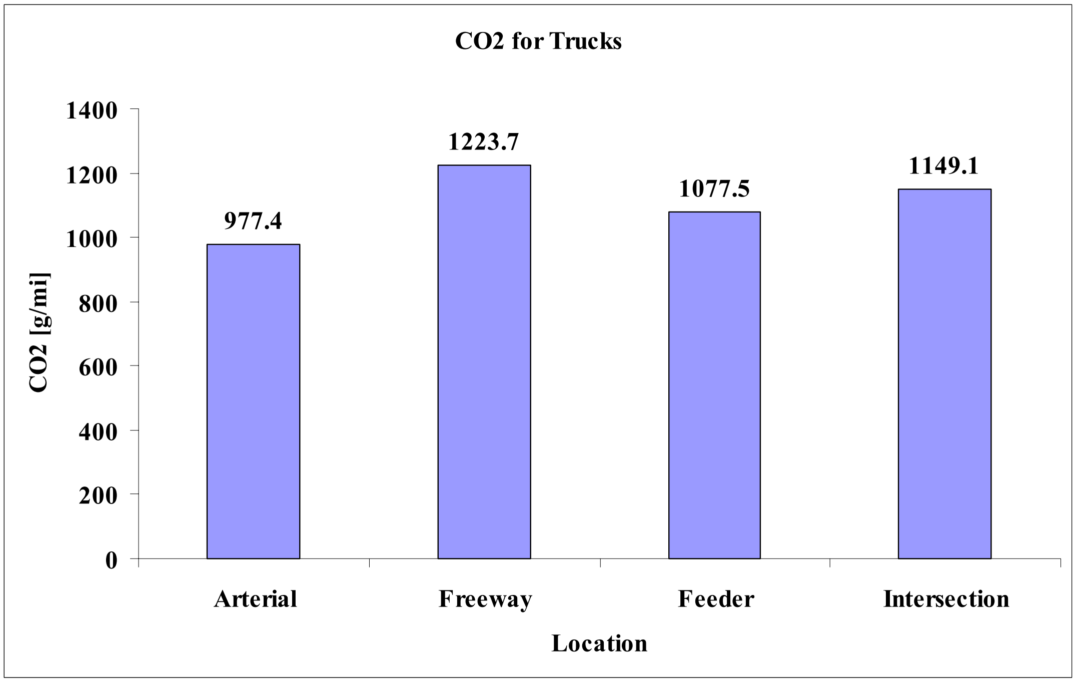

Figure 13. CO_2 for trucks

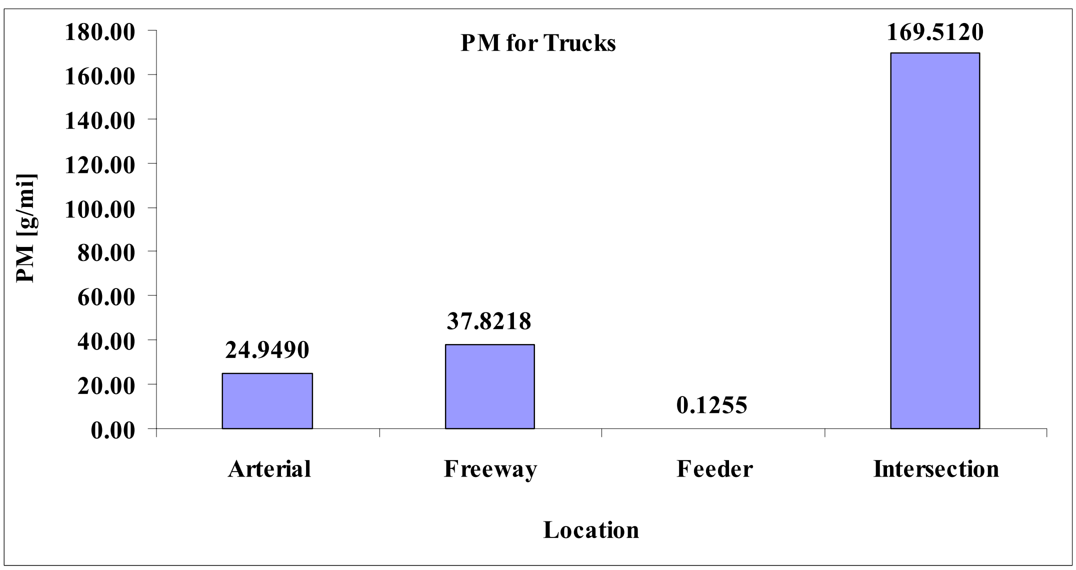

Figure 14. PM for trucks

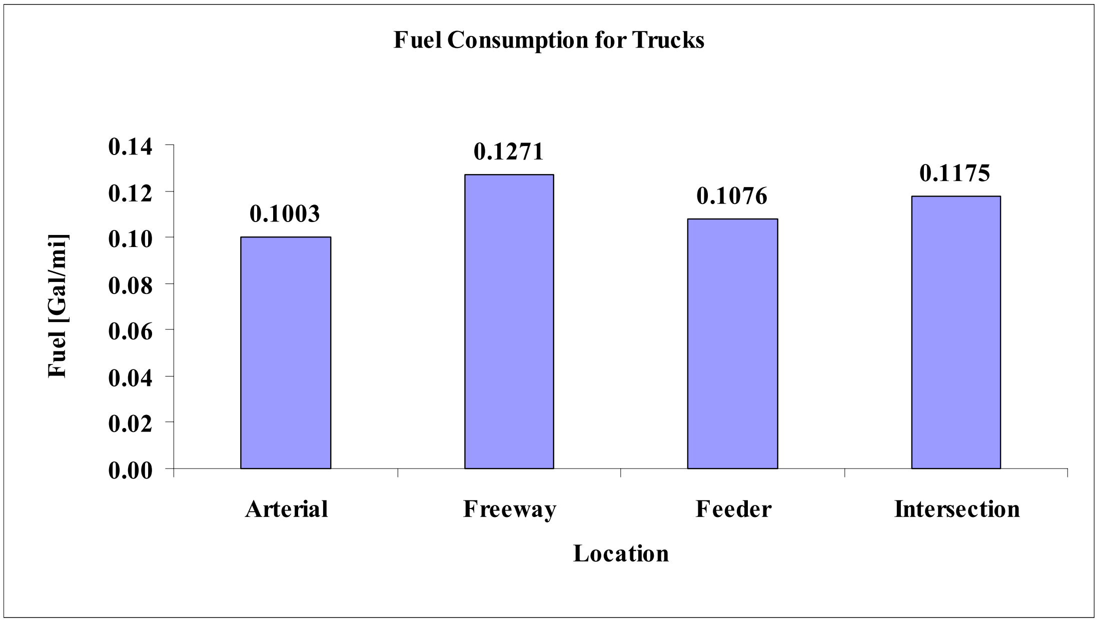

Figure 15. Fuel consumption for truck

The table and figures illustrating the emissions for test cars are in Table 5 and in Figure 16 through 19. Similar to the case of trucks, the measured emissions varies with the road types that the cars drove. For cars, the relative higher emissions occurred when driving not only around intersections, but also on arterial roads, where more stops and therefore decelerations / accelerations are normally needed.

TABLE 5 Car emissions summarized from collected data

Road Type	NO_x [g/mi]	HC [g/mi]	CO [g/mi]	CO_2 [g/mi]	Fuel [Gal/mi]
Arterial	**2.4798**	0.5271	14.7475	**504.4681**	0.0597
Freeway	1.4813	0.2219	4.5354	276.3711	0.0840
Feeder	1.5626	0.1464	6.5745	296.5108	0.9775
Intersection	2.4155	0.3687	**14.8523**	478.3951	**1.7778**
All Roads	1.8530	**0.7710**	7.4959	355.4741	0.0466

Road Type	NO_x [g/min]	HC [g/min]	CO [g/min]	CO_2 [g/min]	Fuel [Gal/min]
Idling	0.0437	0.6798	0.1157	35.6919	0.0059

