Pune Vehicle Activity Study

Conducted March 9-March 22, 2003
Report Updated February 16, 2004

University of California at Riverside

Global Sustainable Systems Research

Table of Contents

I. Introduction

Pune, India was visited from March 9, 2003 to March 22, 2003 to collect and analyze data related to on-road transportation. The study effort was designed to support estimates of the air pollution impacts of on-road transportation in Pune that will be used in the development of air quality management plans for the region. It is also hoped that the collected data can be extrapolated to other Indian cities to support environmental improvement efforts in the other cities as well. The data collection effort was a partnership between Pune local and regional governments, universities, and non-government officials, the USEPA and USAEP offices, staff from Global Sustainable Systems research, and the University of California at Riverside. In all, about thirty persons participated in data collection activities over an approximate two week period.

The study was designed:

- To estimate the technology distribution of vehicles operating on Pune streets.
- To measure driving patterns for the various classes of vehicles operating on Pune streets.
- To estimate the times and numbers of vehicle engine starts for the various classes of vehicles operating on Pune streets.

The technology distribution of vehicles was developed using a combination of two approaches. Vehicles were video taped on a variety of streets and the video tapes were reviewed to count the numbers of the various types of vehicles plying Pune streets. Simultaneous with this data collection process, parking areas were surveyed to collect specific technology information about vehicles operating in Pune.

The driving patterns for the various classes of vehicles were measured using Global Positioning Satellite (GPS) technology. This technology allows for the second by second measurement of vehicle speeds. GPS units were carried on a variety of vehicles on a variety of street types throughout the metropolitan area. Data was collected from 07:00 to 19:00 to provide driving pattern information for differing times of the day.

The vehicle engine start patterns were collected using equipment that senses vehicle system voltage denoted VOCE units. VOCE data can be used to determine when vehicles start, how long they operate, and how long they sit idle between starts. This information is essential to establish vehicle start emissions.

The data collected in this study was formatted to allow vehicle emissions estimates using the International Vehicle Emissions Model (www.gssr.net/ive). This model was developed with USEPA funding to make emissions estimates under different technology and driving situations as found in various countries.

II. Vehicle Technology Distribution

The most critical element of on-road transportation emissions analysis is the nature of the vehicle technologies that operate on the street or in the region of interest. Differing vehicle technologies can produce considerably different rates of emissions. Vehicles operating on the same roads can produce emissions that are 300 times different from one another. The fractions of various types of vehicles in a local fleet and the fractions of these various types of vehicles actually operating on the roadways are not necessarily the same. This difference occurs because some classes of vehicles are operated considerably more than other classes vehicles. For example, a class of vehicles that operates twice as much as another class will produce an on-road fraction that is twice as great even if there are equal numbers of vehicles in the static fleet. The fraction of interest for estimating on-road emissions is the fraction of driving contributed by the various vehicle technologies since this will correspond to the about of air emissions that are produced. Thus, the most accurate estimate of vehicular contribution to air emissions is made by determining the fractions of the various vehicle technology classes actually operating on city streets rather than the distribution of vehicles registered in the region of interest.

To determine the fractions of the various vehicle technology classes operating on city streets, video cameras were set up along the sides of the road and traffic movement taped. Figure II.1 illustrates this process on a residential street in Santiago, Chile and a freeway overpass in Los Angeles, California.

Figure II.1: Video Taping Roadways in Santiago, Chile and Los Angeles California

The completed videotapes were analyzed in slow motion to insure the most accurate counts of vehicles.

It is not possible using the video taping process to determine the exact nature of the vehicle technologies observed. The video taping allowed the determination of the fractions of trucks, buses, passenger vehicles, 2-wheelers, 3-wheelers, and such operating on the roadways of interest. To understand the specific technologies of local vehicles, parking surveys were completed. Parked vehicle surveys allow careful inspection of vehicles so that the engine technology, model year, control equipment, and fuel type can be established. The parked vehicle surveys were used to estimate the more specific natures of the general vehicle classifications determined from the video tape studies. Figure II.2 illustrates a parking lot survey process in Nairobi, Kenya.

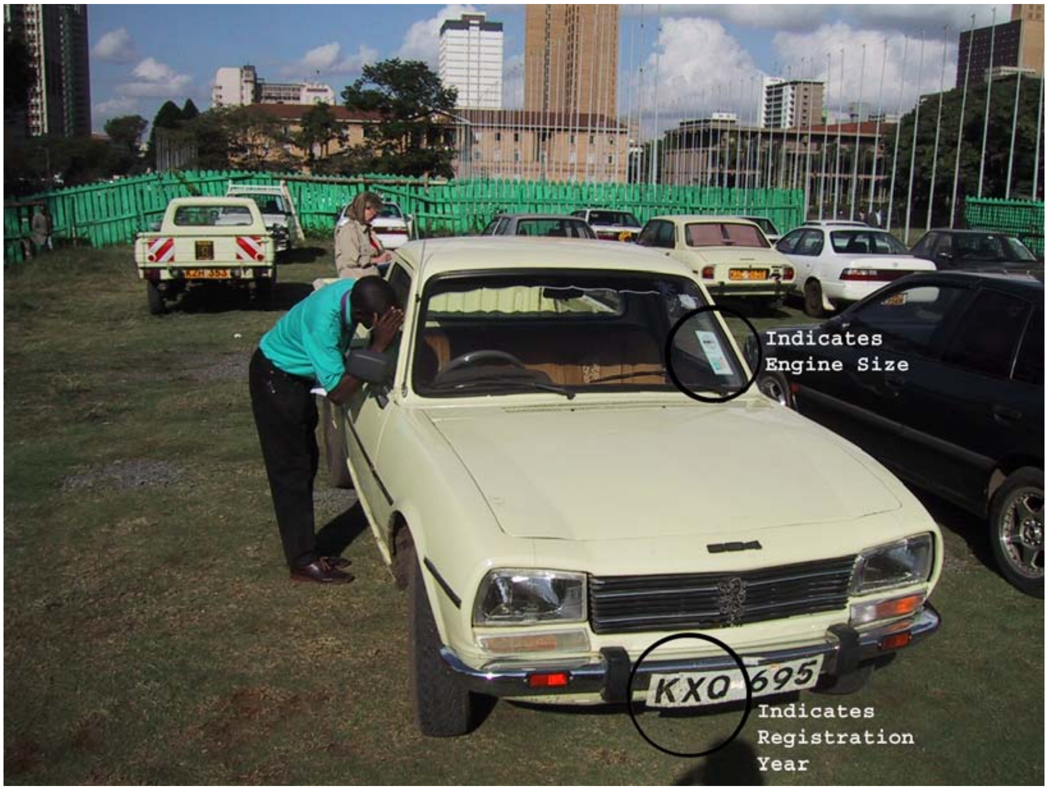

Figure II.2: Parking Lot Survey in Nairobi, Kenya

In order to insure that the most representative data is collected, both video and parked vehicle studies were carried out from 07:00 in the morning to 19:00 in the evening over 6 days in 3 representative sections of the urban area. Surveys were carried out on or near (in the cases of parked vehicle surveys) a residential street, an arterial roadway, and a highway in each area surveyed.

Table II.1 indicates the locations in Pune where video surveys were completed. These locations were suggested by the Pune city officials as representative of the general metropolitan area. They also represent the locations were driving patterns were measured. Parking surveys were completed at locations generally in the vicinity of the video surveys.

Table II.1 Video Locations Surveyed in Pune, India

Street Type	Number of Lanes*	Location	Date and Hour of Surveys
Highway-A1	2.3	Highway to Nashif Phata (suburban section)	Tue, Mar 11/07:00; Tue, Mar 11/10:00; Wed, Mar 12/13:00; Wed, Mar 12/16:00
Highway-A2	3.2	Highway to Nashif Phata (center city section)	Tue, Mar 11/08:00; Tue, Mar 11/11:00; Wed; Wed, Mar 12/14:00; Mar 12/17:00
Highway-A3	3.0	Paud Road/Karve Road	Tue, Mar 11/09:00; Tue, Mar 11/12:00; Wed; Wed, Mar 12/15:00; Mar 12/19:00
Arterial-B1	2.0	F.C. Road/J.M. Road	Thu, Mar 13/08:00; Thu, Mar 13/10:00; Mon, Mar 17/15:00; Mon, Mar 17/18:00
Arterial-B2	3.0	Kumthekar Road/Bajirao Road	Thu, Mar 13/09:00; Thu, Mar 13/11:00; Mon, Mar 17/14:00; Mon, Mar 17/17:00
Arterial-B3	2.0	Laxmi Road/Tilak Road	Thu, Mar 13/07:00; Thu, Mar 13/12:00; Mon, Mar 17/13:00; Mon, Mar 17/16:00
Residential-C1	1.0	Near Southwest Suburban Area	Wed, Mar 19/14:00; Wed, Mar 19/17:00; Thu, Mar 20/07:00; Thu, Mar 20/10:00;
Residential-C2	2.0	Near Southwest Suburban Area	Wed, Mar 19/15:00; Wed, Mar 19/18:00; Thu, Mar 20/08:00; Thu, Mar 20/11:00;
Residential-C3	1.0	Near Southwest Suburban Area	Wed, Mar 19/13:00; Wed, Mar 19/16:00; Thu, Mar 20/09:00; Thu, Mar 20/12:00;

* The number of lanes is based on lane widths used in the United States since lanes are often not marked on the Pune streets and vehicles tend to take advantage of all road width available.

IIa. Video Analysis

Two cameras were placed along roads as described in Table I.1. The cameras were operated for 20 minutes during the hour of interest. The cameras were then moved to the next location of interest and again operated for 20 minutes. The 20 minute operation times were selected to yield a significant amount of data and to allow for disassembly movement to a new location and reassembly in order to collect data in the next hour. The actual 20 minutes surveyed in any hour was random depending upon the time it took to move the cameras from one location and get them set up in a second location. The schedules followed are shown in the preceding Table I.1. The video tapes were reviewed in slow motion and stop action as needed to yield accurate analysis of the roadway vehicle distributions. This is a key advantage of using video tape instead of direct human observation. Table II.1 below indicate the results of the analysis. As can be seen in Table II.1 the distribution of vehicles varies with street type and time of day. Thus, for highly time and street specific analysis, care must be taken to construct a proper technology distribution for the time and street of interest. For this analysis, overall average technology distributions are developed for the general metropolitan area.

Table II.1: Results of Analysis of Pune Videotapes

Road Type	Area	Time	Vehicles /Hour	2-Wheeler	3-Wheeler	Pass. Car	Small Bus	Medium Bus	Large Bus	Small Truck	Medium Truck	Large Truck
Arterial	B-2	12:00	4907	63.9%	25.5%	8.3%	0.0%	0.0%	1.3%	0.5%	0.4%	0.1%
Arterial	B-1	11:00	3264	66.0%	20.8%	12.5%	0.0%	0.0%	0.3%	0.3%	0.1%	0.0%
Arterial	B-3	10:00	1770	62.6%	24.4%	10.5%	0.0%	0.0%	2.1%	0.0%	0.2%	0.2%
Arterial	B-2	9:00	4045	71.5%	16.4%	8.9%	0.0%	0.0%	2.3%	0.0%	0.7%	0.2%
Arterial	B-1	8:00	1615	66.7%	14.8%	16.1%	0.2%	0.0%	0.7%	0.7%	0.7%	0.2%
Arterial	B-3	7:00	771	52.2%	26.0%	15.3%	0.5%	0.5%	3.4%	0.7%	1.1%	0.5%
Arterial	B-3	16:00	3928	65.0%	20.6%	10.6%	0.4%	0.1%	2.2%	0.8%	0.1%	0.1%
Arterial	B-2	17:00	1771	61.7%	20.2%	14.6%	0.0%	0.2%	2.1%	0.0%	1.2%	0.0%
Arterial	B-1	18:00	4476	70.2%	12.7%	16.6%	0.0%	0.2%	0.2%	0.0%	0.2%	0.0%
Arterial	B-2	13:00	4388	70.0%	21.0%	6.8%	0.1%	0.0%	1.5%	0.6%	0.0%	0.0%
Arterial	B-3	14:00	2269	62.4%	20.7%	14.9%	0.2%	0.0%	1.5%	0.2%	0.2%	0.0%
Arterial	B-1	15:00	3330	70.8%	13.1%	14.9%	0.0%	0.0%	0.5%	0.4%	0.4%	0.0%
Highway	A-3	12:00	4347	61.8%	17.8%	18.2%	0.2%	0.0%	1.2%	0.5%	0.3%	0.0%
Highway	A-2	8:00	1201	57.2%	7.6%	18.8%	1.3%	0.0%	8.6%	2.3%	3.6%	0.7%
Highway	A-1	10:00	3324	60.7%	5.8%	22.4%	0.6%	0.1%	3.5%	2.1%	3.7%	1.1%
Highway	A-2	11:00	2236	62.2%	7.6%	18.5%	0.1%	0.0%	6.1%	2.9%	1.9%	0.7%
Highway	A-1	7:00	2008	59.1%	6.9%	10.9%	2.5%	0.6%	11.3%	1.9%	5.8%	1.0%
Highway	A-3	9:00	6951	68.9%	13.2%	13.0%	0.0%	0.0%	3.8%	1.0%	0.1%	0.0%
Highway	A-3	6:00	4977	57.7%	18.9%	19.1%	0.6%	0.4%	2.7%	0.3%	0.2%	0.0%
Highway	A-2	17:00	1913	59.3%	9.2%	22.0%	0.9%	0.9%	4.0%	1.6%	1.9%	0.3%
Highway	A-1	16:00	2663	55.7%	7.3%	26.1%	0.4%	0.5%	4.7%	2.0%	2.9%	0.5%
Highway	A-3	15:00	4431	63.1%	17.8%	15.5%	0.0%	0.2%	2.0%	0.2%	0.7%	0.5%
Highway	A-2	14:00	1827	58.2%	7.3%	22.3%	0.2%	0.2%	6.3%	0.7%	2.3%	2.6%
Highway	A-1	13:00	2364	61.1%	4.7%	25.1%	0.1%	0.7%	3.8%	0.7%	1.1%	2.7%
Residen.	C-1	17:00	1665	66.1%	15.6%	13.3%	0.5%	0.0%	0.9%	0.7%	2.9%	0.0%
Residen.	C-2	18:00	1295	79.4%	3.9%	16.1%	0.3%	0.0%	0.0%	0.0%	0.3%	0.0%
Residen.	C-3	16:00	567	66.7%	14.1%	15.4%	0.0%	0.0%	0.0%	3.2%	0.6%	0.0%
Residen.	C-1	14:00	1283	62.7%	20.1%	11.8%	0.0%	0.6%	1.6%	0.6%	2.5%	0.0%
Residen.	C-2	15:00	767	69.5%	16.4%	13.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%
Residen.	C-3	13:00	960	73.0%	11.0%	14.3%	0.0%	0.0%	0.4%	0.4%	0.8%	0.0%
Residen.	C-1	7:00	859	56.4%	19.5%	15.7%	0.0%	0.8%	5.9%	0.0%	0.8%	0.8%
Residen.	C-2	8:00	1393	53.4%	17.3%	27.0%	0.0%	0.6%	0.0%	0.0%	1.5%	0.3%
Residen.	C-3	9:00	1722	76.2%	7.4%	16.2%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
Residen.	C-1	10:00	1621	72.5%	14.6%	8.6%	0.0%	0.0%	0.5%	0.0%	2.4%	1.4%
Residen.	C-2	11:00	2040	62.7%	19.5%	16.7%	0.3%	0.2%	0.0%	0.3%	0.3%	0.0%
Residen.	C-3	12:00	1026	65.6%	18.1%	14.8%	0.0%	0.0%	0.4%	1.1%	0.0%	0.0%
Overall Arterial	---	---	3600	66.8%	19.2%	11.7%	0.1%	0.0%	1.3%	0.3%	0.3%	0.1%
Overall Highway	---	---	3996	61.6%	12.1%	18.5%	0.4%	0.2%	4.0%	1.1%	1.5%	0.6%
Overall Residen.	---	---	1409	67.2%	14.7%	15.3%	0.1%	0.2%	0.7%	0.4%	1.1%	0.2%
Overall Pune	---	---	---	65.9%	15.9%	14.6%	0.2%	0.1%	1.6%	0.5%	0.9%	0.2%

The overall averages shown in Table II.1 are weighted averages based on the vehicle counts on the various types of streets and the observed technology distributions. It was estimated based on traffic counts and the lengths of the various road types in Pune that 38.0% of overall driving in Pune is on arterials, 19.9% on highways, and 42.1% on residential streets.

