ESP
2002 North Forbes Blvd.
Tucson, AZ 84745

Sri Lanka Remote Sensing Survey Report

Prepared for:

US Agency for International Development and US-Asia Environmental Partnership

August 2004

Table of Contents

List of Tables

List of Figures

GLOSSARY OF TERMS AND ABBREVIATIONS

ASM	Acceleration Simulation Mode
BAR	California Bureau of Automotive Repair
Basic I/M	A set of vehicle I/M program inspection requirements defined by the U.S. EPA that may be used in areas not required to implement an Enhanced I/M program; the inspection procedure usually involves idle testing
CARB	California Air Resources Board
CS	Clean Screening
Clean Screening	The process of identifying vehicles with low emissions that are then exempt from emission inspection at an inspection station
CO	Carbon monoxide
CO2	Carbon dioxide
Cutpoint	An emissions level used to classify vehicles as having met an emissions inspection requirement
Enhanced I/M	A set of more rigorous vehicle I/M program inspection requirements defined by the U.S. EPA that usually involves IM240 testing
EPA	United States Environmental Protection Agency
Excess Emissions	Vehicle emissions that exceed an I/M cutpoint
FTP	Federal Test Procedure
g/mi	Grams per mile, the units of measurement for FTP and IM240 tests
GEI	Gross Emitter Identification
GVWR	Gross Vehicle Weight Rating
HC	Hydrocarbons
High Emitter Identification	The on-road identification of vehicles with high emission levels
I/M	Inspection and maintenance program
Idle Test	A tailpipe emission test conducted when the vehicle is idling and the transmission is not engaged

IM240 Test	A loaded-mode transient tailpipe emission test conducted when the vehicle is driven for up to 240 seconds on a dynamometer, following a specific speed trace that simulates real world driving conditions
LDGV	Light-duty Gasoline-powered Vehicle
LDGT	Light-duty Gasoline-powered Truck
NO_X	Oxides of nitrogen, usually measured as nitric oxide (NO)
OBDII	On board diagnostic system to detect emissions related problems that is required on all 1996 and newer light –duty vehicles
Repairable Emissions	The emission reductions that can be obtained by repairing a vehicle. The amount of repairable emissions is equal to or greater than the amount of excess emissions
RSD	Remote Sensing Device
VIN	Vehicle Identification Number
VMT	Vehicle Miles Traveled

Acknowledgements

ESP would first like to acknowledge and express sincere gratitude to the Government of Sri Lanka for the keen interest in our remote sensing products and services. We are grateful for the opportunity to demonstrate our technology and look forward to the opportunity to further develop remote sensing applications suitable for Sri Lanka.

ESP expresses a sincere thanks to the United States Agency for International Development and the United States-Asia Environmental Partnership for their sponsorship of this study, to the Arizona Department of Commerce for their administration of the funds, and to our local partner, the Industrial Services Bureau, for their dutiful and steadfast support of all on-the-ground study activities.

This study examines in-use emissions through on-road measurement of vehicle exhaust using remote sensing devices. Emissions rate and relative contribution of various vehicle classes are presented and discussed.

1. SURVEY INTRODUCTION AND SUMMARY

US Agency for International Development (USAID) and US-Asia Environmental Partnership (USAEP) contracted Environmental Systems Products (ESP) to conduct a remote sensing device (RSD) study in order to:

1) Characterize the on-road emissions of the active vehicle fleet;

2) Determine the need for further analysis and recommendations on implementation of a larger program or study.

To accomplish the study goals, ESP and it's Sri Lankan partners, Industrial Services Bureau (ISB) and Hayleys, conducted a remote sensing device study in four major metropolitan areas using the RSD 4000 system supplied by ESP. Twenty-four sites were surveyed in 2003 and 22,991 measurements were made of vehicle license plates, speed, acceleration and emissions of HC, CO, NOx and smoke. The vehicle registration information was obtained through the vehicle license plate.

CONCLUSIONS – This document describes the study and its results. Following are the key conclusions drawn from this analysis:

- Remote sensing can effectively characterize and monitor the on-road emissions of motor vehicles in Sri Lanka.
- The remote sensing equipment set-up requires adjustment to measure motorcycles and three-wheelers more effectively because of their small exhaust volumes and variable tailpipe configurations.
- To produce a detailed inventory of on-road emissions requires information about fuel economy and the average distances driven daily by each class of vehicle.
- Petrol vehicles, especially motorcycles and three-wheelers, were the highest contributors of vehicular HC and CO emissions. We estimate motorcycles and petrol three-wheelers emit over 70% of exhaust hydrocarbons.
- Diesel commercial vehicles and motor lorries were the highest NOx contributors. We estimate diesel vehicles emit over 75% of NOx.
- Diesel and two-stroke petrol vehicles emit over 80% of particulates and smoke.

- 1996 and newer petrol motorcycles and cars had significantly lower HC, CO, and NOx emissions than older vehicles but new diesel trucks had emission rates similar to older trucks.
- The dirtiest 10% of vehicles typically have three to five times the emissions of average vehicles.
- Remote sensing could assist the Government of Sri Lanka in its efforts of reducing vehicle emissions by:
    - Providing information about the on-road performance of vehicles and evaluating the benefits of vehicle emission controls and inspection and maintenance programs;
    - Identifying high emitting vehicles and requiring them to obtain an additional and immediate vehicle inspection;

Sections 2.0 through 4.0 provide background information on the development of remote sensing. Section 5.0 describes the remote sensing technology related equipment standards and procedures. Section 6.0 describes the Sri Lanka study design. Sections 7.0 and 8.0 describe the data collected and the results of the data analysis.

2. INTRODUCTION

2.1. *Urban Air Pollution – Sri Lanka*

Emissions of carbon monoxide (CO), hydrocarbons (HCs), and oxides of nitrogen (NO_x) from mobile sources adversely impact human health and the environment by contributing to the formation of photochemical smog, acid deposition, and elevated CO levels. Reactions of NO_x and HCs with hydroxyl radicals in the presence of ultraviolet light lead to the formation of ozone (a principal component of photochemical smog) in the lower atmosphere.[1] The majority of urban NO_x emissions in the United States are from mobile sources and data from the eastern United States indicate that roughly 30-40% of the acid rain is due to nitric acid.[2] Carbon monoxide, like ozone and NO_x, is also a respiratory irritant regulated as a criteria pollutant by the United States Environmental Protection Agency (U.S. EPA). Hydrocarbons and smoke particulates include toxic materials that are very damaging to the public health and increase mortality. Measurement of these constituents in automobile exhaust is therefore important to urban air quality control and the protection of human health and the environment.

The rapidly increasing vehicle population and fuel consumption, particularly diesel; the high proportion of old vehicles and poor vehicle maintenance; the absence of clean fuel; and the high rate of urbanization are contributing to pollution levels in Sri Lanka that are significantly higher than health standards.

Vehicular Emissions - Automobile exhaust is a major source of air pollution in Sri Lanka. Existing evidence has shown that the urban environment of Colombo is heavily contaminated with vehicular emissions. Various studies undertaken by regulatory agencies and researchers clearly indicate that inefficient combustion of petroleum in motor vehicles is the primary cause of growing air pollution in Colombo, the largest metropolitan area with nearly 50% and 30% of the nation's vehicle population and human population, respectively.[3] The observed lead (Pb), total suspended particulate (TSP), sulfur dioxide (SO2), and ozone (O3) levels are significantly higher than the levels recommended by the World Health Organization (WHO) and the Central Environmental Authority (CEA) of Sri Lanka.[4]

Respiratory Disease - Respiratory disease is the 2nd leading cause of hospitalization, and asthma has become a major respiratory disease[5] due in large part to the explosive growth of 3-wheelers (which are mostly 2-stroke) and 2-wheelers (nearly 40% 2-stroke), which represent greater than 50% of overall 1.1M vehicle population and 85% of the operational road vehicles, and the significant increase in diesel fuel consumption.[6]

Diesel Consumption - During the 90s the per capita petrol fuel consumption increased by 23% while per capita diesel fuel consumption increased by 92%.[7] Overall the small diesel fleet increased 300% due to pricing policies of diesel vs. petrol. Even 63% of the 4-wheelers were diesel in 2000 compared with 46% in 1985.[8]

Used Vehicles - The government policy of importing second hand reconditioned vehicles for economics reasons has also aggravated the proliferation of poorly maintained vehicles. Of the total vehicle number, about 25% was new; the rest were reconditioned vehicles.

2.2. <u>RSD Technology</u>

Remote sensing enables the exhaust emissions of a motor vehicle to be measured as the vehicle passes by on the road. Non-dispersive infrared (IR) spectroscopy is

used to measure concentrations of CO and HCs while dispersive ultraviolet (UV) spectroscopy is used to measure NO_x. The system measures the ratio of each pollutant to the emissions of carbon dioxide. By applying the carbon mass balance of petrol combustion, tailpipe concentrations corrected for excess air are calculated.[9] Details of the hardware and software, reports and peer-reviewed publications, including data from many countries around the world are available on the University of Denver's web page.[10] In addition to the source and detector, remote sensors may be equipped with meteorological stations and speed/acceleration systems that provide information used to interpret emissions measurements collected with a remote sensor.

2.3. <u>RSD Applications</u>

RSDs have two general on-road applications:

1) Monitoring of general motor vehicle fleet emissions, and
2) Enforcement of tailpipe pollutant levels in individual vehicles.

The RSD technology is capable of measuring the CO, HC, and NO_x exhaust emissions of many thousands of vehicles per day and provides a practical approach for routinely characterizing on-road vehicle emissions. As such, remote sensing has several potential monitoring uses: determining fleet average emissions for inventory purposes,[11,12] characterizing fleet emissions distributions to evaluate control programs[13] and to compare with other fleets for benchmarking purposes.[14] Previous remote sensing studies have indicated that most of the measured on-road emissions (greater than 50%) come from a disproportionately small percentage of the vehicles (approximately 10-20%).[15,16] This has been shown to be true for CO, HC, and most recently for NO_x and opacity.[17,18] Since the remote sensing signal can be integrated with a video image of the license plate of the passing vehicle, RSDs can also be used to identify high emitters for enforcement purposes (off-cycle inspection), and to identify clean vehicles for reward and exemption from an Inspection/Maintenance program (Clean Screening).[19,20,21]

Numerous federal, state and local regulatory agencies in the United States are using RSDs together with more traditional inspection and maintenance (I\M) programs to enhance their mobile source control efforts, reduce their I\M burden, and lower overall program costs. ESP currently operates continuous clean screening programs in Missouri and Colorado, continuous gross emitter identification program in Texas and Virginia, and eight other periodic fleet evaluation programs in other states. At

least a dozen other countries also operate RSDs and are actively developing remote sensing programs tailored to their particular mobile source control needs. So keen is the interest in remote sensing of automobile emissions that the European Union has funded a consortium of European companies to develop a European remote sensing device with particular emphasis on gaseous pollutant measurement.

3. ESP'S RSD PRODUCT DEVELOPMENT

The growing interest in remote sensing capability has prompted several new development efforts to advance equipment and improve the operational versatility of ESP's AccuScan™ product line. ESP's recently released fourth-generation remote sensing technology, the RSD4000, was applied in India. This new equipment offers numerous benefits over existing instrumentation:

- Smaller and more modular design
- More sensitive, accurate and precise.
- More robust and more portable, allowing for easy transport and shipment.
- More stable and self-correcting for many of the parameters effecting accuracy.
- California BAR compliant.
- A Windows operating system.
- Expandable for additional gas channels.
- A UV opacity channel sensitive to fine particulates.

Several other research programs focused on advancing ESP's fourth generation RSD platform are underway. Among the most active and important is the development of unattended operation capability and the improved characterization and quantification of diesel smoke particulates. Unattended operation is being driven by the desire for greater deployment versatility and lower operating cost. ESP plans to explore joint development of unattended units domestically with the California Bureau of Automotive Repair (BAR) and internationally with its strategic alliance partner, Toyota Tsusho.[22] Diesel capability, including improved NO measurement and detection of NO_2, SO_2 and fine particles, is being driven by the changing motor vehicle landscape worldwide. The domestic heavy-duty diesel fleet has grown substantially because of the greater fuel economy diesels offer, but has come under increased scrutiny due to its disproportionately large contribution to the (<2.5 micron) particulate inventory. Europe has indicated keen interest in cross border diesel truck monitoring as their borders fall and trade is liberalized. Asia reports increases in

NOx limited smog formation and a widening particulate problem. Furthermore, European and Asia manufacturers have plans to produce more diesels in the future due primarily to their higher fuel economy and lower global warming CO_2 emissions.

Study programs are also underway at ESP to adapt the current 4000 platform to measure small-engines vehicles such as motorcycles, and motor scooters, and three-wheelers that are abundant in Asia.

In addition to advancing and adapting the RSD4000 platform, ESP, along with its research and development partners, is actively developing new and innovative measurement technologies that enable expanded analysis of air toxics from a host of different mobile combustion sources. Quantum Cascade Lasers (QCLs) are an exciting new development in infrared spectroscopy, that will enable practical on-road measurement of individual hydrocarbon air toxics, such as 1,3-butadience, formaldehyde and acrolein.[23] Developed at Bell Labs, and now being offered commercially, these lasers offer several advantages over current offerings: (1) near room temperature operation, (2) the ability to tailor the emission wavelength with high precision, (3) broad and continuous tuning, and (4) the use of mature material processing technology borrowed from the telecommunications industry.

4. MILESTONES IN REMOTE SENSING

There are three specific applications for remote sensing that have been formally studied, recognized, and approved by the USEPA:

- Clean Screening (CS). RSD is used to exempt clean vehicles from station inspections (EPA Document – EPA420-P-98-007);
- Gross Emitter Identification (GEI). RSD is used to identify dirty vehicles for off-cycle station inspection (EPA Document – EPA/AA/AMD/EIG/96-01);
- I/M Program Evaluation (PE). RSD is used to evaluate emissions in the vehicle fleet (EPA Document – EPA420-B-02-001).

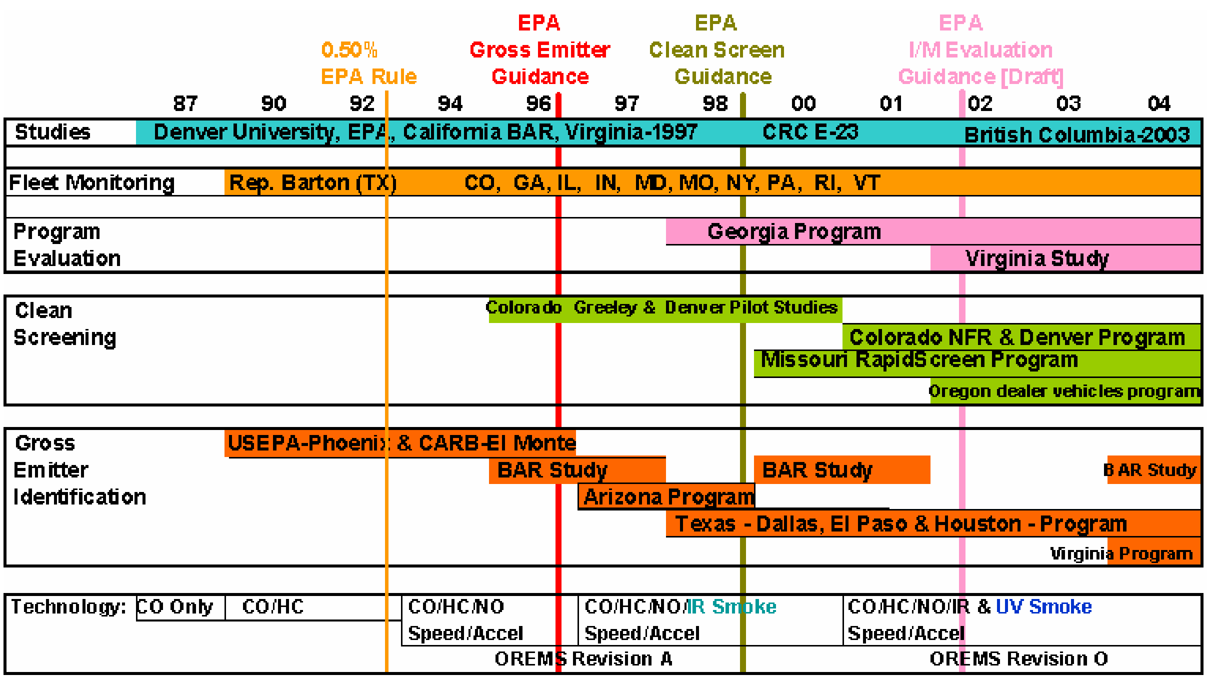
Applied together, the three represent the most comprehensive supplement to traditional inspection and maintenance programs.

Because these applications have been approved by the USEPA, states are now free to incorporate remote sensing as a supplemental enforcement tool in I/M programs and may consult either the General RSD Guidance (“the GEI guidance”) or the CS Guidance when designing their programs and quantifying the air quality impacts of supplemental remote sensing screening programs.[24] The impact is quantified by

modeling the emissions generated by the augmented I/M program. MOBILE5a is the model currently used by states to quantify the benefit of their I/M program although Mobille6 was recently released.[25] Guidance credit utilities contain the algorithms that drive the models and define the emissions reductions (commonly known as "credits") gained or lost by either remote sensing GEI or CS, respectively.

The USEPA has also recognized program evaluation as the third, and potentially most powerful, application of remote sensing. The program evaluation guidance was released in 2002 after being reviewed by government and industry stakeholders.

Appendix A describes remote sensing's history in the US and reviews key studies and reports that led to the widespread acceptance of all three remote sensing applications by the USEPA and state agencies. The figure below shows the timeline of the development of US EPA remote sensing guidance documents and state studies and applications together with remote sensing technology milestones.



5. RSD TECHNOLOGY SPECIFICATIONS/PERFORMANCE STANDARDS

The California Bureau of Automotive Repair has defined procedures and associated performance standards for remote sensing equipment called the On-Road Emissions Monitoring System (OREMS) specifications. The most recent OREMS release was Revision O, which specifies an unattended system. The OREMS specifications have

become a widely accepted standard for RSD equipment performance in the United States and some other countries.