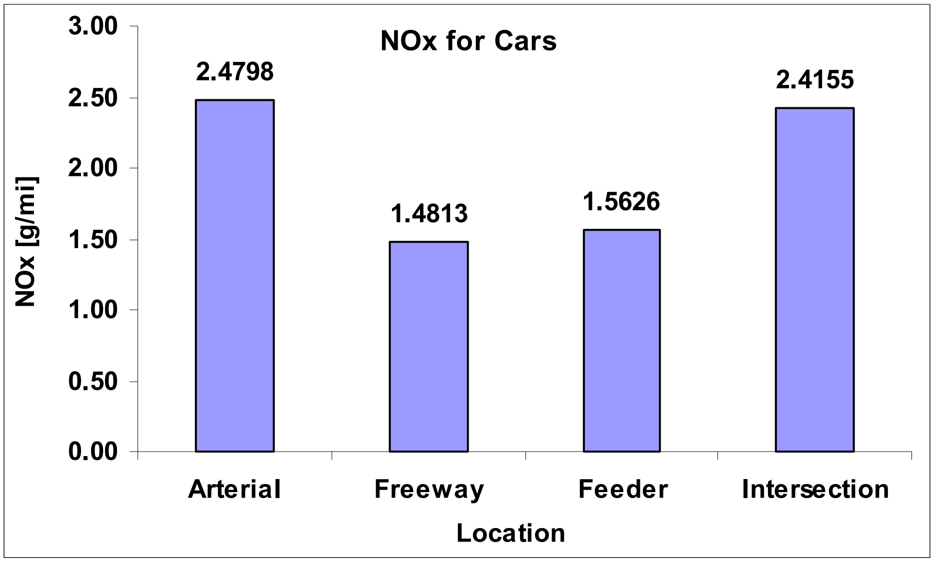

Figure 16. NO_x for cars

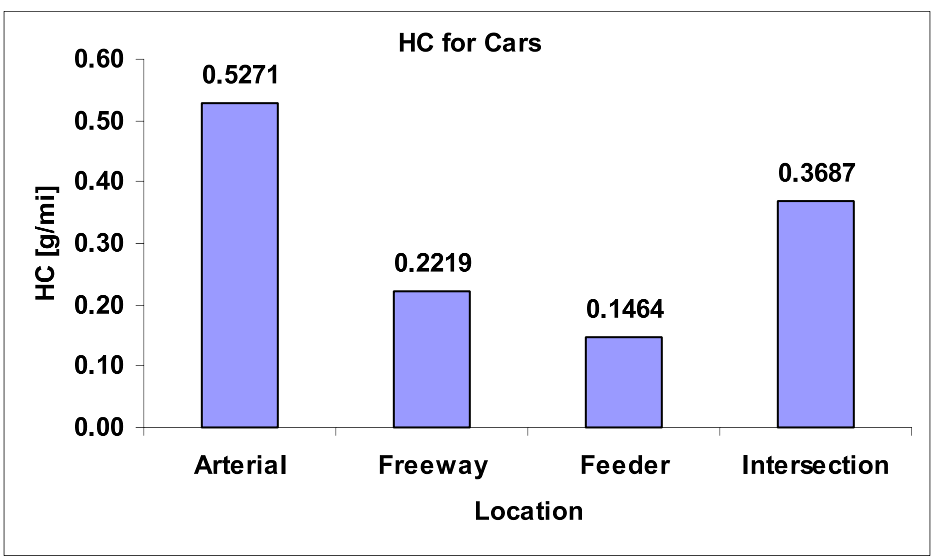

Figure 17. HC for cars

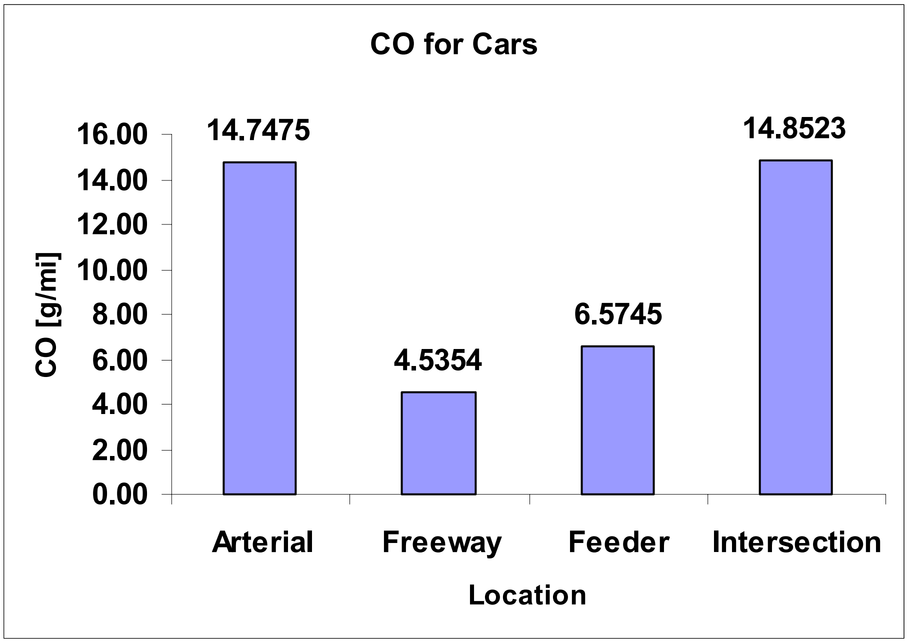

Figure 18. CO for cars

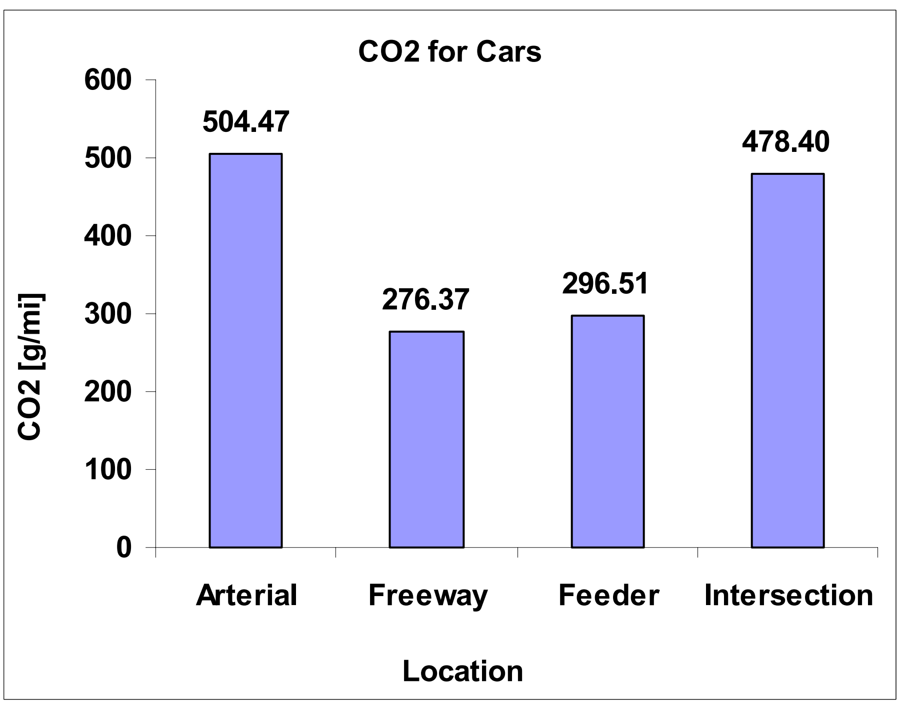

Figure 19. CO_2 for cars

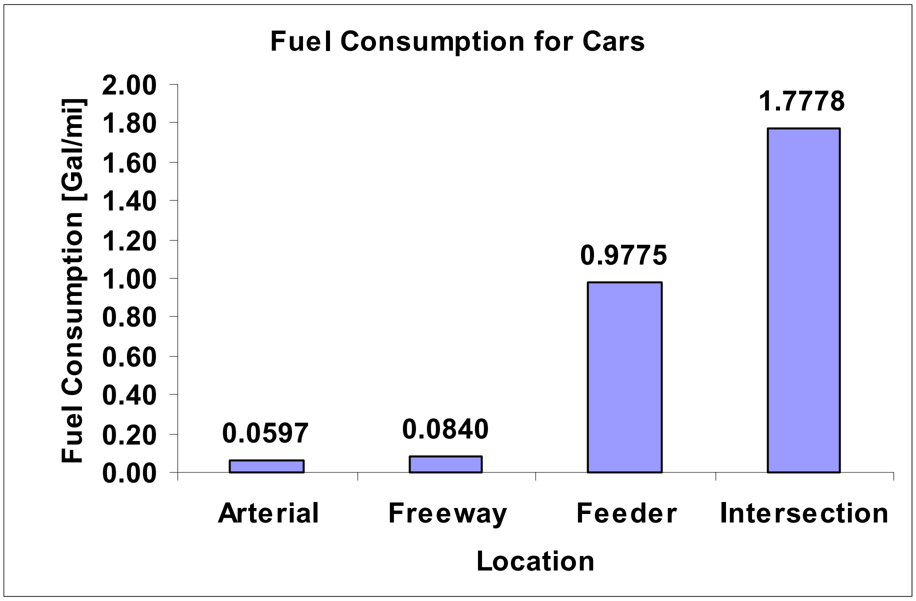

Figure 20. Fuel consumption for cars

4.3 Spatial Distributions of Emissions

The temporal and spatial distributions of emissions are important for understanding how the emissions were distributed. Since the temporal distributions of emissions will be included in the next section on "Relationships between Emissions and Model Variables," only spatial distributions will be presented in this section.

Since there are so many tests conducted, it is not necessary to show all the figures here in this section. The following figures (Figure 21 through Figure 28) illustrate the truck spatial distributions of speed, emission and fuel consumption on March 25, 2004 in Houston. The tested 24 in truck (with the MOBILE6.2 vehicle type HDDV6) started from TSU campus (southwest of Downtown Houston), towards north of Downtown, then US-59 south, I-610 south, I-610 east, 288 North, and back to TSU campus. The total driving distance was 21.45 mi. In Figure 21 rough Figure 28, th backgro d maps were taken from Yahoo

ude coordinates w re take om the GPS data, which were r

a. The sizes of the bobbl theses figures represent the m

eed, emissions and fuel c ption. The thi k part represen

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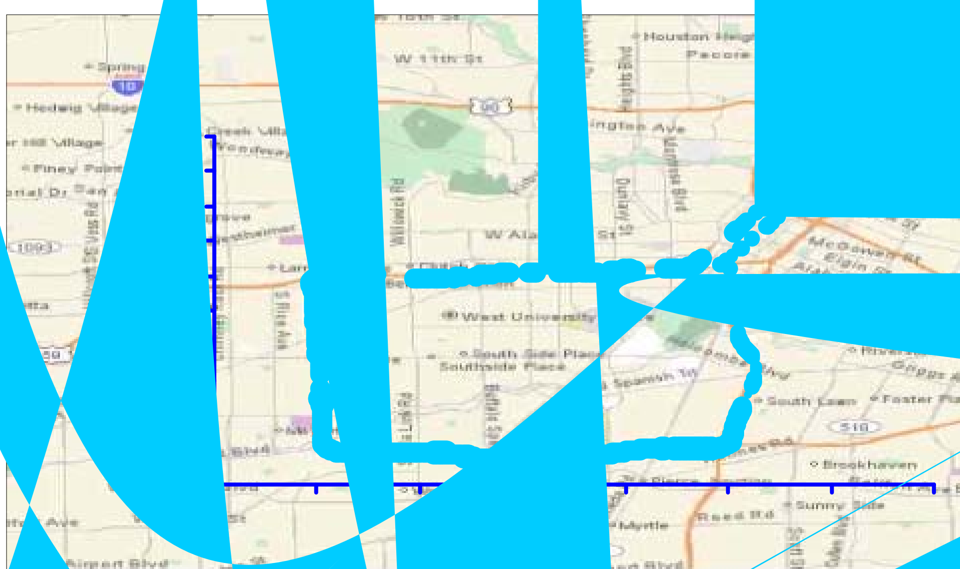
han on local roads. In Fig rough Figure 8, it is seen tha

fuel consumption vary road, especi ly for PM in F

alues are very small b t s elatively big.

For the spatial char s of the tests other days, si

diagrams of which are p the appendix this report.