IIb. Parking Lot Survey

The parking lot survey in Pune was directed by Sumit Sharma of the Society of Indian Automobile Manufacturers (SIAM). Two teams of automobile experts were used in the study. One team was experienced with respect to passenger vehicle technologies and the other group was experienced with respect to 2-wheeler vehicle technologies. The two teams worked the same areas each day following the schedule and locations indicated in the previous Table I.1. The goal of the survey was to identify the specific engine technologies, drive train, control technologies, air conditioning, total use, and model years of the vehicles surveyed. In the end, 1049 vehicles were surveyed. 519 of the surveyed vehicles were 2-wheelers and 530 of the surveyed vehicles were passenger cars. Table IIb.1 indicates some of the general characteristics observed in the surveyed fleet.

Table IIb.1 General Characteristics of the Surveyed Passenger Car and 2-Wheeler Fleet

Passenger Vehicles	Fraction of Passenger Vehicles	2-Wheel Vehicles	Fraction of 2-Wheel Vehicles
Gasoline, 4-stroke, Carburetor, No Catalyst	28.4%	Gasoline, 2-stroke, pre 1997	17.1%
Gasoline, 4-stroke, Carburetor, 2-Way Catalyst	13.0%	Gasoline, 2-stroke, 1997 and later	15.0%
Gasoline, 4-stroke, Carburetor, 3-Way Catalyst	0.6%	Gasoline, 2-stroke, 2-Way Catalyst	10.9%
Gasoline, 4-stroke, Multipoint Fuel Injection, 2-Way Catalyst	21.6%	Gasoline, 4-stroke, pre 1997	5.0%
Gasoline, 4-stroke, Multipoint Fuel Injection, 3-Way Catalyst	10.1%	Gasoline, 4-stroke, 1997-2001	28.5%
Diesel, 4-stroke	25.6%	Gasoline, 4-stroke, post 2001	23.5%
Propane, 4-stroke, Carburetor, No Catalyst	0.6%		
Propane, 4-stroke, Carburetor, 3-Way Catalyst	0.2%		

The engine size of the Pune vehicle fleet was generally small. Table IIb.2a and Table IIb.2b indicate the engine size and use distribution of the passenger vehicle and 2-wheel vehicle fleets respectively.

Table IIb.2a: Size and Use Characteristics of the Surveyed Passenger Car Fleet

Vehicle Engine Size	Low Use (<80 K km)	Medium Use (80-161 K km)	High Use (>161 K km)
Small (<1301 cc)	72.1%	8.0%	0.4%
Medium (1301-2000 cc)	11.6%	4.8%	1.5%
Large (>2000 cc)	1.3%	0.0%	0.2%

Table IIb.2b: Size and Use Characteristics of the 2-Wheeler Fleet

Vehicle Engine Size	Low Use (<25 K km)	Medium Use (26-50 K km)	High Use (>50 K km)
Small (<151 cc)	65.2%	22.7%	9.5%
Medium (151-280 cc)	1.9%	0.0%	0.0%
Large (>280 cc)	0.4%	0.0%	0.2%

Information in Table IIb.1 must be combined with information in Tables IIb.2a and IIb.2b along with the video collected data in Table II.1 to produce the passenger vehicle and 2-Wheeler vehicle fleet information for estimating emissions.

The model year can also be helpful to further differentiate among the multipoint fuel injection vehicles and the improved technologies in 2-Wheeler vehicles. Figure IIb.1 illustrates the model year distribution for active passenger vehicles in Pune.

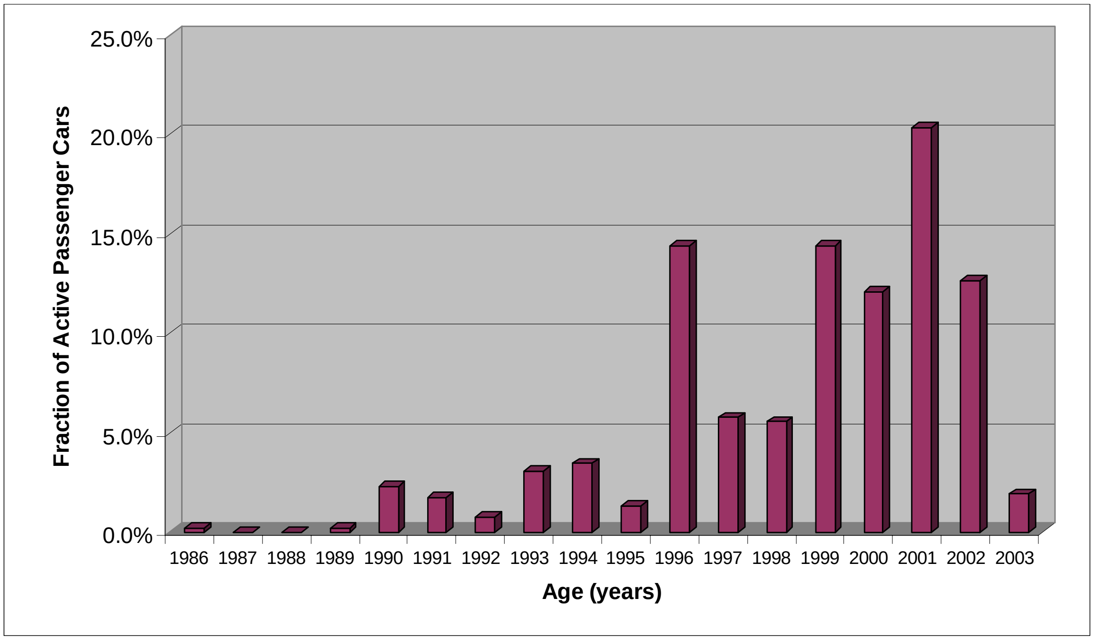

Figure IIb.1: Model Year Distribution in the Pune Passenger Vehicle Fleet

Figure IIb.2 illustrates the model year distribution for active 2-Wheeler vehicles in Pune.

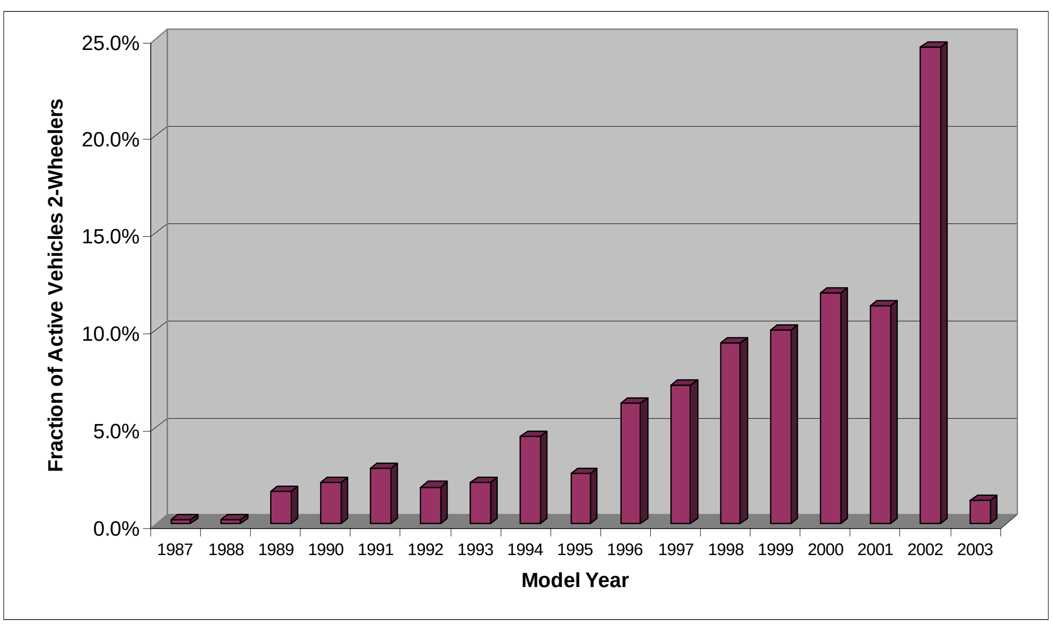

Figure IIb.2: Model Year Distribution in the Pune 2-Wheeler Vehicle Fleet

The absence of significant numbers of 2003 vehicles in the Pune fleet is at least partially due to the fact that the survey was taken during the first quarter of 2003. It is likely that the fraction of 2003 vehicles in the fleet will ultimately at least approximate the 2001/2002 fraction. The absence of 1997 and 1998 vehicles in the passenger car fleet must indicate lower passenger vehicle sales in these years.

IIc. 3-Wheeler Survey

An independent survey was carried out for 3-Wheeler vehicles. Locations over the metropolitan area where 3-Wheelers wait for passengers were sought out and the vehicle owners were questioned about their vehicles. 104 3-Wheeler vehicles were surveyed. Table IIc.1 indicates some general information about the 3-Wheeler fleet in Pune based on the survey.

Table IIc.1: General Characteristics of the Pune 3-Wheeler Fleet in Pune

Vehicle Type	Fraction of Vehicles in the Fleet
Gasoline, 2-stroke, No Catalyst	71.7%
Gasoline, 2-stroke, 2-Way Catalyst	22.5%
Gasoline, 4-stroke, No Catalyst	2.9%
Diesel, 4-stroke	2.9%

Table IIc.2 indicates the general use and engine size of the 3-Wheeler vehicles. The use characteristics were difficult to determine. 3-Wheeler owners tend to disconnect their odometers. Thus, this survey had to rely on owner estimates of the amount of use on their vehicles.

Table IIc.2: Use and Engine Size Characteristics of the Pune 3-Wheeler Vehicle Fleet

Vehicle Engine Size	Low Use (<25 K km)	Medium Use (26-50 K km)	High Use (>50 K km)
Small (<151 cc)	0.0%	0.0%	0.0%
Medium (151-280 cc)	18.6%	3.9%	74.6%
Large (>280 cc)	0.0%	0.0%	2.9%

Tables IIc.1 and IIc.2 can be used to generate a technology distribution for modeling on-road vehicle emissions. Figure IIc.1 illustrates the model year distribution observed in the Pune 3-Wheeler fleet.

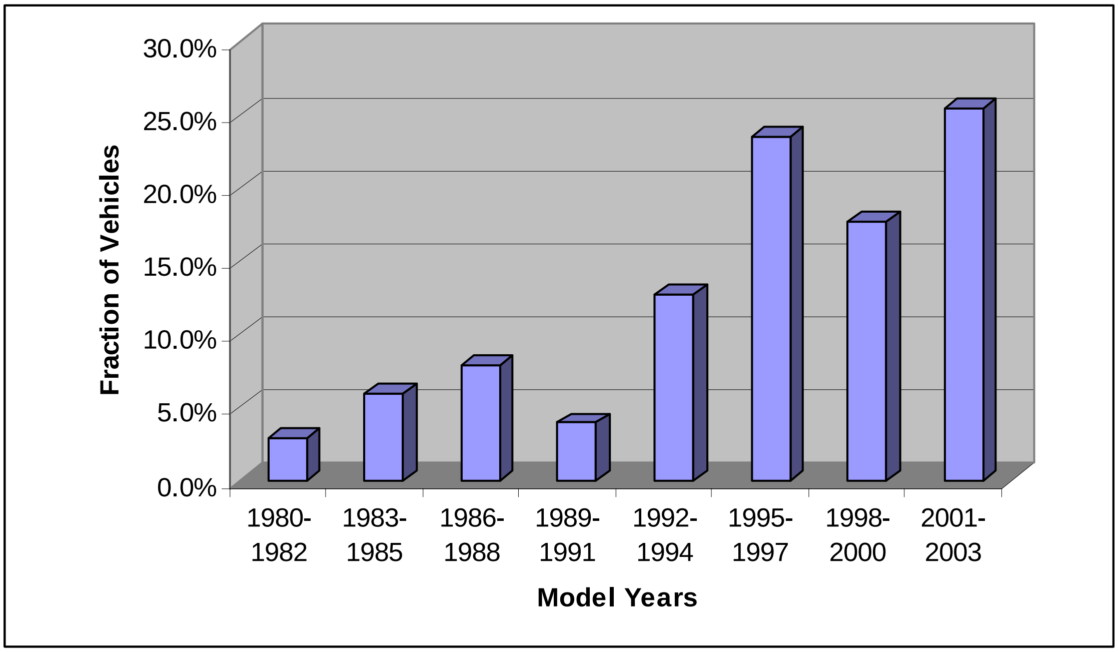

Figure IIc.1: 3-Wheeler Vehicle Model Year Distribution

Since only about 100 3-Wheeler vehicles were surveyed, it would improve the reliability of the results considerably to increase the survey size to 500 or more vehicles, as was the case for passenger car and 2-Wheeler vehicles in this study.

IId. Bus and Truck Survey

Data on buses operating in Pune were obtained from the municipal bus system operator. The bus operations in Pune make use of 890 buses. Table IId.1 presents the characteristics of the bus fleet operating in Pune as reported by the system operator.

Table IId.1: Bus Fleet Information for Pune

Bus Age (years)	Number of Buses	Fraction of Buses	Engine Technology	Fraction of Driving
1	100	11.2%	Euro II	0.18%
3	136	15.3%	Euro l	0.24%
5	50	5.6%	Euro 0	0.09%
7	35	3.9%	Euro 0	0.06%
8.5	120	13.5%	Euro 0	0.21%
9.5	44	4.9%	Euro 0	0.08%
10.5	89	10.0%	Euro 0	0.16%
11.5	76	8.5%	Euro 0	0.13%
12.5	40	4.5%	Euro 0	0.07%
13.5	13	1.5%	Euro 0	0.02%
14.5	68	7.6%	Euro 0	0.12%
15.5	65	7.3%	Euro 0	0.12%
16.5	33	3.7%	Euro 0	0.06%
17.5	19	2.1%	Euro 0	0.03%
18.5	2	0.2%	Euro 0	0.00%

Many of the older buses appear to be in poor condition and produce significant visible emissions. The emission factors used in the IVE model for these vehicles may be significantly underestimating some of the pollutants particularly the PM2.5 emissions. The diesel fuel used by the bus system contains 500ppm sulfur.

Trucks are required to pay entrance taxes. The locations were these taxes are paid provided an opportunity to collect data concerning the larger trucks that operate in the area. There did not appear to be any trucks that fit the large category as seen in the United States operating in the Pune area. However, large trucks are banned from many areas of the city during the daytime. This study did not collect data on driving during the late evening hours. Thus, the fraction of larger trucks operating during the late evening hours may be significantly underestimated. To add to this problem, only 29 trucks were surveyed in Pune; thus, the Truck data is highly questionable and further surveys should be done. To the positive side for emissions estimates, larger trucks are only a small fraction of the fleet and misestimates will thus not impact the emissions estimates to a great degree. Table IId.2 presents the collected truck data.

Table IId.2: Results of Truck Survey

Truck Technology	Truck Engine Size (cc)	Use Classification	Size Classification	Fraction of Fleet
Euro 0 or earlier	3350	High	Small	20.7%
Euro 1	3780	Low	Small	3.4%
Euro 2	3780	Medium	Small	3.4%
Euro 0 or earlier	5810	High	Medium	58.7%
Euro 1	5780	High	Medium	6.9%
Euro 2	5880	Medium	Medium	6.9%

There were no Low or Medium use Euro 0 or earlier. Thus, these categories are omitted from Table IId.2. The same is true for other use and size categories that were not observed in the Pune truck fleet.

IIe. Vehicle Use

Odometer data was recorder during the parking lot surveys. The bus system operator provided information on bus use. The 3-Wheeler operators reported on what they estimated that they drove each day. Thus, some approximation of the use of individual vehicles can be made and this can be extrapolated to make approximations of total vehicle use for Pune.