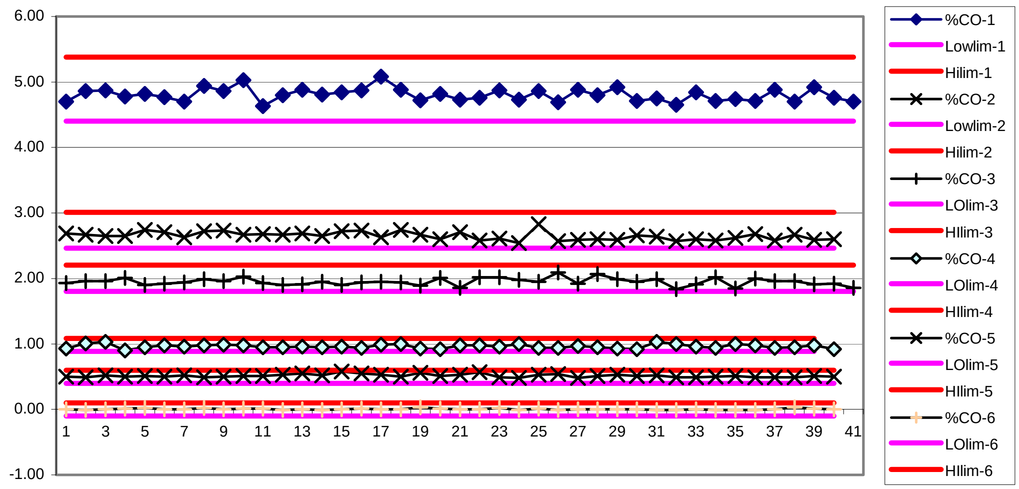
ESP's fourth generation AccuScan system, the RSD-4000, has met California BAR standards for analytical performance. Each RSD unit is tested for accuracy by driving a specially adapted calibration vehicle (known as an "audit truck") past the RSD unit while releasing calibration test gas with a blend of known concentrations of HC, CO, NOx and CO2.

An audit truck is a modified vehicle that uses a long exhaust stack to direct the vehicle engine exhaust upwards and away from the roadway. Audit gases of known concentrations are dispensed through a simulated tailpipe routed to the rear of the audit truck.   When the truck is driven past a roadside remote sensing SDM/VTM set of modules, the system measures the pollutant concentrations in the dispensed test gas instead of the vehicle engine exhaust.

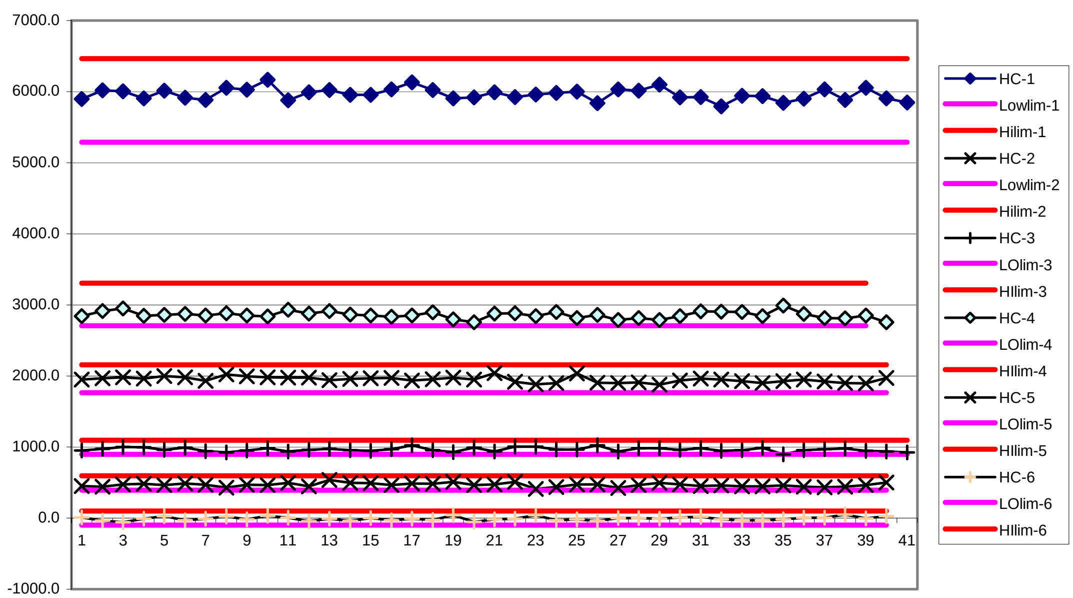
Different blends of calibration test gas are used to test the RSD unit over a wide range of concentrations for each pollutant.

The following figures show the pollutant concentrations measured by an RSD unit during 200 passes of an audit truck. Forty consecutive passes were made using five different blends of calibration test gas. The limit lines in the figures below show the ranges within which the RSD measurements should fall to meet the accuracy specification.

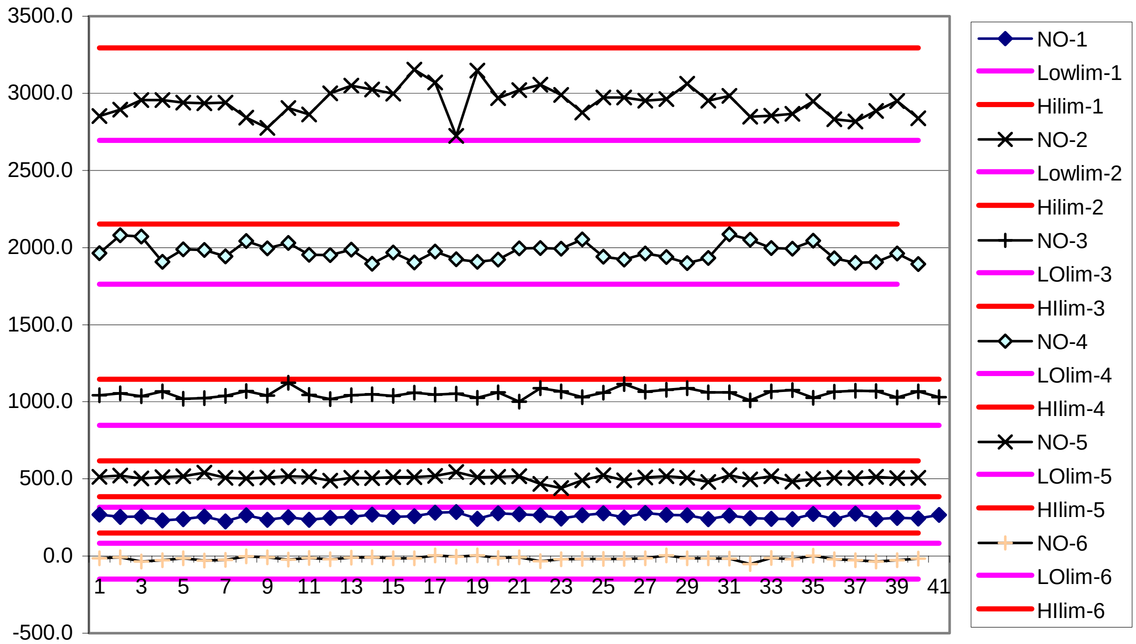
%CO 4001
Perfect: 4.89, 2.74, 2.00, 0.99, 0.50, 0.00
Means: 4.80, 2.65, 1.95, 0.96, 0.51, 0.00
Stdev: .0986, .0619, .0568, .0307, .0241, .0107
Limits shown are +/-10%. BAR cert is +/-10% or +/-0.25% >3% CO; <3% +/-15% or +/-250ppm.



ppmHC 4001
Perfect: 5876, 1963, 996, 3006, 494, 0
Means: 5964, 1951, 965, 2859, 467, -7
Stdev: 81.4, 39.9, 27.5, 49.1, 25.8, 26.6
Limits shown are +/-10%. BAR cert is +/-15% or +/-250ppm.



ppmNO 4001
Perfect: 234, 467, 997, 1958, 2994, 0
Means: 255, 506, 1053, 1970, 2941, -16
Stdev: 15.3, 17.9, 26.0, 55.3, 93.4, 11.7
Limits shown are +/-10%. BAR cert is +/-15% or +/-250ppm.



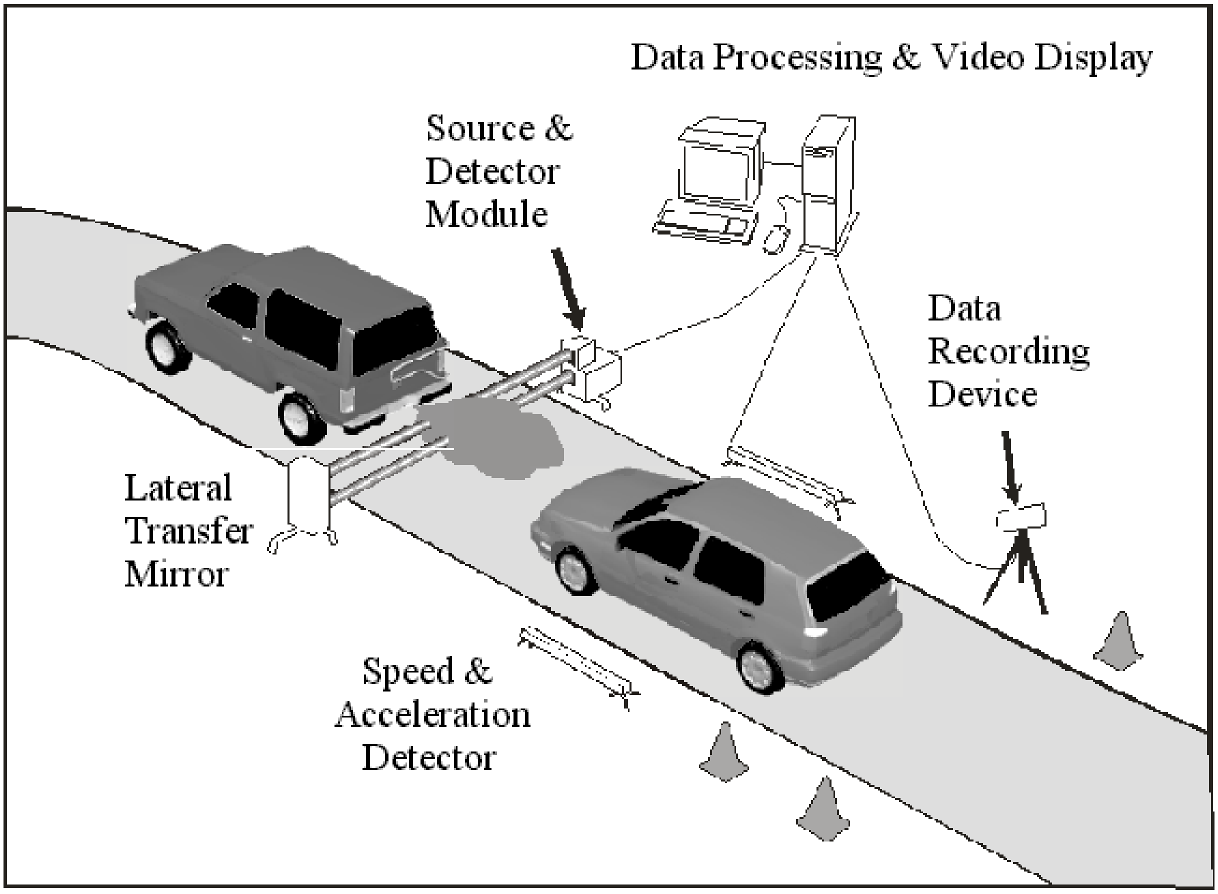
6. SRI LANKA STUDY DESIGN

6.1. Equipment Description

The Sri Lanka Study utilized the RSD4000. The RSD4000 is based on the same underlying technology as the University of Denver systems pioneered by Dr. Stedman but has been engineered to improve reliability and accuracy and variable in the most challenging on-road conditions.

The RSD4000 detects vehicle emissions when a car drives through an invisible light beam the system projects across a roadway. Figure 6-1 illustrates the remote sensing equipment set-up. The process of measuring emissions remotely begins when the RSD4000 Source & Detector Module (SDM) sends an infrared (IR) and ultraviolet (UV) light beam across a single lane of road to a lateral transfer mirror. The mirror reflects the beam back across the street (creating a dual beam path) into a series of detectors in the SDM.

Figure 6-1: On-Road Remote Sensing Set-Up



Fuel specific concentrations of HC, CO, CO2 and NOx and smoke are measured in vehicle exhaust plumes based on their absorption of IR/UV light in the dual beam path. During this process, the data-recording device captures an image of the rear of the vehicle, while the Speed & Acceleration Detector measures the speed of each vehicle.

In ideal conditions, the RSD units are housed in converted vans. These vans are equipped with heating/cooling, a generator, and adequate storage for all components. The vans carry a full compliment of road safety equipment and tools for making small repairs. The vans can be equipped with additional lighting for testing during pre-dawn and post dusk hours.

6.2. <u>Equipment QA/QC Audits:</u>

6.2.1. Factory Testing and Certification

When an RSD system is built at the Tucson Technology Center, it undergoes several steps to ensure accuracy. First, the source detector module is bench calibrated. It is

then audited in the laboratory using several blends of gas. When the system is fully calibrated and assembled, it is tested again in the parking lot using an audit truck. These unit tests are based on the BAR OREMS specification.

The remote sensing unit is setup in a parking lot to avoid interference from other traffic. The auditor drives the audit truck through the remote sensing system 40 times for each gas blend during acceptance testing. ESP detector accuracy, including speed and acceleration, meets the detector accuracy tolerances shown below for at least 97.5% (39/40) runs for each gas. Five different audit gas blends are used to verify the unit accuracy over a range of pollutant concentrations.

OREMS Detector Accuracy:

1) Carbon monoxide (CO %) reading within ± 10% of the Certified Gas Sample, or an absolute value of ± 0.25% CO (whichever is greater), for a gas range less than or equal to 3.00% CO. CO % reading within ± 15% of the Certified Gas Sample for a gas range greater than 3.00% CO. Negative values are included and not rounded to zero.

2) Hydrocarbon reading (recorded in ppm hexane) within ± 15% of the Certified Gas Sample, or an absolute value of ± 250 ppm HC, (whichever is greater). Negative values are included and not rounded to zero.

3) Nitric oxide reading (ppm) within ± 15% of the Certified Gas Sample, or an absolute value of ± 250 ppm NO, (whichever is greater). Negative values are included and not rounded to zero.

Propane vs. Hexane

The RSD 4000 is calibrated using propane and reports hydrocarbons in terms of propane or C_3. Most vehicle emissions inspection equipment and inspection standards are in hexane units or C_6. In this report, the remote sensing measurements have been converted to hexane equivalent values by dividing by two.

Speed and Acceleration Accuracy:

4) The vehicle speed measurement is recorded within ± 1.0 mile per hour.

5) The vehicle acceleration measurement is recorded within ± 0.5 mile per hour / second.

6.2.2. Daily Set-Up and Calibration

Every scheduled work day, the operator drives to an existing or new test site. The operator's first duty is to provide himself and passing motorists with a safe work area. The next step is to set up the source detector module (SDM) and allow electronic components to warm up for a minimum of 30 minutes. Following the set up and alignment of the other components, the SDM is aligned and ready for Calibration.

A puff audit calibration is a method of testing the equipment without the need to drive an audit truck past the unit. During a gap in the passing traffic, a test gas with a known blend of HC, CO, CO2 and NOx, is puffed into the optical path of the remote sensing beam. If necessary, the instrument set-up is adjusted and the system is recalibrated so that the pollutant values measured by the unit, match the known concentrations of pollutants in the test gas blend.

Calibration for the RSD4000 occurs once at the beginning day and periodically during the day as conditions warrant.

6.3. Site Selection Criteria

The sites were selected using the following guidelines to:

1) Provide a representative sampling of the area motor vehicle fleet

2) Maximize valid records without compromising geographic coverage and data quality.

3) Yield a measurement distribution roughly similar to the vehicle population.

Sites were chosen using these criteria in addition to the above:

1) One-way traffic allowing a single lane to be safely and effectively monitored.

2) Most polluted area and area of most concern to the public

3) Traffic flow is relatively high, yet at moderate speeds of 30 to 60 km/hr, and capable of being captured under moderate engine load.

6.4. Site Locations

6.4.1. Site Selection Results

In total, 24 sites were used. The site locations are listed in Table 6-1.

Table 6-1: Site Locations

SITE	LOCATION
KU01	Kurunegala (Kurunegala - Kandy Road)
KU02	Kurunegala (Kurunegala - Colombo Road)
KU03	Kurunegala (Kurunegala- Trincomalee Road)
GA01	Galle (Galle – Colombo Road on Gnithota bridge)
GA02	Galle (Galle – Colombo Road)
GA03	Galle (Galle – Matara Road)
GA04	Galle (Galle – Colombo Road) Modara Bridge
NE01	Negombo (Colombo – Negombo Road) Vehicles moving towards Negombo
NE02	Jaela (Colombo – Negombo Road) Vehicles moving towards Colombo
NE03	Negombo (Colombo – Negombo Road)
NE04	Jaela (Colombo – Negombo Road) Vehicles moving towards Negombo
CO01	Kirrillawala (Colombo – Kandy Road) Vehicles moving towards Kandy
CO02	Kirrillawala (Colombo – Kandy Road) Vehicles moving towards Colombo
CO03	After Mirriswatta junction close to Yakkala (Colombo – Kandy Road) Vehicles moving towards Kandy
CO04	Colombo city In front of Hayleys
CO05	Colombo city In front of Hayleys
CO06	Colombo city Ward Place (Vehicles moving away from the city)
CO07	Kribathgoda Sapugaskanda road - Outskirt of Colombo (Vehicles moving towards Colombo)
CO08	Ratanapitiya, Colombo Piliyandala road - Outskirt of Colombo (Vehicles moving away from Colombo)
CO09	Colombo city In front of Hayleys
CO10	Pannipitiya, High Level Road, Outskirt of Colombo (vehicles moving towards Colombo)
CO11	Pannipitiya, High Level Road, Outskirt of Colombo (vehicles moving away from Colombo)
CO12	Moratuwa, Galle Road (Vehicle moving away from Colombo)
CO13	Near Parliament (vehicles moving towards Colombo)

Figures 6-2 and 6-3 illustrate the distribution of the sites in Sri Lanka. Sites were located in Colombo, Negombo, Galle and Kurunegala. Figure 6-4 shows the equipment set-up at a site in Kurunegala site.