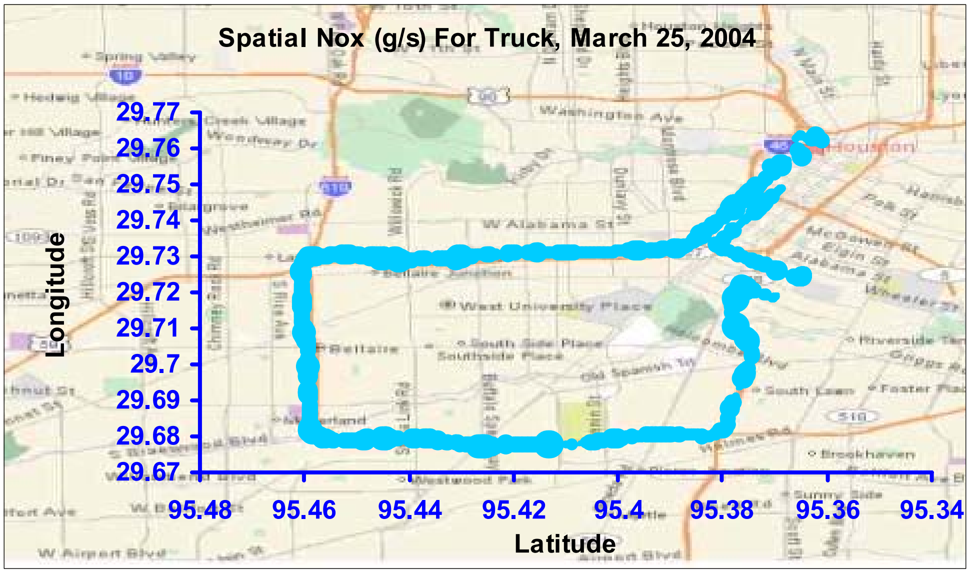


Figure 22. Truck spatial NO_x distributions for the test on March 25, 2004 in Houston

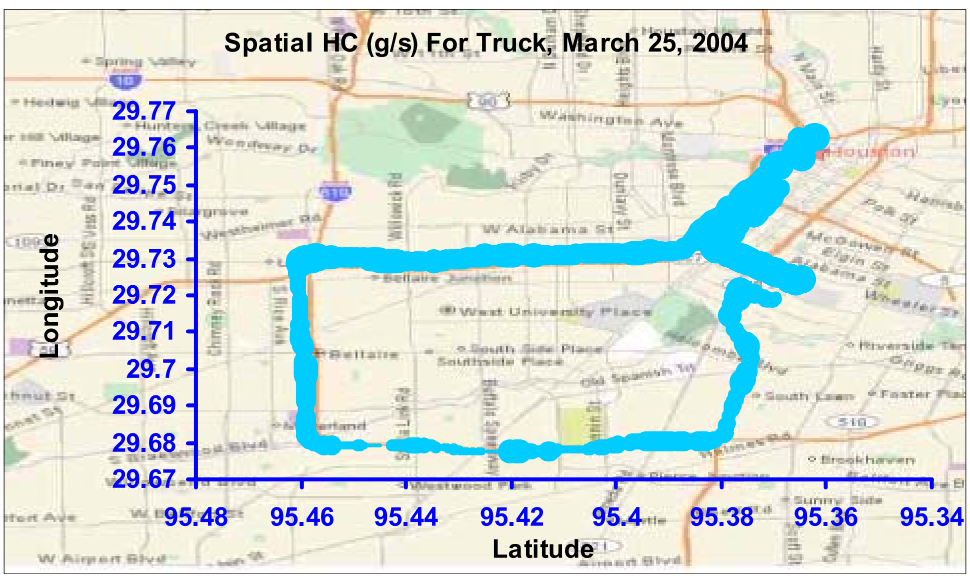


Figure 23. Truck spatial HC distributions for the test on March 15, 2004 in Houston

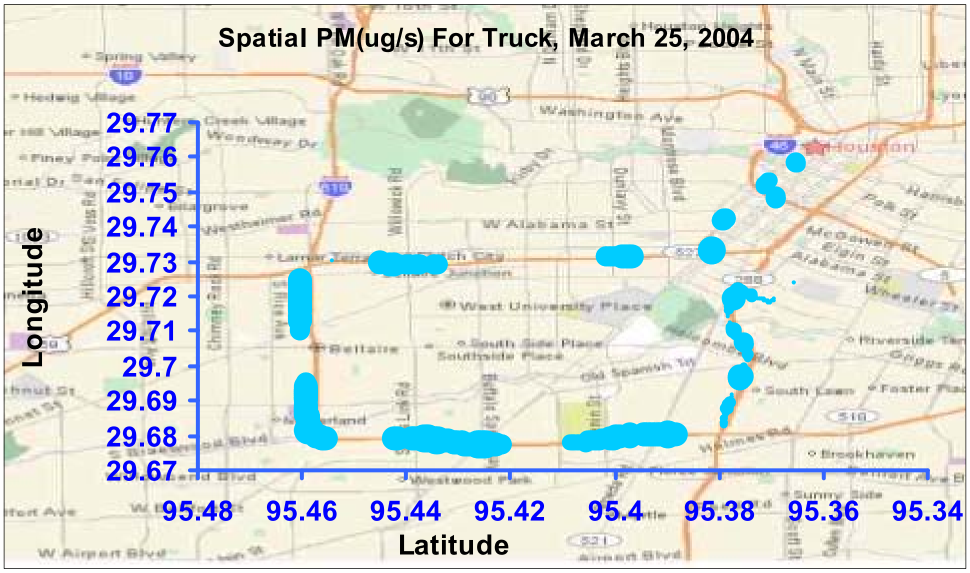


Figure 26. Truck spatial PM distributions for the test on March 25, 2004 in Houston

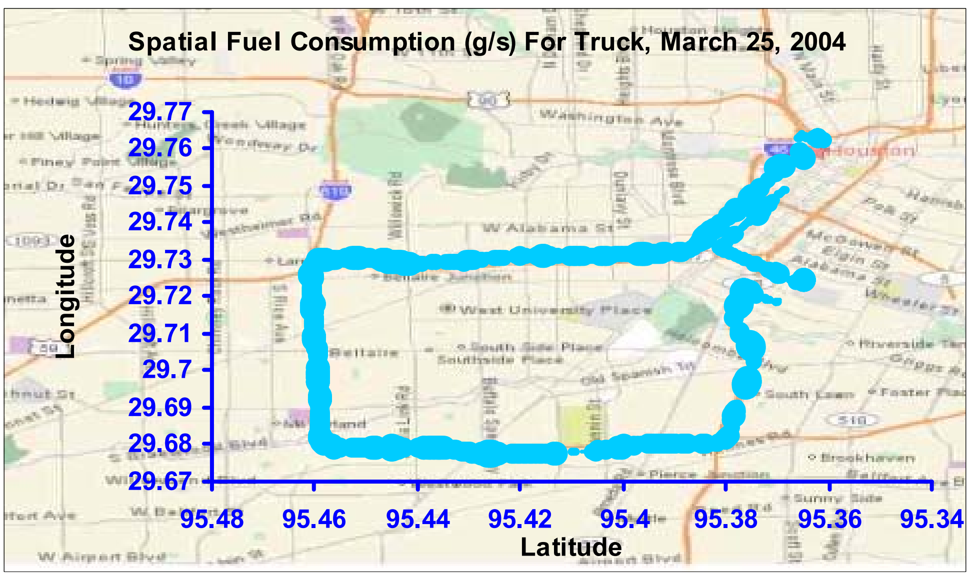


Figure 27. Truck spatial fuel distributions for the test on March 25, 2004in Houston

4.4 Relationships between Emissions and Model Variables (Speed, Accelerations, rpm)

The relationships between emissions and model variables (speed, accelerations, rpm) were conducted in the temporal axis. Therefore, the temporal distributions of the emissions and the model variables can also be identified from these plots. There are six emissions/fuel indexes and three model variables (speed, accelerations and rpm), so for a single test a total 18 figures could be generated from the collected data. The following gives an example of the plotted relationships for the test on March 25, 2004 in Houston.

In Figure 28 through Figure 45, different color represents the different variables for different bags. Bags were set along time axis depending on what types of road the testing truck drove. From these figures strong relationships can be easily found between the emissions / fuel consumption and model variables (speed, acceleration and engine rpm.) For example, before about 11:40', the idling test was in process. So there were no speed and acceleration. The only model variable that had values is engine rpm, which normally kept a value of 700 rpm. During that idling period, the emissions and fuel consumptions were relatively steady.

From about 11:40' to about 12:00', the testing truck was driven from TSU campus to north of Downtown Houston and then south of Downtown Houston. During this period, the speed was low and all the emissions varied with model variables. During the time period of about 12:00' to 12:20', when the truck was on the freeways (US-59, I-610 and 288,) the emissions and fuel consumption also changed with the three model variables. From 12:20' to 12:25', the truck exited freeway and ran back to TSU campus with relatively lower speed and higher emissions. After 12:25', the truck was in another idling test, it seems that the emissions and fuel then were more similar to the idling before 11:40' then to the on-road periods.

In Figure 28 through Figure 45, it is shown that the variations of the emissions were different for different model variables. When speed was low and acceleration/engine rpm varied frequently, which happened from 11:40' to 12:00' (driving within Downtown Houston) and from

12:20' to 12:25' (towards TSU campus), emissions varied more frequently than the periods when speed was higher and acceleration/engine rpm were steady.

