ESP
2002 North Forbes Blvd.
Tucson, AZ 84745

DRAFT – DO NOT CITE

New Delhi Remote Sensing Pilot Demonstration – An On-road Characterization for the In-use emissions of Delhi's Motor Vehicle Fleet Through Remote Sensing Devices (RSD).

Prepared for:

US-Asia Environmental Partnership
Automotive Research Association of India
The Department of Transport, the Govt. of NCT of Delhi

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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

1. SURVEY INTRODUCTION AND SUMMARY

US-Asia Environmental Partnership (US-AEP) awarded Environmental Systems Products (ESP) a grant to conduct a remote sensing device (RSD) pilot study in order to:

1) To demonstrate the characterization of the on-road emissions of the active vehicle fleet in New Delhi using RSD;
2) Provide the basis for design and execution of a full-scale fleet characterization that will provide the information for the government to make effective policy decisions to combat air pollution from vehicular emissions;
3) Transfer information and expertise on the use of RSD to local authorities.

To accomplish the study goals, ESP worked with the Automotive Research Association of India (ARAI) and the Delhi Department of Transport (DOR). Twenty-four sites were surveyed in 2003 and 22,991 measurements were made of vehicles license plate, 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:

- Two wheel vehicles were the highest emitters of HC and are large producers of smoke.
- Three wheeler vehicles in Delhi have much lower HC and smoke emissions than in Pune

- Commercial vehicles were the highest NOx emitters and are also large producers of smoke.
- The dirtiest 10% of each type of vehicle is several times dirtier than typical vehicles.
- Remote sensing can effectively characterize and monitor the on-road emissions in India.
- The Government of India should consider using remote sensing:
    - To identify high emitting vehicles and require them to obtain an additional out-of-cycle vehicle inspection;
    - For fleet characterization and inspection program evaluation.

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 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

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] Delhi has had severe air quality problems that have started to be addressed in recent years with the conversion of transport buses and taxis to CNG, nevertheless, commercial diesel vehicles continue to be a major source of NOx and particulates. 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. In Delhi, 2-wheelers, which represent 70% of the on-road vehicles and growing, account for 70% of all hydrocarbon and 50% of all carbon monoxide emissions.[3] Measurement of these constituents in automobile exhaust is therefore important to urban air quality control and the protection of human health and the environment. Environmentalists and scientists alike are calling for the implementation of more effective emissions inspection programs.[4]

2.2. RSD Technology

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.[5] 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.[6] 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. RSD Applications

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,[7,8] characterizing fleet emissions distributions to evaluate control programs[9] and to compare with other fleets for benchmarking purposes.[10] Previous remote sensing studies have indicated that most of the measured on-road emissions (over 50%) come from a disproportionately small percentage of the vehicles (approximately 10%).[11,12] This has been shown to be true for CO, HC, and most recently for NO_x and opacity.[13],[14] 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).[15,16,17]

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 programs in other states. ESP is the product and services provider to all domestic users and nearly all international users. 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

Environmental Systems Products is the world leader in remote sensing products and services. The growing interest in remote sensing capability has prompted several new development efforts to advance its equipment and improve the operational versatility of its 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. This will eliminate the need for frequent periodic gas calibrations.
- Windows operating system.
- Expandable for additional gas channels.
- A UV opacity channel sensitive to fine particulates.

Several other research programs focused on advancing ESPs 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 for the Japanese market with its strategic alliance partner, Toyota Tsusho.[18] Diesel capability 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.

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.[19] 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:

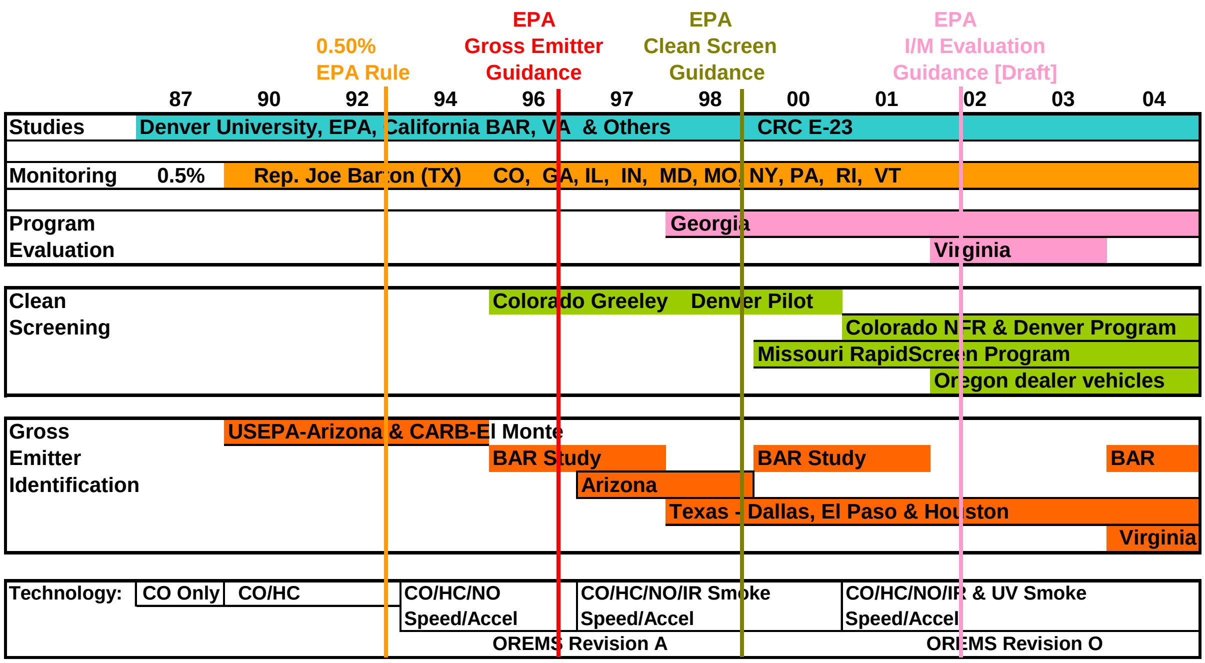
- Clean Screening (CS). RSD is used to exempt clean vehicles from station inspections (EPA Document – EPA420-P-98-007);
- Gross Emitter Identification (GEI). RSD is used to identify dirty vehicles for off-cycle station inspection (EPA Document – EPA/AA/AMD/EIG/96-01);
- I/M Program Evaluation (PE). RSD 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 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 impact of the remote sensing supplement.[20] 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.[21] 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 lead 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 applications together with ESP's AccuScan technology milestones.



5. RSD TECHNOLOGY SPECIFICATIONS/PERFORMANCE STANDARDS

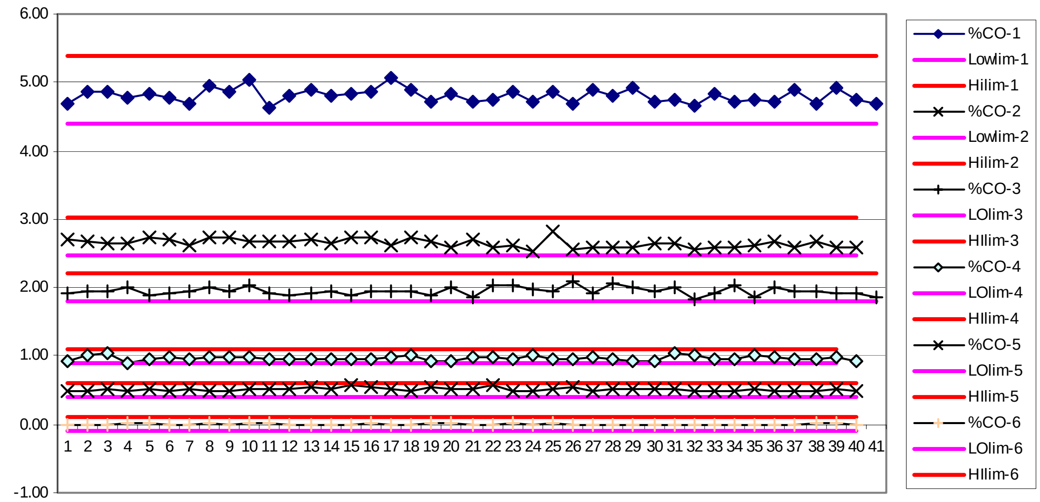
The California Bureau of Automotive Repair has defined procedures and associated performance standards for remote sensing equipment called the On-Road Emissions Monitoring System (OREMS) specifications. The most recent OREMS release was Revision O, which specifies an unattended system. The OREMS specifications 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 or exceeded industry standards for analytical performance. Each RSD unit is tested for accuracy