Figure IIe.1 on the next page shows the passenger vehicle use taken from vehicle odometers. The figure also includes a second order least square fit to the data. As is typical for the United States and all other countries studied so far, vehicle use decreases with vehicle age. A new passenger car in Pune will be driven about 14,000 km per year. Using the age distribution illustrated in previous Figure IIb.1, the average passenger car age in Pune is 4.6 years. This translates to an average daily driving of 28.5 kilometers of driving per day over the year. The scatter in the data for the high use years is due to the small numbers of vehicles observed with higher ages and the fact that the odometers themselves become unreliable. The equation shown in Figure IIb.1 will produce unreasonable results if extrapolated beyond 20 years due to the uncertainty in the odometer readings for vehicles older than 12 years. It may be more appropriate to replace the second order term in the vehicle use equation with a value that is similar in a relative sense to those measured in other countries.

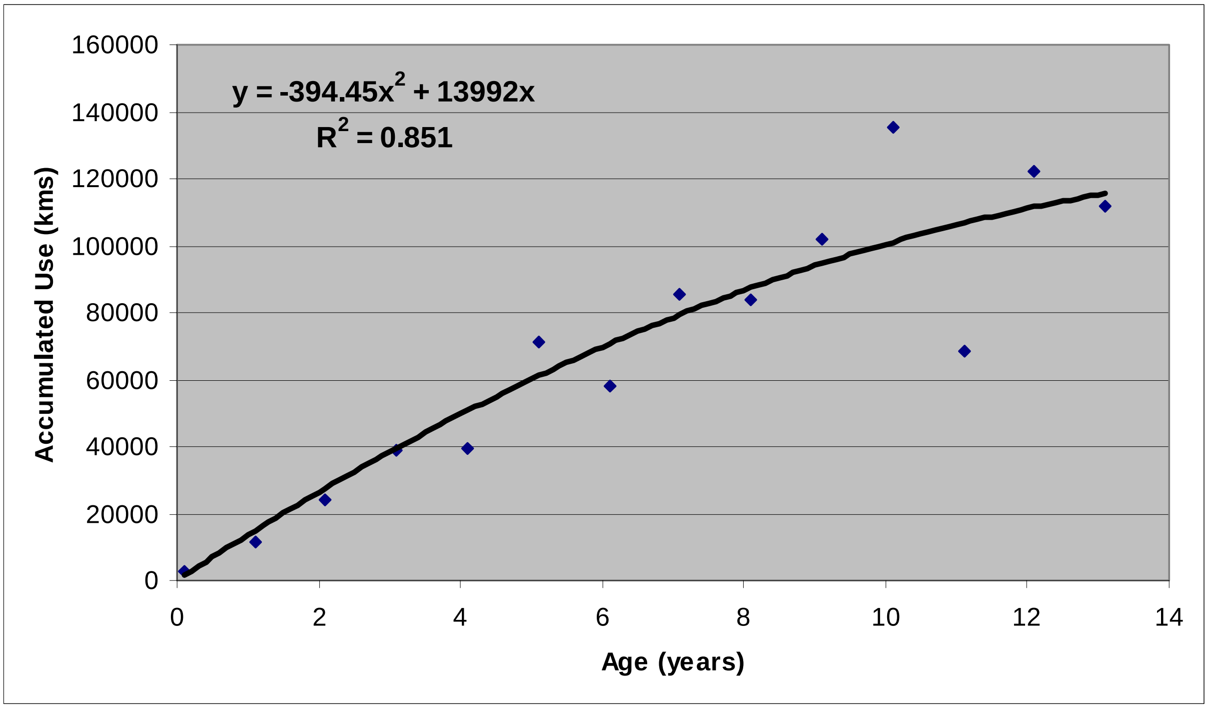

Figure IIe.1: Passenger Vehicle Use During the First Thirteen Years of Age

Figure IIe.2 presents 2-Wheeler vehicle use over the first 14 years of vehicle life. As with passenger vehicles, 2-Wheeler use decreases with vehicle age.

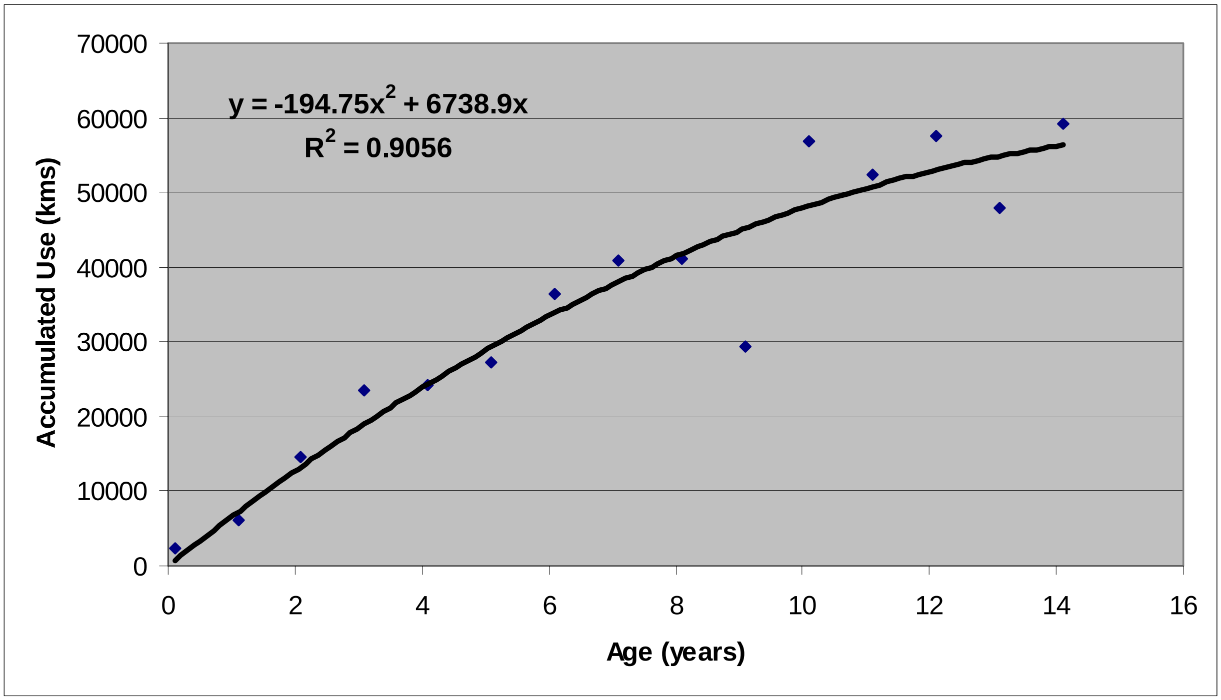

Figure IIe.2: 2-Wheeler Vehicle Use During the First Fourteen Years of Age

It is noteworthy that a new 2-Wheeler is operated about 6740 kilometers per year. This is about half of the operation of passenger vehicles. Using the age distribution illustrated in previous Figure IIb.2, the average age of 2-Wheelers operating in Pune is 4.6 years. Interestingly, this is the same as the passenger car average age. This translates to an average daily use of 13.5 kilometers for the 2-Wheeler fleet. The equation in Figure IIe.2 will produce unreasonable results if extrapolated beyond 15 years. This, as is the case for passenger vehicles, is due to the fact that on older vehicles the odometer may have turned over, been disconnected, or failed making vehicle use readings for older vehicles less reliable.

3-Wheeler vehicle owners reported that they operated their vehicles about 150 kilometers per day. This seems optimistic. The average 3-wheeler operational speed (discussed later in this report) is about 24 kilometers per hour. A 3-wheeler operator would have to operate their vehicle for 6.5 hours continuously each day to reach 150 kilometers. Based on limited observation of the operations of 3-Wheeler vehicles in Pune it seems that average use of 3-Wheelers would be more like 120 kilometers per day (5 hours of actual driving each day).

The metropolitan bus operators reported that they operated their buses an average of 200 kilometers per day. Similar to the 3-Wheeler operators, this translates to 8.3 hours of actual driving per day. However, in this case, this seems more likely given that multiple drivers can be used to keep the buses running.

It should be noted that the survey process used to estimate vehicle use is biased high. The reason is that the parking lot survey favors vehicles that are used more. The more used vehicles will tend to show up more often. A statistical analysis of data collected in Santiago and Nairobi indicates that the parking lot survey approach will result in driving estimates that are 12% to 18% high. At this point, we are reducing the annual use estimates from the parking lot surveys by 15%.

Simple algebra can be used to demonstrate that the total amount of driving in the region can be estimated by multiplying the number of vehicles of a type in the region times the average driving per day for that vehicle type divided by the fraction of those types of vehicles observed on the street. The number of vehicles of different types operating in the city is not well known due to the registration process used in Pune. However, estimates can be made from registration data. Table IIe.1 below provides the estimated total driving based on measurements made in this study.

Table IIe.1: Estimation of Total Driving in Pune

Type of Vehicle	Number of Vehicles in Region (N)	Average Driving for Vehicle Type per Day (A) (kms/day)	Fraction of Vehicle Type Observed in the Fleet (f)	Estimated Total Driving in Pune (N*A/f) (kms/day)
Passenger Car	72,000	24.2	14.60%	11,946,575
2-Wheeler	660,000	11.5	65.90%	11,492,413
3-Wheeler	17,000	120	15.90%	12,830,189
Bus	890	200	1.50%	11,866,667
Total Vehicles	749,890		**Overall Average**	12,033,961

The values shown in Table IIe.1 should only be treated as approximations, but they should be in the ballpark of the true total driving occurring in Pune in 2003.

A final issue of interest is to compare Pune driving with other areas. Figure IIe.3 illustrates the total driving per vehicle for the countries studied to date. As can be seen, passenger cars are driven the most in the United States and the least in Pune. Driving observed in Nairobi and Santiago are between the driving amounts for the United States and Pune.

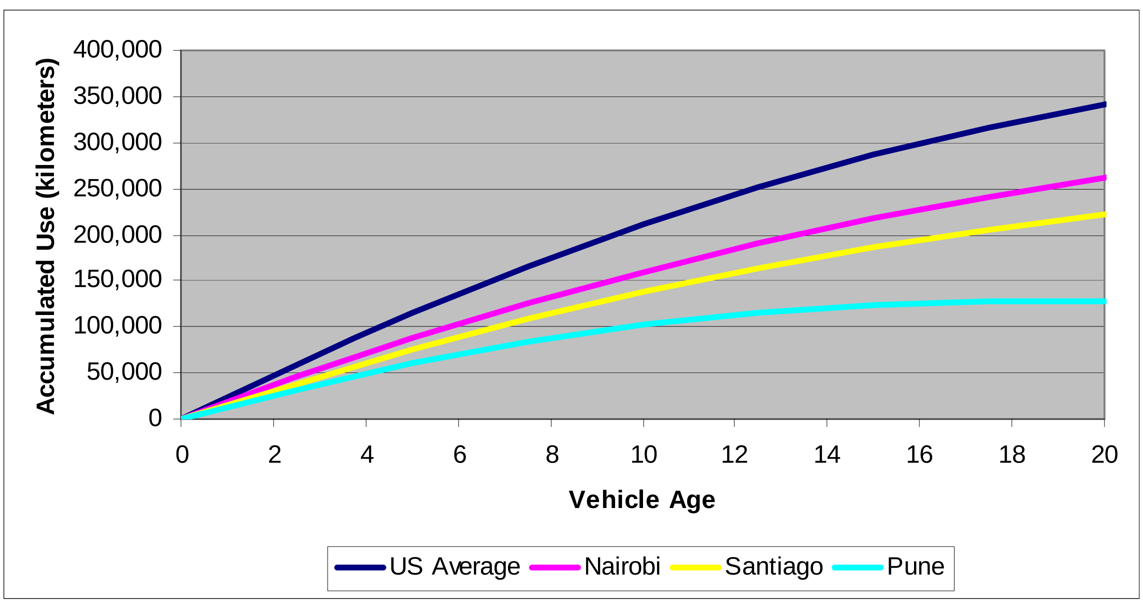

Figure IIe.3: Comparison of Passenger Vehicle Use in Different Countries

In estimating the greenhouse gas emissions from the Pune fleet, the values will be much lower per vehicle compared to the United States and Nairobi because the Pune fleet is smaller and driven less than either the United States or Nairobi fleets.

III. Vehicle Driving Patterns

Vehicle driving patterns were measured using GPS technology as described in Appendix A. This technology allows the measurement each second of vehicle location, speed, and altitude. The altitude reading is the least certain of the data collected by a GPS unit, but it is still useful for estimating road grade. Figure III.1 illustrates the location data collected from one of the study days in Pune. A student was asked to get on buses with the computerized GPS equipment and ride the buses for about 7 hours. On this day the selected buses were generally in the eastern portion of Pune.

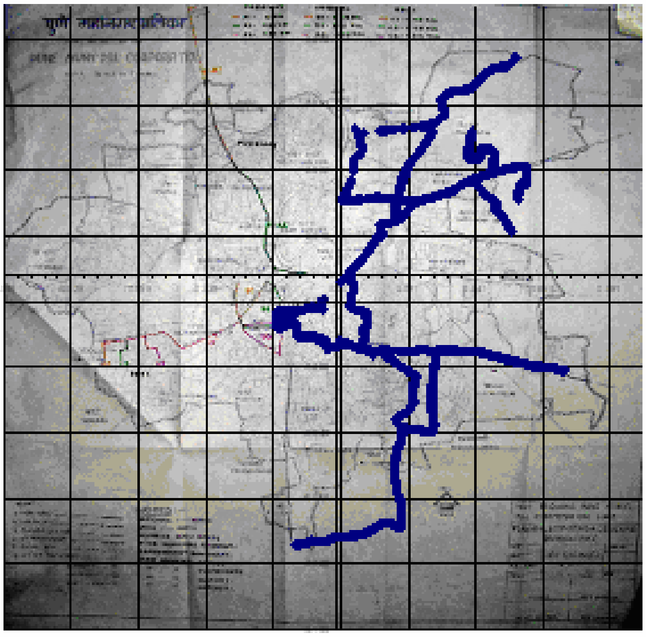

Figure III.1: Example of Bus Routes for One Day of Study

Figure III.2 presents an example of speeds as measured by the GPS unit for about 90 seconds around 11:30.

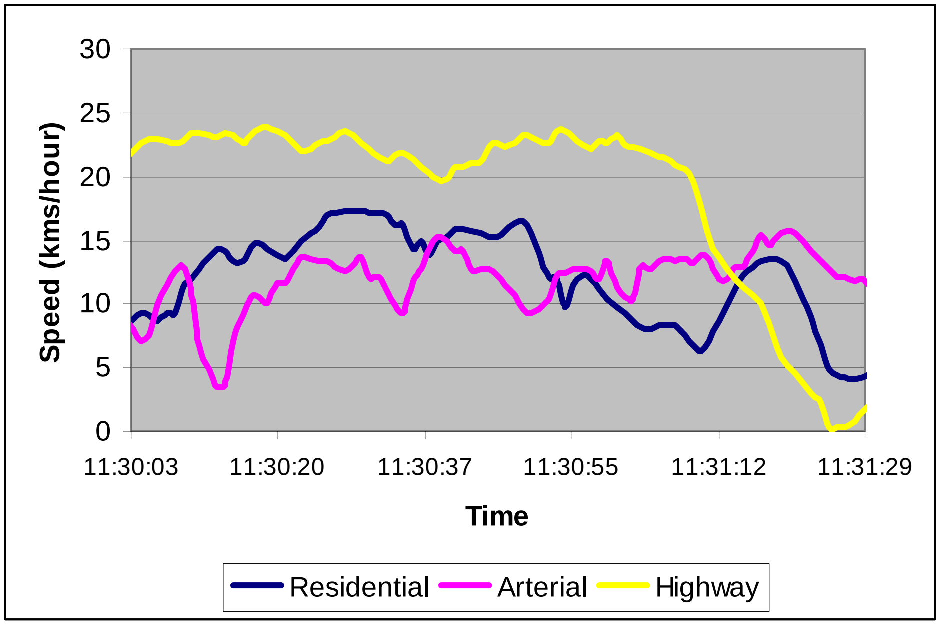

Figure **III.2: Example of Residential, Arterial, and Highway Driving at 11:30 in Pune**

Figure III.3 presents an example of altitude recorded while driving on an arterial over a 10 minute drive. As noted earlier, the altitude measurement is the least accurate of the GPS determinations.