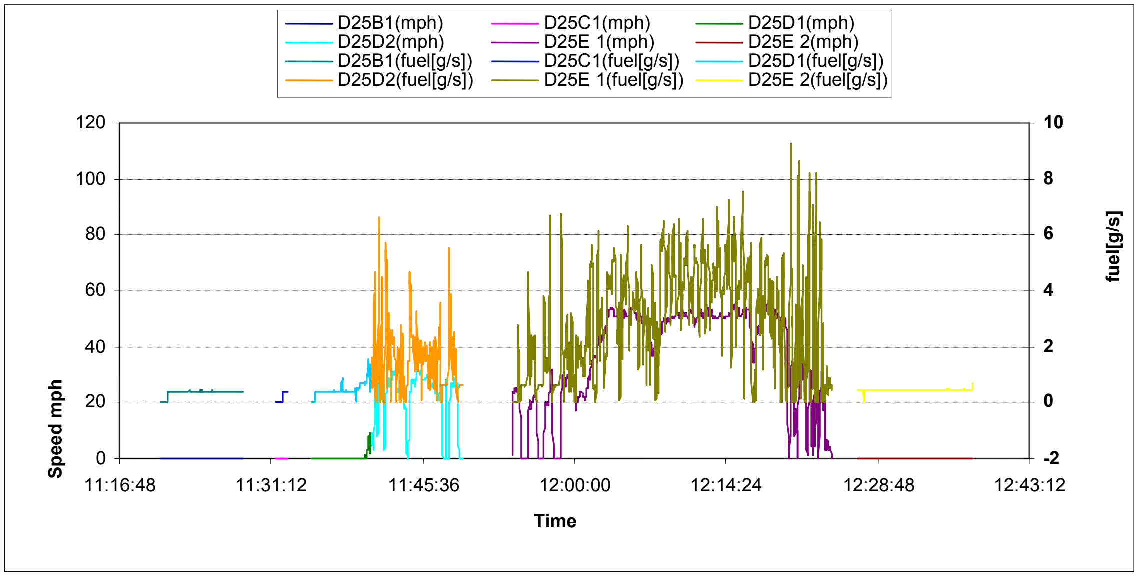


Figure 28. Comparison of truck fuel consumption with speed for the test on March 25, 2004 in Houston

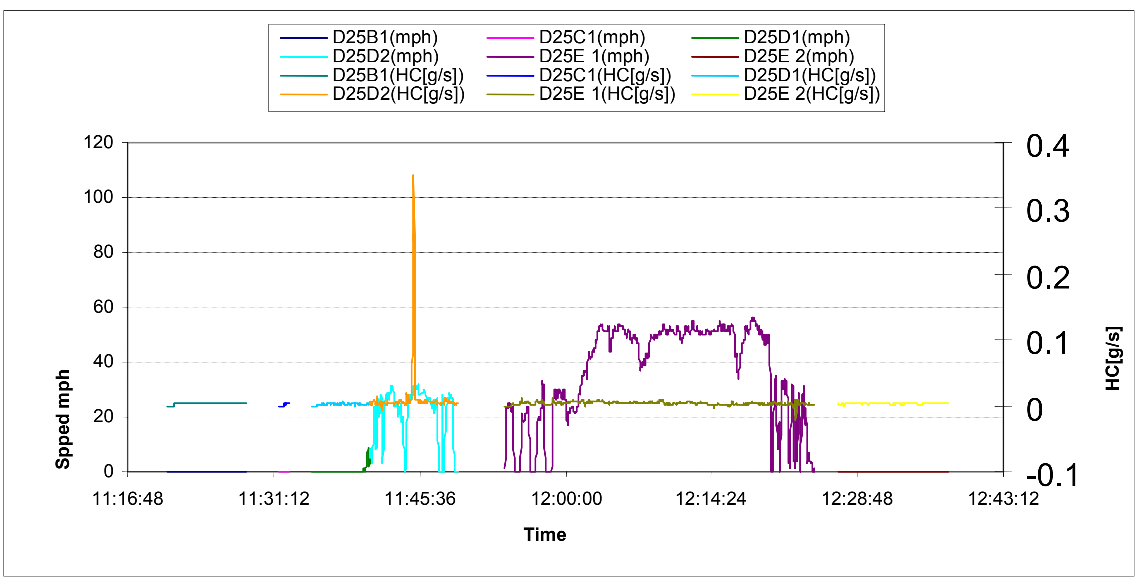


Figure 29. Comparison of truck HC with speed for the test on March 25, 2004 in Houston

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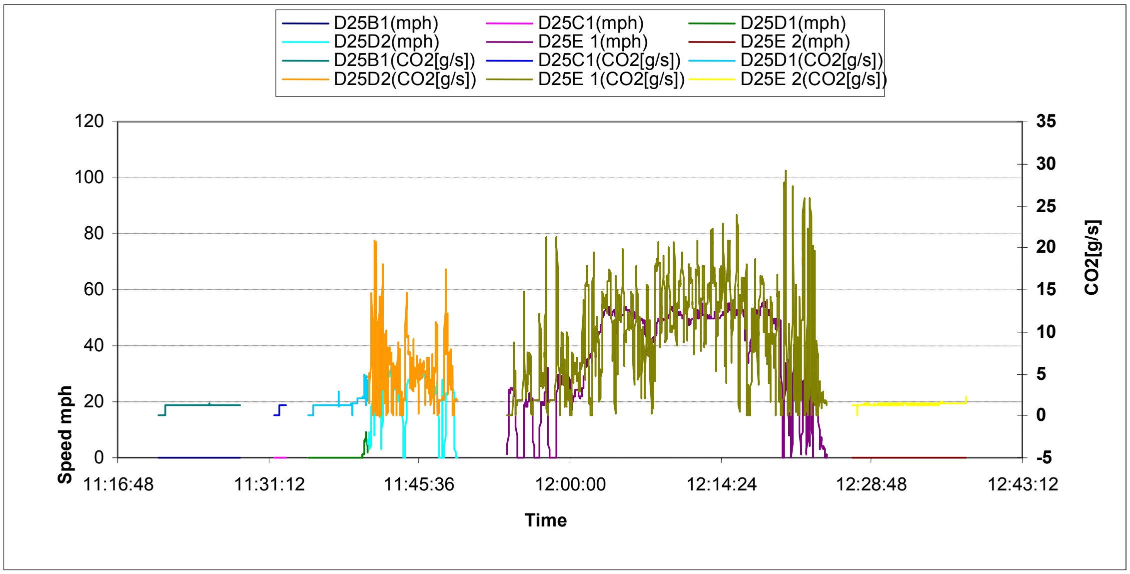


Figure 32. Comparison of truck CO_2 with speed for the test on March 31 around TSU

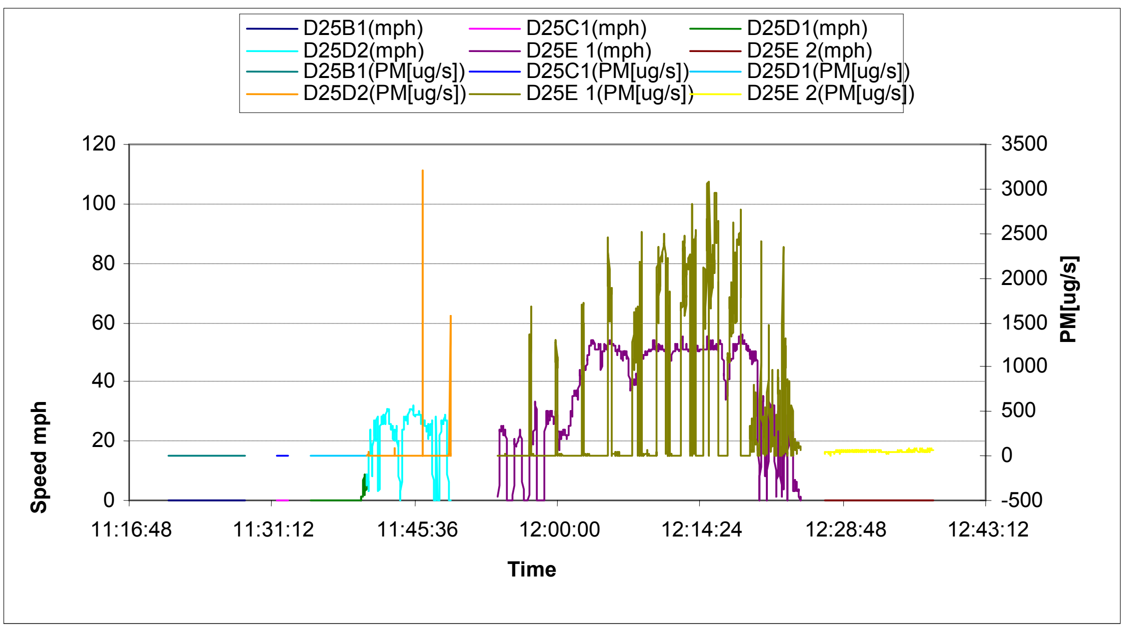


Figure 33. Comparison of truck PM with speed for the test on March 25, 2004 in Houston

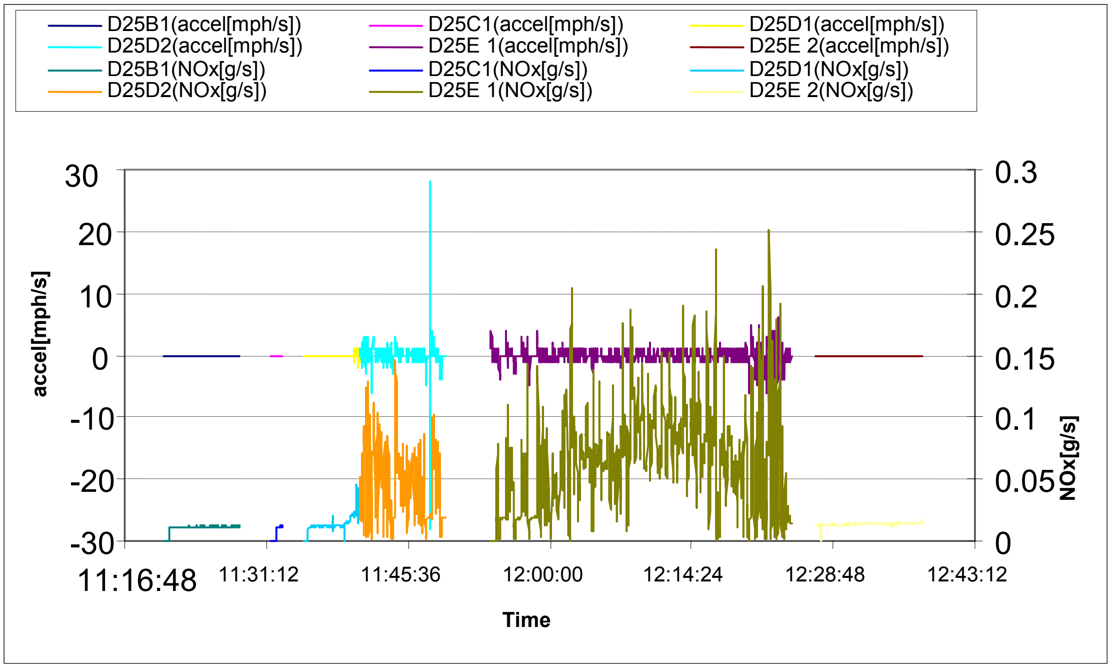


Figure 34. Comparison of truck NO_x with acceleration for the test on March 25, 2004 in Houston