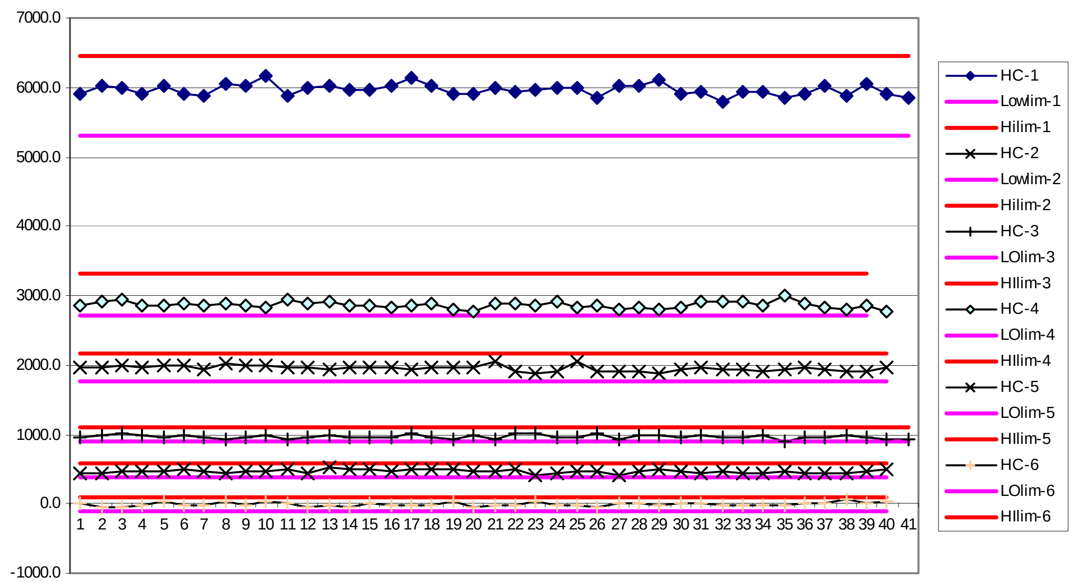
by driving a specially adapted calibration vehicle (known as an “audit truck”) past the RSD unit while releasing calibration test gas with a blend of known concentrations of HC, CO, NOx and CO2. Different blends of calibration test gas are used to test the RSD unit over a wide range of concentrations 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 show the ranges within which the RSD measurements should fall to meet the accuracy specification.

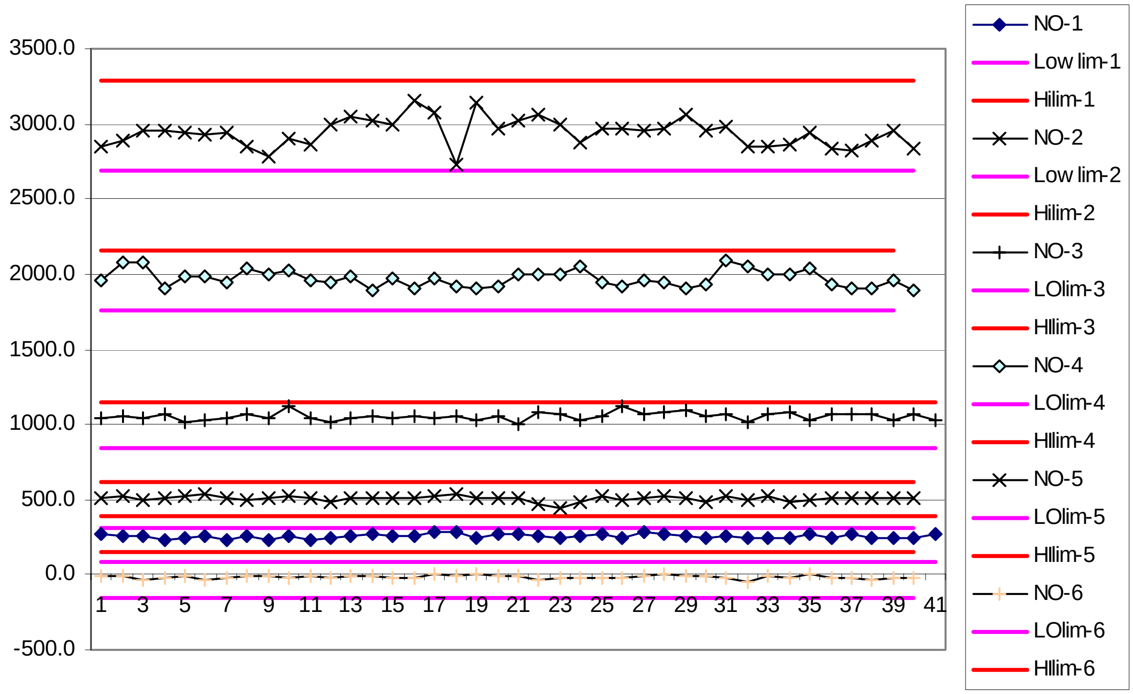
%CO PROD #1
Perfect: 4.89, 2.74, 2.00, 0.99, 0.50, 0.00
Means: 4.80, 2.65, 1.95, 0.96, 0.51, 0.00
Stdev: .0986, .0619, .0568, .0307, .0241, .0107
Limits shown are +/-10%. BAR cert is +/-10% or +/-0.25% >3% CO; <3% +/-15% or +/-250ppm.



ppm HC PROD #1
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.



ppm NO PROD #1
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.



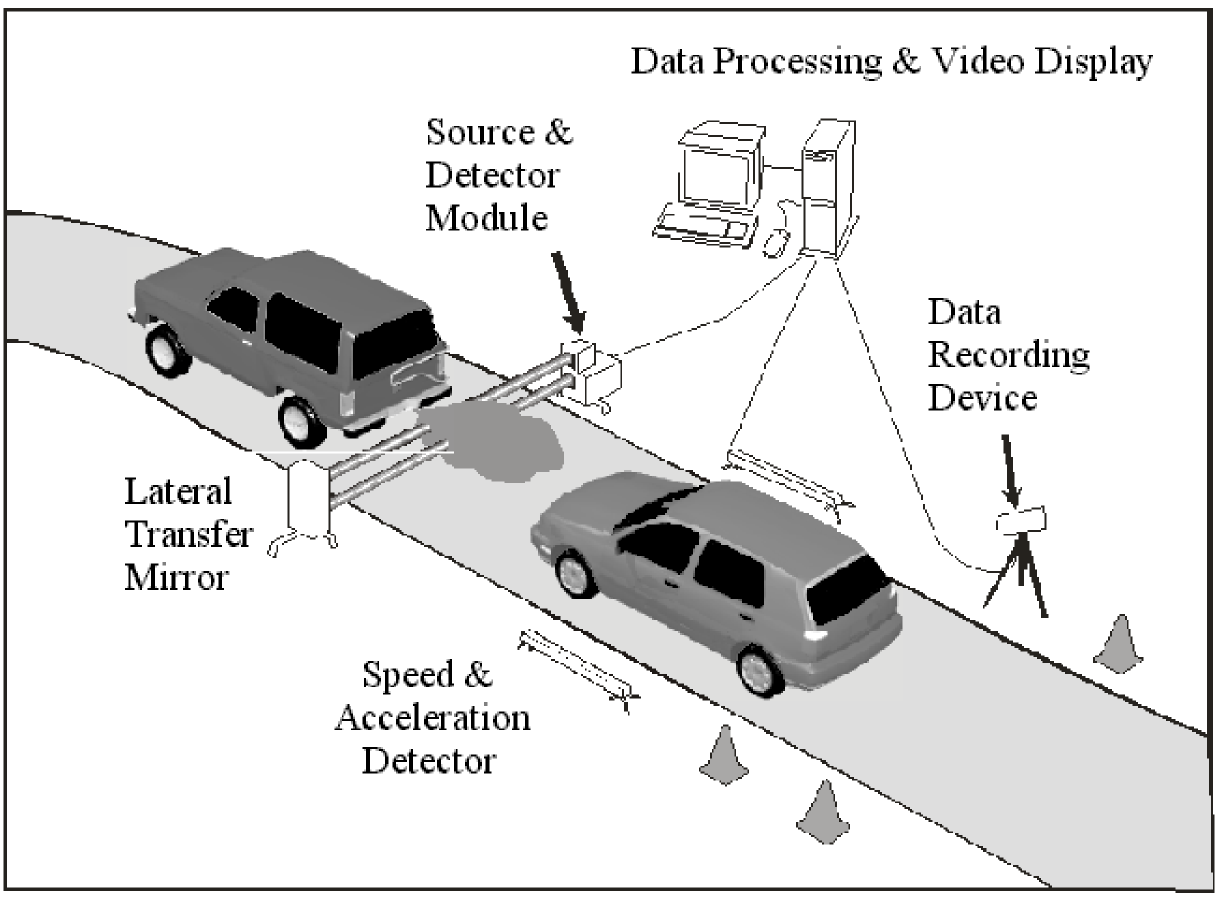
6. STUDY DESIGN

6.1. Equipment Description

The India pilot study utilized the well proven 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. It is a more durable, easily operable, deployable and portable system that significantly improves operator and program effectiveness through greater capture rates of more accurate vehicle emissions readings.

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 opacity 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 fully outfitted 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 are equipped with additional lighting for testing during pre-dawn and post dusk hours.

6.2. __Equipment QA/QC Audits:__

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 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. The unit tests are based on the BAR OREMS specification.

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.

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. The BAR OREMS Specification calls for the use of five different audit gas blends to verify the unit accuracy over a range of pollutant concentrations.

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.

Speed and Acceleration are also tested for 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 and allow the electronic components within 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 so that the pollutant values measured by the unit will 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. <u>Site Selection Criteria</u>

The sites were selected using following guidelines to:

1) Provide a representative sampling of the area 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
2) Most polluted area and area of most concern to the public
3) Traffic flow is relatively high

6.4. Site Locations

6.4.1. Site Selection Results

The site locations are listed in Table 6-1.