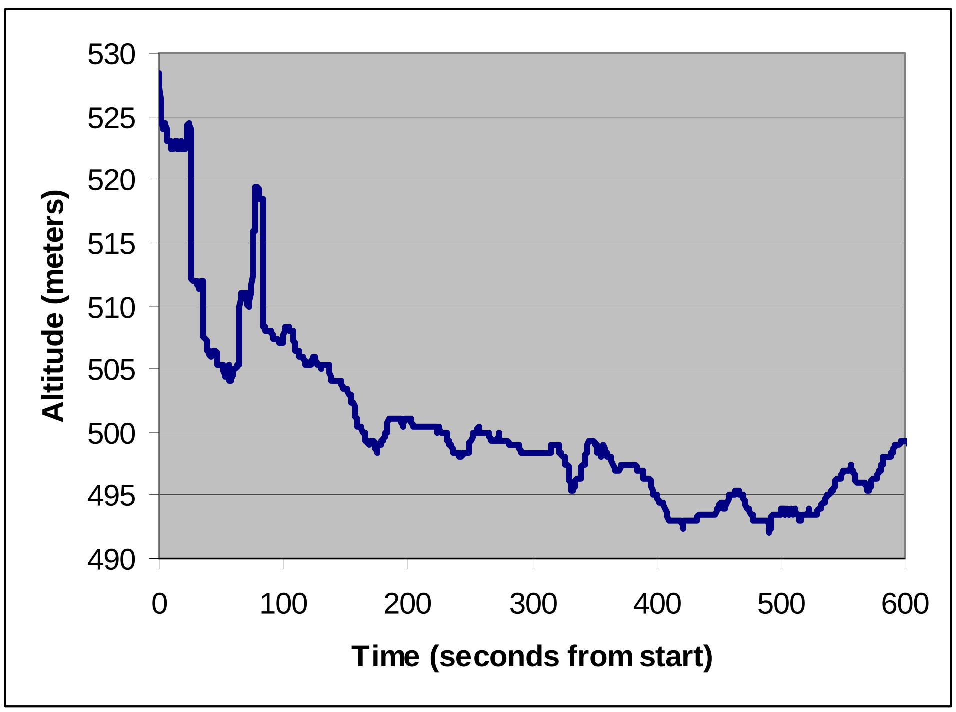

Figure III.3: Example of Altitude Recorded by GPS over 10 Minute Arterial Drive

In using this data to estimate road grade, care must be taken to look at multiple adjacent sample points to make the most appropriate estimate of road grade.

The IVE model uses a calculation of the power demand on the engine per unit vehicle mass to correct for the driving pattern impact on vehicle emissions. This power factor is called vehicle specific power (VSP). The VSP is the best, although imperfect, indicator of vehicle emissions relative the vehicles base emission rate. Equation III.1 presents the for of VSP equation used in the IVE model.

$$VSP = 0.132*S + 0.000302*S^2 + 1.1*S*dS/dt + 9.81*Atan(Sin(Grade)) \qquad \text{III.1}$$

Where,

S = vehicle speed in km/second.
dS/dt = vehicle acceleration km/second/second.
Grade = grade of road grade radians.

About 65% of the variance in vehicle emissions can be accounted for using VSP. To further improve the emissions correction for vehicle driving, a factor denoted vehicle stress was developed. Vehicle stress (STR) uses an estimate of vehicle RPM combined with the average of the power exerted by the vehicle in the 15 seconds before the event of interest. Equation III.2 indicates the calculation for STR.

$$STR=RPM + 0.08*PreaveragePower \qquad \text{III.2}$$

Where,

RPM = the estimated engine RPM/1000 (an algorithm was developed by driving many different vehicles and measuring RPM compared to vehicle speed and acceleration. The minimum RPM allowed is 900.

PreaveragePower = the average of VSP the 15 seconds before the time of interest. The 0.08 coefficient was developed from a statistical analysis of emissions and speed data from about 500 vehicles to give the best correction factor when combined with VSP.

Ultimately the GPS data for each vehicle type studied is broken into one of 20 VSP bins and one of 3 STR Bins. Thus, each point along the driving route can be allocated to one of 60 driving bins. A given driving trace can be evaluated to indicate the fraction of driving that occurs in each driving bin. These fractions are used to develop a correction factor for a given driving situation.

IIIa. Passenger Cars

Data on passenger car driving was collected in three parts of Pune (see Table II.1) over six days. Due to limited data, the driving data collected was allocated into 2 hour groups instead of 1 hour groups. Table IIIa.1 indicates the average speed for each type of road studied for each 2-hour group.

Table IIIa.1: Average Passenger Car Speeds on Pune Roads

Time	Highway	Arterial	Residential Street
05:30	45.15	30.79	26.65
07:30	42.23	29.54	22.55
09:30	27.45	20.06	22.13
11:30	25.75	15.21	20.85
13:30	30.02	22.57	22.19
15:30	30.98	26.42	22.66
17:30	29.67	20.37	20.86
19:30	26.20	19.27	15.80

Speed is not a good indicator of vehicle power demand. Vehicle acceleration consumes considerable energy and is not indicated by average vehicle speed. Tables IIIa.2 to IIIa.4 below provide the power bin distribution for the driving on Pune Highways, Arterials, and Residential streets respectively averaged over all hours. For use in the IVE model, the power bin distributions can also be used in the two hour groupings indicated in Table IIIa.1 to make hourly estimates of emissions from passenger vehicles.

It should be noted that Power Bins 1-11 represent the case of negative power (i.e. the vehicle is slowing down or going down a hill or some combination of each). Power Bin 12 represents the zero or very low power situation such as waiting at a signal light. Power Bins 13 and above represent the situation where the vehicle is using positive power (i.e. driving at a constant speed, accelerating, going up a hill or some combination of all three.

Table IIIa.2: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Highways Averaged Over All Hours (average speed: 30.22 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.01%	0.04%	0.11%	0.32%	0.80%	2.02%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	8.52%	40.73%	27.79%	15.45%	3.55%	0.50%	0.05%	0.02%	0.01%	0.01%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.03%	0.01%	0.00%	0.01%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table IIIa.3: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Arterials Averaged Over All Hours (average speed: 21.52 kilometers/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.01%	0.01%	0.01%	0.02%	0.07%	0.24%	0.64%	1.99%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	9.14%	49.82%	23.35%	11.17%	2.65%	0.51%	0.16%	0.07%	0.03%	0.04%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.02%	0.01%	0.00%	0.01%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table IIIa.4: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Residential Streets Averaged Over All Hours (average speed: 22.08 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.02%	0.00%	0.01%	0.01%	0.03%	0.06%	0.08%	0.17%	0.57%	2.15%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	9.91%	46.52%	26.50%	9.94%	2.40%	0.53%	0.11%	0.05%	0.02%	0.07%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.01%	0.02%	0.03%	0.06%	0.08%	0.10%	0.08%	0.05%	0.03%	0.06%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.07%	0.05%	0.03%	0.15%

It is clear looking at Tables IIIa.2 through IIIa.4 that the times in the zero power bin, 12, (stopping and idling) increases from the highway case to the residential case. It is also noteworthy that the high stress, high power demand driving only shows up on residential streets likely due to fast accelerations from stops on less crowded streets.

IIIb. 2-Wheeler Vehicles

Data on 2-Wheel vehicles was collected in the same three portions of Pune as was used to collect passenger car data. Different 2-Wheel vehicles with one or two passengers were operated on Pune streets and data was collected using GPS technology. Table IIIb.1 shows the average speeds recorded by the 2-Wheel vehicles in this study.

Table IIIa.1: Average 2-Wheel Vehicle Speeds on Pune Roads

Time	Highway	Arterial	Residential Street
05:30	35.93	30.83	25.28
07:30	35.93	22.28	25.28
09:30	34.40	12.79	23.17
11:30	22.50	16.74	21.21
13:30	25.74	14.16	20.18
15:30	25.42	13.61	25.15
17:30	24.95	13.35	18.30
19:30	21.97	30.79	16.91

Although the average speeds are lower for 2-Wheelers, a similar pattern of speeds can be observed compared to passenger vehicle speeds. The peak driving speeds occur at 05:30. The minimum traffic speeds on the Highway and Arterial occur at 17:30. On a residential street, the minimum traffic speed occurs at 09:30; although, the residential speed at 17:30 is very close to the 09:30 value.

Tables IIIb.2 through IIIb.4 provide the percentage of driving time in each of the 60 power bins used in the IVE model.

Table IIIb.2: Distribution of Driving into IVE Power Bins for 2-Wheel Vehicles Operating on Highways Averaged Over All Hours (average speed: 26.48 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.05%	0.01%	0.01%	0.02%	0.02%	0.03%	0.04%	0.09%	0.31%	1.41%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	6.90%	44.01%	37.13%	8.44%	1.00%	0.20%	0.05%	0.03%	0.02%	0.06%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.01%	0.00%	0.02%	0.01%	0.01%	0.02%	0.03%	0.03%	0.00%	0.06%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table IIIb.3: Distribution of Driving into IVE Power Bins for 2-Wheel Vehicles Operating on Arterials Averaged Over All Hours (average speed: 18.87 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.04%	0.01%	0.02%	0.01%	0.05%	0.06%	0.06%	0.14%	0.40%	1.88%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	9.52%	51.81%	27.10%	7.24%	1.01%	0.26%	0.07%	0.05%	0.02%	0.07%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.01%	0.00%	0.03%	0.03%	0.02%	0.02%	0.05%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table IIIb.4: Distribution of Driving into IVE Power Bins for 2-Wheel Vehicles Operating on Residential Streets Averaged Over All Hours (average speed: 22.07 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.03%	0.06%	0.25%	1.34%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	9.11%	45.77%	34.03%	7.92%	1.08%	0.24%	0.06%	0.02%	0.01%	0.02%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

IIIc. 3-Wheel Vehicles

3-Wheel vehicles were not restricted to specific streets. They were simply asked to operate their vehicles as they normally would picking up passengers and dropping them off over the Pune metropolitan area. Table IIIc.1 shows the average speeds recorder for the 3-Wheel vehicles.

Table IIIc.1: Average 3-Wheel Vehicle Speeds on Pune Roads

Time	Overall
05:30	25.48
07:30	21.41
09:30	18.98
11:30	22.10
13:30	12.58
15:30	21.28
17:30	20.06
19:30	17.00

The 3-Wheel vehicle speeds are, as expected, lower than passenger vehicle or 2-Wheel vehicle speeds. The minimum speed however occurs at 11:30. The minimum might represent a drop in passengers at this hour and thus more idle time.

Table IIIc.2 presents the power-binned data for the 3-Wheel vehicle averaged over all hours.

Table IIIc.2: Distribution of Driving into IVE Power Bins for 3-Wheel Vehicles Averaged Over All Hours (average speed: 19.02 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.08%	0.02%	0.02%	0.03%	0.03%	0.06%	0.09%	0.18%	0.53%	1.92%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	8.24%	51.34%	26.96%	8.24%	1.32%	0.39%	0.15%	0.06%	0.03%	0.08%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.01%	0.00%	0.01%	0.01%	0.02%	0.03%	0.02%	0.01%	0.04%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.06%

IIId. Buses

Table IIId.1 indicates average 3-Wheel vehicle speeds in Pune. The maximum speed is at 11:30. This may indicate the least passenger use. In the case of Buses, they do not stop and idle like 3-Wheel vehicles do when passengers are not there. Buses continue to run their routes with fewer stops and with higher average speeds.

Table IIId.1: Average Bus Speeds on Pune Roads

Time	Overall
05:30	19.30
07:30	19.30
09:30	13.36
11:30	17.29
13:30	14.72
15:30	19.86
17:30	16.42
19:30	10.71

Table IIId.2 indicates the power bin distributions for a bus averaged over all hours.

Table IIId.2: Distribution of Driving into IVE Power Bins Buses Averaged Over All Hours (average speed: 16.55 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.05%	0.01%	0.02%	0.03%	0.03%	0.08%	0.13%	0.40%	0.92%	2.30%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	6.92%	56.48%	21.48%	9.02%	1.36%	0.39%	0.14%	0.07%	0.06%	0.08%
Med	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.01%	0.01%
High	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

IIIe. Summary of Driving Pattern Results

Figure IIIe. 1 compares driving speeds by hour for the four types of vehicles studied. In general, congestion lowers the average velocity during the daytime hours by 20 to 30 percent of free flow velocities. It was assumed that the early morning and late evening velocities were similar to the late evening and 6 AM data because no data was collected between 10 pm and 5 AM. Overall, various road types and vehicle types have similar average velocities. The passenger vehicle highway and 2 wheel highway driving have the highest average velocities, while the buses and 2 wheel arterial driving have the lowest velocities.

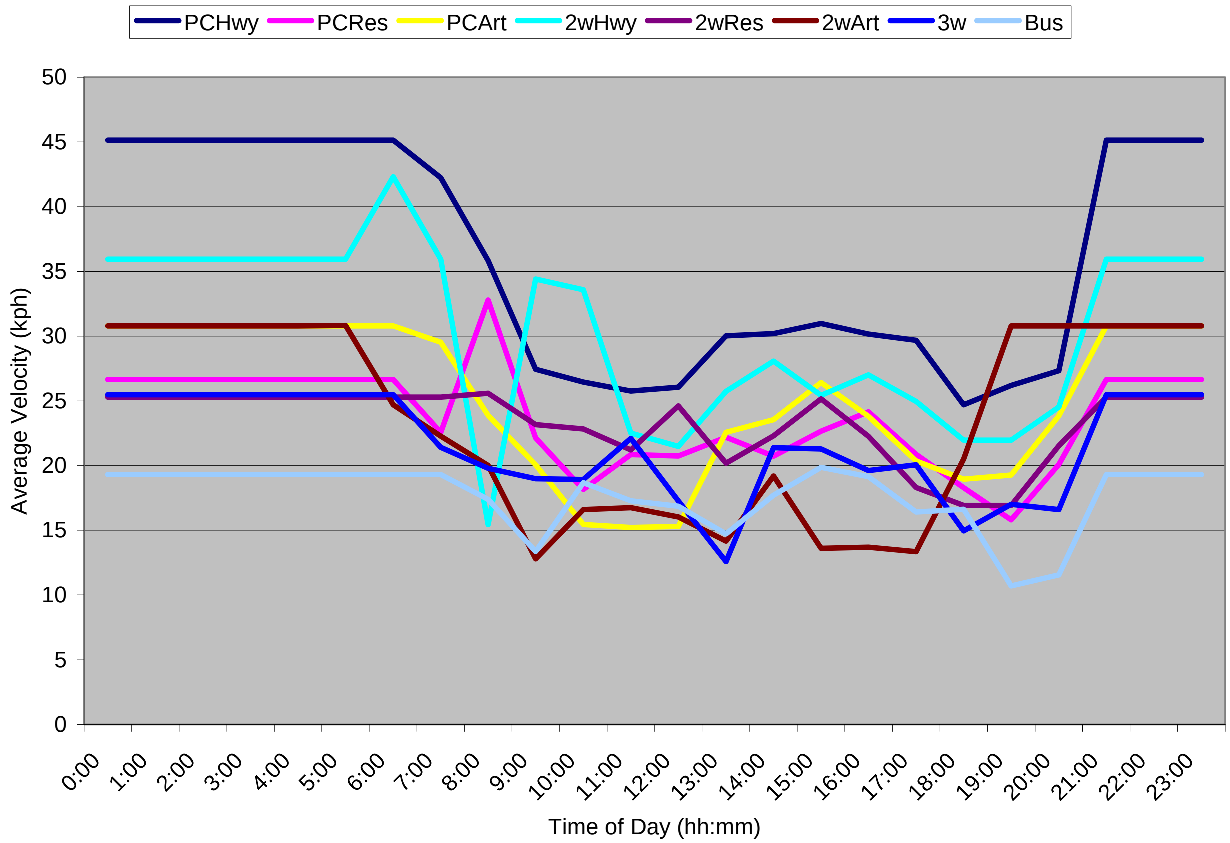

Figure IIIe.1: Average Speeds for All Road Types and Vehicle Classes in Pune

Figure IIIe.1 shows the distribution into driving bins for four of the main classes of driving at 05:30. There is little to distinguish the driving patterns between passenger vehicles, 3-Wheel vehicles, and buses at this time of the morning. The 2-Wheel vehicles and passenger vehicles are using slightly more relative power (i.e. accelerations) in driving under free flow conditions.