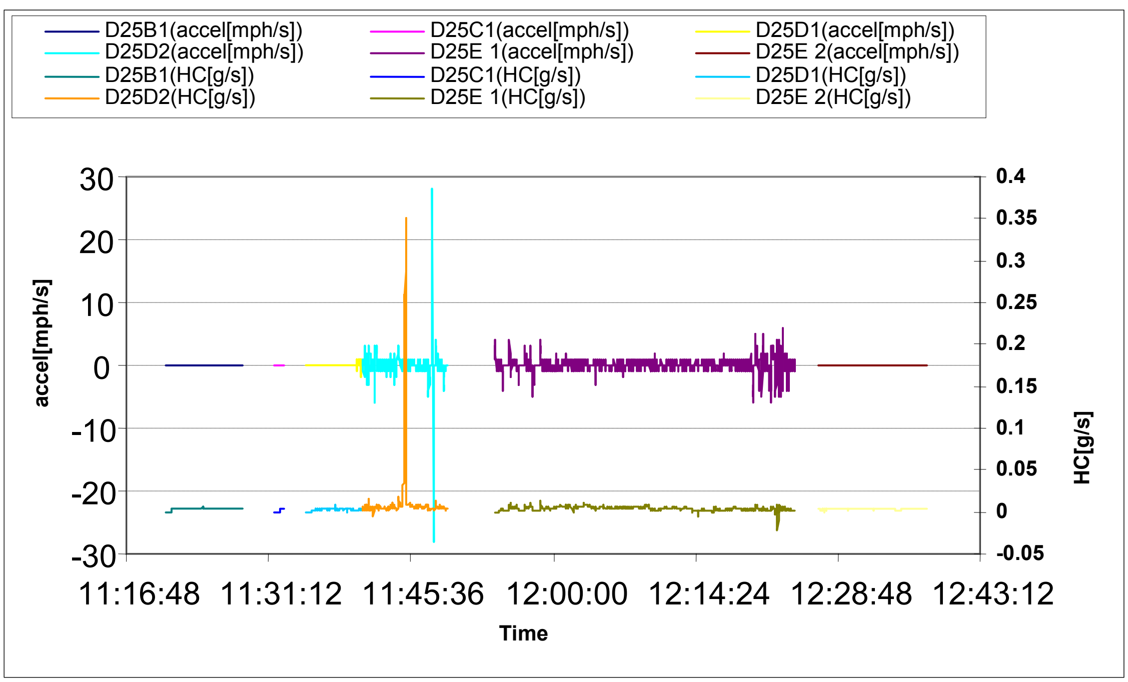


Figure 35. Comparison of truck HC with acceleration for the test on March 25, 2004 in Houston

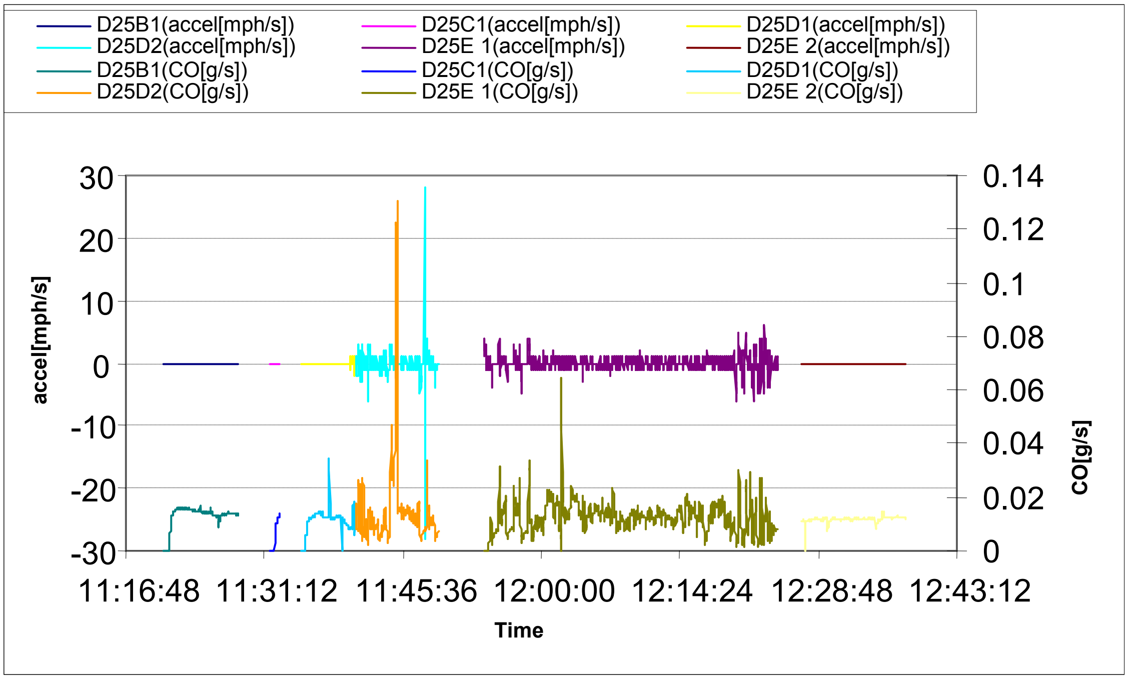


Figure 36. Comparison of truck CO with acceleration for the test on March 25, 2004 in Houston

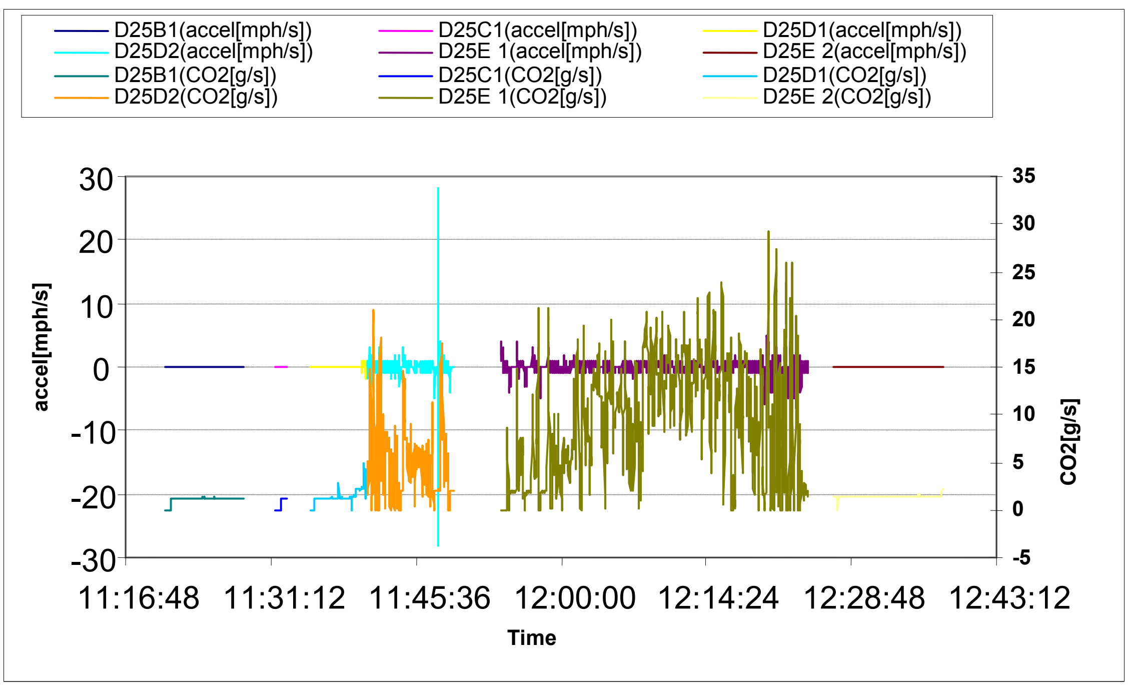


Figure 37. Comparison of truck CO_2 with acceleration for the test on March 25, 2004 in Houston

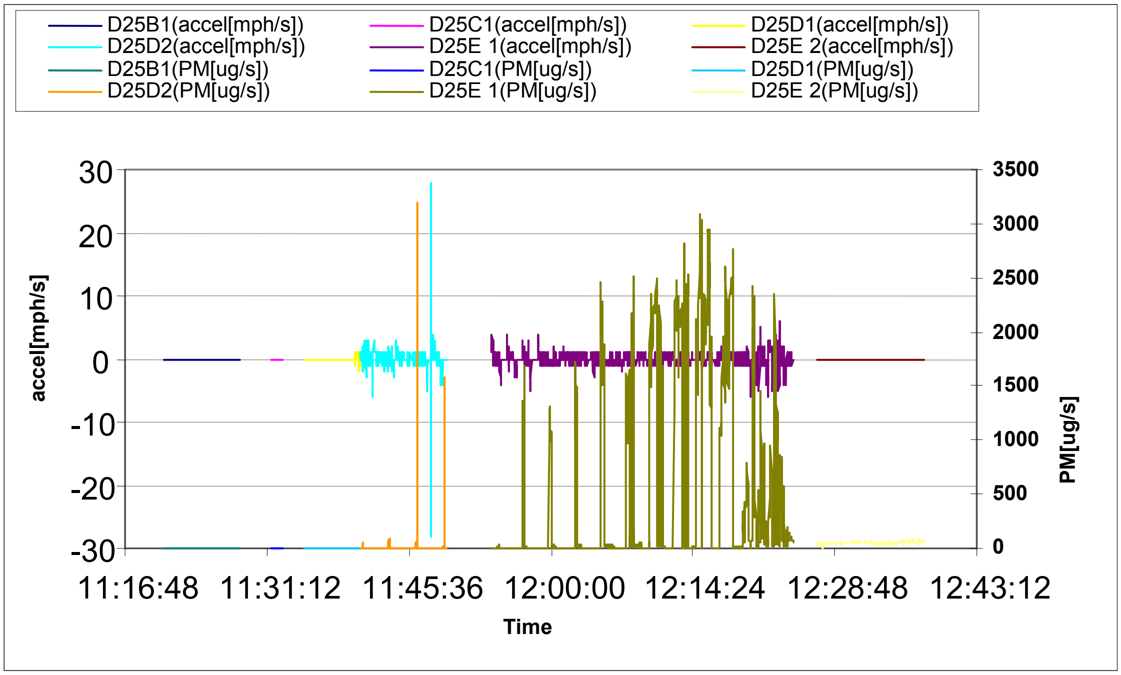


Figure 38. Comparison of truck PM with acceleration for the test on March 25, 2004 in Houston