Table 6-1: Site Locations

PUNE

- 22nd January 04 – Karve Road, Kothrud
- 23rd January 04 – Karve Road, Kothrud
- 29th January 04 – Ganeshkhind
- 30th January 04 – Ganeshkhind

DELHI

- 14th April 04 – Sundar Nagar, Opposite Jukaso Inn
- 15th April 04 – Ridge Road
- 17th April 04 – Mehrauli – Badarpur road, Opposite Five Sense Garden, Lado Sarai
- 19th April 04 – Ridge Road (Same as 17th April 04)

The following series of figures illustrate the locations of the sites and the equipment set-up.

Figure 6-2: Site Locations, Pune

Figure 6-3: 22nd January 2004, Pune

Figure 6-4: Delhi Site Map

Figure 6-5: Delhi Locations

14th April 2004 **15th April 2004** **17th & 19th April 2004**

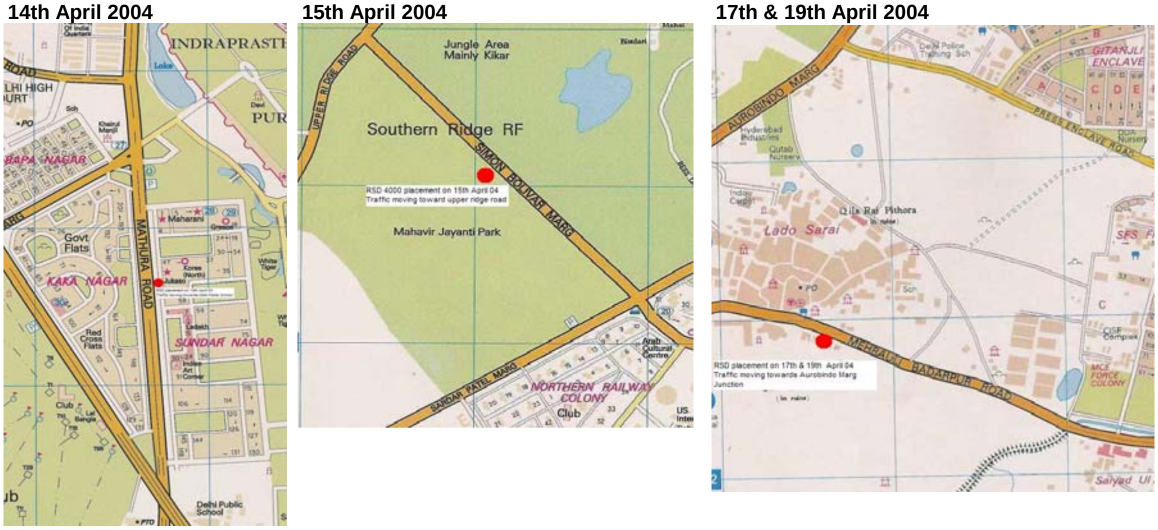


Figure 6-6: 14th April 04 at Sundar Nagar, Delhi

Figure 6-7 17th April 04 at Mehrauli – Badarpur road Road, Delhi

6.5. Data Screening

The RSD4000 unit takes many measurements of each exhaust plume in the one half second after each vehicle passes the equipment. The RSD unit takes multiple rapid readings for each vehicle to characterize the exhaust plume profile and evaluate whether a valid measurement of a vehicle's exhaust 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, and correction for changes in background concentrations of emissions.

Vehicles that are decelerating emit small exhaust plumes because the engine is not doing any work. These small plumes often do not produce measurements that meet the screening criteria and the emissions readings are flagged as invalid.

7. DATA COLLECTION

7.1. Collection Statistics

Table 7-1 shows the overall collection statistics. In total, approximately 20,000 measurements were made in Delhi & Pune each and emissions were successfully measured on less than 50%. Typically greater than 70% valid measurements are registered in US traffic where the majority of passing vehicles are light duty passenger vehicles. The abundance of 2- and 3-wheel vehicles reduced the overall valid capture rate on Indian roads.

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

Location	Pune	Delhi
Total Number of Data Collection-Days Readings Taken	4	4
Total measurements made	19,803	21,460
Measurements with valid speed and emissions values	8,576	10,208

Table 7-2 shows the frequency of observation of each type of vehicle in Pune and Delhi. The table shows the number and percentage of observations for which emission were successfully measured. The success rate for motorcycle and three-wheel vehicles is much lower than for four-wheel vehicles and buses, because of their smaller exhaust gas volume, variability in operating mode and position of the tailpipe.

Table 7-2: Observations by Vehicle Type

	Pune			Delhi			
Type	Vehicles Observed	Emissions Measured	% Emissions Measured	Vehicles Observed	Emissions Measured	% Emissions Measured	Approx. Delhi Registrations
2WM	7,126	2,095	29%	2,705	293	11%	1,600,000
2WS	4,704	1,326	28%	1,987	249	13%	1,000,000
3WV	3,695	2,065	56%	1,602	529	33%	73,772
4WD	975	759	78%	1,349	973	72%	122,625
4WV	1,689	1,558	92%	8,750	6,846	78%	1,233,064
Bus - CNG				1,565	1,318	84%	24,678
Other	1608	773		3502			
	19,797	8,576		21,460	10,208		4,054,139

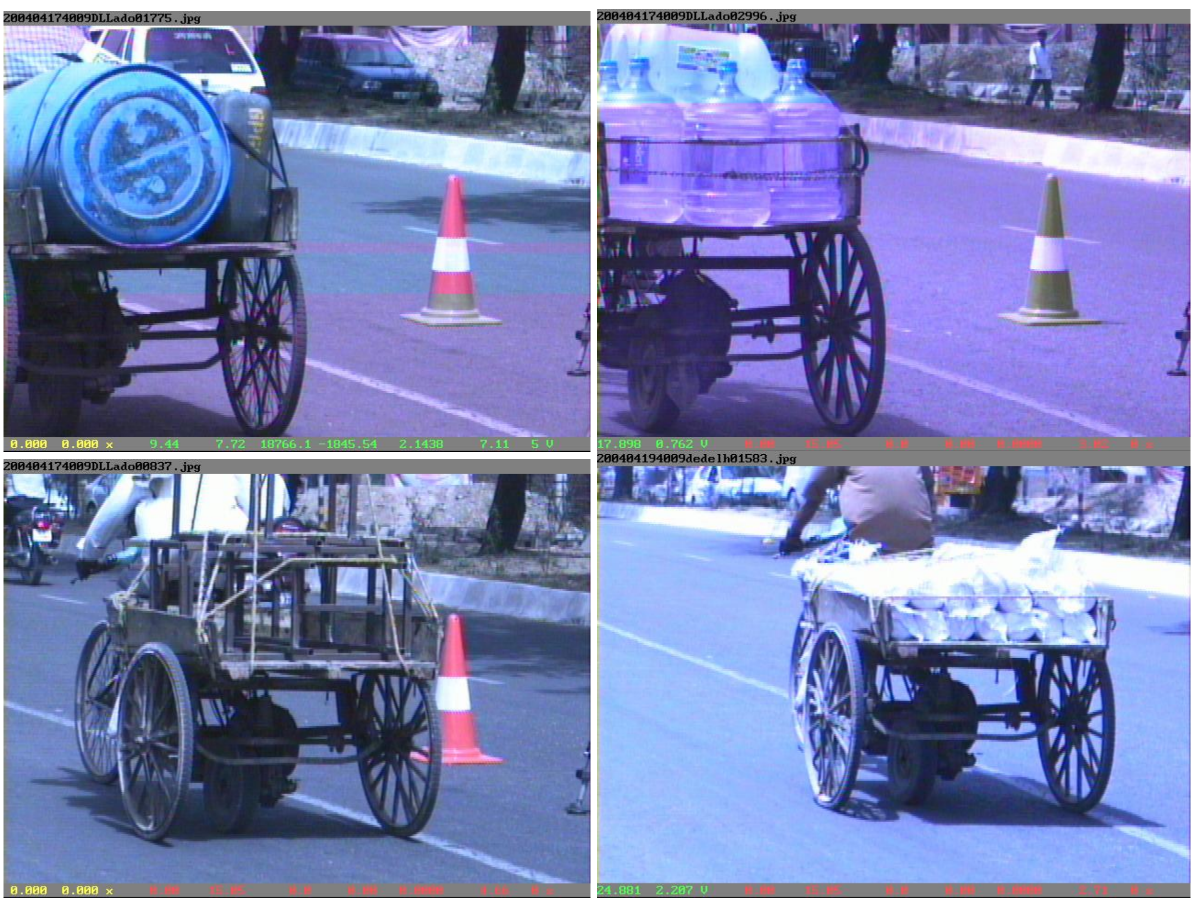
The remote sensing equipment set-up was best for measuring cars and larger vehicles. A number of the motorcycles and three wheelers were also missed because the license plates were not visible in the RSD pictures and the vehicles could not be positively identified. Consequently, the overall percentage of vehicle measurements with complete information was lower than normal. Efforts are

underway to augment RSD technology and deployment methodology for the challenges of measuring small plumes from variable height tailpipes in free traffic flow.
Many license plate images also were not successfully captured because of:

- Fancy number plates that are hard to read
- Auto rickshaw number plates that are very small and often covered by hangings
- Buses plates located in a variety of positions on the back of the vehicle

Several Jugad vehicles were observed. These are vehicle conversions of a manual tri-cycle or manual cycle rickshaw fitted with old 2 stroke engine of a scooter and used as a luggage carrier. Pictures of 6 RSD camera images are shown below. Emissions measurements were obtained from one of these that had very high HC of 16,000ppm (1.6%).