Figure 6-2: Site Locations in Sri Lanka

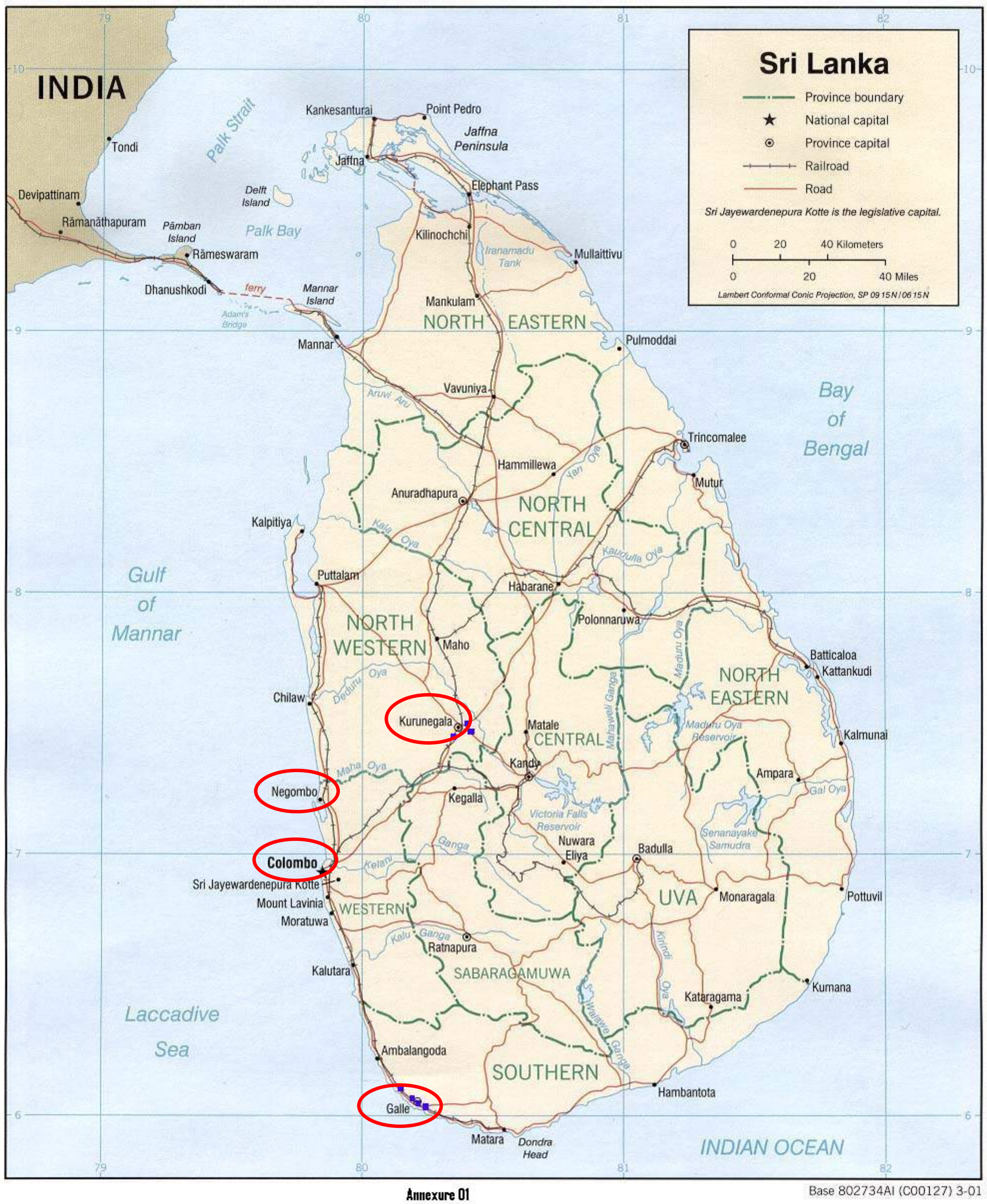
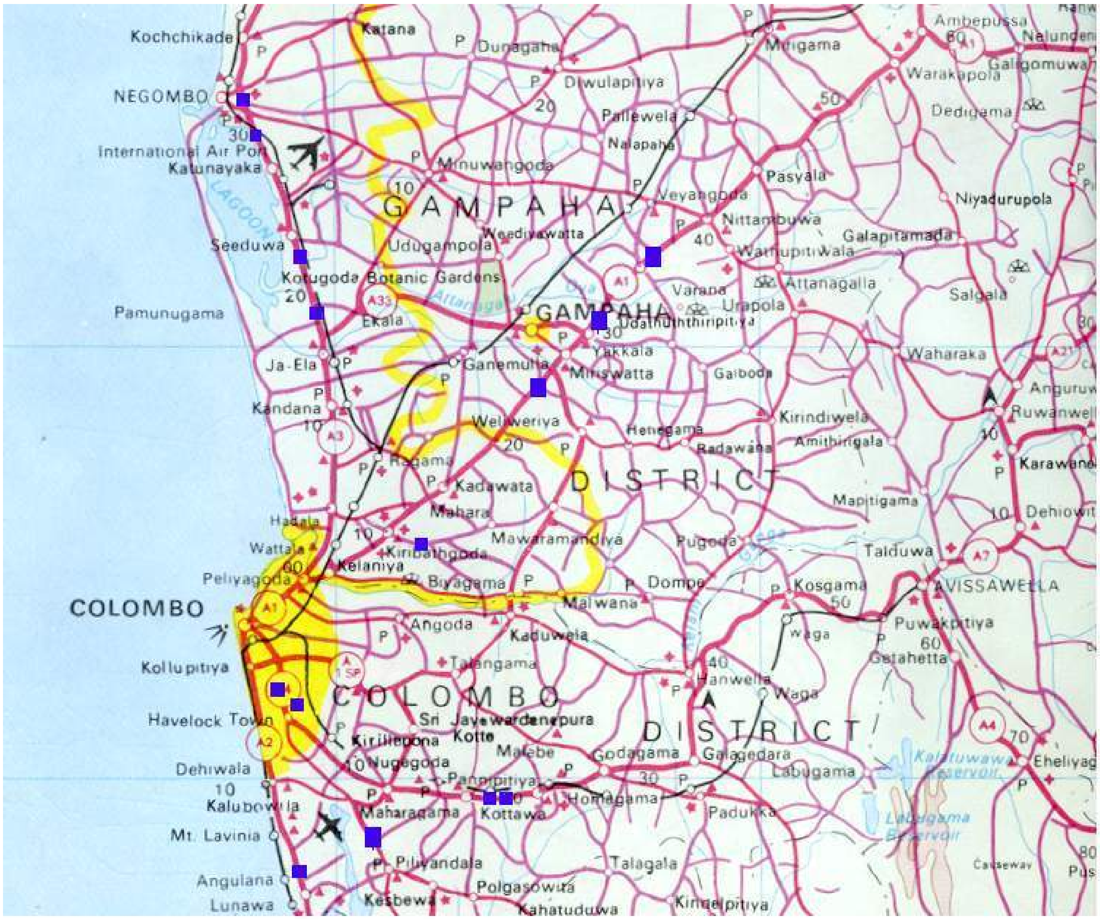


Figure 6-3: Site Locations in Colombo and Negombo



Annexure 02

Figure 6-4: Remote Sensing Van

Figure 6-5 Remote Sensing at a Colombo Site

Figure 6-6 Remote Sensing Near Parliament

Figure 6-7 Remote Sensing at a Kurunegala Site

6.5. Data Screening

The RSD4000 unit takes 50 measurements of each exhaust plume in the one half second after each vehicle passes the equipment. The RSD software evaluates the 50 measurements in real-time to determine whether a high quality (“valid”) reading has been achieved. The criteria include how much vehicle exhaust plume is available for the duration of a 0.6 second sampling period, evaluation of whether plume measurements are consistent with normal plume dissipation during loaded mode operation, and correction for changes in background concentrations of emissions.

Coasting and deceleration often result in high numbers of invalids because of the relatively small exhaust volume associated with reduced engine throttle. Ambient wind, other vehicle wakes, or an unusual tailpipe height may also cause the software to reject a vehicle measurement.

A further 173 records were flagged as invalid for having significant negative emission values that are believed to be the result of an infrequent interference between a high NOx or smoking vehicle being closely followed by a clean vehicle.

7. DATA COLLECTION

7.1. Statistics and RSD Coverage

Table 7-1 shows the overall collection statistics. In total, 100,000 measurements were made in which about 60% of vehicles had the license plate captured in the vehicle picture. After transcribing the visible license plates 45,968 vehicles were matched to the motor vehicle registrations and, about half of these, 22,817, have measurements for both speed and the vehicle emissions of HC, CO, NOx and smoke.

Table 7-1: Number of Remote Sensing Records by License Plate

	Records
Total Number of Sites Utilized	24
Total Number of Data Collection-Days Readings Taken	21
Total measurements made	100,000
Measurements with Plates matched to Registrations	45,968
Measurements matched to a Registration and valid speed and emissions values	22,817

The remote sensing equipment set-up was best for measuring cars and larger vehicles. A number of the motorcycles and three wheelers were missed because the license plates were not visible in the RSD pictures and the vehicles could not be positively identified. The equipment set-up should be adjusted to capture a higher fraction of these vehicles. In addition, the registration database used to match the plates in the RSD pictures did not contain all records for vehicles older than 1990. Therefore, older vehicles often could not be positively identified. Consequently, the overall percentage of vehicle measurements with complete information was lower than normal.

7.2. RSD Measurements by Model Year

Table 7-2 shows the age distribution of each type of vehicles measured during this survey. Diesel Dual Purpose vehicles are the largest group and a majority of them are more than seven years old. There are also many older Diesel Commercial vehicles and Petrol Three Wheeler. Cars are newer and a majority of them are 1996 and newer.

Table 7-2: Observations by Vehicle Type and Model Year Range

Vehicle Type	1970 and Older	1970-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001 and Newer	Total
Diesel Car	2	5	19	534	971	1,918	86	3,533
Diesel Commercial		3	183	992	2,188	1,866	583	5,815
Diesel Dual Purpose	1	15	125	3,945	10,506	3,741	208	18,540
Diesel Land Vehicle		3	3	2	15	21	14	58
Diesel Motor Lorry		10	85	1,117	2,501	1,547	128	5,388
Diesel Three Wheeler						59		59
Other			2		10	4	11	27
Petrol Car	1	2	11	756	2,247	4,893	693	8,602
Petrol Dual Purpose			4	17	29	278		328
Petrol Motor Cycle			6	106	156	274	119	661
Petrol Motor Lorry		1		3	11	35	2	52
Petrol Three Wheeler		1		28	1,054	1,304	528	2,915
Total	4	40	438	7,500	19,688	15,940	2,372	45,978

7.3. Projected RSD Coverage

The number of RSD units required for survey and programs depends on the number of unique registered vehicles in the area and the percentage of the vehicles that are to be measured. Some vehicles will not be observed at the RSD sites, some will be measured only once and some will be measured many times depending on their

routes and activity. For example, in order to obtain at least one measurement on 70% of the vehicles registered in an area it is typically necessary to make more than twice as many measurements as the number of vehicles registered. This is illustrated by Figure 7-1 that shows projected coverage for an RSD program and was developed as part of an ESP study in the USA[26]. Each point on the chart represents a different registration county or district.

Remote sensing distribution doesn't generally mirror registration distribution. Older vehicles are often slightly under represented while newer vehicles are typically overrepresented, more closely reflecting in the likelihood of observing such vehicles because of their numbers of vehicle miles traveled.

Figure 7-1: RSD vs. Mobile6

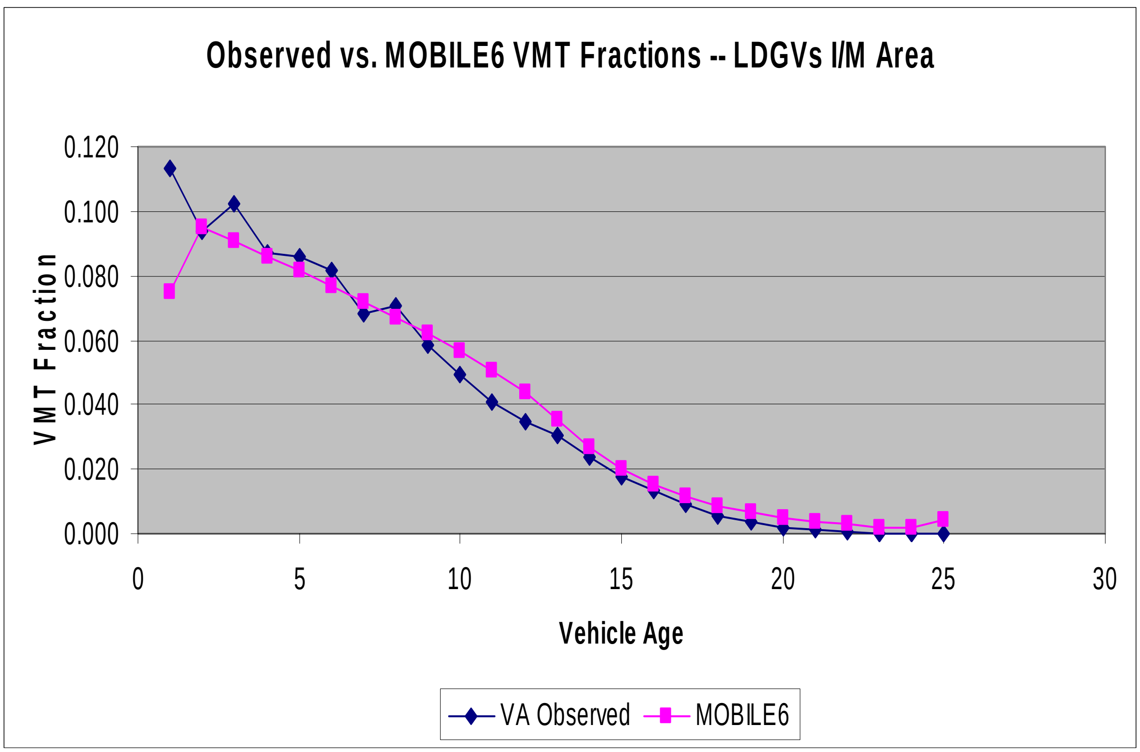
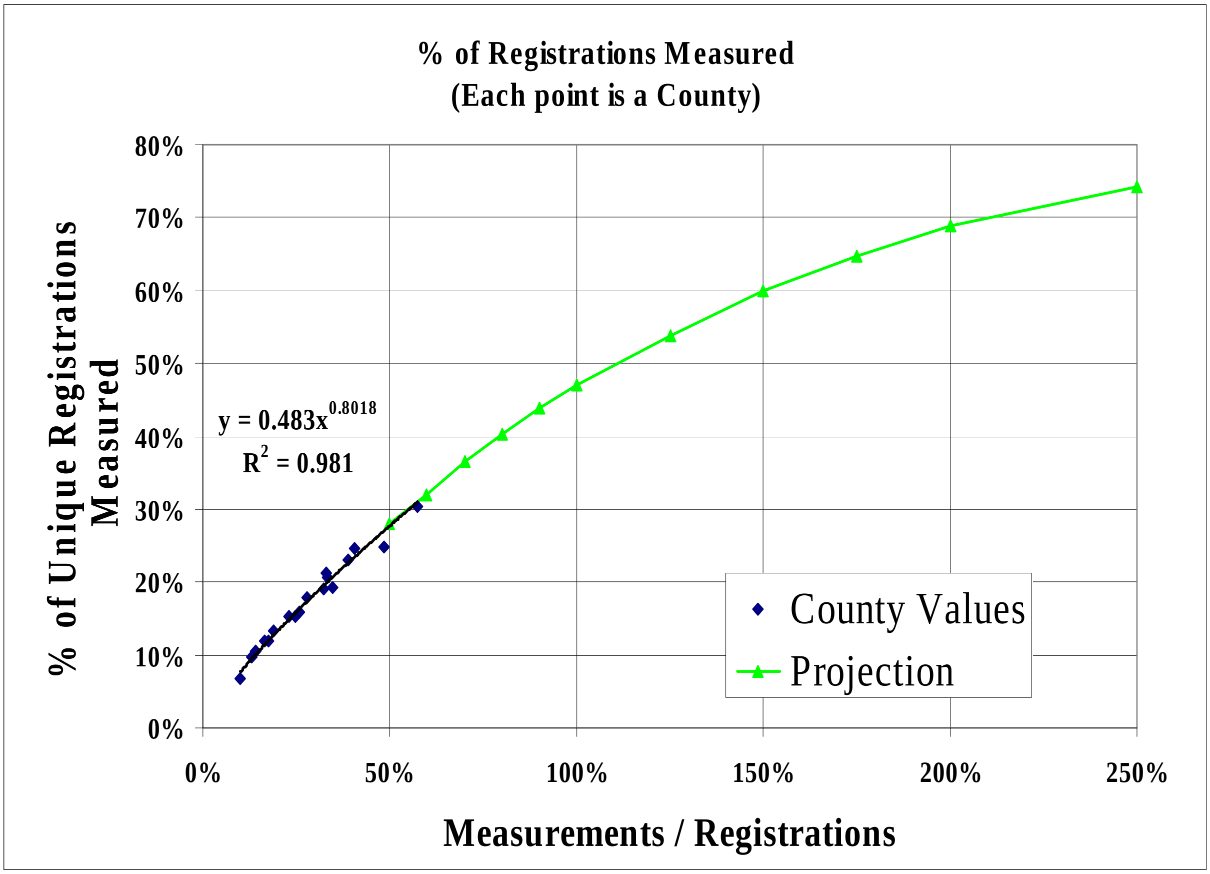


Figure 7-2: Percentage of Registrations Measured vs. Total Measurements



8. STATISTICAL ANALYSIS AND CHARTS

8.1. Vehicle Fleet Emission Rates

8.1.1. Emissions Rates by Type of Vehicle

The average emission rates by type of vehicle are shown in Table 8-1 and in Figures 8-1 through 8-3. Petrol vehicles have higher HC and CO emissions. Motorcycles and three wheel vehicles have the highest emission rates of HC and CO. Diesel vehicles have high emission rates of NOx but petrol cars also emit significant NOx.

The few diesel three-wheel vehicles produced the highest smoke values. For diesel vehicles, an RSD smoke value of 1.00 corresponds to particulate mass equivalent to 1% of fuel mass.

The dirtiest 10% of vehicles for each pollutant have typically three to five times the emissions of average vehicles.