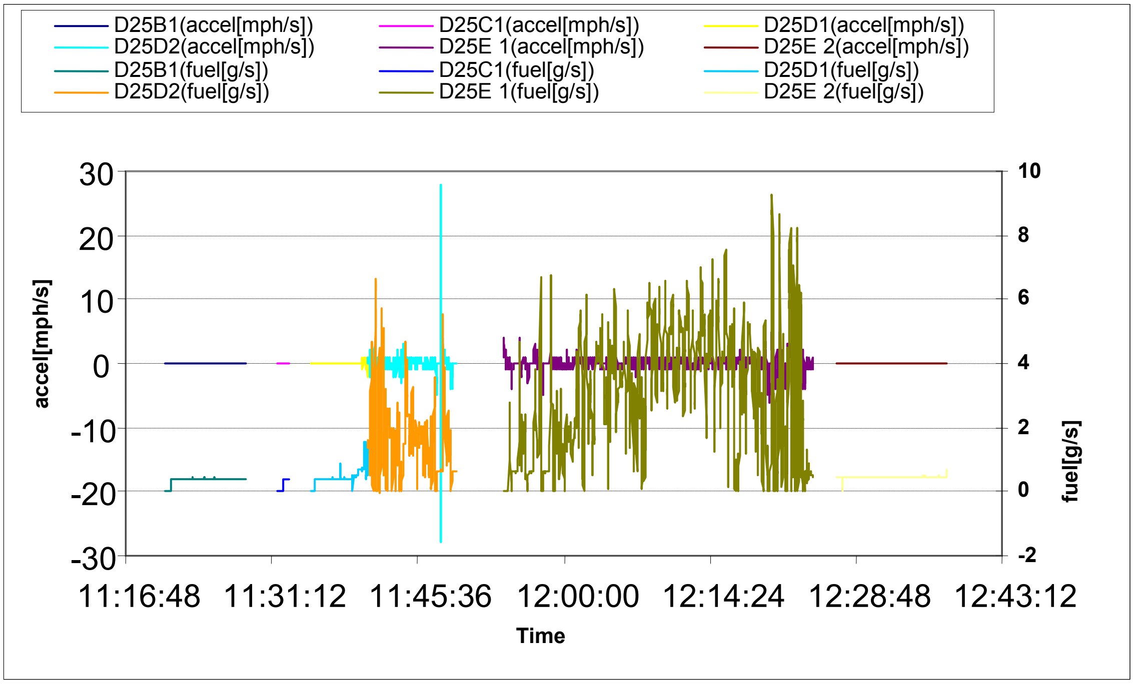


Figure 39. Comparison of truck fuel consumption with acceleration for the test on March 25, 2004 in Houston

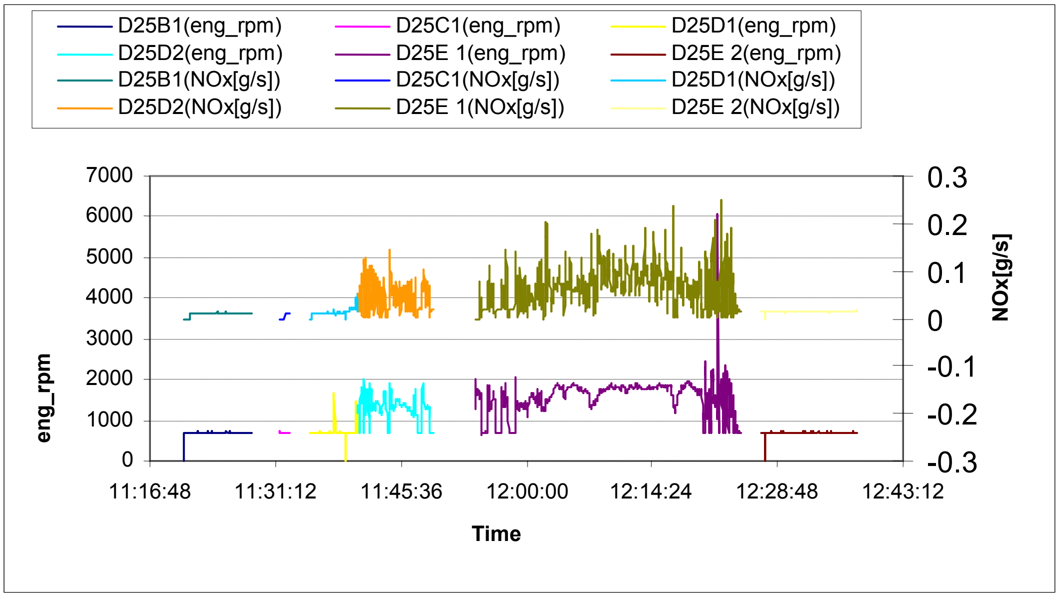


Figure 40. Comparison of truck NO_x with rpm for the test on March 25, 2004 in Houston

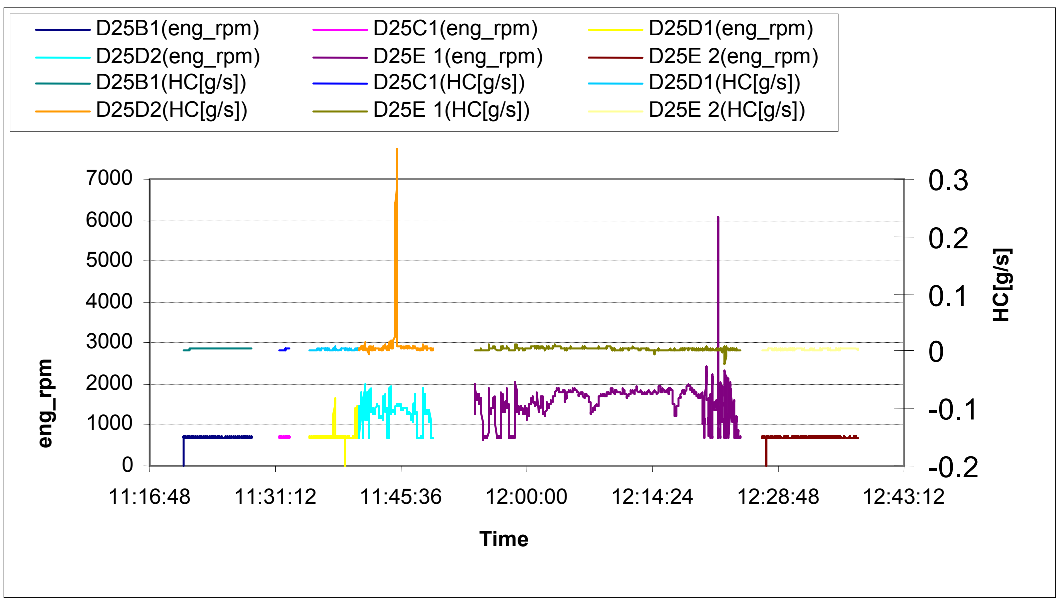


Figure 41. Comparison of truck HC with rpm for the test on March 25, 2004 in Houston

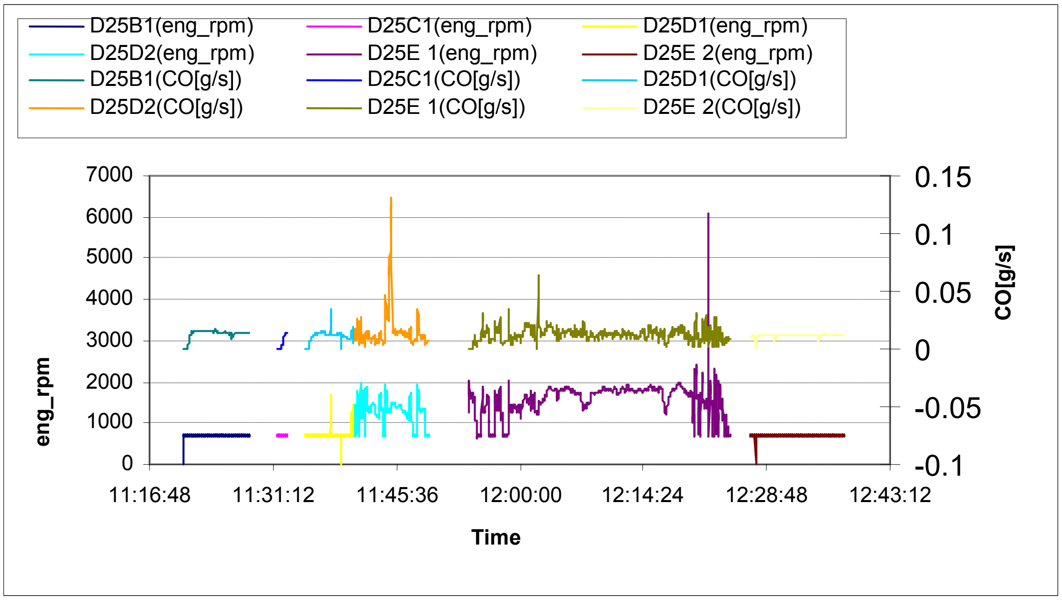


Figure 42. Comparison of truck CO with rpm for the test on March 25, 2004 in Houston