Figure 7-1 Jugad Vehicles



8. EMISSIONS 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 8-4. Tailpipe emissions concentrations have been converted to grams per kilogram of fuel to make the results between different types of vehicle more comparable. Two and three wheel vehicles have much higher HC and CO emissions, reflecting their typical rich operating condition[i]. Diesel vehicles have the highest emission rates of NOx (reflecting their typically lean operating condition[ii]) but petrol cars also emit significant NOx.

Three-wheel vehicles in Delhi have lower HC emissions and less smoke than in Pune, a testament to the success of Delhi's CNG program. The tradeoff is higher NOx from these leaner burning CNG engines.

Table 8-1: RSD Emissions by Vehicle Type

	Pune				Delhi			
Type of Vehicle	**CO g/kg**	**HC g/kg**	**NO g/kg**	**Smoke g/kg**	**CO g/kg**	**HC g/kg**	**NO g/kg**	**Smoke g/kg**
Two wheel motorcycle	347	212	6.6	13.24	350	179	4.9	11.64
Two wheel motor scooter	331	258	0.2	20.84	357	226	0.9	18.48
Three wheeler	226	252	0.5	32.19	244	150	7.4	6.89
Commercial vehicles	102	56	19.5	11.24	65	46	20.7	9.31
Four wheel vehicles	137	28	11.7	2.76	126	27	7.0	1.61
Bus					132	37	34.9	0.41

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[i] Air to fuel ratio of less than 1.

[ii] Air to fuel ratio greater than 1.

Figure 8-1: Average CO Emissions by Vehicle Type

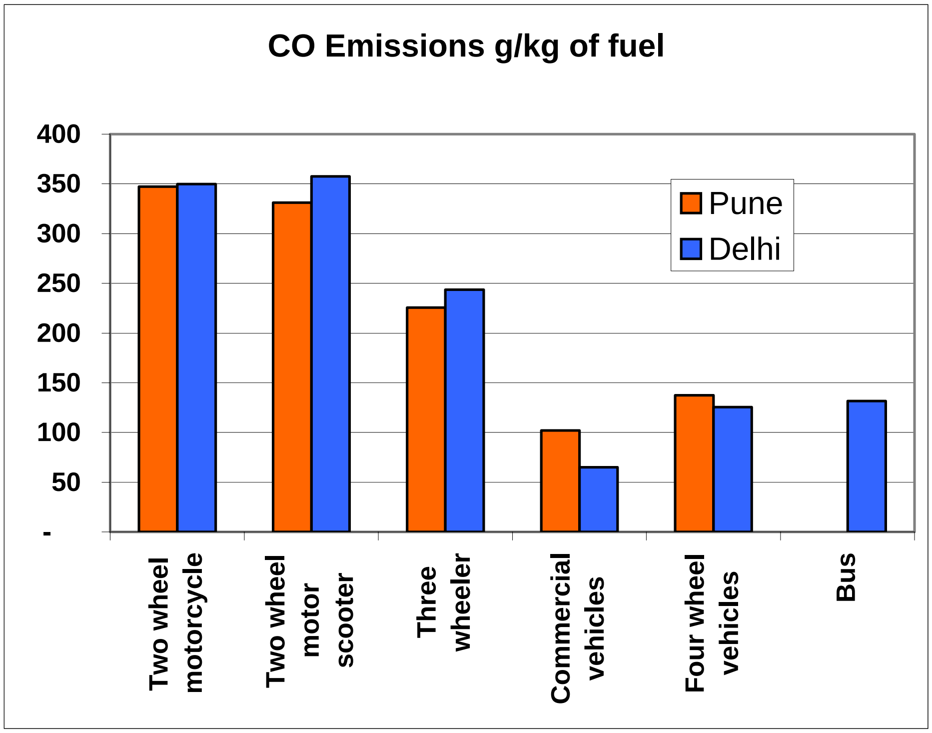


Figure 8-2: Average HC Emissions by Vehicle Type

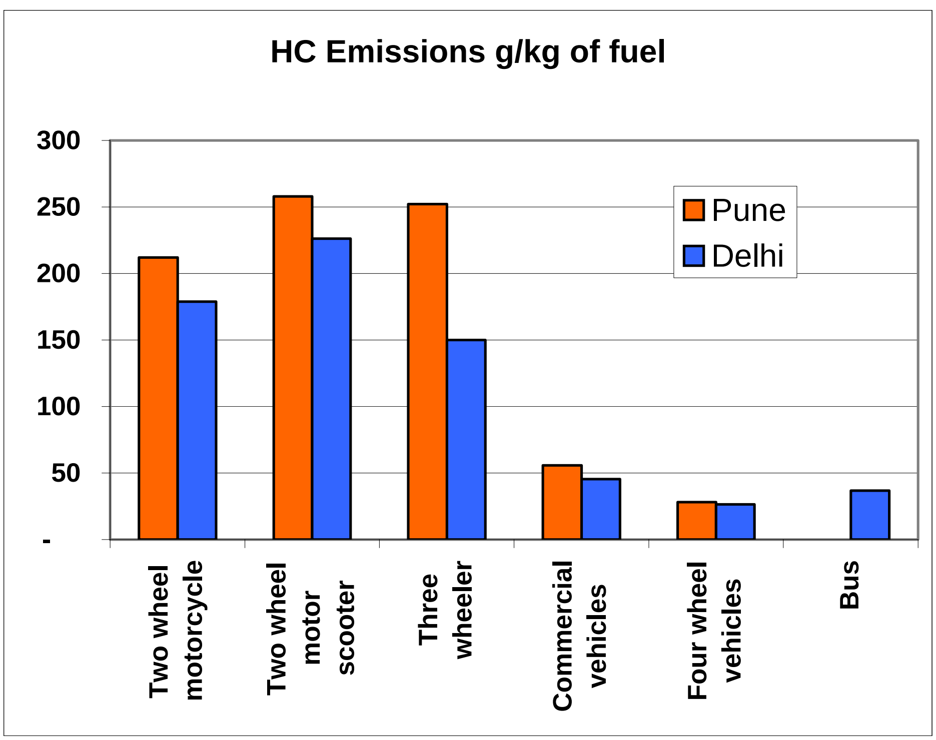


Figure 8-3: Average NO Emissions by Vehicle Type

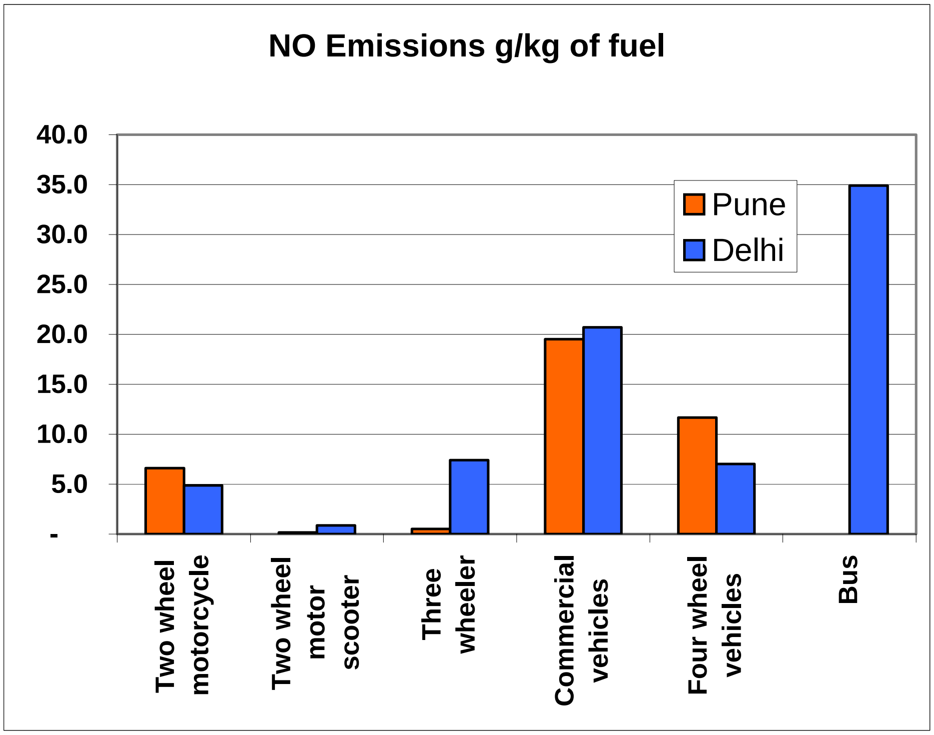
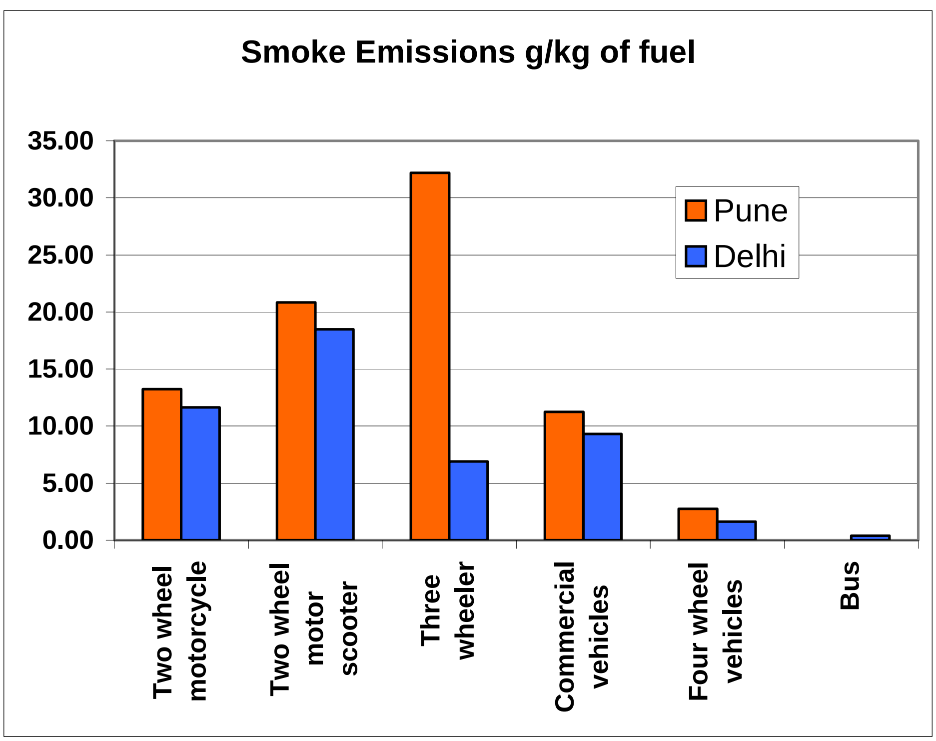