Table 8-1: RSD Emissions by Vehicle Type

		Average Emissions				Average of Dirtiest 10% of Vehicles			
Vehicle Type	**Count**	**CO %**	**HC ppm**	**NOx ppm**	**Smoke**	**CO %**	**HC ppm**	**NOx ppm**	**Smoke**
Diesel Car	1,649	0.11	87	385	0.47	0.45	333	1,261	1.77
Diesel Commercial	3,172	0.17	137	1,134	0.73	0.67	509	3,106	2.36
Diesel Dual Purpose	9,242	0.12	100	407	0.52	0.58	354	1,207	2.22
Diesel Land Vehicle	24	0.79	961	936	1.13	4.12	3,667	2,734	4.18
Diesel Motor Lorry	3,271	0.15	168	1,007	0.70	0.66	612	2,731	2.12
Diesel Three Wheeler	27	0.29	542	1,094	2.22	0.65	1,509	2,465	5.32
Other	13	1.65	1,280	1,120	0.52	6.88	7,418	1,915	1.32
Petrol Car	3,911	1.68	407	1,065	0.21	7.18	2,134	2,902	1.39
Petrol Dual Purpose	166	1.65	272	390	0.18	6.32	1,298	1,649	1.45
Petrol Motor Cycle	246	4.22	2,651	399	1.45	12.36	11,239	2,484	5.56
Petrol Motor Lorry	22	1.95	582	570	0.14	5.95	2,276	2,672	0.70
Petrol Three Wheeler	1,248	2.66	3,917	368	2.37	8.24	10,449	2,378	7.22

Figure 8-1: Average CO Emissions by Vehicle Type

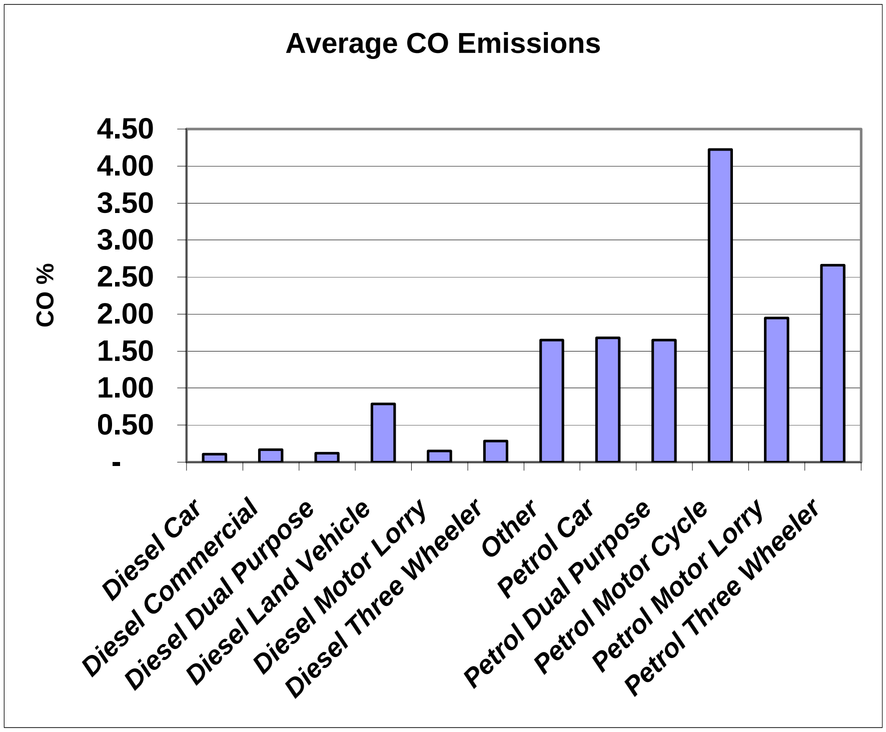


Figure 8-2: Average HC Emissions by Vehicle Type

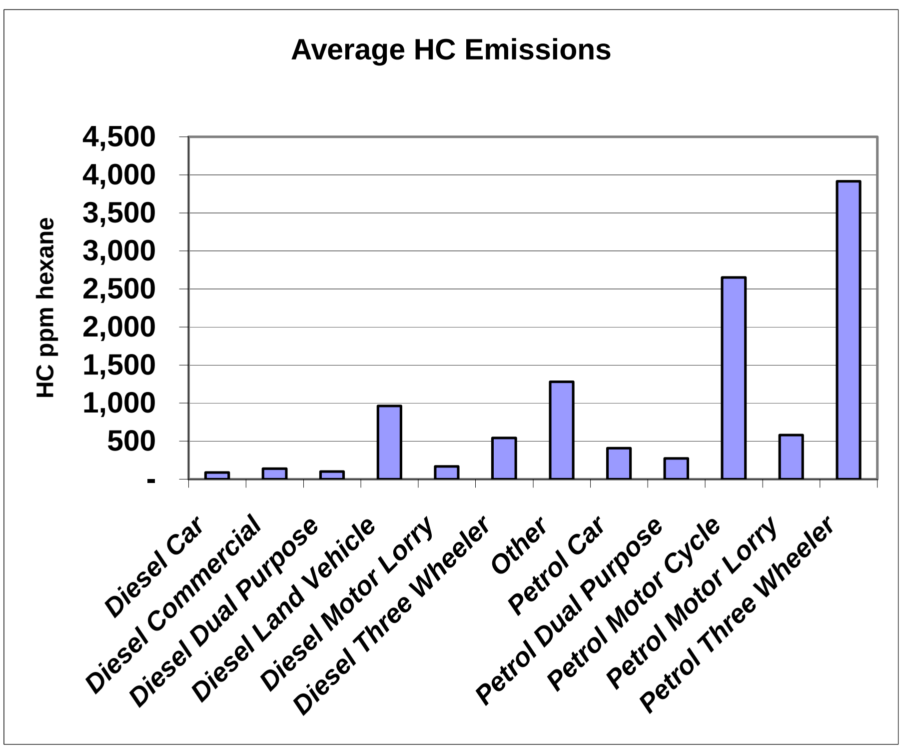


Figure 8-3: Average NOx Emissions by Vehicle Type

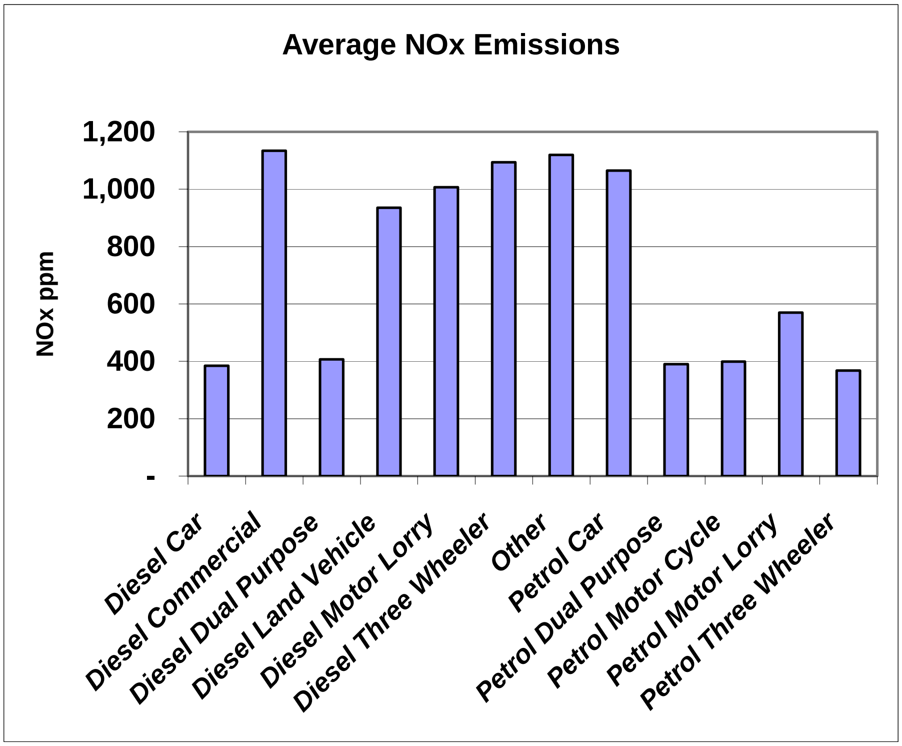
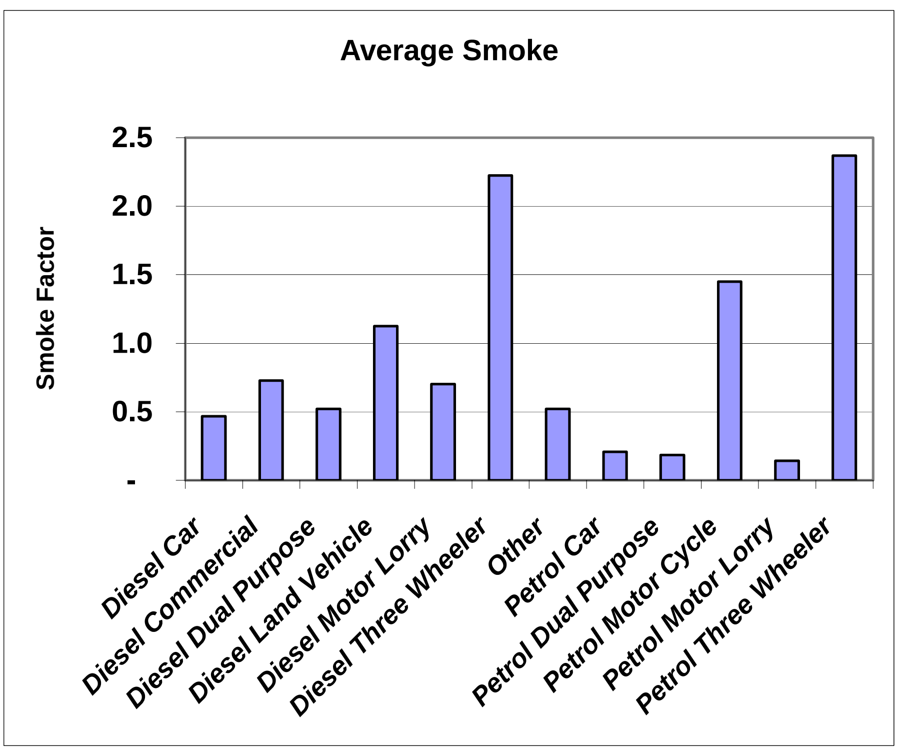


Figure 8-4: Average Smoke Emissions by Vehicle Type



8.1.2. Emissions Rates by Type and Age of Vehicle

ESP compared emission rates by model year group for vehicles falling into the following categories:

1) 1970 & Older
2) 1971-1980
3) 1981-1985
4) 1986 - 1990
5) 1991 - 1995
6) 1996 - 2000
7) 2000 & Newer

The number of vehicles in each bar in the following series of charts is shown in the table below. These include only vehicles with valid HC, CO and NOx emissions measurements. To clarify the charts and reduce variability, only bins with five or more vehicles are plotted on the emissions charts.

Table 8-2: RSD Valid Counts by Vehicle Type and Model Year Range

Vehicle Type	1970 and Older	1970-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001 and Newer	Total
Diesel Car	2	3	7	264	448	883	31	1,636
Diesel Commercial		2	111	589	1,272	963	233	3,170
Diesel Dual Purpose	1	8	63	1,904	5,283	1,836	99	9,193
Diesel Land Vehicle			2	1	5	7	9	24
Diesel Motor Lorry		5	55	686	1,512	926	82	3,266
Diesel Three Wheeler						27		27
Other			1		9	1	2	13
Petrol Car	1	2	5	346	1,033	2,192	314	3,892
Petrol Dual Purpose			2	11	17	134		164
Petrol Motor Cycle				39	50	97	42	228
Petrol Motor Lorry		1		1	3	17		22
Petrol Three Wheeler				7	424	507	244	1,182
	-	21	246	3,848	10,056	7,590	1,056	22,817

Figures 8-5 to 8-8 show the results of this analysis. Figures 8-5 and 8-6 show that the newest petrol vehicles are much cleaner than older vehicles. Figure 8-7 shows that levels of NOx emissions are less dependent on age.

Figure 8-5: Average Percent CO by Vehicle Type and Model Year

Vehicle Type	1970-	1970-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001+
Diesel Car	-	-	0.07	0.09	0.12	0.11	0.08
Diesel Commercial	-	-	0.19	0.20	0.15	0.19	0.10
Diesel Dual Purpose	-	0.10	0.10	0.12	0.13	0.12	0.09
Diesel Land Vehicle	-	-	-	-	-	0.82	1.18
Diesel Motor Lorry	-	-	0.22	0.17	0.15	0.13	0.19
Diesel Three Wheeler	-	-	-	-	-	0.29	-
Other	-	-	-	-	2.01	-	-
Petrol Car	-	-	-	3.65	2.30	1.22	0.68
Petrol Dual Purpose	-	-	-	2.68	2.88	1.36	-
Petrol Motor Cycle	-	-	-	7.34	6.62	3.10	1.63
Petrol Motor Lorry	-	-	-	-	-	1.72	-
Petrol Three Wheeler	-	-	-	3.34	3.31	2.84	1.57

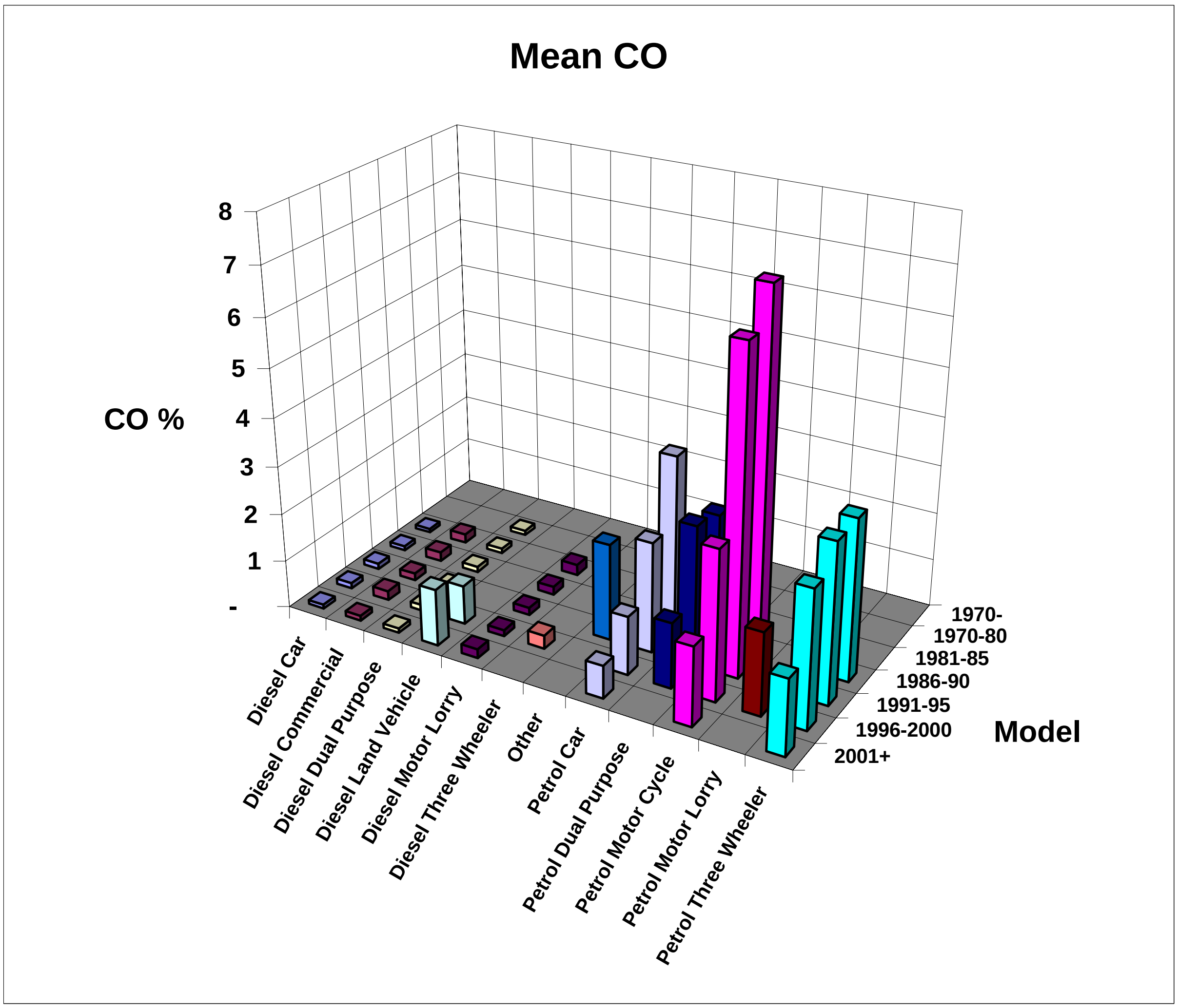


Figure 8-6: HC ppm hexane by Vehicle Type and Model Year

Vehicle Type	1970-	1970-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001+
Diesel Car	-	-	110	87	89	84	165
Diesel Commercial	-	-	162	127	139	148	113
Diesel Dual Purpose	-	133	145	109	102	96	82
Diesel Land Vehicle	-	-	-	-	-	469	1,140
Diesel Motor Lorry	-	-	223	209	157	154	128
Diesel Three Wheeler	-	-	-	-	-	542	-
Other	-	-	-	-	1,813	-	-
Petrol Car	-	-	-	1,248	483	284	242
Petrol Dual Purpose	-	-	-	484	525	218	-
Petrol Motor Cycle	-	-	-	5,283	5,163	1,846	1,393
Petrol Motor Lorry	-	-	-	-	-	459	-
Petrol Three Wheeler	-	-	-	2,307	4,334	4,519	3,516