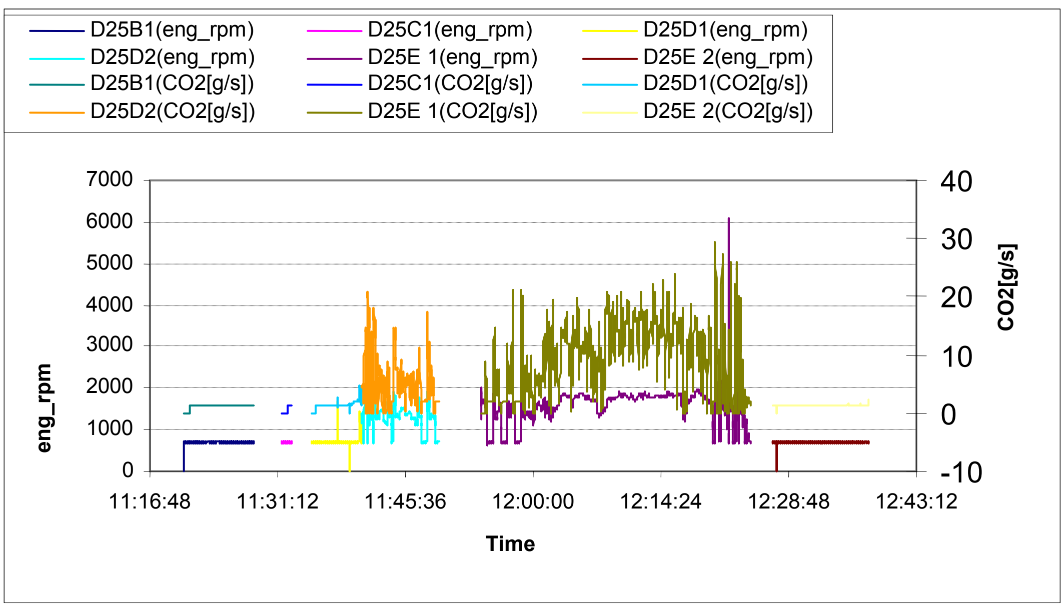


Figure 43. Comparison of truck CO_2 with rpm for the test on March 25, 2004 in Houston

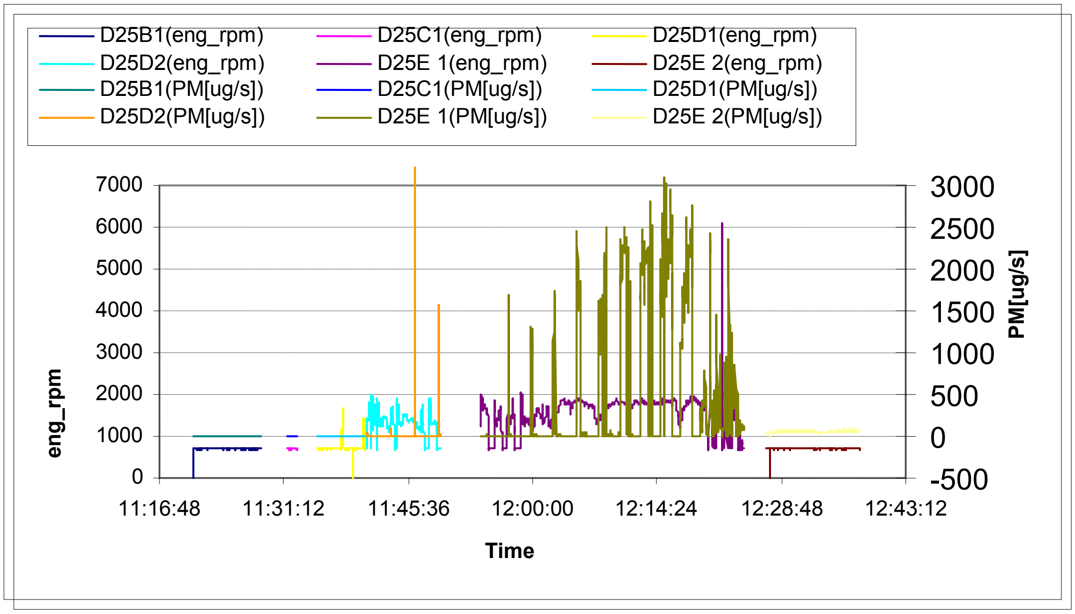


Figure 44. Comparison of truck PM with rpm for the test on March 25, 2004 in Houston

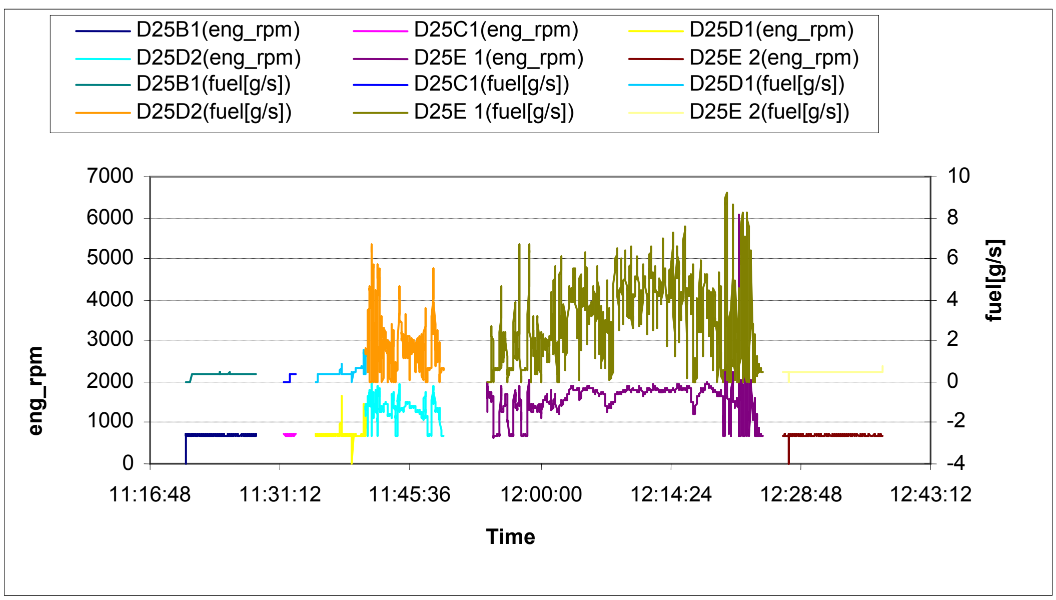


Figure 45. Comparison of truck fuel consumption with rpm for the test on March 25, 2004 in Houston

4.5 Comparison with MOBILE6 Factors

The tested emissions can be compared with the EPA approved emission estimation model MOBILE6.2. The following table (Table 6) is the comparison result.

TABLE 6. Comparison of tested and MOBILE6.2 provided emissions

Test Condition	Factor	T/M	LDGV	HDGV3	HDDV6
Arterial /Feeder	HC	Test	0.4830	0.0284	0.8191
		MOBILE	0.238	1.383	0.452
	CO	Test	13.7996	0.6360	2.0913
		MOBILE	7.52	33.75	1.395
	NOx	Test	2.3735	0.6939	8.9699
		MOBILE	0.613	6.3	7.202
Freeway	HC	Test	0.2219	0.0638	0.5215
		MOBILE	0.235	1.117	0.235
	CO	Test	4.5354	1.3022	1.4657
		MOBILE	9.17	36.39	1.158
	NOx	Test	1.4813	0.3822	6.1840
		MOBILE	0.644	7.067	6.521
Local /Intersection	HC	Test	0.3687	0.1273	1.2603
		MOBILE	0.322	4.251	0.904
	CO	Test	14.8523	1.1077	2.8525
		MOBILE	5.67	81.13	3.348
	NOx	Test	2.4155	0.7109	10.3289
		MOBILE	0.587	5.205	9.073
Idling	HC	Test	0.6798	0.0214	0.2677
		MOBILE	0.859	9.164	0.88
	CO	Test	0.1157	0.0457	0.9448
		MOBILE	22.41	169.78	5.629
	NOx	Test	0.0437	0.0108	0.9430
		MOBILE	1.243	4.81	8.744

The comparison in Table 6 is sorted based on test conditions, emission factors, and vehicle types. Test conditions contain “Arterial/Feeder,” “Freeway,” Local/Intersection,” and

"Idling." The compared emission factors are HC, CO and NO_x. CO_2 and PM are not included since they are not shown in MOBILE6.2 outputs. Vehicle types that were involved in the tests are LDGV (light duty gasoline vehicle,) HDGV3 (class 3 heavy duty gasoline vehicle,) and HDDV6 (class 6 heavy duty diesel vehicle.) All the tested personal cars belonged to LDGV. The 15 ft gasoline truck that was used in the emission test had a GVWR (gross vehicle weight rating) of 11,000-12,000, which is within the range of the HDGV3 GVWR (10,001 to 14,000 lbs) by EPA (2001). The 24 ft trucks that were in tests had GVWR up to 25, 9000 lbs, which is in the range of HDDV6 GVWR (19,501 to 26,000 lbs) by EPA (2001).

The testing distances and idling durations of the three types of vehicle are different, which are listed in Table 7.

TABLE 7. Distances and durations for different testing conditions

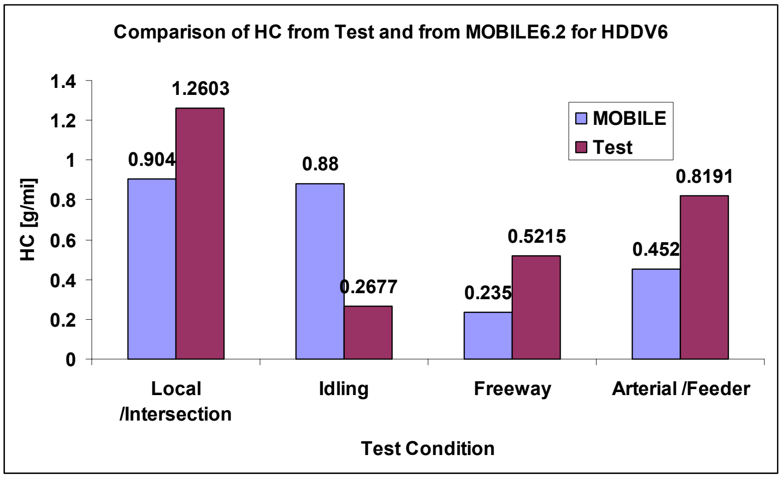
Test Condition	**LDGV**	**HDGV3**	**HDDV6**	**Total**
	Distance (mi)			
Arterial/Feeder	13.8	17.0	66.9	**97.6**
Freeway	46.2	32.9	179.9	**259.0**
Local/Intersection	1.4	7.2	93.9	**102.4**
Total	**61.4**	**57.0**	**340.6**	**459.0**
	Duration (min)			
Idling	158.2	104.4	551.3	**813.9**

Of the total 459.0 mi of on-road testing, HDDV6 took 340.6 mi. This is because heavy duty diesel trucks can produce more emissions that the personal cars and heavy duty gasoline trucks. So the understanding of the characteristics of emissions from heavy duty diesel vehicles is more important.