Figure 8-4: Average Smoke Emissions by Vehicle Type



8.1.2. Approximate Emissions Contributions

The RSD system measures pollutant concentrations within vehicle exhaust plumes from which the mass of pollutants per kilogram of fuel can be calculated. Therefore, the daily mass of exhaust pollutants emitted by a type of vehicle can be calculated from the RSD emission measurements times the average vehicle kilometers traveled per day divided by the average fuel economy, e.g.:

Three-wheeler mass emissions per day (g/day) = Number of three-wheelers x average travel per day (km/day) x average RSD measured emissions rate (g/kg) / fuel economy (km/kg)

Studies have shown that the frequency with which vehicles are observed by RSD is proportional to the distance they are driven. If the average daily distances driven, are not easily determined by other means, then the number of RSD observations can be used as a substitute for the number of vehicles times their average daily travel to determine the relative contribution to emissions by each type of vehicle.

To perform the calculations described for each type of vehicle, the numbers of vehicles, daily travel and fuel economies shown in the Table 8-3 were used to illustrate an emissions inventory example for the Delhi region. The results for Delhi are shown in

Table 8-3 Registrations, Daily Travel and Fuel Economy

Type of Vehicle	Approx. Vehicles	Daily km	Fuel Economy km/l	Fuel Density kg/l	Fuel Economy km/kg
Two wheel motorcycle	1,600,000	40	35	0.73	47.9
Two wheel motor scooter	1,000,000	40	35	0.73	47.9
Three wheeler	73,772	75	15	0.73	20.5
Commercial vehicle	122,625	100	4	0.81	4.9
Four wheel vehicle	1,233,064	40	10	0.73	13.7
Bus	24,678	100	5	0.73	6.8
	4,054,139				

NOTE: Two wheel MOTORCYCLE are good in mileage – avg. can be min. 50Km/L as manufacturer's claim 70 to 80 Km/L

Table 8-4 Delhi Example Estimated Daily Tonnes Emissions

Vehicle Type	Vehicles	Daily Travel km/d	Fuel Economy km/kg	CO t/d	HC t/d	NO t/d	Smoke t/d
Two wheel motorcycle	1,600,000	40	48	467	239	6	16
Two wheel motor scooter	1,000,000	40	48	298	189	1	15
Three wheeler	73,772	75	21	66	40	2	2
Commercial vehicle	122,625	100	5	161	113	51	23
Four wheel vehicle	1,233,064	40	14	452	95	25	6
Bus	24,678	100	7	47	13	13	0
Total				1,492	690	98	62

In the example, the calculations are only approximate. Data values should be adjusted for the actual average daily travel and fuel economy for each type of vehicle in the region.

The approximate relative percentage of total emissions produced by each vehicle type is shown in Figures 8-5 to 8-8. The sum of all the columns in each chart adds up to 100%. These charts show that two wheel vehicles (motorcycles and scooters) and four wheel vehicles (cars and SUVs) produce the largest mass of CO exhaust emissions and two wheel vehicles produce a large part of the HC. Commercial vehicles (diesel trucks) produce the largest mass of NOx emissions followed by cars. Although buses appear to have high NOx emissions concentrations, they appear much cleaner in terms of smoke emissions. This is consistent with the 2004 measurement of CNG buses in Boston, Massachusetts, USA. Bus NOx contribution is still outweighed by commercial vehicles because there are five times as many commercial vehicles registered. Commercial vehicles and two wheel vehicles produce the most smoke. These estimates do not consider evaporative HC emissions or higher emissions that may occur when cold vehicles are started.