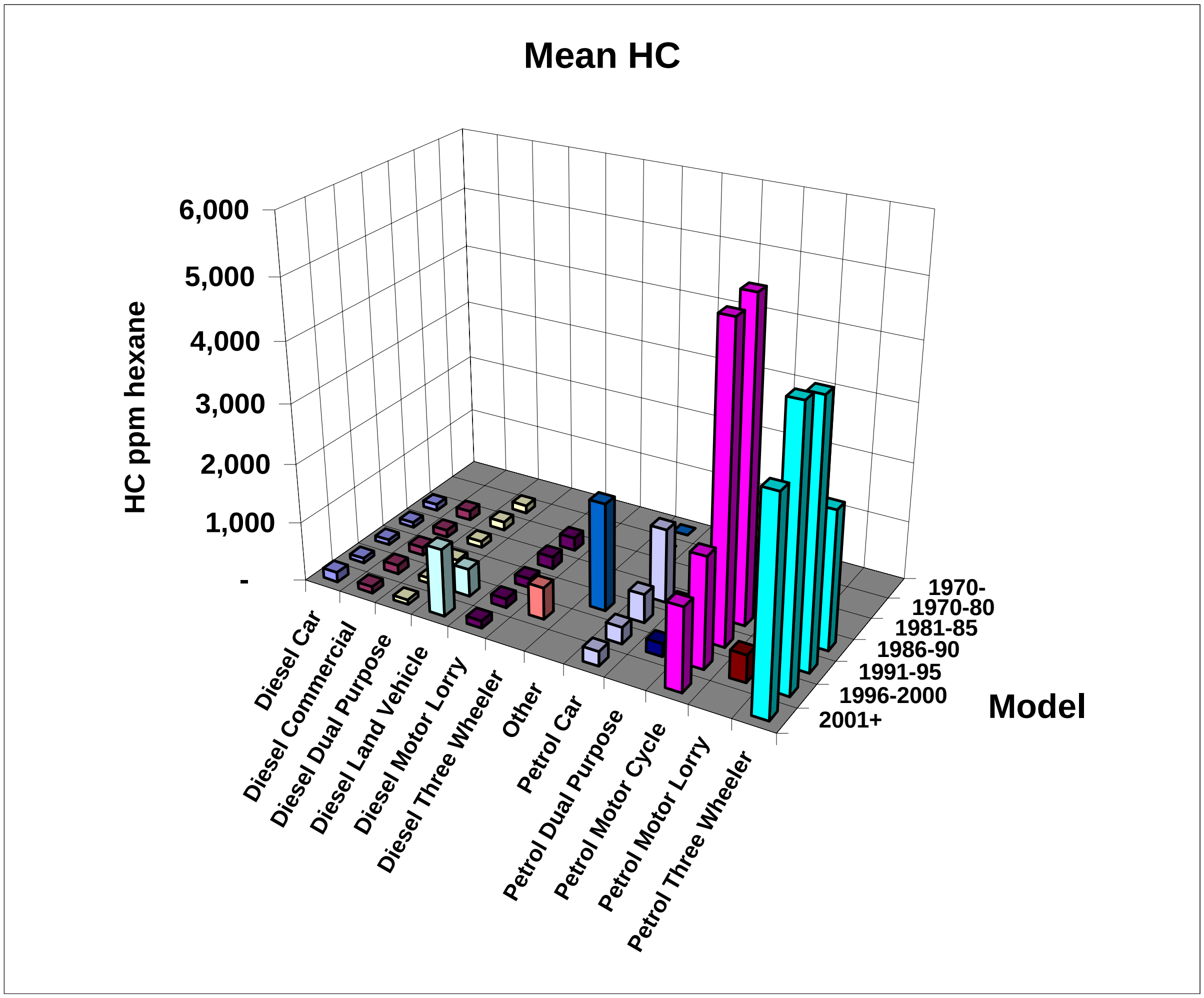


Figure 8-7: NOx by Vehicle Type and Model Year

Vehicle Type	1970-	1970-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001+
Diesel Car	-	-	1,088	417	386	354	654
Diesel Commercial	-	-	1,139	811	897	1,456	1,909
Diesel Dual Purpose	-	409	440	430	393	414	599
Diesel Land Vehicle	-	-	-	-	1,000	679	995
Diesel Motor Lorry	-	954	950	1,158	992	844	1,914
Diesel Three Wheeler	-	-	-	-	-	1,094	-
Other	-	-	-	-	1,028	-	-
Petrol Car	-	-	716	805	1,177	1,083	865
Petrol Dual Purpose	-	-	-	820	314	366	-
Petrol Motor Cycle	-	-	-	55	243	578	492
Petrol Motor Lorry	-	-	-	-	-	437	-
Petrol Three Wheeler	-	-	-	353	270	394	486

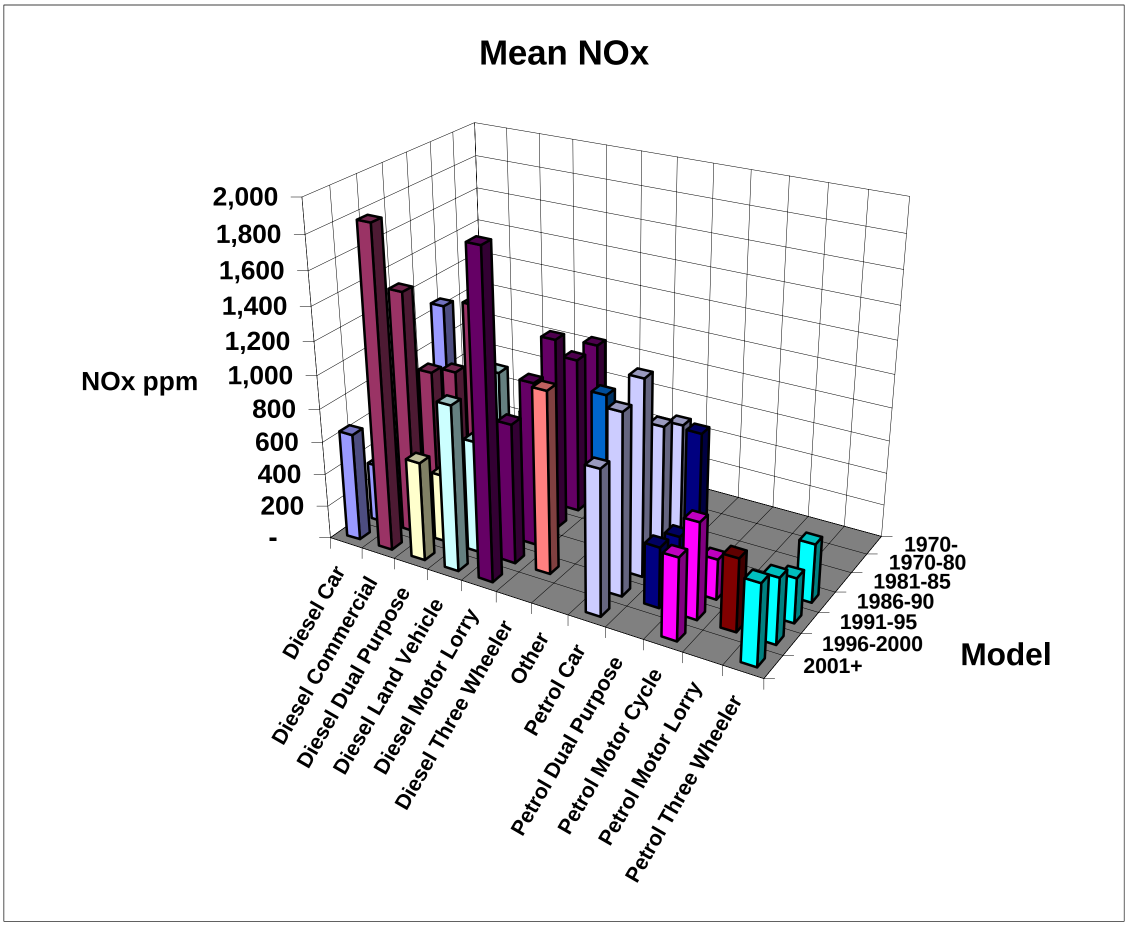
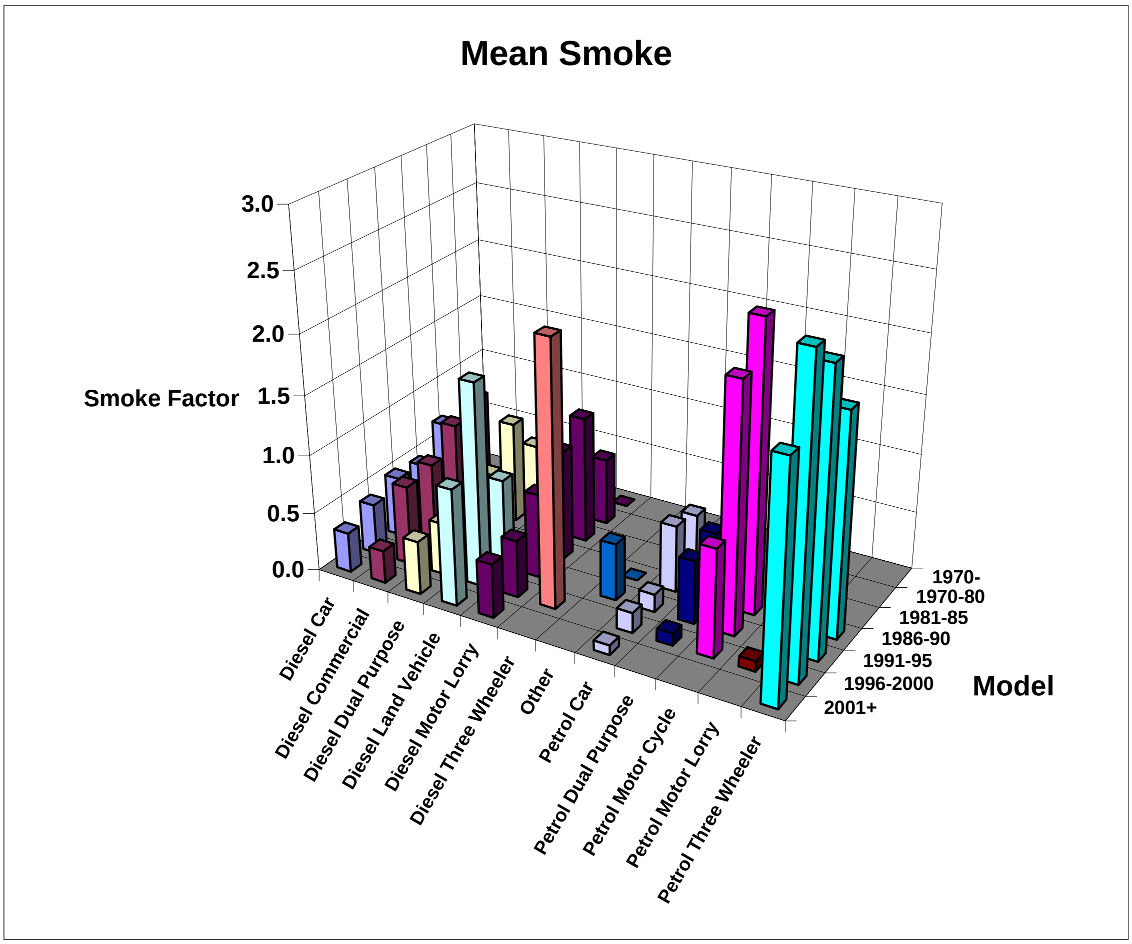


Figure 8-8: Smoke Factor by Vehicle Type and Model Year

Vehicle Type	1970-	1970-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001+
Diesel Car	-	-	0.71	0.48	0.51	0.43	0.34
Diesel Commercial	-	-	1.03	0.92	0.72	0.68	0.28
Diesel Dual Purpose	-	0.53	0.87	0.57	0.52	0.45	0.46
Diesel Land Vehicle	-	-	-	-	0.76	1.72	0.99
Diesel Motor Lorry	-	0.58	1.08	0.94	0.72	0.49	0.46
Diesel Three Wheeler	-	-	-	-	-	2.22	-
Other	-	-	-	-	0.49	-	-
Petrol Car	-	-	0.50	0.57	0.15	0.17	0.08
Petrol Dual Purpose	-	-	-	0.60	0.54	0.10	-
Petrol Motor Cycle	-	-	-	2.41	2.07	0.90	-
Petrol Motor Lorry	-	-	-	-	-	0.09	-
Petrol Three Wheeler	-	-	-	1.86	2.34	2.58	1.95



8.1.3. Approximate Emissions Contributions

The RSD system measures pollutant concentrations within vehicle exhaust plumes from which the pollutant grams per gallon of fuel can be calculated. The mass of pollutant emitted by a vehicle is, therefore, proportional to the pollutant concentration times the rate of fuel consumption. The total mass of exhaust pollutants emitted by a particular type of vehicle is proportional to the number of active vehicles of that type times their average kilometers driven times their average pollutant concentration times their average rate of fuel consumption.

The distribution of vehicle activity on-road among types of vehicle can normally be determined directly from the RSD observations. However, the RSD set-up was optimized for cars and light trucks and the observation rate of motorcycles, land vehicles and heavy trucks was lower than the number of such vehicles passing the RSD. Therefore, to correct this imbalance, a combination of registration statistics and the RSD measurements were used to estimate the relative mass of emissions from different types of vehicle. The distribution of activity by vehicle type shown in Table 8-3 was calculated from 2001 registration statistics of the types of vehicle registered, the RSD observed fraction of diesels and petrol vehicles within each vehicle type, and the RSD observed frequency of vehicles by model year within each type. Motorcycles and land vehicles were especially under-represented in the RSD measurements. Most of the activity for land vehicles is off-road so the small number of land vehicles measured is to be expected. With the current equipment set-up, however, many motorcycles were not measured.

The fuel economies shown in the Table 8-4, which are approximate estimates based on overseas vehicles, were used to calculate the rates of fuel consumption. The fuel consumption rates were combined with the distribution of active vehicles and their emission concentrations to estimate the percentage of total vehicle exhaust emissions produced by each type of vehicle shown in Table 8-5.

Table 8-3 Approximate Distribution of Vehicle Activity

Vehicle Type	1970 and Older	1970-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001 and Newer	Total
Diesel Car	22	55	210	5,904	10,736	21,206	951	39,062
Diesel Commercial	-	16	1,003	5,437	11,993	10,228	3,196	31,874
Diesel Dual Purpose	6	95	792	25,006	66,594	23,713	1,318	117,519
Diesel Land Vehicle	-	2,959	2,959	1,973	14,796	20,715	13,810	57,213
Diesel Motor Lorry	-	193	1,644	21,607	48,378	29,925	2,476	104,223
Diesel Three Wheeler	-	-	-	-	-	1,977	-	1,977
Other	-	-	144	-	721	288	793	1,946
Petrol Car	11	22	122	8,364	24,861	54,136	7,667	95,172
Petrol Dual Purpose	-	-	29	124	212	2,033	-	2,398
Petrol Motor Cycle	-	-	4,220	74,554	109,722	192,716	83,698	464,910
Petrol Motor Lorry	-	20	-	61	223	709	40	1,053
Petrol Three Wheeler	-	33	-	931	35,034	43,343	17,550	96,891
	-	3,395	11,124	143,962	323,269	400,989	131,499	1,014,238

Table 8-4 Assumed Average Fuel Economies

Vehicle Type	Fuel Economy kM/l
Diesel Car	12.6
Diesel Commercial	9.0
Diesel Dual Purpose	10.2
Diesel Land Vehicle	3.6
Diesel Motor Lorry	3.6
Diesel Three Wheeler	18.0
Other	10.0
Petrol Car	10.0
Petrol Dual Purpose	8.5
Petrol Motor Cycle	25.0
Petrol Motor Lorry	3.0
Petrol Three Wheeler	15.0
Total	9.9

Table 8-5 Approximate Emissions Contributions

Vehicle Class	HC	CO	NOx	Smoke
Diesel Car	1%	0%	2%	2%
Diesel Commercial	1%	0%	6%	3%
Diesel Dual Purpose	1%	1%	7%	8%
Diesel Land Vehicle	16%	8%	15%	21%
Diesel Motor Lorry	5%	3%	46%	22%
Diesel Three Wheeler	0%	0%	0%	0%
Other	0%	0%	0%	0%
Petrol Car	3%	12%	11%	1%
Petrol Dual Purpose	0%	0%	0%	0%
Petrol Motor Cycle	46%	61%	10%	26%
Petrol Motor Lorry	0%	1%	0%	0%
Petrol Three Wheeler	27%	13%	3%	17%

These calculations are approximate and assume that each type of vehicle is driven the same distance per day. The estimates should be adjusted according to the actual annual mileage and fuel consumption of each type of vehicle in Sri Lanka.

The calculations suggest that:

- Motorcycles emit 61% of exhaust CO;
- Motorcycles and petrol three wheelers emit 73% of exhaust HC;
- Diesel trucks and land vehicles emit 60% of exhaust NOx, and
- Diesel trucks and land vehicles emit 43% of exhaust smoke, and, motorcycles and three-wheelers emit another 43% of exhaust smoke.

In addition to exhaust HC, petrol vehicles may create additional evaporative emissions from refueling activities, petrol vapor from fuel tanks and small petrol leaks from fuel lines and fuel delivery systems.

The percentage of total emissions produced by each vehicle type is further shown in Figures 8-9 to 8-12. The sum of all the columns in each chart adds up to 100%.