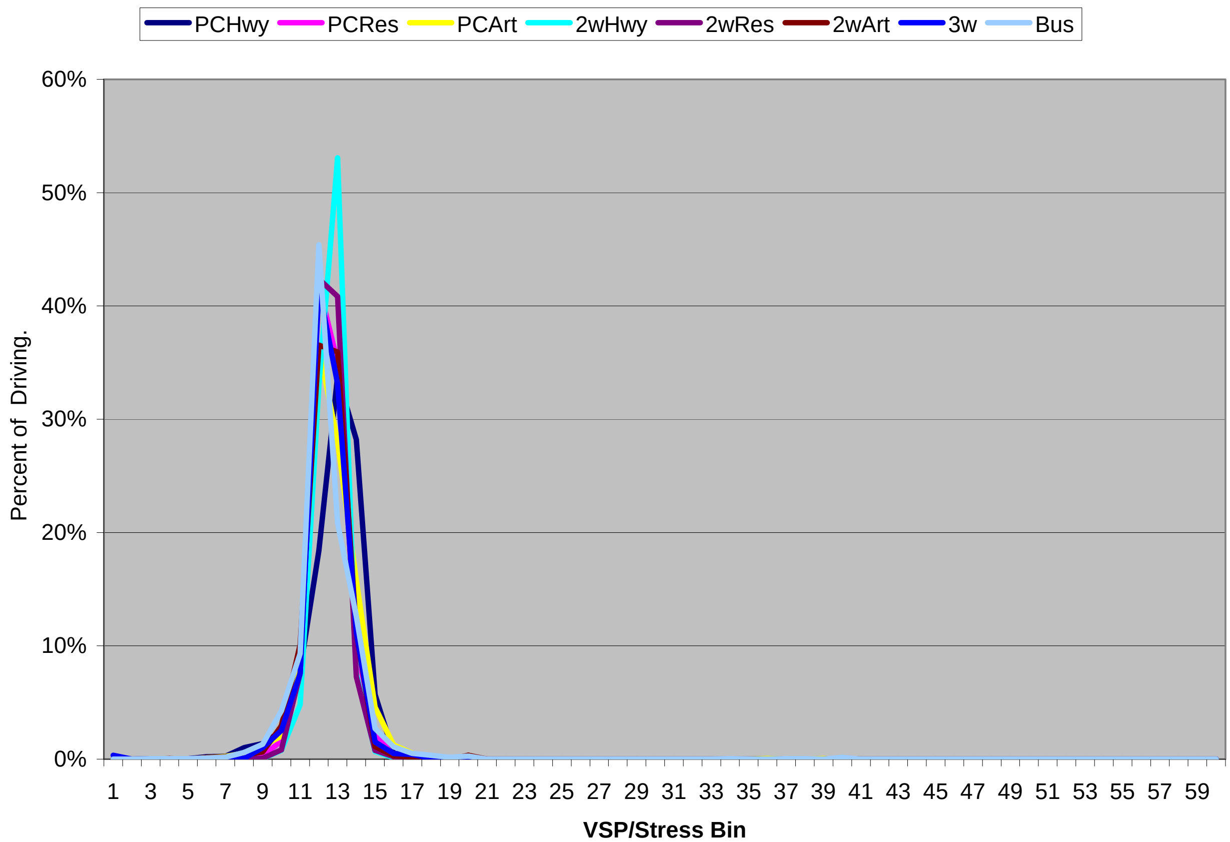

Figure IIIe.1: Comparison of Driving Patterns for Four Major Vehicle Classes for 05:30

Figure IIIe.2 represents driving at 09:30. In this case, the passenger vehicle and 2 wheel highway driving look very similar and contain more higher power driving. The 2 wheel driving and the passenger car residential driving even contain a small amount of medium and high stress driving, (bins above 20) which is caused by hard accelerations. Buses have the lowest fraction of positive power. Overall, the heavy traffic congestion is trapping most drivers into similar patterns.

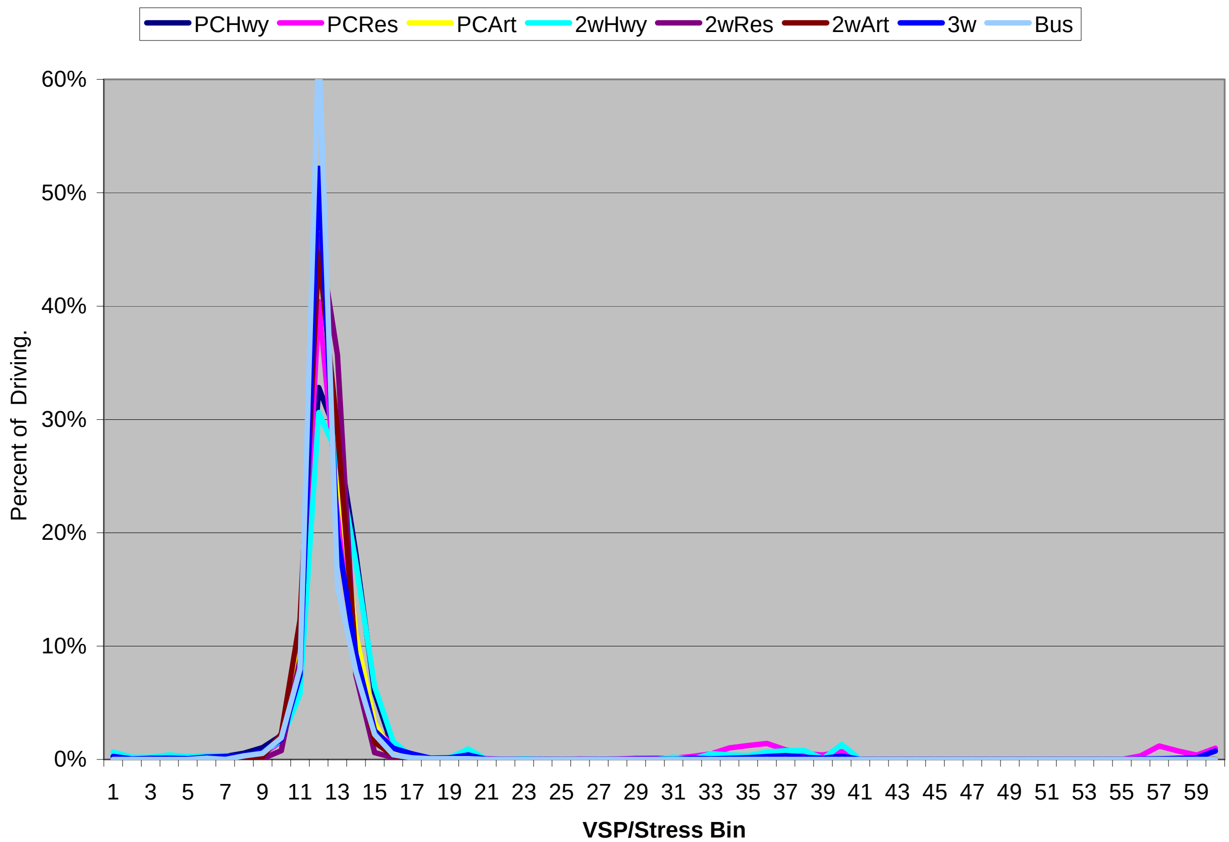

Figure IIIe.2: Comparison of Driving Patterns for Four Major Vehicle Classes for 09:30

Figure IIIe.3 represents the 12:30 time frame. This hour of the day represents the most uniform driving among the various vehicle classes. The 2-Wheel vehicles still demonstrate slightly greater relative power demands and the 3-Wheel vehicles show more idle time. Very little high stress driving is seen here.

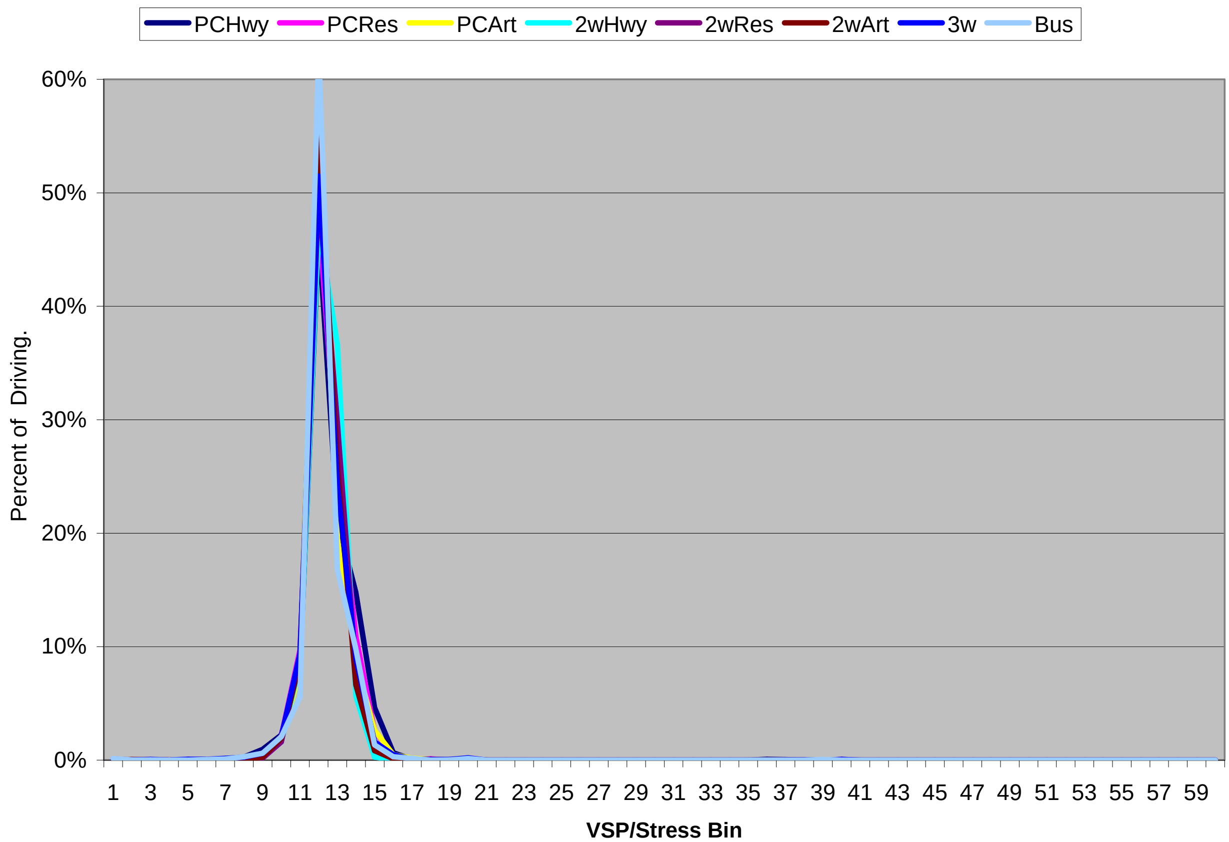

Figure IIIe.2: Comparison of Driving Patterns for Four Major Vehicle Classes for 12:30

Data sets using the binned data and average speeds are used in the IVE model to correct emission estimates for local driving patterns.

IV. Vehicle Start Patterns

Between10% and 30% of vehicle emissions come from vehicle starts in the United States. This is a significant amount of emissions. Thus, it is important to understand vehicle start patterns in an urban area to fully evaluate vehicle emissions. To measure start patterns, a small device that plugs into the cigarette lighter or otherwise hooks into a vehicles electrical system has been developed. The voltage fluctuations in the electrical system can be used to estimate when a vehicle engine is on and off. This process is described in Appendix A.

The analysis of start patterns in Pune was complicated by the fact that vehicle operators are encouraged to turn their engines off at signal lights if they contemplate a wait of more than 30 seconds. Thus, Pune vehicles showed voluminous vehicle starts compared to other urban areas. This forced us to make a decision if engine off times on the order of 4 or less minutes should be considered as a start. It was decided that these stops would be discounted for this analysis. However, it is not clear to the authors if these very short stops increase vehicle emissions or decrease vehicle emissions. Some research needs to be conducted into this phenomenon in Pune and elsewhere in India is helping or harming the environment. However, as noted here, stops of less than 4 minutes were not considered to be stops and were treated as idling.

Table IV.1 indicates the measured start and soak patterns for passenger vehicles in Pune. Data was successfully collected from about 33 passenger vehicles over about 3 days for each vehicle. This provides about 100 vehicle days of data. While this amount of information is significant, it was felt that hour by hour data would include too few events and would thus not be meaningful. Thus, the data was lumped into 3 hour groups.

Table IV.1: Passenger Vehicle Start and Soak Patterns for Pune

Soak Time (hrs)	Overall PC	PC 05:00-07:59	PC 08:00-10:59	PC 11:00-13:59	PC 14:00-16:59	PC 17:00-19:59	PC 20:00-22:59	PC 23:00-4:59
0.25	33.8%	15.0%	36.6%	28.7%	37.2%	37.4%	23.7%	45.5%
0.5	17.1%	5.0%	19.9%	19.1%	14.0%	17.9%	15.8%	9.1%
1	15.1%	5.0%	8.7%	25.7%	25.6%	9.8%	26.3%	9.1%
2	6.8%	0.0%	0.6%	9.6%	9.3%	7.3%	7.9%	0.0%
3	6.8%	0.0%	0.6%	8.8%	7.8%	13.0%	5.3%	9.1%
4	2.9%	5.0%	0.0%	1.5%	2.3%	4.1%	10.5%	0.0%
6	2.4%	0.0%	1.2%	0.0%	1.6%	7.3%	2.6%	0.0%
8	1.9%	5.0%	1.9%	0.0%	0.0%	2.4%	7.9%	18.2%
12	7.9%	60.0%	21.1%	0.0%	0.0%	0.0%	0.0%	9.1%
18	5.3%	5.0%	9.3%	6.6%	2.3%	0.8%	0.0%	0.0%
Events	621	20	161	136	129	123	38	11
Fraction		3.2%	26.1%	22.0%	20.9%	19.9%	6.1%	1.8%

Overall, Pune passenger vehicles were started 7.02 times per day (discounting soak times less than 4 minutes). This is typical of what is observed in other urban areas that have been studied. Starts per day vary from 6-8 for passenger vehicles in the urban areas studied to date.[1] As expected, most starts occur in the 08:00 to 11:00 time frame. The highest number of starts after an 8 or more hour weight occurs in the 05:00 to 08:00 time frame as would be expected. These long soak times leave the engine cold and result in much greater start emissions.

Table IV.2 indicates the measured start and soak patterns for 2-Wheel vehicles. Overall, 2-Wheel vehicles were started on average 7.18 times per day. This is very close to the start number for passenger vehicles. No 2-Wheel vehicle start and soak patterns have been collected by CE-CERT outside of Pune, India. Thus, there is no way to compare these results. Of interest if Table IV.2 is compared with Table IV.1 is the fact that passenger vehicle owners tended to start earlier in the day than 2-Wheel owners.