Figure 8-5: Approximate CO Contributions

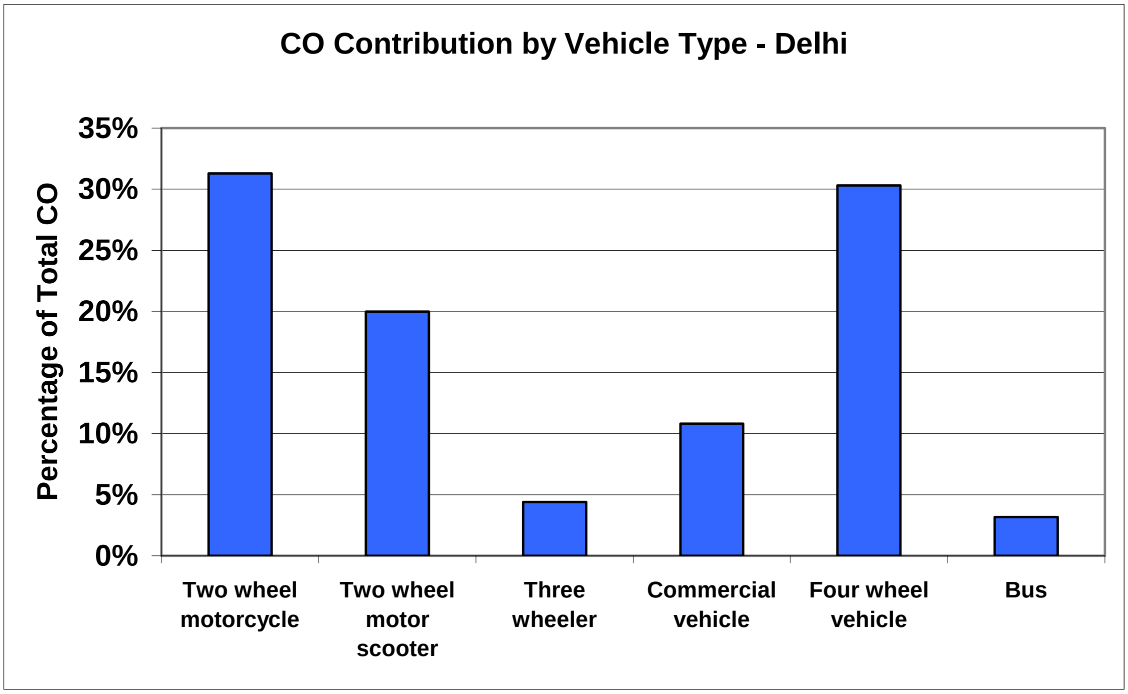


Figure 8-6: Approximate HC Contributions

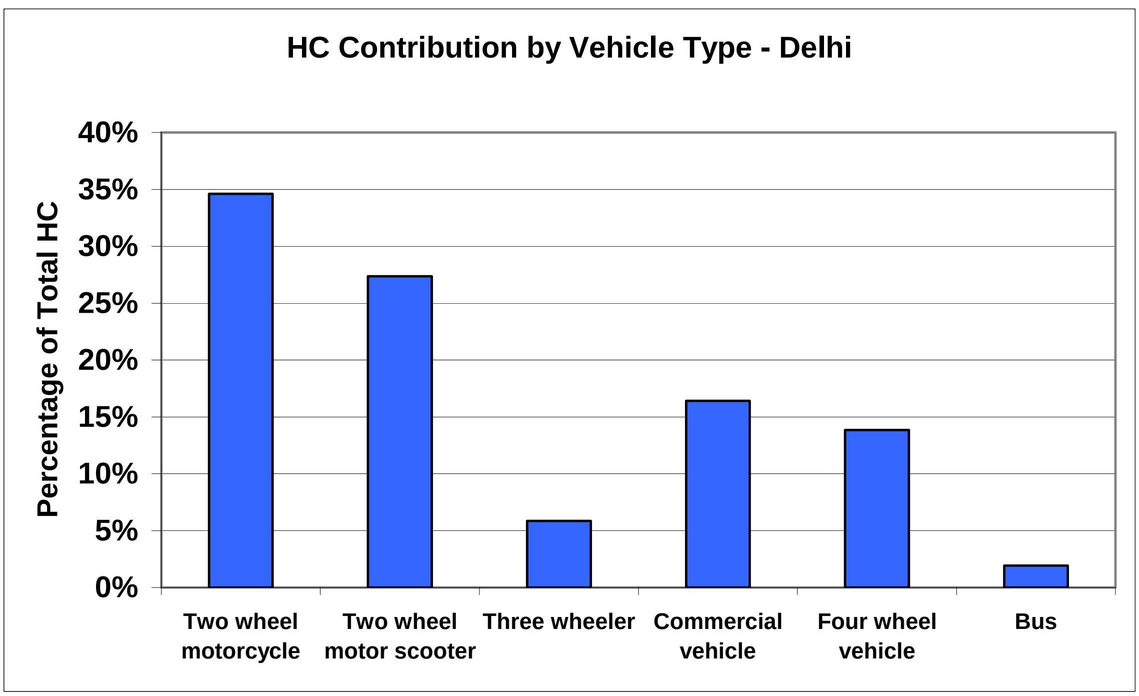


Figure 8-7: Approximate NO Contributions

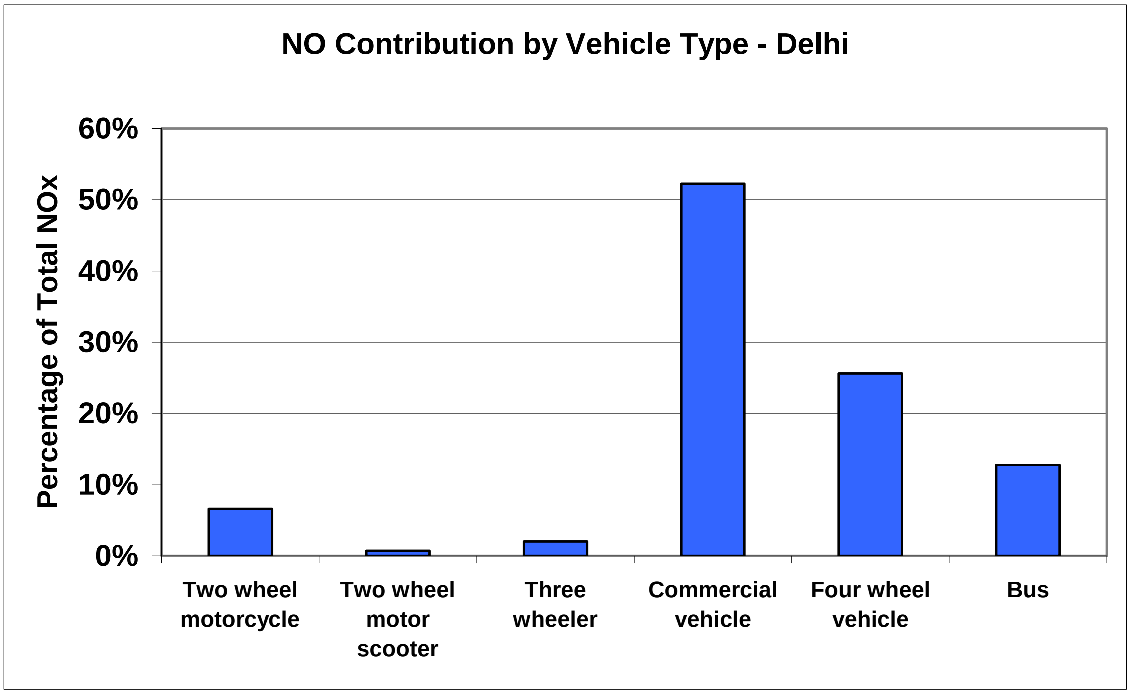
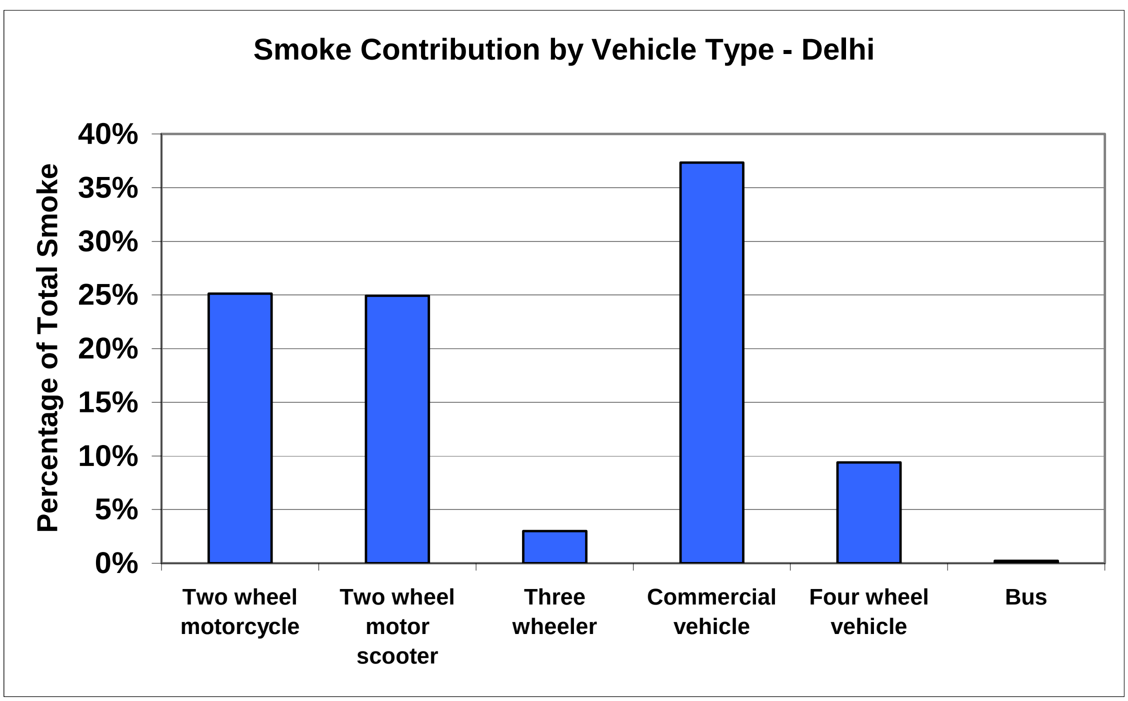


Figure 8-8: Approximate Smoke Contributions



8.1.3. Emission Deciles Within Type of Vehicle

Delhi RSD measurements were first sorted by type of vehicle. For each type of vehicle, the results were then sorted from cleanest to dirtiest and divided into ten groups with 10% of the vehicles in each group. The dirtiest 10% of vehicles for each pollutant have typically three to five times the emissions of average vehicles.

Figures 8-9 to 8-12 show the average emissions of these groups. The results show that within vehicles of the same type, the dirtiest 10% have much greater emissions than the typical vehicle. These dirty vehicles can normally be repaired to reduce their emissions substantially.