Figure 8-9: Approximate CO Contributions

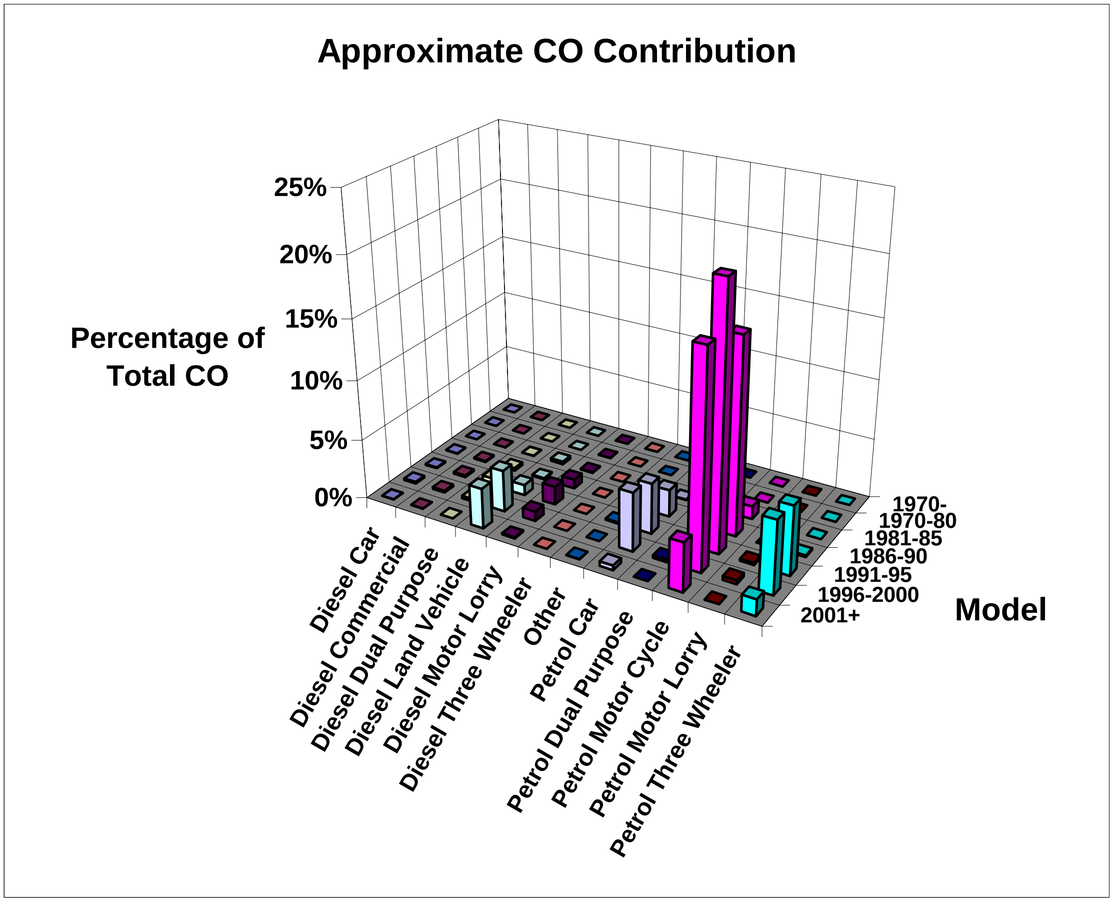


Figure 8-10: Approximate HC Contributions

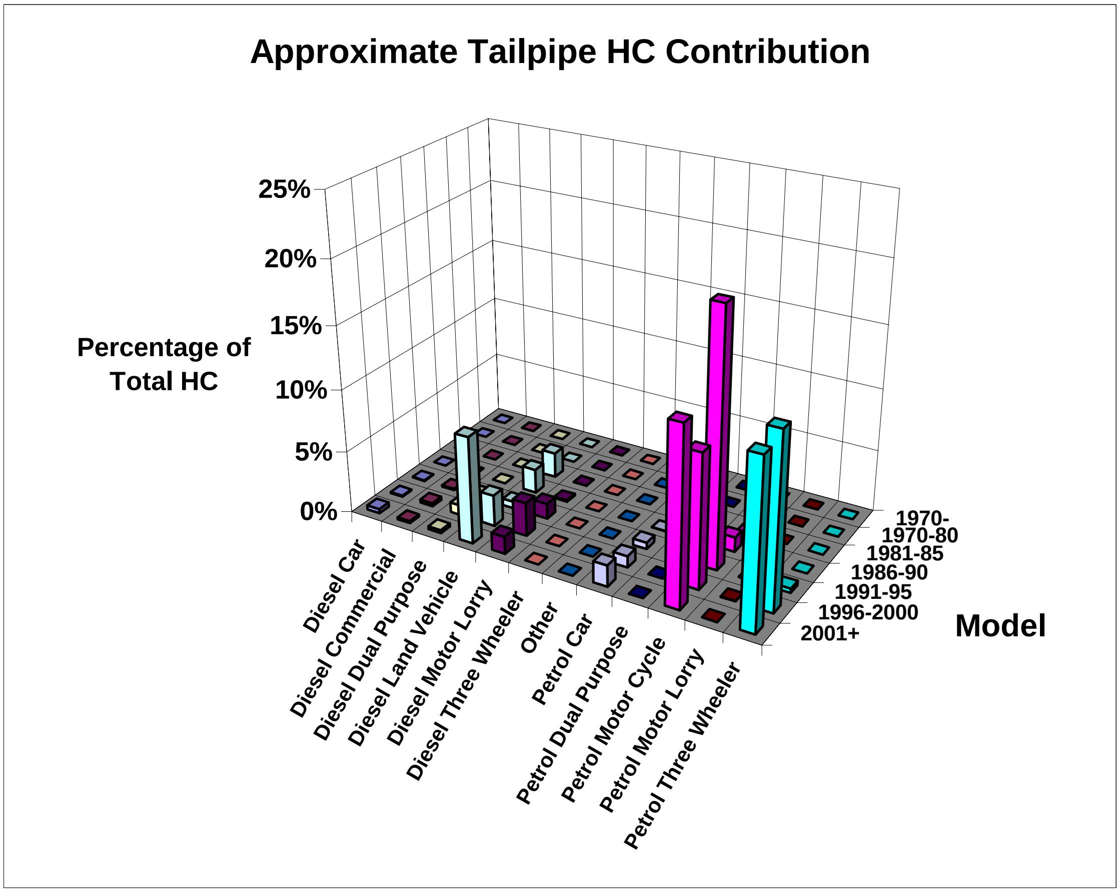


Figure 8-11: Approximate NOx Contributions

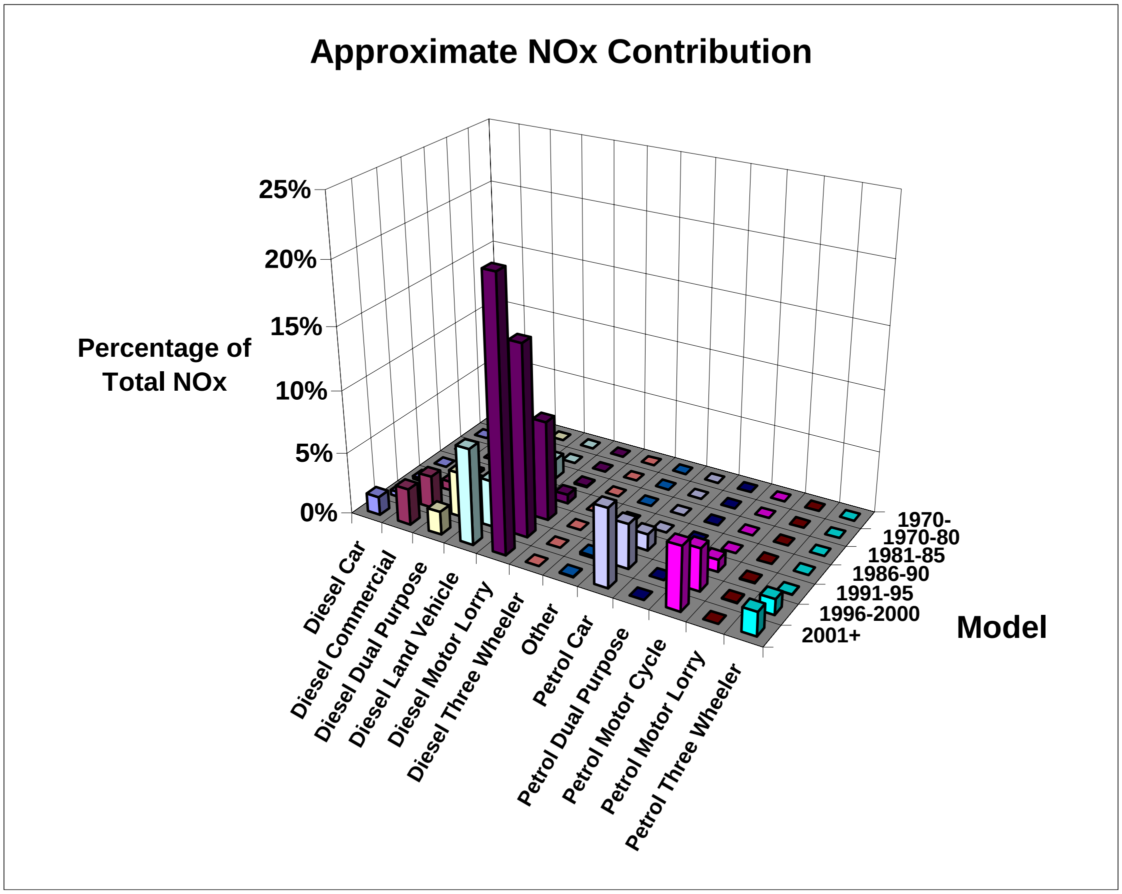
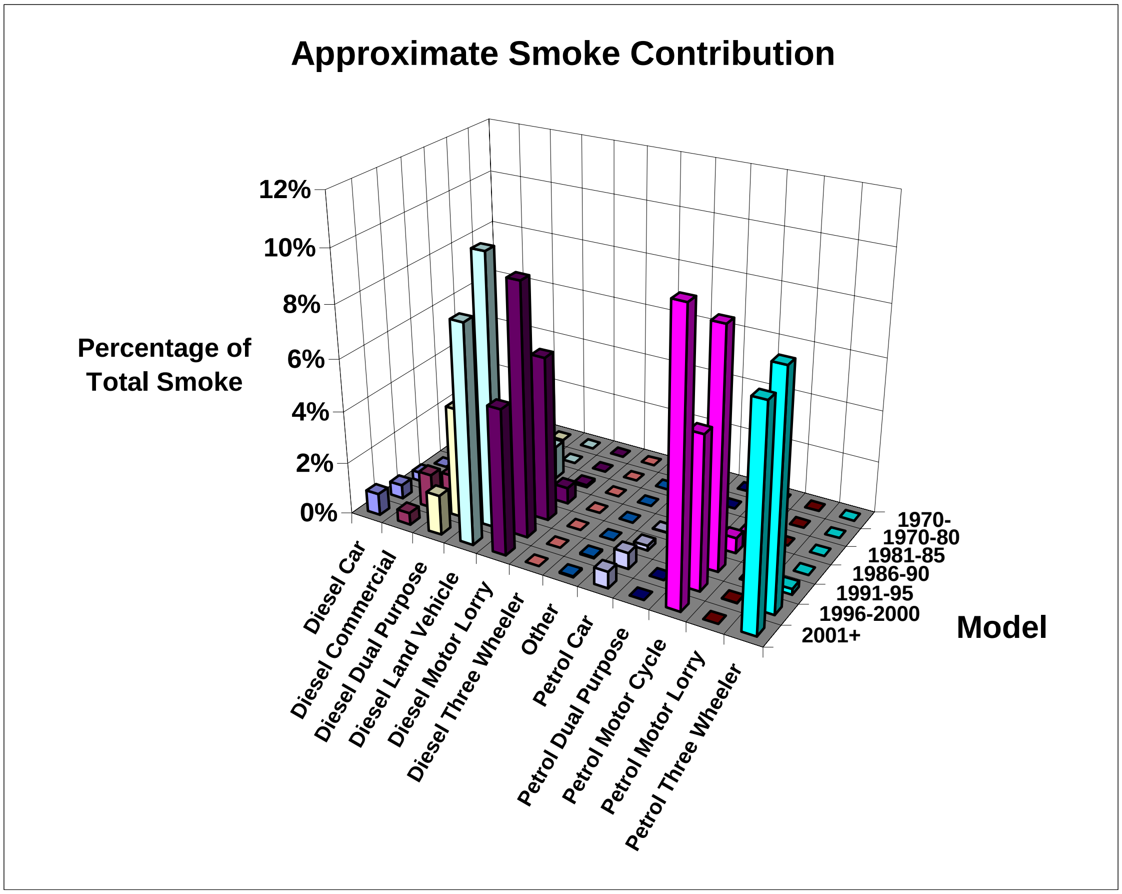


Figure 8-12: Approximate Smoke Contributions



8.1.4. Emission Deciles within Type of Vehicle

RSD measurements were first sorted by type of fuel and vehicle. For each fuel and vehicle type, the results were then sorted from cleanest to dirtiest and divided into ten groups with 10% of the vehicles in each group. Figures 8-13 to 8-17 show the average emissions of these groups. Motorcycles and three-wheelers stand out as having exceptionally high HC and smoke.

The results show that within vehicles of the same type a few dirty vehicles have much greater emissions than the typical vehicle. These dirty vehicles can normally be repaired to reduce their emissions substantially.