Table IV.2: 2-Wheel Vehicle Start and Soak Patterns for Pune

Soak Time (hrs)	2W Overall	2W 05:00-07:59	2W 08:00-10:59	2W 11:00-13:59	2W 14:00-16:59	2W 17:00-19:59	2W 20:00-22:59	2W 23:00-4:59
0.25	25.2%	14.3%	28.7%	29.1%	25.9%	26.6%	15.6%	15.4%
0.5	16.2%	0.0%	13.0%	17.4%	18.5%	13.8%	28.1%	0.0%
1	17.3%	35.7%	9.3%	19.8%	14.8%	11.7%	29.7%	38.5%
2	13.2%	0.0%	2.8%	20.9%	20.4%	12.8%	15.6%	23.1%

[1] Studies to date have been conducted in Los Angeles, USA; Santiago, Chile; Nairobi, Kenya; and Pune, India.

3	6.5%	0.0%	0.9%	8.1%	11.1%	9.6%	4.7%	15.4%
4	3.2%	7.1%	0.0%	2.3%	5.6%	7.4%	1.6%	0.0%
6	2.8%	0.0%	0.9%	0.0%	1.9%	8.5%	3.1%	0.0%
8	4.4%	7.1%	12.0%	0.0%	0.0%	4.3%	0.0%	7.7%
12	7.9%	35.7%	25.0%	0.0%	0.0%	1.1%	1.6%	0.0%
18	3.5%	0.0%	7.4%	2.3%	1.9%	4.3%	0.0%	0.0%
Events	433	14	108	86	54	94	64	13
Fraction		3.2%	24.9%	19.9%	12.5%	21.7%	14.8%	3.0%

Four 3-Wheel vehicles were outfitted with VOCE units to measure start patterns. In every case there was a problem. Thus, no start and soak patterns are available for 3-Wheel vehicles. Hopefully this can be corrected in future studies. 3-Wheel vehicles should have a large number of starts since they often sit for more than 4 minutes waiting for passengers. For analysis in the interim, the 2-Wheel start patterns will be used. However, this is considered to underestimate the emissions from starting 3-Wheel vehicles.

Approximately 4 days of start and soak times were recorded for 2 buses. Thus, the bus data should be considered to be subject to considerable error. Table IV.3 indicates the overall results for the bus measurements collected. Due to the limited data, no effort was made to calculate starts by the hour of the day. Overall, the buses showed 8.68 starts per day.

Table IV.3: Bus Start and Soak Patterns Collected in Pune

Soak Time (hrs)	BUS Overall
0.25	10.3%
0.5	24.1%
1	13.8%
2	10.3%
3	0.0%
4	6.9%
6	0.0%
8	0.0%
12	27.6%
18	6.9%
Events	58

Overall, the mean weighted starts per vehicle per day in Pune is 7.2.

V. Results

The total daily driving in Pune is on the order of 12,000,000 kilometers based on the estimation process indicated in Table IIe.1. The fraction of driving per hour can be estimated using traffic counts shown in Table II.1 and averaged according to the fraction of driving on each type of street discussed in Section IIa. Based on the observed number of vehicles on the different road types and the total length of each type of road in Pune, it was estimated that 38% of the driving is on arterials, 20% of the driving is on highways, and 42% of the driving is on residential streets.
The results are shown in Table V.1. Since no data was collected between 0:00 and 06:00 and between 19:00 and 0:00 these values were estimated using fractions observed in other urban areas.

In the case of vehicle starts, Tables IV.1 and IV.2 were weighted by the fraction of passenger vehicles and 2-Wheel vehicles in the fleet. A total of 750,000 vehicles were assumed to be in daily operation in 2003.

Table V.1: Estimated Fraction and VMT and Starts By Hour in Pune

Time (times in red had to be estimated from data collected in other urban areas since these times were not observed in Pune)	**Pune Estimated Driving Fractions in Each Hour**	**Total Estimated Driving by Hour in Pune** (kilometers)	**Fraction of Starts in Each Hour**	**Total Estimated Starts by Hour in Pune**
0:00	1.31%	157,200	0.5%	25,039
1:00	0.80%	96,000	0.5%	25,039
2:00	0.54%	64,800	0.5%	25,039
3:00	0.41%	49,200	0.5%	25,039
4:00	0.38%	45,600	0.5%	25,039
5:00	0.55%	66,000	1.1%	58,208
6:00	1.53%	183,600	1.1%	58,208
7:00	4.43%	531,600	1.1%	58,208
8:00	5.06%	607,200	8.3%	452,559
9:00	7.37%	884,400	8.3%	452,559
10:00	7.64%	916,800	8.4%	452,559
11:00	8.27%	992,400	6.7%	364,462
12:00	6.99%	838,800	6.7%	364,462
13:00	7.28%	873,600	6.7%	364,462
14:00	5.49%	658,800	4.7%	251,728
15:00	5.02%	602,400	4.7%	251,728
16:00	6.11%	733,200	4.7%	251,728
17:00	6.02%	722,400	7.1%	384,905
18:00	7.09%	850,800	7.1%	384,905
19:00	4.76%	571,200	7.1%	384,905
20:00	4.35%	522,000	4.4%	238,060
21:00	3.75%	450,000	4.4%	238,060
22:00	2.85%	342,000	4.4%	238,060
23:00	2.00%	240,000	0.5%	25,039
	Total	12,000,000		5,400,000

The calculations shown above are for illustrative purposes only. They are approximations and more extensive measurements should be completed in Pune to improve the estimate of total daily driving in Pune and hourly driving outside of the hours measured in this study. 3-Wheel vehicle data should also be collected to improve the start estimates per hour.

Figure V.1 shows the modeling results using the data developed or estimated from this study for Carbon Monoxide. The top line reflects start and running emissions added together.

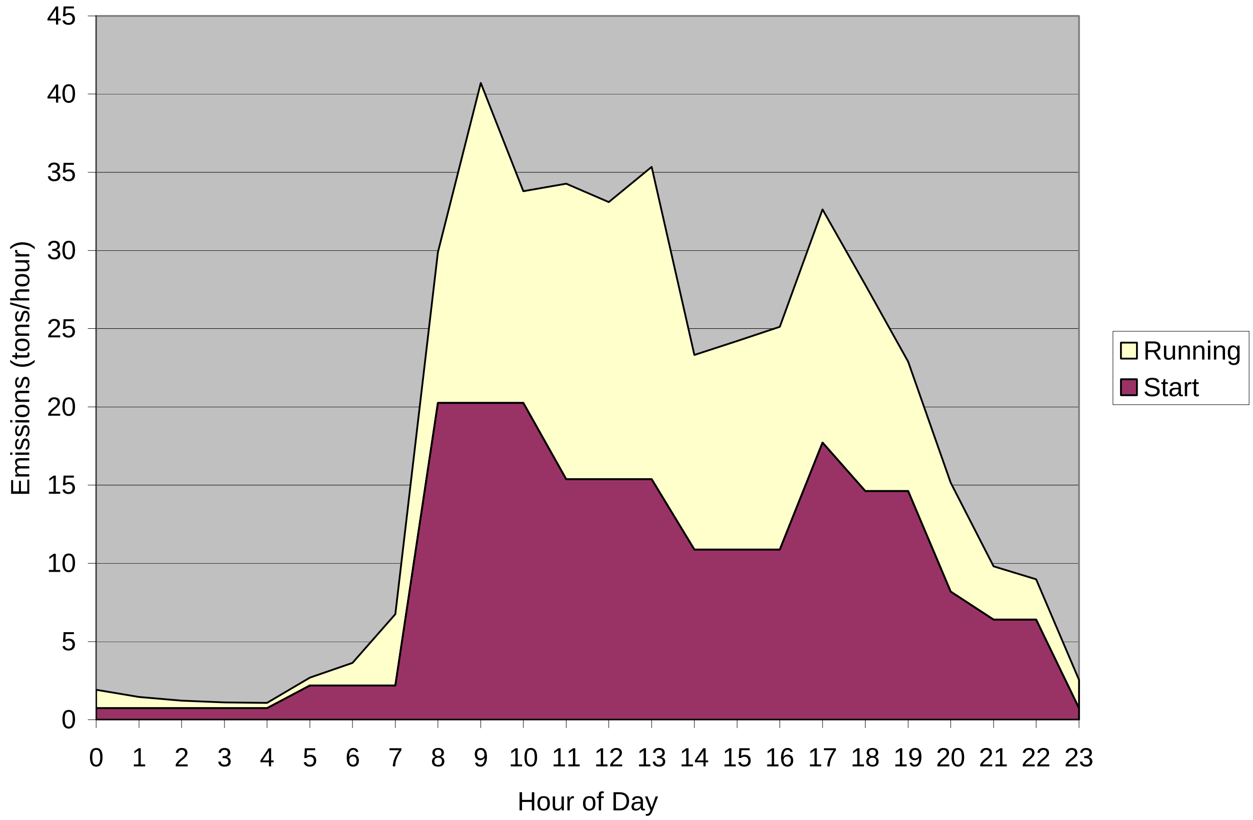

Figure V.1: Overall Pune Carbon Monoxide Emissions

The peak CO emissions are occurring between 08:00 and 12:00. The minimum during the day occurs around 15:00. Off course, emissions are very low from midnight to 05:00. It is also valuable to note the importance of start emissions in Pune. Most of the time, they represent more than half of vehicle emissions and this discounts any effects of engine stops at signal lights and in traffic jams. Overall, Figure V.1 reflects a total of 419 metric tons of CO emitted per day into the air over Pune or an overall daily average emission rate of 35 grams/kilometer traveled including starting and running emissions.

Figure V.2 shows the modeling results using the data developed or estimated from this study for volatile organic compounds (VOC) including evaporative emissions. The top line reflects start, running, and evaporative emissions added together.

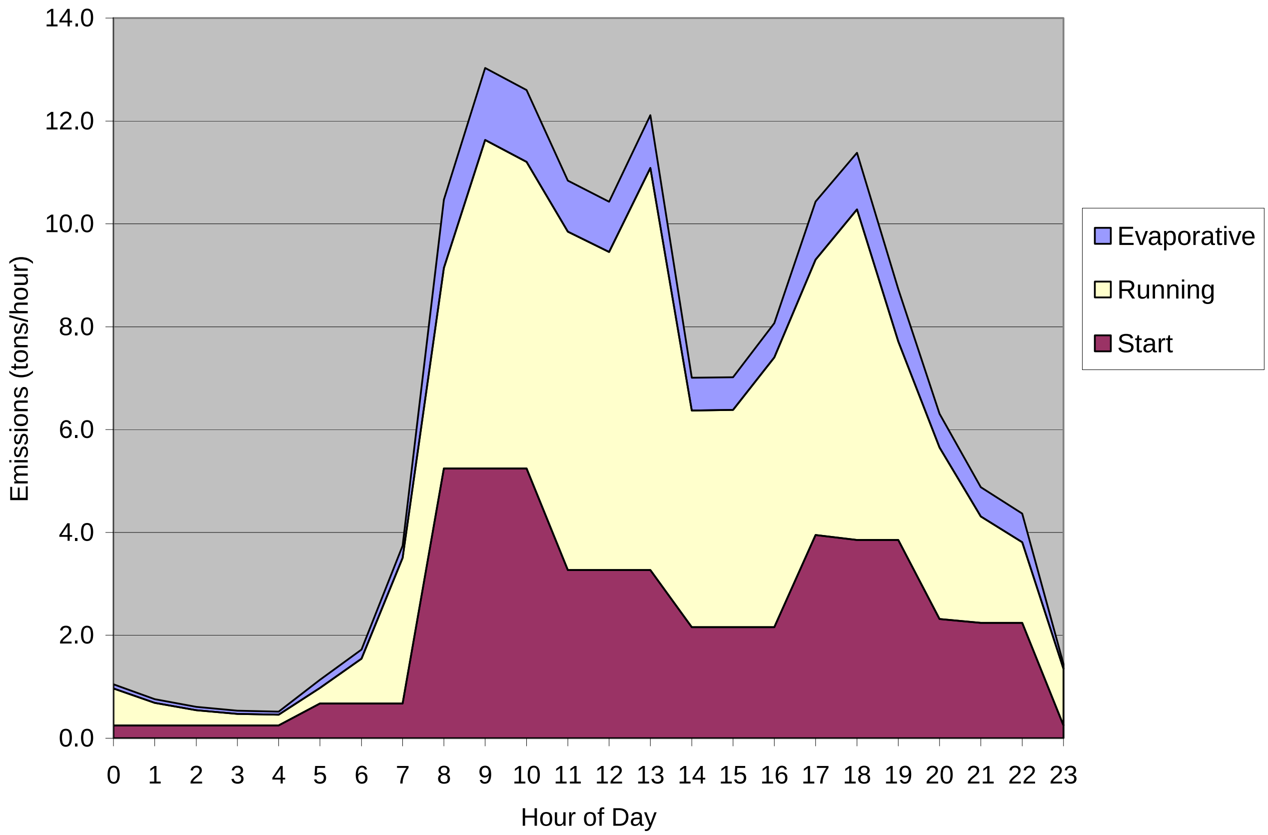

Figure V.2: Overall Pune Volatile Organic Emissions

The peak VOC emissions are occurring in the morning in Pune, which could facilitate ozone formation. Start emissions are not as great a percentage of emissions as is the case for CO, but they are still large. Evaporative emissions are important as well. Figure V.2 reflects a total of 134 metric tons per day of VOC emissions going into the air over Pune or an overall daily average emission rate of 11 grams/kilometer including starting, running, and evaporative emissions.

Figure V.3 shows the modeling results using the data developed or estimated from this study for Nitrogen Oxides (NOx). The top line reflects start and running emissions added together. Start emissions are much lower in this case although still large. As is the case for CO and VOC, the largest emissions are occurring in the morning. Figure V.3 reflects a total of 18 metric tons per day of NOx going into the air over Pune or an overall daily average emission rate of 1.5 grams/kilometer including starting and running emissions.

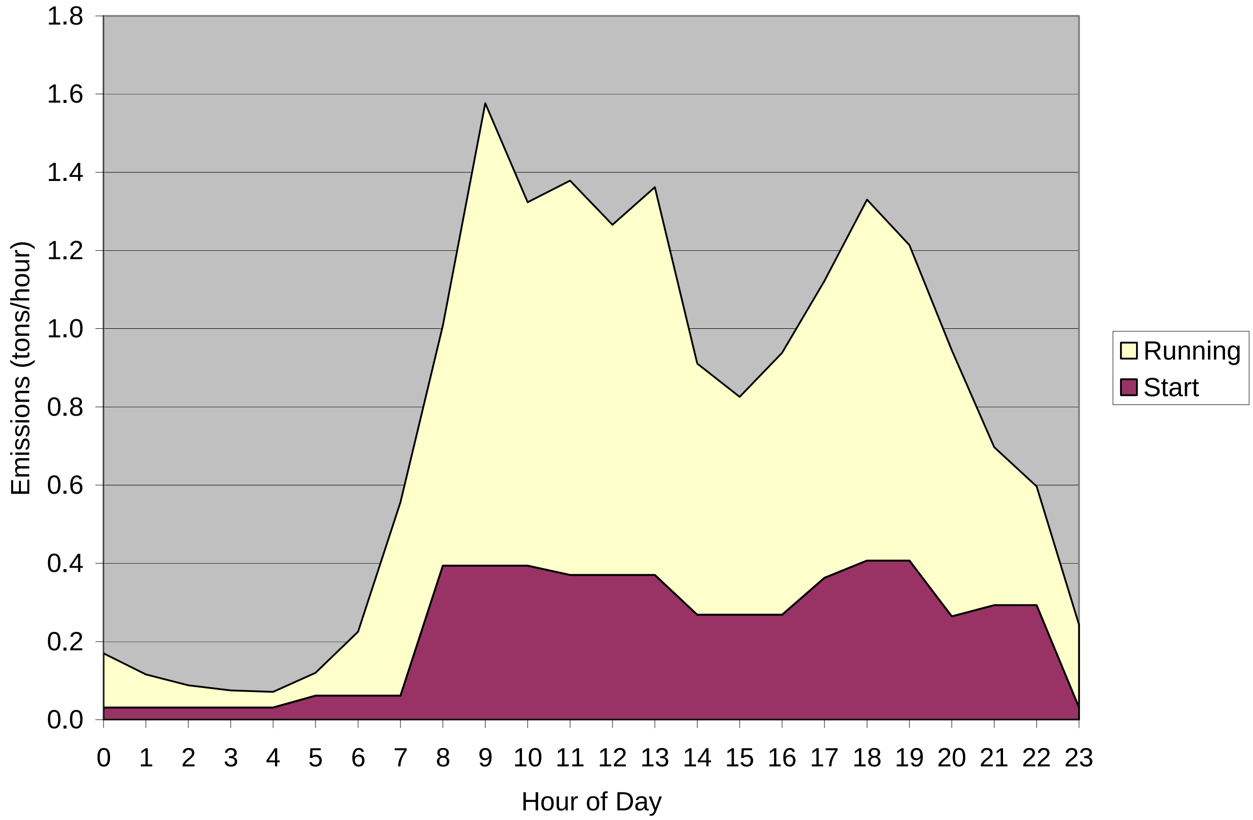

Figure V.3: Overall Pune Nitrogen Oxide Emissions

Figure V.4 shows the modeling results using the data developed or estimated from this study for Particulate Matter (PM). The top line reflects start and running emissions added together. Start emissions are much lower in this case although still large. As is the case for CO and VOC, the largest emissions are occurring in the morning. Figure V.4 reflects a total of 5 metric tons per day of NOx going into the air over Pune or an overall daily average emission rate of 0.4 grams/kilometer including starting and running emissions.