Figure 8-9: Delhi Vehicle CO Emission Deciles

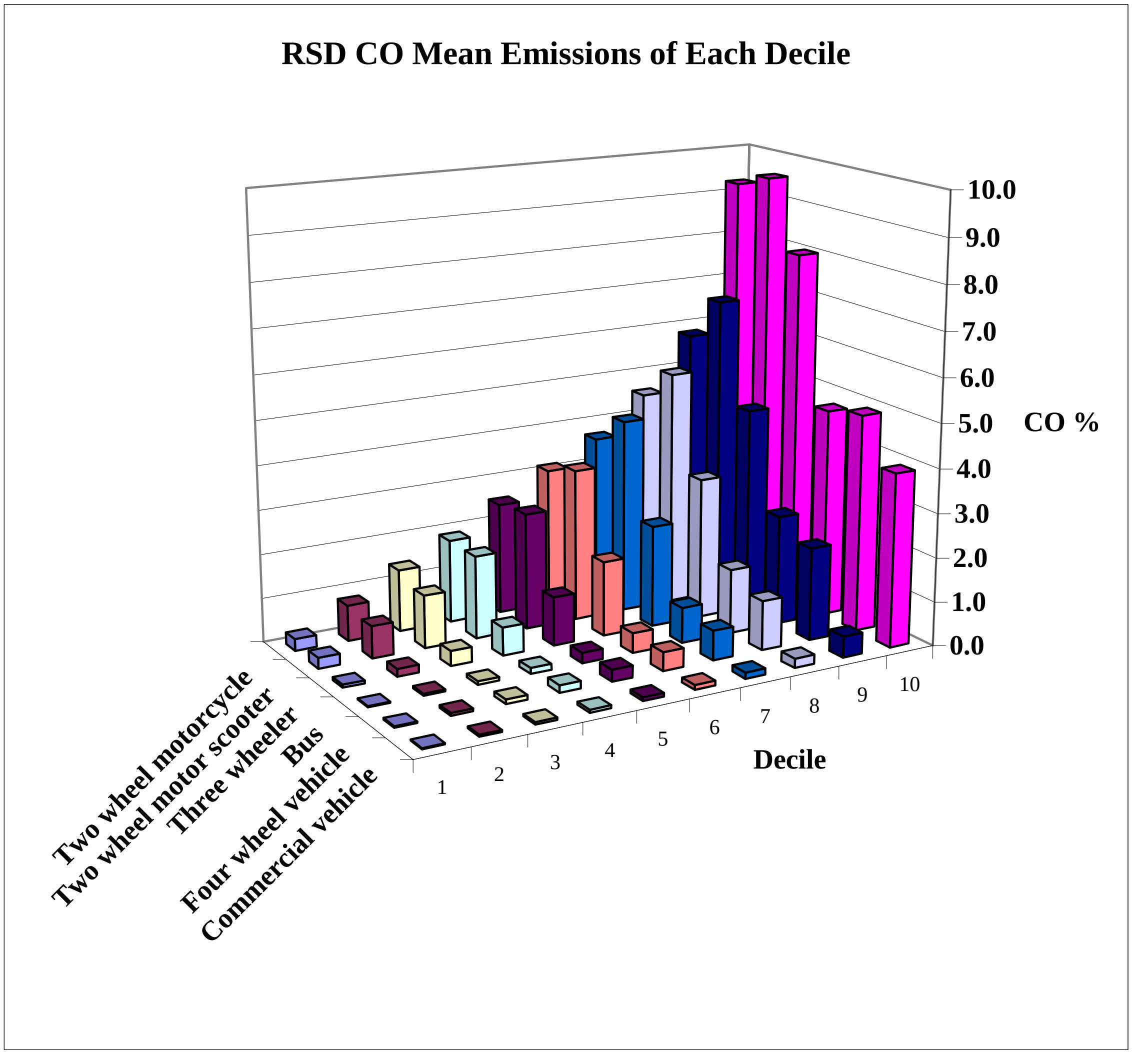


Figure 8-10: Delhi Vehicle HC Emission Deciles

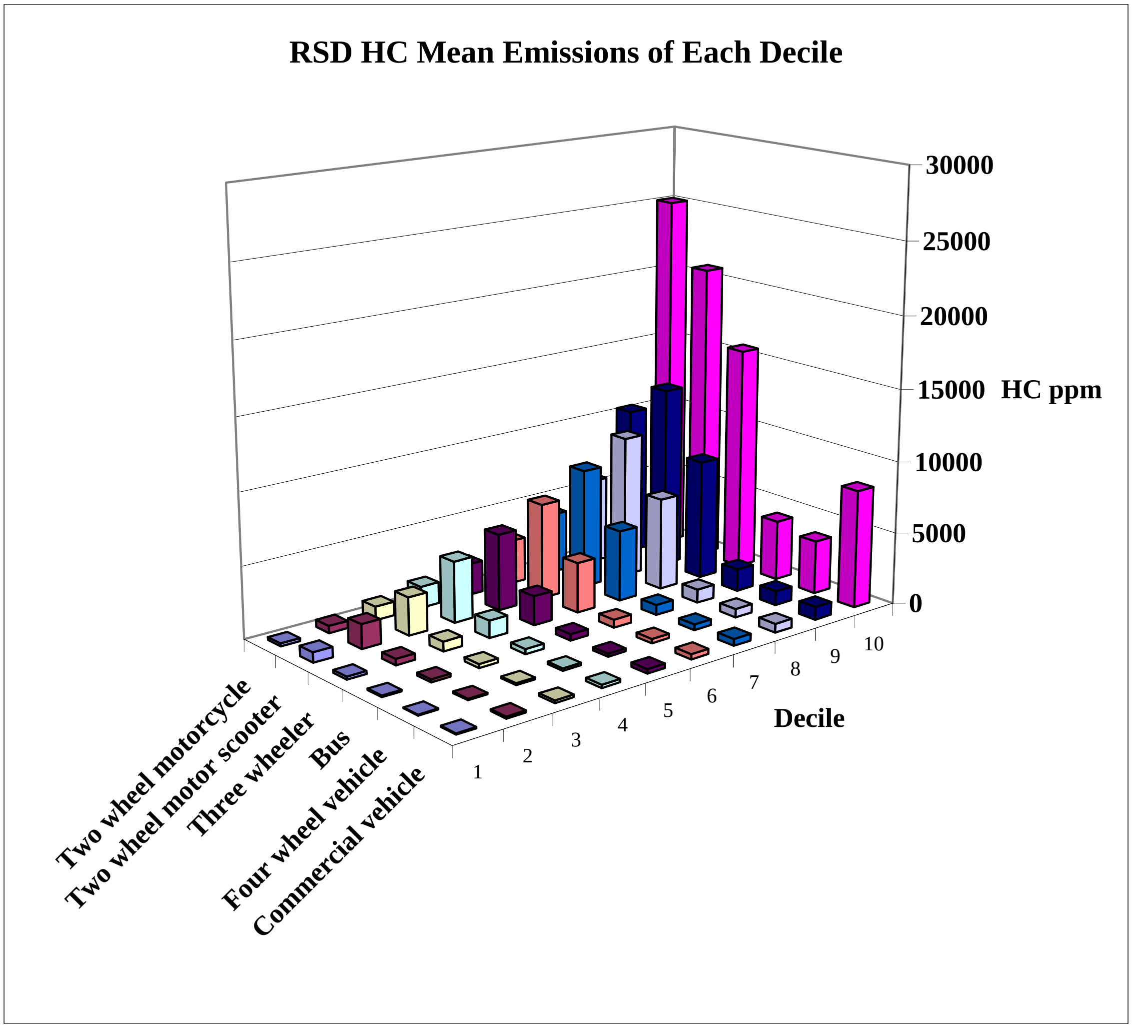


Figure 8-11: Delhi Vehicle NO Emission Deciles

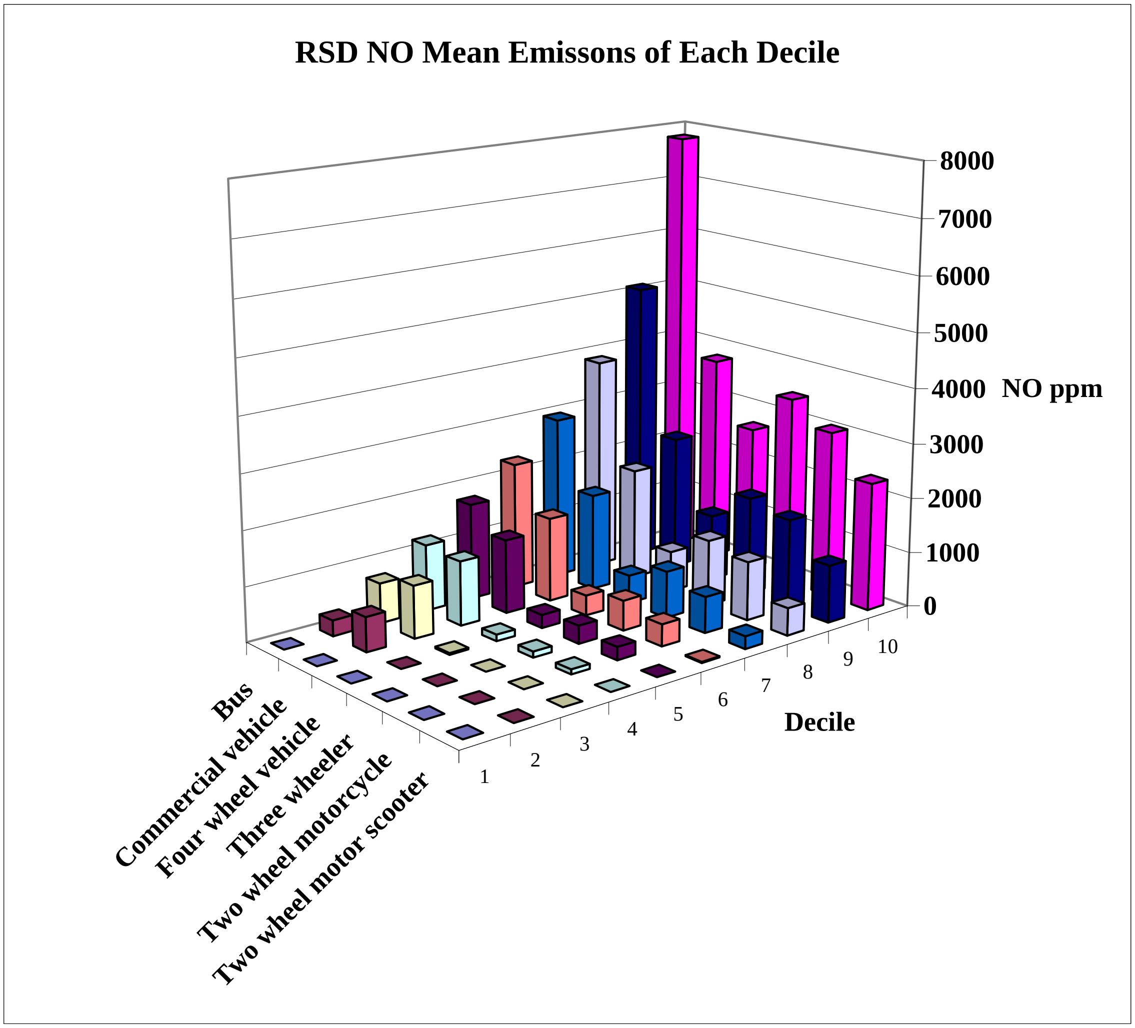
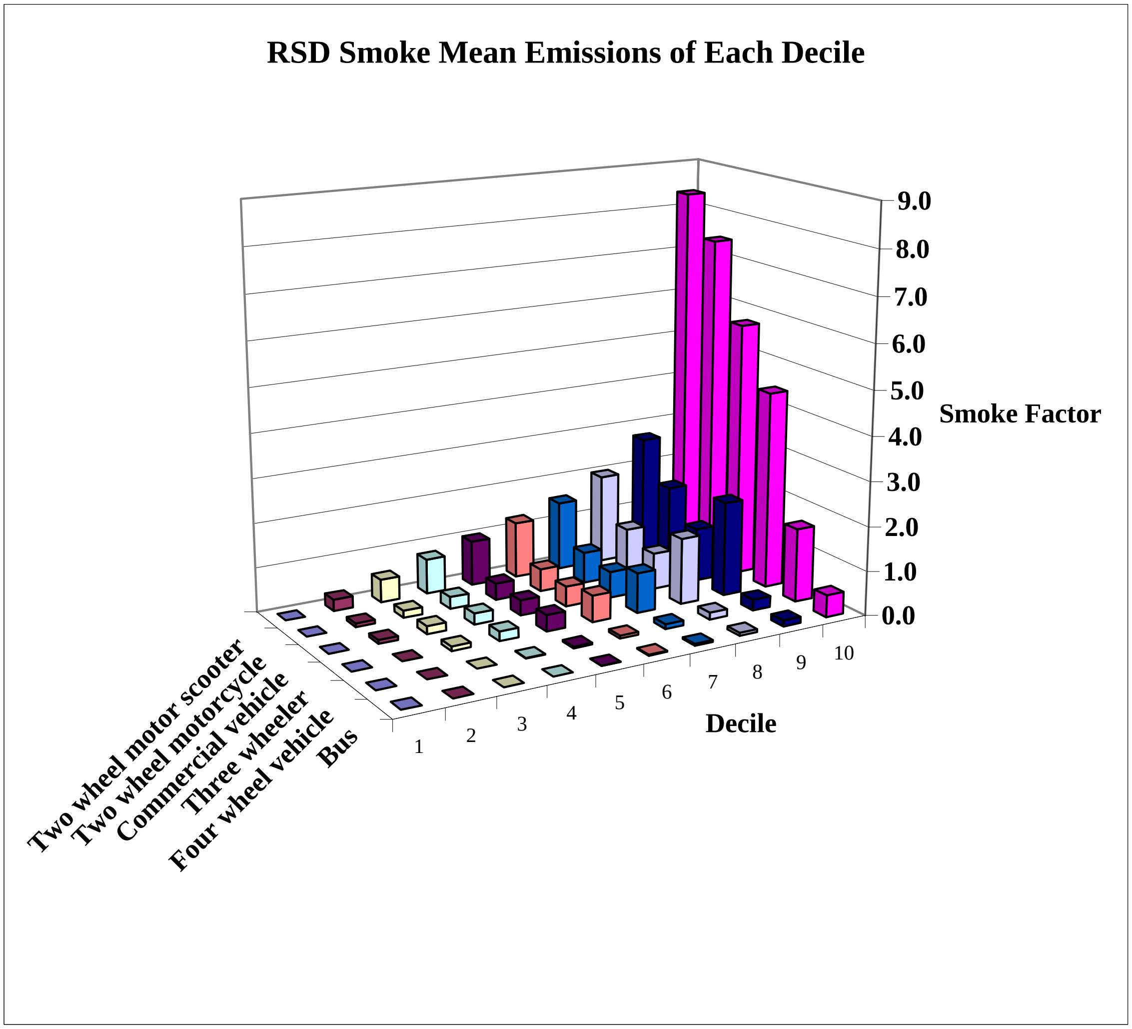


Figure 8-12: Delhi Vehicle Smoke Emission Deciles



9. CONCLUSIONS

The RSD equipment was able to measure the emissions of vehicles on-road but special set-up of the equipment is required to capture a high percentage of two and three wheel vehicles.

Petrol vehicles have higher HC and CO emissions per kilogram of fuel than diesels. Motorcycles and motor scooters have the highest emission rates and produce the largest mass of HC emissions and smoke. In Pune, three wheel vehicles have high HC and even higher smoke emissions than two wheel vehicles. But in Delhi the three wheel vehicles, which have been converted to CNG, produced much lower HC and smoke.

Two wheel vehicles also have the highest rates of CO and produce approximately 50 of total CO emissions in Delhi. Four-wheel vehicles are also significant contributors of CO emissions producing 30% of total CO emissions in Delhi.

Diesel vehicles have high emission rates of NOx and smoke producing 50% of the NOx emission in Delhi and 35% of the smoke. Four-wheel vehicles produce another 25% of the total NOx from vehicles.

Emissions are unevenly distributed among vehicles with the dirtiest vehicles creating a disproportionate amount of the total emissions. The dirtiest 10% of vehicles within each type create three to five times more emissions than typical vehicles of the same type.

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.

In closing, ESP would like to express a sincere thanks to the Government of India for the keen interest in our remote sensing products and services; the US-AEP for the sponsorship of this pilot study; and to the ARAI for the partnership in executing the study. We are grateful for the opportunity to demonstrate our technology and look forward to the opportunity to further develop remote sensing applications suitable for India.