In Table 6, it is shown that there are big differences between the tested emissions and the MOBILE6.2 estimates. For both LDGV and HDGV3, most of the measured emissions are less than the MOBILE6.2 estimates. This is partly because that the total testing distances for these two vehicle types were less than that for HDDV6. Another possible reason is that the testing HDGV3 truck was a new one.

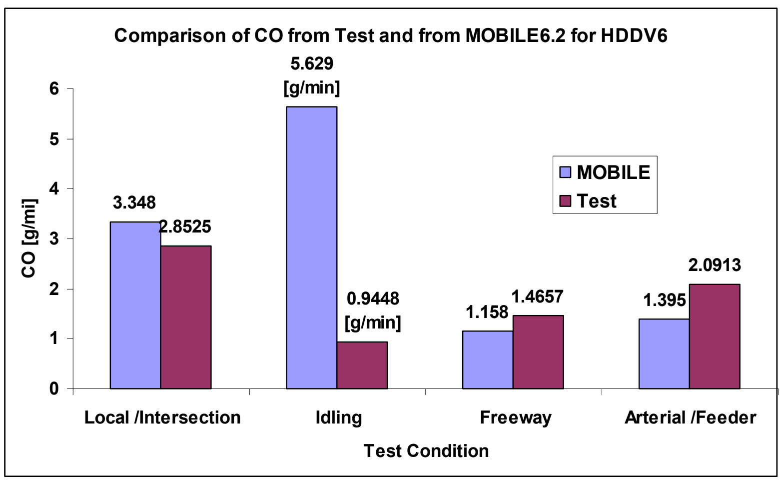
For HDDV6, the measured emissions are sometimes higher, sometimes lower than the MOBILE6.2 estimates. Figure 46 through 48 illustrate the comparisons for HDDV6 for different emission factors. For HC in Figure 46, the measured emissions on local, freeway and arterial streets are higher than the MOBILE6.2 estimates. However for idling, the measure one is lower than MOBILE6.2 estimate. In Figure 47, the measured CO on freeway and arterial are higher than MOBILE6.2 estimates, while lower on local and for idling. In Figure 48, the measured NOx on local and arterial streets are higher while lower on freeway and for idling.

Recall that MOBILE6.2 estimates were based on the lab test results. Theoretically speaking, the on-road emission tests should reflect more real situations in Houston. It should be noted that since only limited tests were conducted at this time, these on-road test results cannot fully represent the vehicle emission characteristics in Houston. As more and more on-road vehicle tests are conducted, the accuracy and reliability of the testing results should increase.



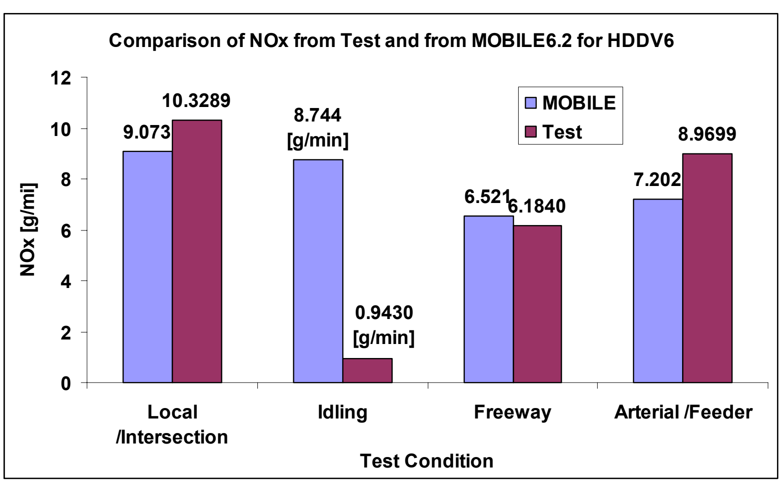
Note: the unit for idling is (g/min)

Figure 46. Comparison of HC test and from MOBILE6.2 for HDDV6



Note: the unit for idling is (g/min)

Figure 47. Comparison of CO test and from MOBILE6.2 for HDDV6



Note: the unit for idling is (g/min)

Figure 48. Comparison of NO_x test and from MOBILE6.2 for HDDV6

4.6 Other Opportunities for the Use of Data

Besides the bag-based analysis, the spatial and temporal distribution analysis and relationship analysis, there are many other opportunities to use the collected data. For example, the characteristics of idling emissions can be further identified from the collected data. Sometimes even for the same testing vehicle, the idling emissions are quite different depending on the running situations before idling tests, the duration the idling tests lasted, etc. Another opportunity that could use the collected data is to further analyze the emission differences for the same vehicle on the same road type but on different segments. This is also not only interesting but also very important to the entire emission estimation. Furthermore, the impacts of whether, temperature, driver behavior, etc. to the emissions can also be analyzed from the collected data since all the relevant information have been recorded in the data base. Additionally, the collected emission data and the analysis results can be used in the re-calibration of many transportation models for providing more accurate emissions estimates. Such models include the transportation simulation model INTEGRATION, CORSIM, etc.

CHAPTER 5

Summary and Recommendations

In this chapter, the summary and conclusions of this research will be provided followed by the recommendations suggested.

5.1 Summary

In this research report, the newly developed on-road emission testing equipment OEM-2100 was firstly introduced. This emission data collection equipment is designed to measure vehicle mass exhaust emissions under actual on-road driving conditions using vehicle and engine operating data and concentrations of pollutants in exhaust gas sampled from the tailpipe. The OEM-2100 unit may be placed in or on the test vehicle. For in-vehicle installation, exhaust sample lines can be routed through a window and secured to the exhaust system using hose clamps. The diagnostic port interface cable is routed to the unit from the port connector. For sensor array installations, sensors are installed on the applicable engine systems and are then routed to the OEM-2100. Power is drawn from a cigarette lighter outlet or from a cable clamped directly onto the battery. The unit is secured by adjustable tie-down straps. Besides many built-in good features, there are several optional equipments including the GPS, the pre-catalyst sampler, the heated-sample line, heavy-duty engine scanner, and the universal sensor array.

According to the work plan, the research team was trained on how to use this on-road testing equipment to collect emission data for the needs of the project. Training was firstly conducted in the manufacturing company (CATI) in Buffalo, NY. Training courses covered the theory of measuring mechanism; operating and maintenance of the equipment; the test designs and uses of GPS; field tests; the data processing techniques; etc. After the Buffalo training, pioneer testing was conducted in Houston and problems were found in both hardware and data processing. So a second round of Houston training was conducted with the CATI technician coming to Houston not only replacing the failed parts, but also providing in-depth training on sensor array placement, further data processing techniques, etc. The close communication between the researchers and CATI technicians lasted throughout a research including all the tests and post data processing processes. This ensured the quality of data collection and analysis.

The formal data collection work was conducted from January through March, 2004. Six vehicles were involved in the tests and ten full working days were occupied by the tests with some days having two vehicles in testing. The terminology “bag” was used to represent each different testing condition. Normally, one vehicle will be tested on multiple bags. In summary, a total of 170 bags were set, meaning that emission data for 170 different testing conditions were collected.

The roadway types for the tests included arterial, freeway, feeder, intersection or local. Idling tests were also considered as one of the testing scenarios. Vehicle type included car and truck with emphasis on 24 ft truck. Most of the testing vehicles were from rental companies. Some were from the volunteers.

All collected emission data were stored in text files together with their corresponding GPS data. The GPS data were saved in .gps format, which has the same property as text file.

The analysis and evaluations of the collected emission data followed a six step procedure. The collected raw data were quality controlled first, and then the summary of each collected index was conducted on the bag basis. Then, the temporal and spatial speed diagrams were plotted with the spatial information coming from GPS. After that, the temporal and spatial diagrams of emissions and fuel consumptions were plotted, and the relationships between emissions/fuel and model variables (speed, acceleration, and engine rpm) were drawn. Finally the comparison between the measured emissions and the estimated emission by MOBILE6.2 was conducted.

Based on the analysis and evaluations of collected emission data, it is shown that the collected emissions and fuel consumption have strong relationships with the engine variable including speed, acceleration, and rpm. This can be observed from the various plots generated. The tested total emissions for cars and trucks were quite different with those that were estimated by the EPA model MOBILE6.2. This is probably because the vehicle emissions vary a lot with local specifications. Sometimes even for the same vehicle and same driving routes, the emissions may change significantly.

In summary, the collection of the emissions in this project sets up a good data base for researchers to identify the emission characteristics in Houston area. This is good not only for the in-depth analysis of microscope relationships of emissions, but also for the calibrations of many transportation models that provide emission estimates.

5.2 Conclusions

Based on the analysis and evaluation of the collected emission data, the following conclusions can be drawn.

1. The vehicles emissions are highly related to the road types. It is found that truck emissions are higher when driving around intersections, especially for NOx, HC and PM, and also for CO. This is easy to understand since it is difficulty for trucks to make turning around intersections so that additional accelerations / decelerations may occur. For cars, the relatively higher emissions happen when driving not only around intersections, but also on arterial streets, where more stops and therefore decelerations / accelerations are normally needed.

2. Emissions also vary spatially along roads. By spatial analysis it is found that the vehicle emissions are not constant when driving. The variations are sometimes very high, especially for tuck PM.

3. Vehicle emissions vary highly with the model variables (speed, acceleration, and engine rpm.) Lower speed and frequently changed acceleration and engine rpm will result in higher variations of emissions.

4. Compared with MOBILE6.2 estimates, the measured emissions for vehicle type LDGV and HDGV3 are lower. However for the vehicle type HDDV6, the measured emissions are higher for some cases and lower for the other cases. It is expected that the measured emissions can be used to correct the MOBILE6.2 estimates for Houston if the data collection is sufficient enough.

5. The variations of measured vehicle emissions are higher for all tests. This is true even for the same vehicle driving on the same road. This implies that the characteristics of vehicle emissions are much more complicated.

5.3 Recommendations

As has been described before, the vehicle emissions vary with many factors. It is recommended that the emission data be collected for a wider range of vehicles in Houston to enrich the established on-road emission data base.

Based on the researchers' experiences, the data processing process is very complex and time-consuming although its concept is relatively straightforward. So it is also recommended that a user-friendly EXCEL-based utility to be developed to process the mass emission data for both general purposes and specific utilization.

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