Figure 8-13: Petrol Vehicle CO Emission Deciles

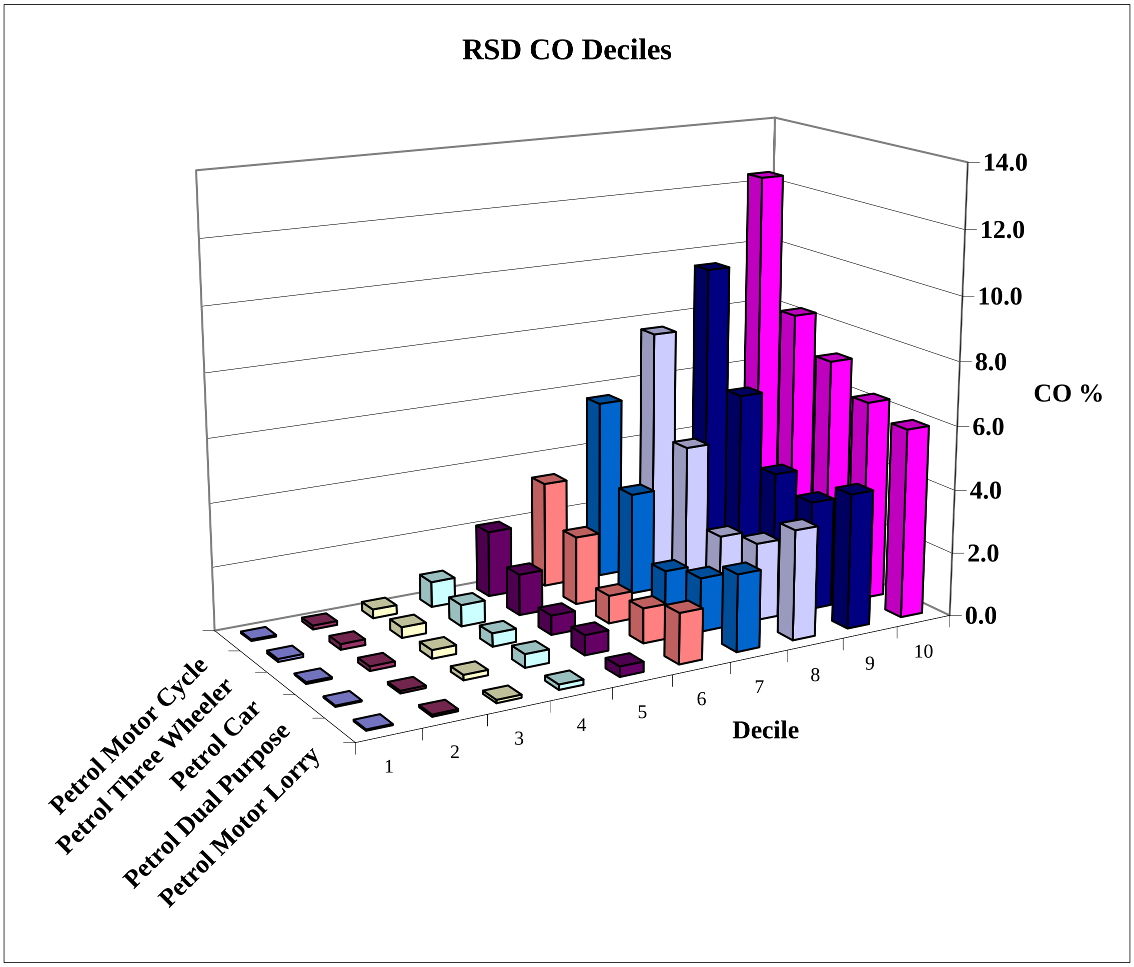


Figure 8-14: Petrol Vehicle HC Emission Deciles

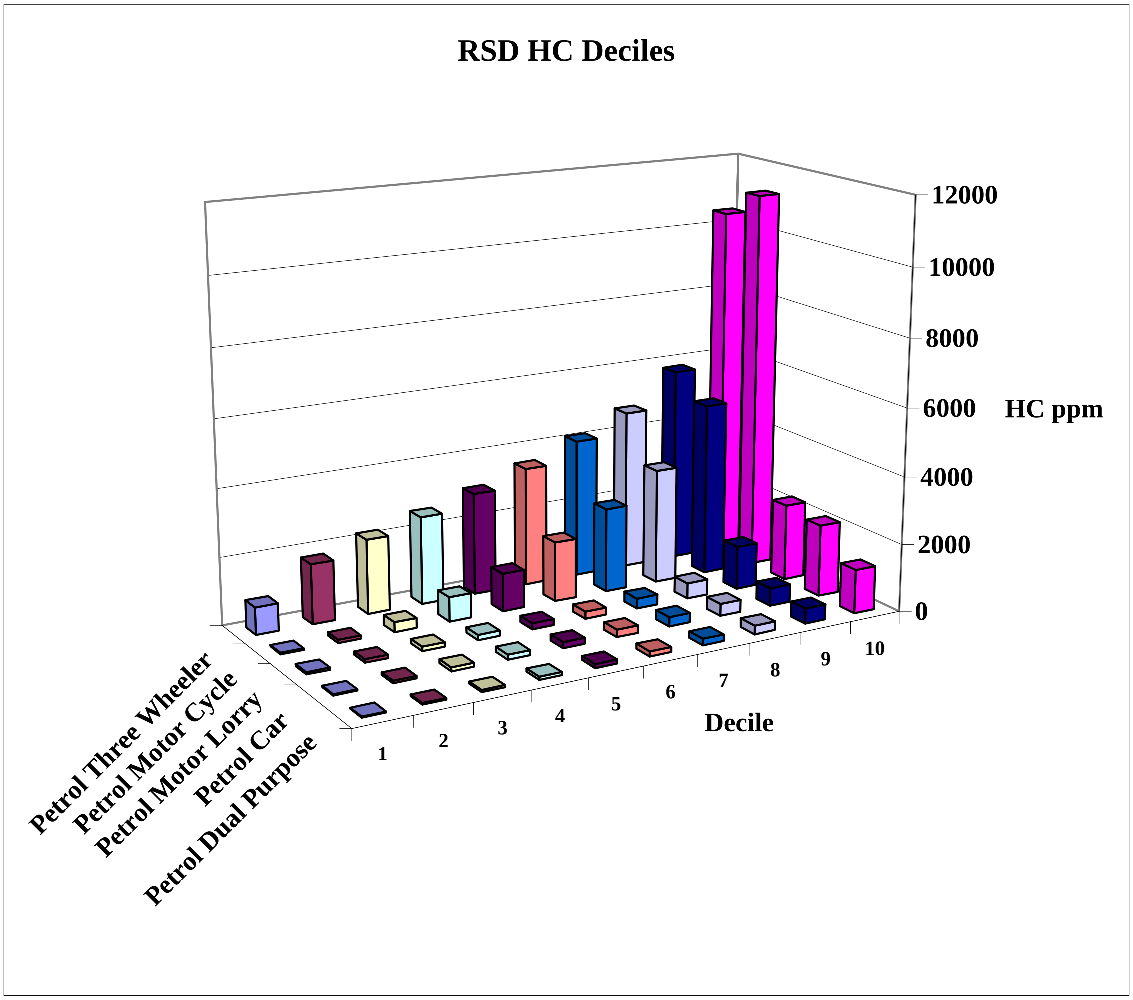


Figure 8-15: Diesel Vehicle NOx Emission Deciles

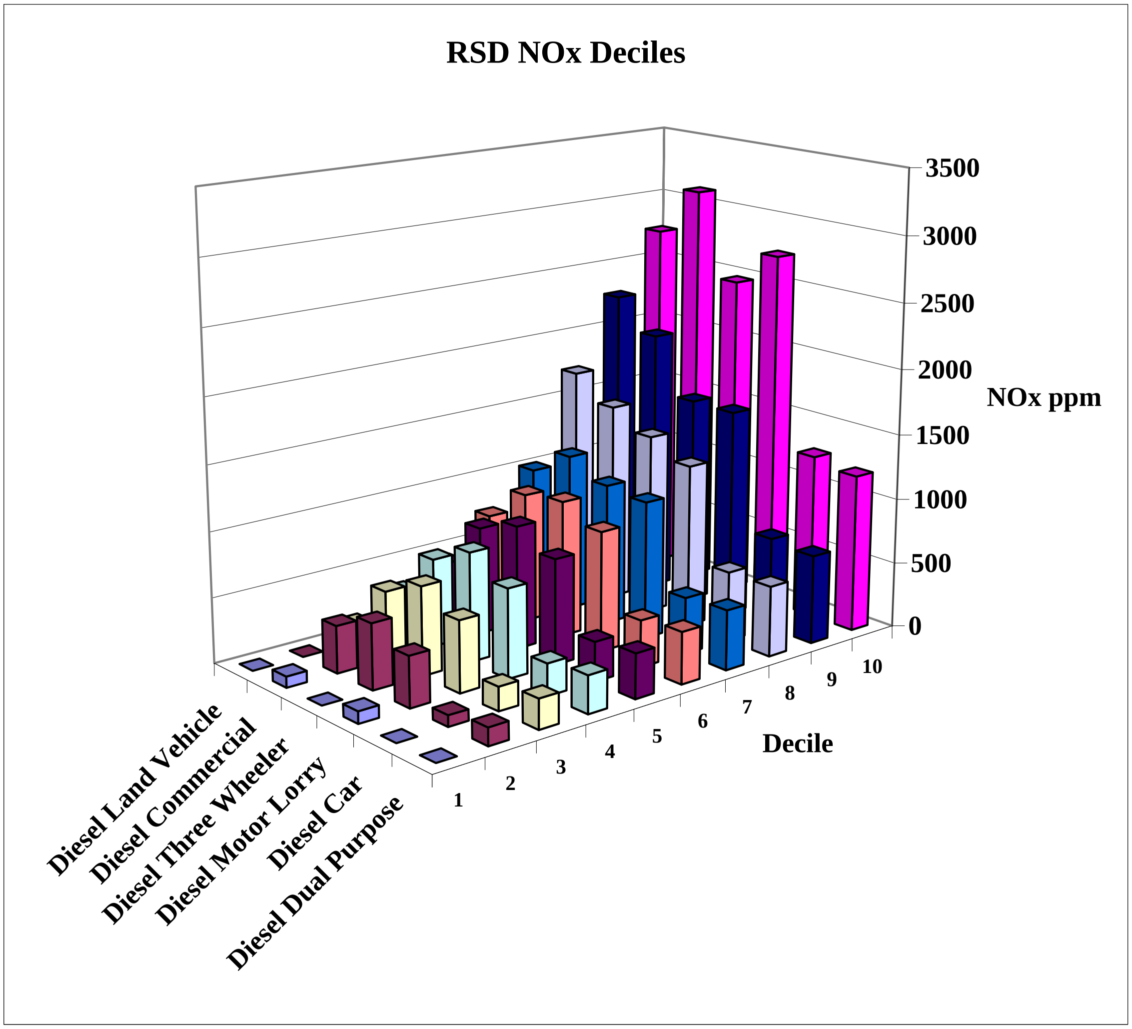


Figure 8-16: Petrol Vehicle Smoke Emission Deciles

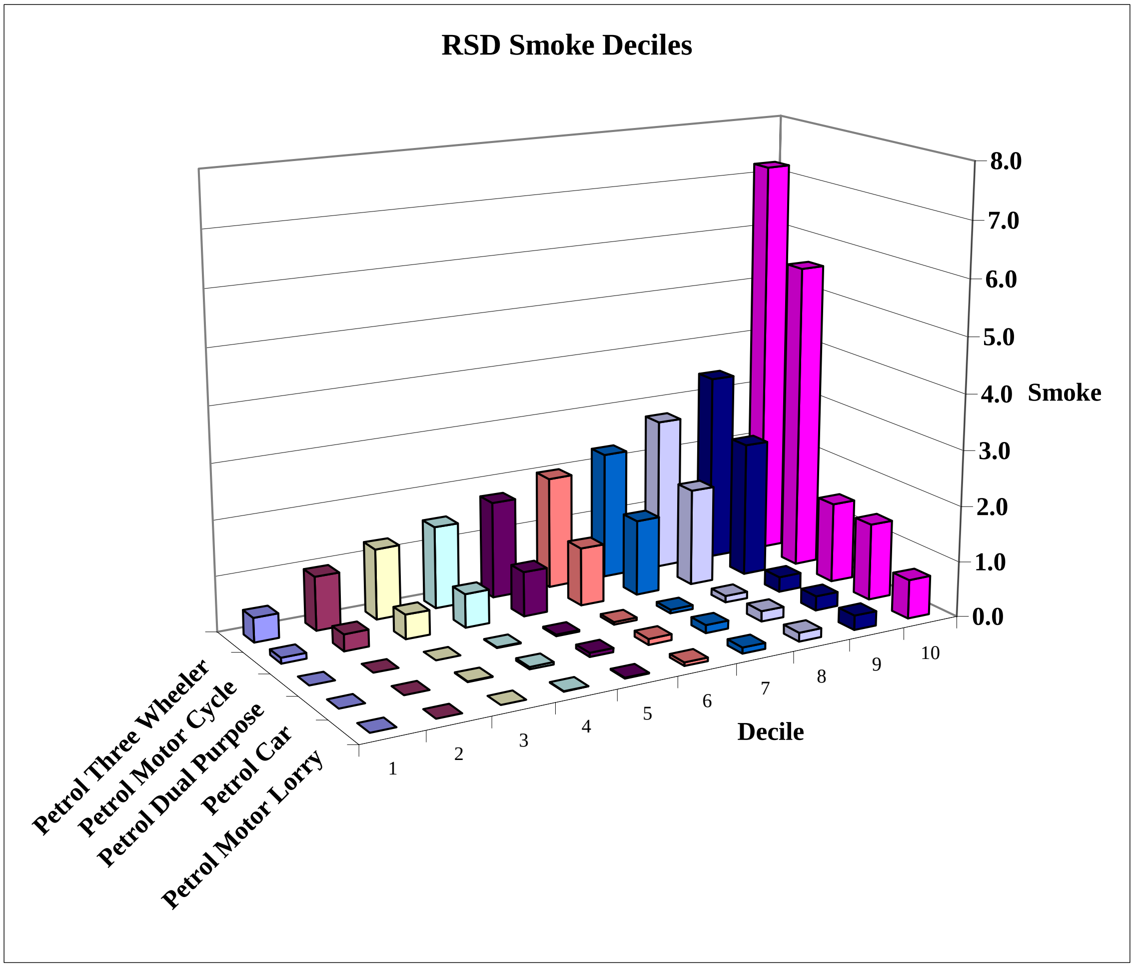
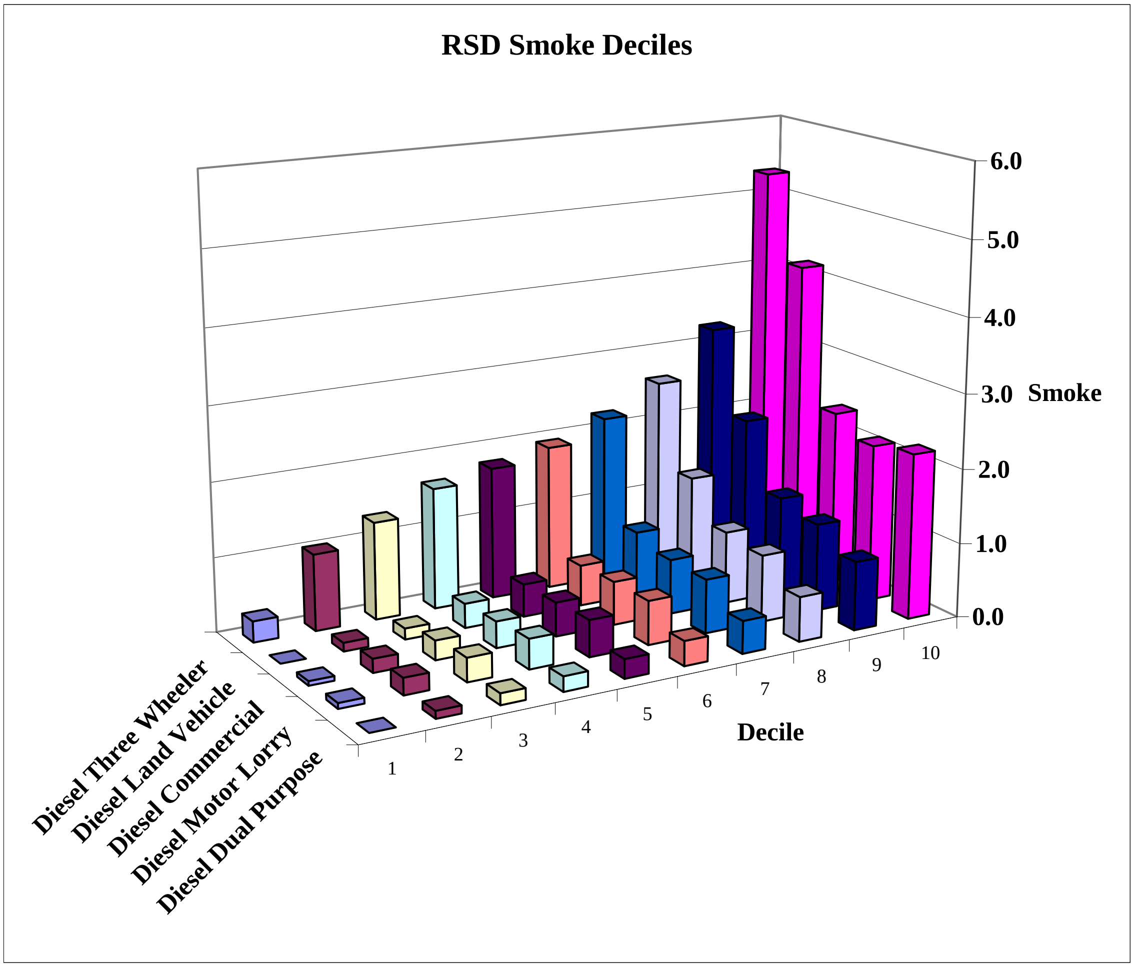


Figure 8-17: Diesel Vehicle Smoke Emission Deciles



8.1.5. On-Road Vehicles Exceeding HC and CO Standards

Figures 8-18 and 8-19 show pairs of bars for types of petrol vehicle. The left bars show the percentage of vehicles measured on-road with emissions higher than the 2003 HC and CO emissions test standards shown in Table 8-6. The right bars show the percentage of total fleet emissions that comes from these vehicles. The results show that the vehicles with emissions exceeding the test standards produce a large percentage of the total emissions.

It is normal for light cars and trucks to operate with a lower ratio of HC and CO to CO2 when they are driving on-road than when they are idling. Therefore, we expect that the failure rates in the vehicle emissions inspection program, which tests vehicles at idle, will be higher than reported here.

Table 8-6 Emissions Test Standards

	Test Standard	
Type of Vehicle	**CO %**	**HC ppm**
Petrol Car	4.5	1,200
Petrol Dual Purpose	4.5	1,200
Petrol Motor Lorry	4.5	1,200
Petrol Motor Cycle	6.0	9,000
Petrol Three Wheeler	6.0	9,000

Figure 8-18: Percent of Vehicles Exceeding CO Emissions Standard

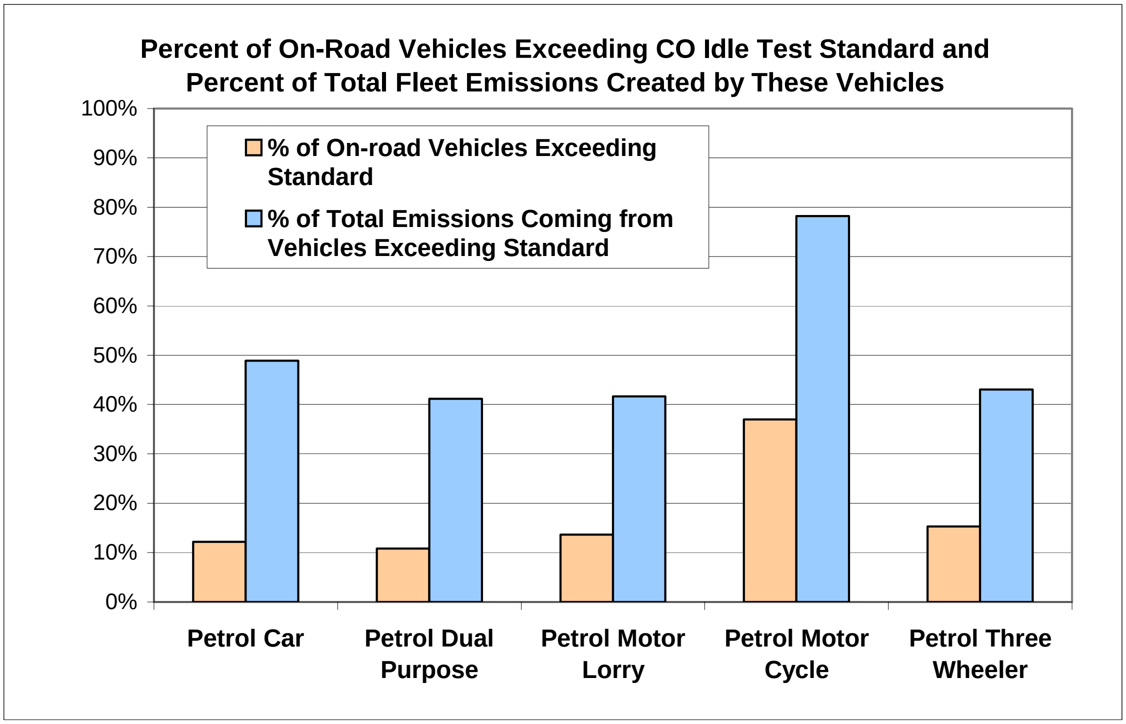
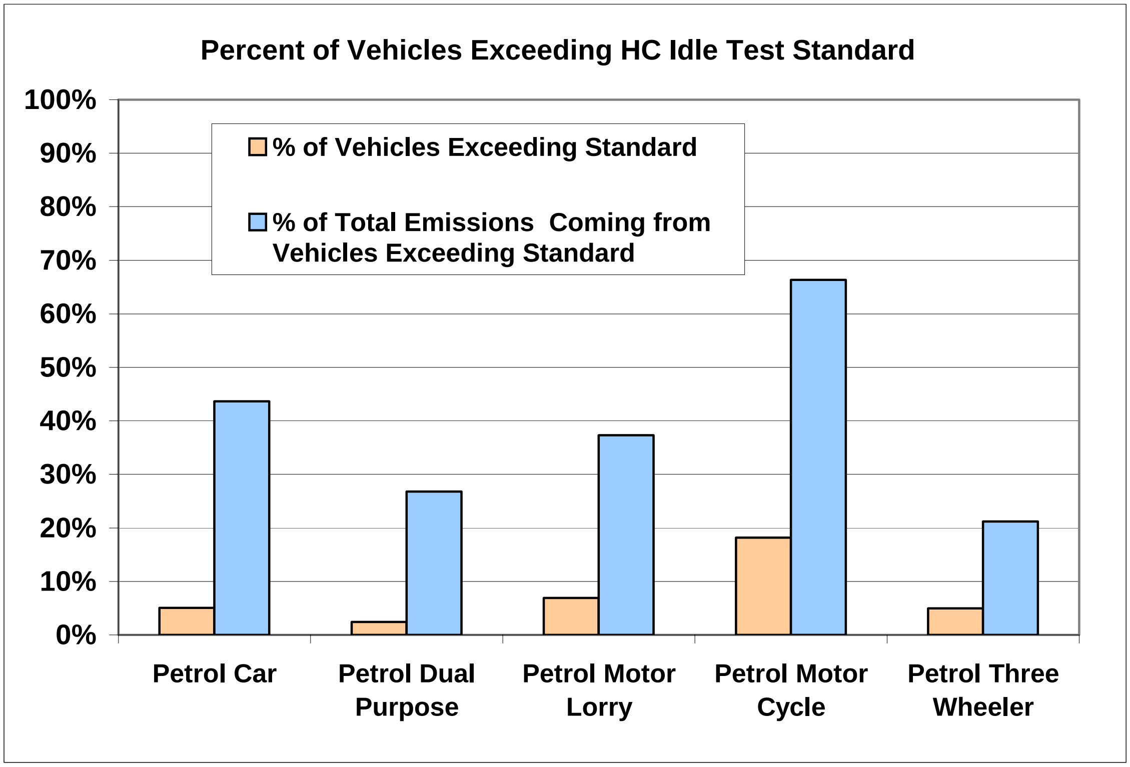


Figure 8-19: Percentage of Vehicles Exceeding HC Standards



9. CONCLUSIONS

The study showed that RSD can be used to monitor the emissions of vehicles on-road and can be used to assess the overall exhaust emissions inventory. However, the set-up of the equipment needs to be adjusted to measure more of the motorcycles and three-wheelers. With more accurate measurements of on-road vehicle activity and fuel consumption, a detailed inventory of the source of on-road emissions could be developed.

Motorcycles and three wheel vehicles have the highest emission rates of HC and CO and contribute over 70% of HC. The 1995 and newer petrol vehicles have lower levels of HC and CO emissions than older vehicles. Diesel vehicles have high emission rates of NOx accounting for more than 75% of NOx. The new diesel vehicles have NOx emissions rates similar to older vehicles. Diesel vehicles and two-stroke petrol vehicle combined create 80% of the particulates and smoke.