APPENDIX A

A1 The1992 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 great enthusiasm by others.

The supporters were pitching RSD as the silver bullet that would replace I/M. The early skeptics, among them the USEPA, set out to prove it could not replace the I/M program it had develop and implemented over the 1980s. Glover and Clemmens (91) compared RSD results to IM240 results.[22] 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.[23]

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 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 performed in the enhanced areas of CO, CT, GA, IL, IN, MD, NY, PA and NV.

A-2 The1996 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

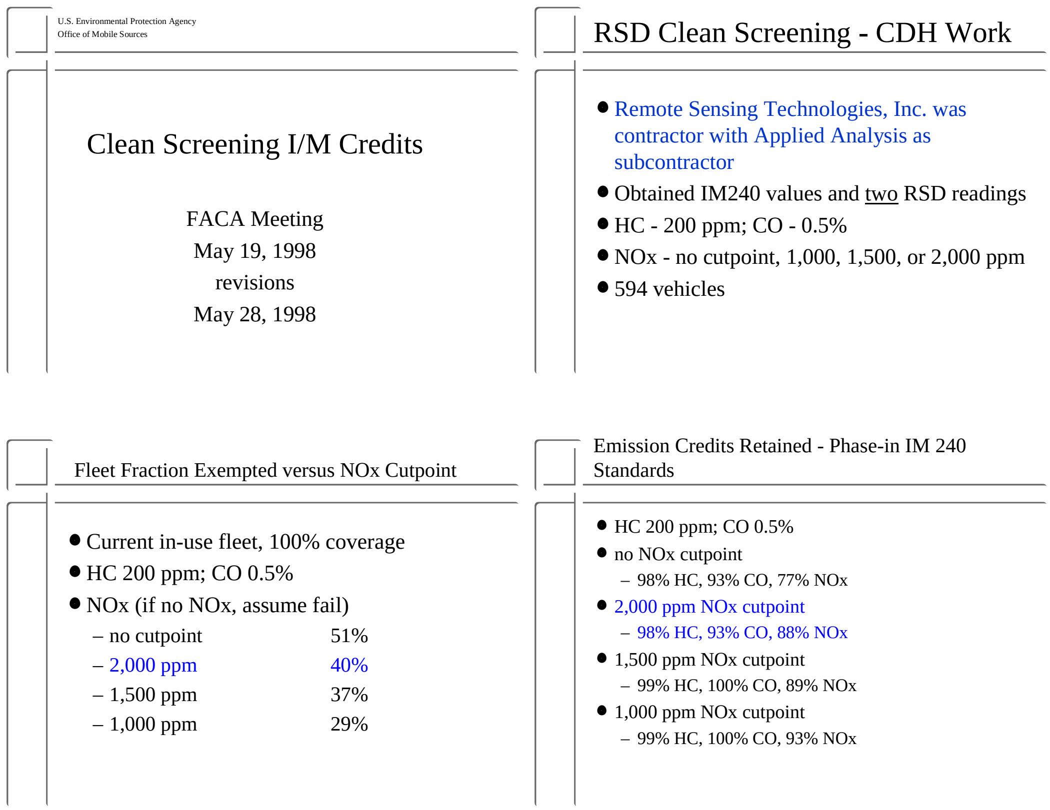
provides some credits for RSD programs. In the User guide, EPA-OMS admits it "*faced a tradeoff between when its first formal guidance on RSD credits would be released and how comprehensive and representative those credits could be. The choice EPA has made is to provide its credits sooner than later, 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.*"[24] 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 The1996 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 the need for a burdensome 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.[25] The Clean Screen guidance document was issued in late1996.

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



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).[26]

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".[27] In October 1998, EPA published a guidance memorandum that outlined what the Agency considered to be acceptable, "sound," alternative program evaluation methods[28].

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 the most effective tool for program effectiveness evaluation, a sentiment echoed by the National Research Council's Committee on Emissions Inspection and Maintenance Programs.[29]

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[26] 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.

[27] EPA Rule, January, 1998

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