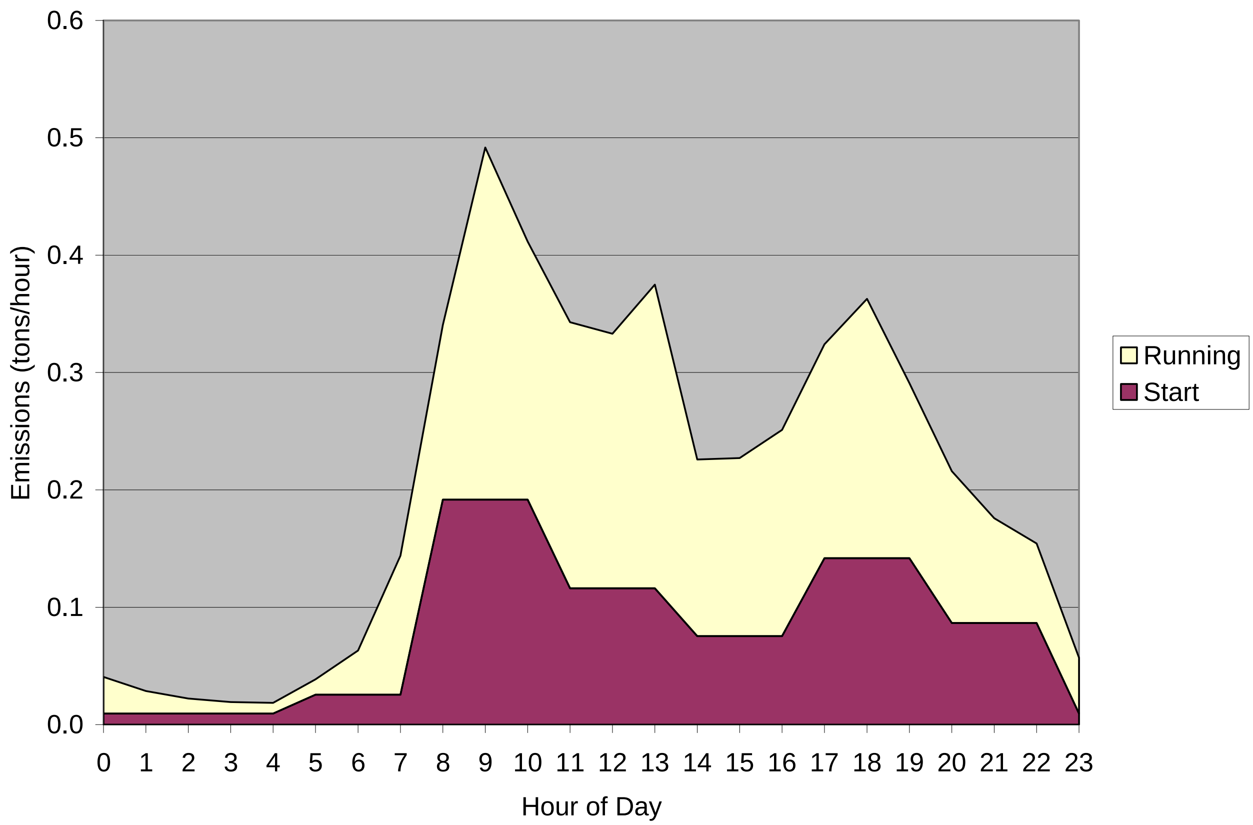

Figure V.4: Overall Pune Particulate Matter Emissions

Figures V.1-V.4 were calculated based on a total daily driving of 12,000,000 kilometers and a fleet of 750,000 vehicles. The emission numbers will of course have to be modified if the total kilometers per day measured in Pune are greater than 12,000,000 and/or if the number of vehicles actually operating daily in Pune are different from 750,000. Pune has also collected some hour by hour driving data for the full 24-hour period. This data should be used if believed to be reliable in place of the estimates used for this analysis.

To better understand the emissions created from the Pune vehicle fleet, it is useful to look at the contribution of each type of vehicle class. For Pune, the major vehicle categories include light duty passenger vehicles and trucks (LD), two wheeled passenger vehicles (2W), three wheeled taxis (3W), buses (Bus), and trucks (Truck). The fraction of travel from each of these types of vehicles is shown in Figure V.5. The percent contribution each of these vehicle types to vehicular CO, VOC, and NOx emissions is also shown in Figure V.5. These results indicate the majority of vehicular CO and VOC are from the 2 and 3 wheelers, while the majority of the NOx comes from Buses and light duty vehicles.

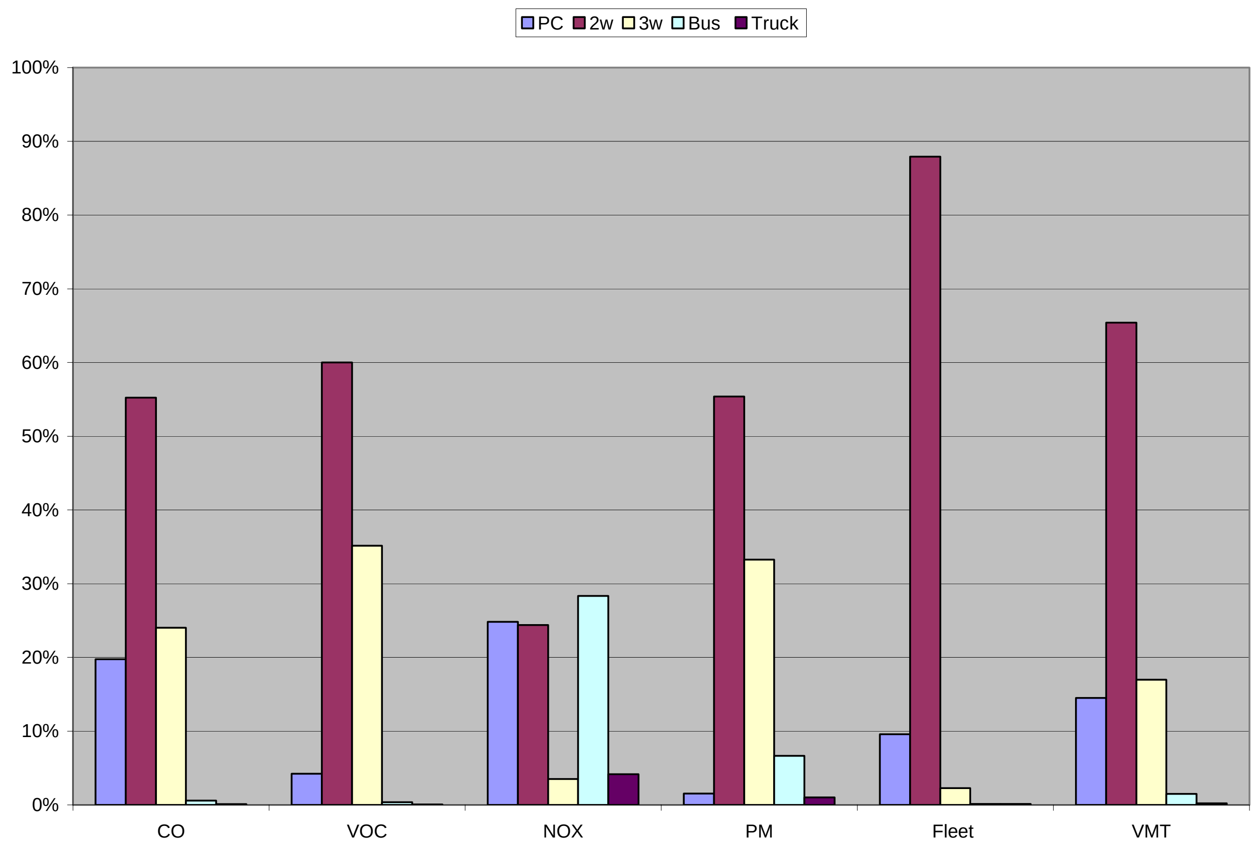

Figure V. 5 Emission Contribution of Each Vehicle Type in Pune

Clearly, to reduce CO and VOC emissions in Pune, 2-Wheel and 3-Wheel vehicles must be controlled. To reduce NOx, buses, trucks, and passenger vehicles must be further controlled.

Another calculation that is of interest is the overall per kilometer emissions of Pune vehicles compared to vehicle fleets in cities of other countries. Figure V.7 compares Pune with Los Angeles, Santiago, and Nairobi. It should be noted that the emissions shown in Figure V.7 and later in Figure V.8 include start and evaporative emissions that were prorated over the daily driving for all fleets shown.

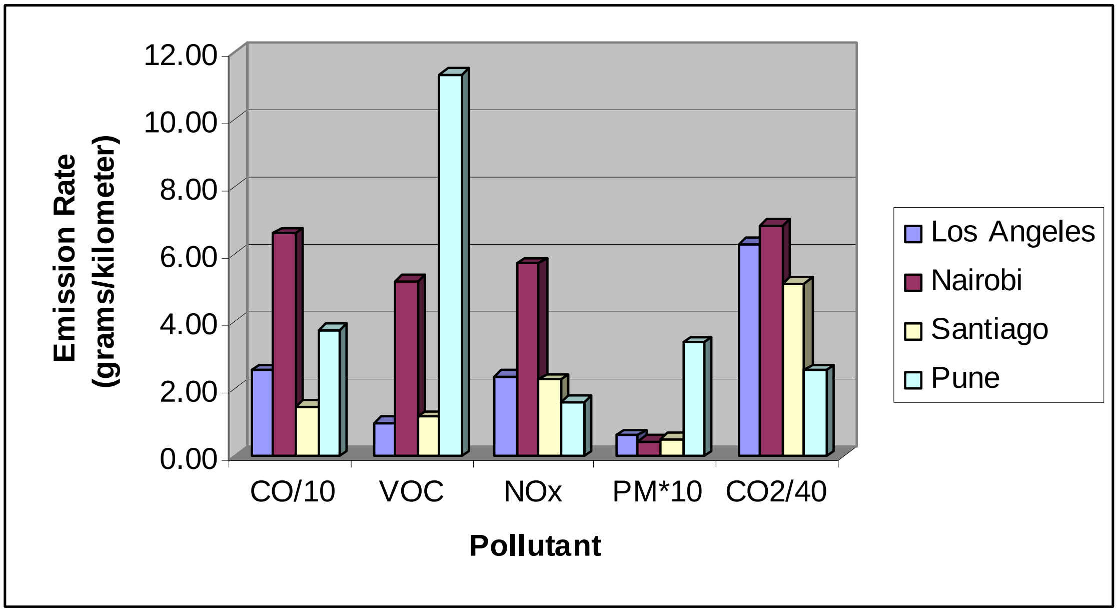

Figure V.7: Comparison of Daily Average Emissions in Countries Studied to Date

The Pune fleet has high emissions of CO, VOC, and Particulate Matter. It is a lower producer of NOx and CO_2. The high VOC emissions are particularly troubling because they suggest a commensurate high emission rate of toxics. Figure V.8 compares toxic emissions from the Pune fleet compared to other locations. As expected, the Pune fleet projects the highest toxic emission rates of the fleets studied to date with the exception of Benzene associated with the Nairobi fleet.

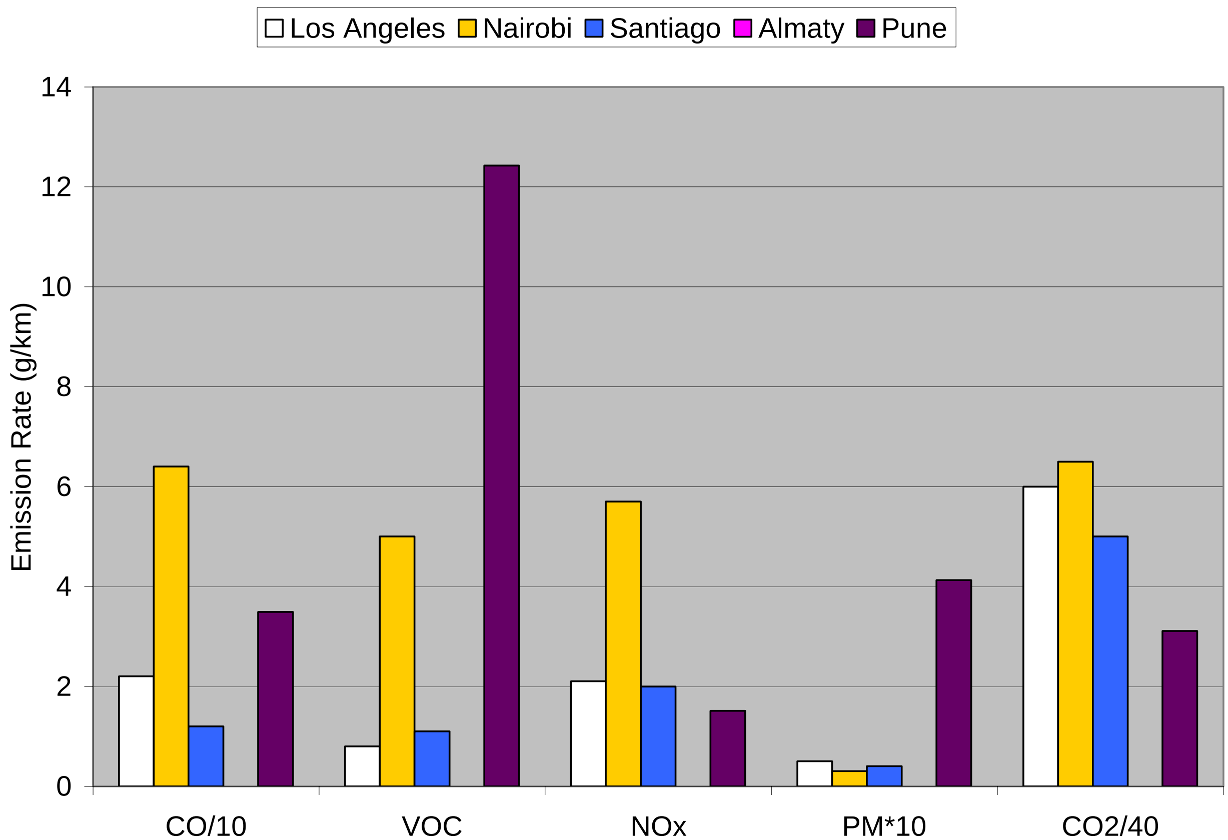

Figure V.8: Comparison of Daily Average Toxic Emissions in Countries Studied to Date

Some caution should be exercised in using the toxic emission data as shown in Figure V.8 due to the lack of information on toxic emissions from 2-Wheel and 3-Wheel vehicles. Much of the data used to make the estimates for toxics shown in Figure V.8 are based on studies of passenger vehicles due to the lack of data from 2-Wheel and 3-Wheel vehicles. However, these high emission rates clearly call for more studies concerning these toxic emission rates.

Figure V.9 provides a view of a possible future emissions scenario in Pune.