The dirtiest 10% of vehicles on the road create three to five times more emissions than the typical vehicle. The dirtiest 20% of petrol vehicles contribute 50% of the CO and 70% of the HC emitted by petrol vehicles. The dirtiest 20% of diesel vehicles contribute 46% of diesel NOx emissions.

A May 2003 Economy and Environment Program for Southeast Asia study reports that petrol and diesel vehicles account for 78% and 22% of total vehicular emissions. Cars and 2-stroke motorcycles account for 55% of vehicle emissions among petrol driven vehicles, whereas buses and lorries account for about 90% of emissions among diesel-driven vehicles. The study strongly discourages importation of 2-stroke motorcycle because of their considerable amount of vehicular emissions. The 2-stroke motorcycles account for about 25% of the total vehicular emissions in Colombo and 74% of the particulate emissions among petrol-driven vehicles.[27] The remote sensing study results reinforce the conclusions of this 2003 study.

The two enforcement applications of Clean Screening (CS) and Gross Emitter Identification (GEI), and the monitoring application known as I/M Program Evaluation (PE) can be applied together to supplement the new vehicle inspection and maintenance program and help reduce harmful vehicle emissions. In addition, program evaluation and fleet characterization are two important tools that can be applied to ensure that the vehicle inspection and maintenance program achieves its objectives.

APPENDIX A

A1. The 1992 Clean Air Act Amendments

Dr. Donald Stedman of the University of Denver is credited with inventing motor vehicle remote sensing. He built his prototype CO only device in 1987 under a USEPA grant. The concept of on-road emissions measurement was received early on with great skepticism by some and with great enthusiasm by others.

The supporters were pitching RSD as the silver bullet that would replace traditional I/M. The early skeptics, among them the USEPA, set out to prove it could not replace the I/M programs developed and implemented over the 1980s. Glover and Clemmens (91) compared RSD results to IM240 results.[28] Despite the lack of speed and acceleration data, Glover concluded RSD could identify a portion of the gross emitters, and touted its monitoring value. In his subsequent study, Whitney and Glover (1992) established definitively that RSD cannot replace I/M, but would serve as a fine supplement.[29]

All "enhanced" areas are required by the Clean Air Act Amendments to supplement their Enhanced I/M programs with an on-road remote sensing element. The Clean Air Act Amendments require that a minimum of 0.5% of the eligible motor vehicle population in the I/M area be tested annually.

Section 51.371 of the Code of Federal Regulation (CFR) covering Enhanced I/M programs defines on-road testing as the measurement of HC, CO, NOx and/or CO2 emissions on any road or roadside in the non-attainment area or the I/M program area. On road testing is required in enhanced I/M areas and is an option for basic I/M areas.

The general requirements specified in CFR 51.371 are:

1) On-road testing is to be part of the emission testing system, but is to be a complement to testing otherwise required.

2) On-road testing is not required in every season or on every vehicle but shall evaluate the emission performance of 0.5% of the subject fleet, including any vehicles that may be subject to the follow-up inspection provisions of paragraph 4) below, each inspection cycle.

3) The on-road testing program shall provide information about the emission performance of in-use vehicles by measuring on-road emissions through the use of remote sensing devices or roadside pullovers including tailpipe emission testing. The program shall collect, analyze and report on-road sensing data.

4) Owners of vehicles that have previously been through the normal periodic inspection and passed final retest and found to be high emitters shall be notified that the vehicles are required to pass and out-of-cycle follow-up inspection; notification may be by mailing in the case of remote sensing on-road testing or through immediate notification if roadside pullovers are used.

Despite the legislative mandate, states managed to avoid the 0.5% testing because of controversy surrounding the overall “enhanced” testing requirements, particularly centralized IM240 testing. States wanted flexibility to choose the I/M test and the I/M program design. The USEPA questioned the equivalence of others approaches. The California EPA and the USEPA agreed to study the matter in 1994. It was not until a 1995 California Air Resources Board (CARB) study determined the relative benefits of IM240 vs. ASM and the USEPA granted states flexibility to choose their I/M program test and design, that the USEPA began enforcing the 0.5% RSD rule.

Annual 0.5% surveys are currently being performed in the enhanced areas of CO, CT, GA, IL, IN, MD, NY, PA and NV.

A-2. The 1996 Gross Emitter Guidance

The 1992 USEPA 0.5% testing rule established the precedent for high emitter identification with language calling for out-of-cycle follow-up inspection. However, states interested in supplementing their programs with GEI had no basis for estimating the additional credit they would receive for implementing GEI. The community lacked guidance. The 1992 USEPA evaluation was accompanied by other independent industry studies that produced favorable conclusions. Among them was an April 1996 study by the Desert Research Institute that concluded that a GEI program could reduce Orange County, California CO and HC emissions by 46 and 36 percent at a cost of $9 per vehicle. The I/M community was beginning to

recognize the air quality benefits of remote sensing based GEI, and the USEPA came under increasing pressure to formalize guidance and a credit utility.

In September 1996, the EPA's Office of Mobile Sources (EPA-OMS) issued the "User Guide and Description for Interim Remote Sensing Program Credit Utility" which provides some credits for RSD programs. In the User guide, EPA-OMS admits it "*faced a tradeoff between when its first formal guidance on RSD credits would be released and how comprehensive and representative those credits could be. The choice EPA has made is to provide its credits sooner than later, realizing that they may not be as large as they could be with more investment in time, and may not cover every case of interest to users. One tradeoff has been the availability of relevant data; EPA has chosen to make use of data collected up to and including the 1994-95 El Monte study; and not wait to receive and analyze data collected in Arizona or elsewhere in 1996 and 1997.*"[30] The availability of more current program results with state-of-the art RSD technology recently prompted the USEPA to revisit gross emitter credit allocation. A new gross-emitter credit utility is expected in 2005.

A-3. The 1996 Clean Screen Guidance

Colorado was one of the first states to comply with the 0.5% RSD testing requirement and had amassed a sizeable dataset by the time the 1996 GEI guidance was issued. Although Colorado was an "enhanced" I/M area, its air quality had improved substantially since it began testing motor vehicles and was looking for ways to lessen the burden of the I/M program on Colorado motorists.

Examination of its RSD dataset revealed that its cleanest on-road vehicles could be conveniently and effectively identified as "clean" without station-based test. Encouraged by the comparison of its 0.5% RSD data to previous and subsequent IM240 results on the same vehicle, Colorado elected to commission a more definitive clean screen evaluation in its northern city of Greeley. ESP's predecessor company (RSTi) had provided the 0.5% data and was chosen to perform the Greeley study. The Greeley results showed low false passes and demonstrated that RSD was an effective tool for clean screening. ESP prepared a formal report to the USEPA. Based on the Greeley data, the USEPA's FACA Committee recommended a credit scheme that included clean screening up to 50% of the fleet with minimal loss of excess repairable emissions.[31] The Clean Screen guidance document was issued in late1996.

Figure A-1: Clean Screening I/M Slides Presented at 5/19/98 FACA Meeting

U.S. Environmental Protection Agency
Office of Mobile Sources

Clean Screening I/M Credits

FACA Meeting
May 19, 1998
revisions
May 28, 1998

RSD Clean Screening - CDH Work

- Remote Sensing Technologies, Inc. was contractor with Applied Analysis as subcontractor
- Obtained IM240 values and two RSD readings
- HC - 200 ppm; CO - 0.5%
- NOx - no cutpoint, 1,000, 1,500, or 2,000 ppm
- 594 vehicles

Fleet Fraction Exempted versus NOx Cutpoint

- Current in-use fleet, 100% coverage
- HC 200 ppm; CO 0.5%
- NOx (if no NOx, assume fail)
  - no cutpoint 51%
  - 2,000 ppm 40%
  - 1,500 ppm 37%
  - 1,000 ppm 29%

Emission Credits Retained - Phase-in IM 240 Standards

- HC 200 ppm; CO 0.5%
- no NOx cutpoint
  - 98% HC, 93% CO, 77% NOx
- 2,000 ppm NOx cutpoint
  - 98% HC, 93% CO, 88% NOx
- 1,500 ppm NOx cutpoint
  - 99% HC, 100% CO, 89% NOx
- 1,000 ppm NOx cutpoint
  - 99% HC, 100% CO, 93% NOx

A-4. The 2002 Program Evaluation Guidance

Congress's Clean Air Act (CAA) Amendments and the USEPA's I/M rule require biennial program effectiveness evaluation (a quantification of the mobile source emissions reduced by the I/M program).[32]

In January 1998, EPA revised the I/M rule's original provisions for program evaluation by removing the requirement that the evaluation be based on IM240 or some equivalent, mass-emission transient test (METT) and replacing this with the more flexible requirement that the program evaluation methodology simply be "sound".[33] In October 1998, EPA published a guidance memorandum that outlined what the Agency considered to be acceptable, "sound," alternative program evaluation methods[34].

All the methods approved in the October 1998 guidance were based on tailpipe testing and required comparison to Arizona's enhanced I/M program as a benchmark using a methodology developed by Sierra Research under contract to EPA. Even

though EPA recognized that an RSD-based program evaluation method might be possible, a court-ordered deadline of October 30, 1998 for release of the guidance prevented EPA from approving an RSD-based approach at that time. EPA420-S-98-015, October 1998, Inspection and Maintenance Program Effectiveness Methodologies identifies four methods for program evaluation: The Sierra Research Method, The NYTEST (VMAS) Method, The RG240 Method, and the RSD fleet characterization method. It approved the first three while reserving judgment on RSD, which required further study. The most powerful use of remote sensing has unfortunately been the most neglected.

In 2002, the USEPA, with the help of other government and industry stakeholders, drafted a guidance document that recognized the value of remote sensing program evaluation and identified three RSD-based PE techniques. The guidance recommends three methods (the Step Change, the Comprehensive, and the Reference Methods) for RSD-based program evaluation and considers the combination of RSD and one of the original three as among the best evaluation tool going forward.

The Step Change and Comprehensive evaluation methods are quite similar. Remote sensing measurements are made on a fleet of vehicles in an I/M area. The fleet is then divided into two sub-fleets, based on whether or not individual vehicles have been tested under the current I/M program. The emissions of the two sub-fleets are then compared, after accounting for differences in vehicle type and age. The difference in the emissions of the tested fleet and the untested fleet is the apparent benefit of the I/M program in reducing emissions.

The Reference Method is designed to measure the full effect of an I/M program on a vehicle fleet, by comparing the emissions of a fleet subject to I/M with the emissions of a fleet not subject to I/M. ESP recently concluded a reference evaluation of the northern Virginia I/M fleet by comparing it to the southern Virginia non-I/M fleet. The report is available at the Virginia Department of Environmental Quality web site www.deq.state.va.us/air/news.html.

The USEPA considers the combination of remote sensing and I/M data to be an effective tool for program effectiveness evaluation, a sentiment echoed by the National Research Council's Committee on Emissions Inspection and Maintenance Programs.[35]

Active Programs:

There are four active screening programs in the United States; two operate gross-emitter programs and two operate clean-screen programs.

Texas and Virginia operate remote sensing based high emitter identification programs in their respective I/M areas. Texas issues approximately 300 high emitter notices per month. Virginia plans to issue its first notices in 2005, after program implementation in late 2004/early 2005.

Missouri and Colorado operate remote sensing clean screen programs in their I/M areas. Colorado exempts approximately 25% of inspection volume each year. Colorado expects to issue its first exemptions in October 2005.

Taiwan plans to formalize a 2 year pilot high emitter program in 2005. Taiwan is the only official international remote sensing screening program known of today.

---

[1]. Finlayson-Pitts, B.J.; Pitts, Jr., J.N. *Atmospheric Chemistry: Fundamentals and Experimental Techniques*; John Wiley and Sons: New York, 1986, 522-535.

[2]. Wark K., Warner C.F. Air Pollution: Its Origin and Control, 2nd Ed., HarperCollins Publishers, 1981; p. 409, p. 28.

[3] Chandrasiri, Sunil; Controlling Automotive Air Pollution: The Case of Colombo City; Economy and Environment Program for Southeast Asia; Research Reports, May, 2003; p. 1 of 28. [http://web.idrc.ca/uploads/user-S/10536134820ACF1B6.pdf]

[4] Chandrasiri, Sunil; Controlling Automotive Air Pollution: The Case of Colombo City; Economy and Environment Program for Southeast Asia; Research Reports, May, 2003; p. 1 of 28. [http://web.idrc.ca/uploads/user-S/10536134820ACF1B6.pdf]

[5] Senarath, Chandralatha; "An Overview of Air Pollution and Respiratory Illnesses in Sri Lanka"; Proceedings of the Third International Conference of Environment and Health, Chennai, India, 15-17 December 2003.

[6] Jayaweera, Don S.; "Vehicle Inspection and Maintenance Policies and Programme – Sri Lanka"; Deputy Director Planning of Ministry of Transport and Environment, Sri Lanka; March, 2001. [http://www.un.org/esa/gite/iandm/jayaweerapaper.pdf]

[7] Jayaweera, Don S.; "Vehicle Inspection and Maintenance Policies and Programme – Sri Lanka"; Deputy Director Planning of Ministry of Transport and Environment, Sri Lanka; March, 2001; p. 1. [http://www.un.org/esa/gite/iandm/jayaweerapaper.pdf]

[8] Jayaweera, Don S.; "Vehicle Inspection and Maintenance Policies and Programme – Sri Lanka"; Deputy Director Planning of Ministry of Transport and Environment, Sri Lanka; March, 2001; p. 2. [www.un.org/esa/gite/iandm/jayaweerapaper.pdf]

[9] Dry gas combustion equation (www.feat.biochem.edu/assets/reports/ftmath.pdf)

[10] The University of Denver on-road emissions web site is www.feat.biochem.du.edu.

[11]. Stephens, R.D.; Cadle, S.H.; Qian, T.Z. Analysis of Remote Sensing Errors of Omissions and Commission Under FTP Conditions, *J. Air & Waste Manage. Assoc.* 1996, 46, 510.

[12]. Stephens, R.D.; Cadle, S.H.; Remote sensing measurements of carbon monoxide emissions from on-road vehicles, *J. Air & Waste Manage. Assoc.* 1991, 41, 39.

[13]. Davis, L.D.; DuBose, R.S.; Walden, T.; Rodgers, M.O. Estimating I/M Program Effectiveness Through Analysis of I/M Records and Remote Sensing Results in Atlanta, The Emission Inventory: Programs and Progress, Air & Waste Management Association, Raleigh, NC, October, 1995.

[14]. Fogelson, M.S.; Canon, M.B.; Grodzinsky, G.; DuBose, R.S.; Klochko, P.; Barker, T.; Rodgers, M.O. Comparison of Remote Sensing Results from Different Cities with Centralized and Decentralized I/M Programs, In Proceedings of the AWMA/EPA Conference on Emissions Inventory: Durham, NC, October 1995.

[15]. Stedman, D.H.; Bishop, G.A.; Zhang, Y. ; Guenther, P.L. Remote sensing of automobile emissions, in *Traffic Technology International 94*, UK & International Press, 1994, 194-198.

[16]. Peterson, J.E.; Stedman, D.H.. Find and fix the polluters, *Chemtek* 1992, Jan., 47.

[17]. Zhang, Y.; Stedman, D.H.; Bishop, G.A.; Beaton S.P.; Guenther, P.L.; McVey I.F.; Enhancement of Remote Sensing for Mobile Source Nitric Oxide, *J. Air & Waste Manage. Assoc.* 1996, 28, 25-29.

[18] “Virginia Remote Sensing Device Study Addendum – Vehicle Opacity” ESP report for Virginia Department of Environmental Quality, February 2003. (www.deq.virginia.gov/pdf/air/opacityAdd.pdf)

[19]. Lawson, D.R.; Groblicki, P.J.; Stedman, D.H.; Bishop, G.A.; Guenther, P.L. Emissions from in-use motor vehicles in Los Angeles: A pilot study of remote sensing and the inspection and maintenance program, *J. Air & Waste Manage. Assoc.* 1990, 40, 1096.

[20] User Guidance and Description for Interim Remote Sensing Program Credit Utility, EPA/AA/AMD/EIG/96-01, United States Environmental Protection Agency, Office of Air and Radiation, September 1996.

[21] Description and Documentation for Interim Vehicle Clean Screening Credit Utility, EPA420-P-98-008, United States Environmental Protection Agency, Office of Air and Radiation, October 1998.

[22] April 2nd Press Release; Clean Air Today, EIN Publishing; April 9th, 2002

[23] QC Lasers, an exciting new development in infrared spectroscopy, Aerodyne Research, Inc. 1999.

[24] Documents can be obtained from the USEPA website: www.epa.gov/oms/rsd.htm.

[25] There are a number of routes by which to obtain further and more detailed information about the MOBILE model. The best of these is the Modeling page within the Office of Mobile Sources Web site: www.epa.gov/omswww/models.htm. A User's Guide to MOBILE5a and MOBILE6 (currently under development are also available there.

[26] Klausmeier, Robert and McClintock, Peter "Virginia Remote Sensing Device Study" ESP report prepared for Virginia Department of Environmental Quality, March 2003.
[27] Chandrasiri, Sunil; Controlling Automotive Air Pollution: The Case of Colombo City; Economy and Environment Program for Southeast Asia; Research Reports, May, 2003; p. 24 of 28. [http://web.idrc.ca/uploads/user-S/10536134820ACF1B6.pdf]

[28] Identifying Excess Emitters with a Remote Sensing Device: A Preliminary Analysis; Glover, Edward L. and William B. Clemmens, SAE Paper 911672 1991.

[29] Evaluation of the Ability of Multiple Remote Sensing Devices to Identify High Emitters; Whitney, Kevin A. and Glover, Edward L., SAE Paper 922315, 1992.

[30] The gross emitter guidance can be viewed at www.epa.gov/oms/rsd.htm.

[31] The Denver 0.5% report, the Greeley Clean Screen report, and the FACA Committee report are available on the USEPA website: www.epa.gov/oms/rsd.htm.

[32] Section 182(c)(3)(C) of the CAA requires that all states subject to enhanced I/M biennially prepare a report to the Administrator which assesses the emissions reductions achieved by the program.

[33] EPA Rule, January, 1998

[34] EPA Memo, October 30, 1998

[35] Holmes, K. John, NRC Senior Staff Officer; Evaluating Vehicle Inspection and Maintenance Programs; National Research Council's Committee on Vehicle Emissions Inspection and Maintenance Programs; Presentation at the 2001 Clean Air Conference, Estes Park, Colorado; September 12th, 2001; www.ncvecs.colostate.edu/cac.docs/cac18.docs/CAC17PrelimAgenda.htm.