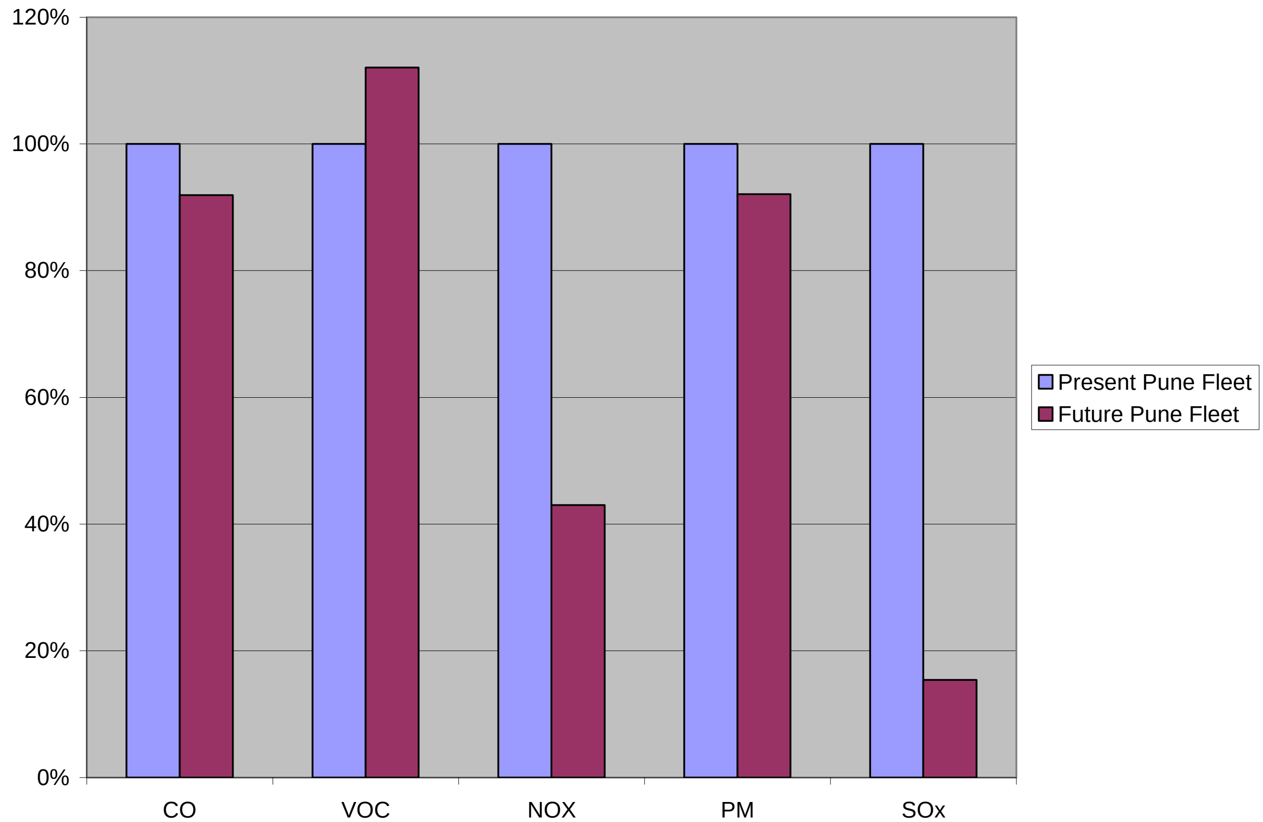

Figure V.9: Change In Emissions with an Improved Fleet in Pune

To create Figure V.9, it was assumed that a future vehicle fleet would meet Euro III standards and that future buses would be natural gas. This would, of course, require years to accomplish. It is also assumed that driving in Pune doubles during the time the fleet is being improved, and that low sulfur fuel and a loaded mode Inspection and Maintenance (I/M) program are put into place. The result is emission rates that are significantly lower than present US values. Figure V.9 is only intended to illustrate that significant improvement in local emissions can take place using today's modern vehicle technologies and improved fuel quality even with considerable growth in driving in Pune.

In conclusion, this study has developed basic data to allow for improved estimates of emissions from the Pune fleet. Additional studies are needed to further improve emission estimates in Pune, but significant planning activities can occur using the data in this report. Our recommendations are as follows:

1. Use the IVE model along with air quality measurements to map out a strategy for improved future air quality, and then seek to improve the air quality management process by further upgrading the Pune database.

2. Investigate the start emissions for very short engine stops (or soaks). The analyses presented here are based on the assumption that there are no cold start emissions associated with vehicle soaks of less than 4 minutes. Another way of stating this is that the emissions saved

by having the vehicle turned off for a few seconds to a few minutes offsets the added emissions associated with a hot start. Data is needed to verify this hypothesis.

3. Improve emission factors for in-use 2-Wheel and 3-Wheel vehicles. During the development of this report, some data was obtained from Thailand, which indicated higher emission rates, but not enough to justify changing the base emission factors in the IVE model. Emission estimates for 2-Wheel vehicles from Mobile 6 are much higher than those used in this analysis. However with respect to the US values, 2-Wheel vehicles are minor sources of emissions in the US and relatively little work has been done on this class of vehicles. More emission studies are needed to verify the operating emissions of 2-Wheel and 3-Wheel in-use vehicles in India to insure that the best emission factors are being used including evaporative emissions.

4. Improve the estimate of total VMT for Pune to support overall emission estimates.

5. Directly measure toxic emissions from 2-Wheel and 3-Wheel vehicles to better quantify the toxic emission rates from these sources.

Appendix A

Data Collection Program Used in Pune

International Vehicle
Emissions Model

Field Data Collection Activities

Table of Contents

I. Introduction

This paper provides a description of the activities involved in a 2-week cooperative on-road vehicle study carried out in selected international urban areas. This International Vehicle Emissions (IVE) study is designed to efficiently collect important vehicle related data to support development of an accurate estimate of on-road vehicular emissions for the selected urban area.

Emissions from on-road vehicles vary considerably depending upon three factors: 1) vehicle type, 2) driving behavior, and 3) local geographic and climatic conditions. Vehicle type is defined by the engine air/fuel management technology and engine size, emissions control technology, fuel type, accumulated use and age of the vehicle. Driving behavior can be described by a measured velocity profile of the local driving, the number and distribution of vehicle starts and daily miles traveled. Local conditions that affect vehicle emissions include road grade, fuel quality, ambient temperature, ambient humidity, and altitude of operation. Data collection in this study will help to define vehicle types and driving behavior in the urban area by collecting four types of information as indicted in Table I.1.

Table I.1 Types of Data Collection in the IVE Study

Data Collection	Method of Data Collection	Described in Section
On-Road Driving Patterns	GPS Instrumented Passenger, Bus, 2-Wheeler, and 3-Wheeler Vehicles	III
Vehicle Technology Distribution	Digital Video Collection and Parking Lot Surveillance	IV, V
Vehicle Counts on Selected Streets	Digital Video Collection	IV
Vehicle start-up patterns	VOCE units placed in recruited vehicles	VI

The collected data will be formatted so that it is usable in the new International Vehicle Emission Model developed for estimating criteria, toxic, and global warming pollutants from on-road vehicles. The collected data may also be useable for other purposes by the local urban area.

Local temperatures, humidity, fuel quality, total vehicular counts, and total driving amounts are not determined as a part of this study. Locally collected data is typically relied upon for these parameters. It may be possible to make a very rough approximation of total vehicle driving from the collected data if the number of vehicles in the urban area is known, but this approximation is subject to considerable error. To make an accurate emission analysis, the total amount of driving in an urban area must be assessed. If key data outside of the scope of this study is not available, then steps should be considered to determine this important data. CE-CERT will work with the urban area to suggest ways to make such assessments.

II. Collecting Representative Data

Before the specific study elements are described, it is important to consider the overall data collection process. The IVE study is carried out over a single 2-week study period. Given that there is limited equipment and study personnel, it is not possible to collect a complete data set over an entire urban area. Thus, the study must be designed to collect representative data that can be extrapolated to the full urban area. The IVE study process has been designed with this thought in mind.

On-road driving varies by the time of the day, by the day of the week, and by the location in an urban area. To account for this, during the IVE study, data is collected at different times of the day and in different locations within an urban area. This study is not designed to generally capture data on the weekend or very late at night. Thus, the study is primarily applicable to weekday driving and only limited weekend extrapolations and assumptions about traffic flow very late at night can be made. Conducting a weekend study will produce valuable information and should be considered for future research[2]. It should also be noted that the collected data could be improved in the future by replicating data collection activities to improve statistics, expanding the parts of the city studied, and expanding the times that are studied.

A. Selecting Parts of a City for Study

Three representative sections of the city are normally selected for the IVE study. The areas selected should represent the fleet makeup and the general driving taking place in the city. It is recommended that one of the study areas represent a generally lower income area of the city, one of the study areas represent a generally upper income area of the city, and one of the study areas represent a commercial area of the city. The sections representing the upper and lower income areas of the city for study should not be the absolute poorest or richest part of the city. It is better to select areas that are representative of the lower half of the income and the upper half of the income. Normally the urban center is selected as the best commercial area to study. **Due to their much greater knowledge of their own city, it is an important role of the local partners for an IVE study to play a primary role in the selection of the three appropriate parts of the urban area to study.** CE-CERT is amenable to modifications in the recommended study areas due to unique situations that might occur in a particular urban area. For example, there may not be a large enough discernable upper or lower income area.

The following criteria should be used as guidelines for selecting adequate sites:

- **Selection of a low income, upper income, and commercial area with a variety of streets (i.e. residential, freeway, and arterial) in the area.**

- **Accessibility to a representative parking lot or on-street parking where up to 150 parked vehicles can be studied within 10 minutes walking of each site selected.**

[2] In Los Angeles, some of the worst air pollution levels now occur on the weekend. This is due to the modified driving patterns and fleet mix that occurs on weekends compared to weekdays.

B. Selecting Driving Routes for Study

Within each of the study areas, different types of streets must be analyzed to gather data representative of all of urban streets. Streets are often classified into three general groupings. The first group represents streets that are major urban connectors and can connect one urban area to another. These streets are typically characterized by the highest traveling speed in free-flow traffic with minimal stops from cross-flow traffic and are commonly referred to as **highways** or **freeways** in some cases. The second classification of streets represents streets that connect sections of an urban area. They may connect one section of an urban area with another or may provide an important connection within a section of the urban area. These streets are typically referred to as **arterials**. The third classification of streets represents the streets that take people to their homes or small commercial sections of an urban area, and are usually one- or two-lane roadways with a relatively lower average speed and frequent intersections. These streets are typically referred to as **residential** streets.

Due to time limitations, only nine street-sections can be effectively studied during the IVE project. The term "street-section" as used in this study can include parts of more than one street, but to simplify data analysis, the streets that are included within a single street-section should all be the same street classification. For example, residential streets should not be mixed with highways in a single street-section. It is important that the nine selected street sections represent each of the important street types in the urban area.

The following criteria should be used as guidelines for selecting suitable street- sections:

- ♦ **For each of the street-sections, accessibility to a safe and legal location for the camera team to be dropped where 2 cameras & tripods can be set up with a clear view of the nearby traffic (tripods are approximately 0.5 meters in diameter). This location should be within approximately 5 minutes of the driving route. Preferably, the cameras will capture a portion of the driving trace[3] being covered by the chase vehicles.**

- ♦ **Access to the different street types in a part of the city so that the chase vehicle can move from one street-section type to another within 10 minutes driving time. This insures that time loss in moving from the highway street-section to the residential street section to the arterial street section and back does not require too much lost driving time.**

- ♦ **A driving trace for each street segment must be defined so that the driver can complete it in 50 minutes or less under the worst traffic conditions that will be encountered during the study.**

In the upper and lower income sections of the city, it is recommended that a highway street-section, an arterial street-section, and a residential street-section be selected in each of the two areas. In the commercial area it is recommended that a highway section and two arterial sections be selected for study. As noted earlier, the defined street-sections do not have to be the same street, although they should be the same classification of street for a street-section grouping. Figure II.1 shows an example of three street-segments designed for an upper-income area in Los Angeles, California.

---

[3] A driving trace is the route followed by the chase vehicles as they drive along one of the selected street-sections.

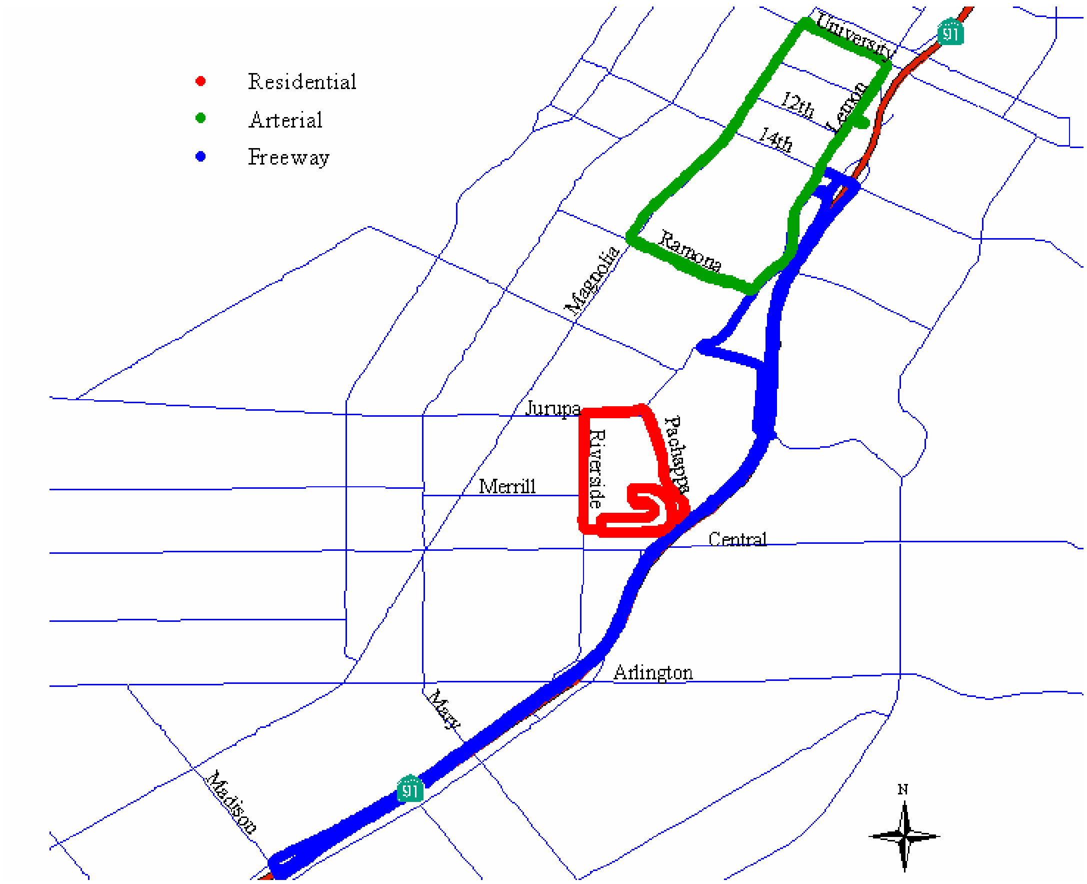

Figure II.1 Example of a Residential, Arterial, and Freeway Street-Segment Selected for a Single Study Area

Designing a set of interconnected arterials or residential streets that ultimately connect to one another to form a circular drive can provide an effective street-section for this study. This circular design is often not possible with highways and the driver may have to drive one way on a highway and then return on that same highway on the other side of the street. During less congested times, it is often possible that a driver can drive the designated street-section more than one time. This is not a problem and simply adds to the database during a time period. **As is the case with selecting general areas of the city to study, it is an important role of the local partners to select the nine streets to be studied.** CE-CERT will review the nine selected street sections and make recommendations as necessary.

C. Times of Data Collection

It is also important to collect data at different times of the day to account for traffic congestion and resulting changing flow rates as the day progresses. Testing is carried out normally over a 6 day period for the collection of urban driving patterns and vehicle technology data. Since driving in difficult traffic situations and collecting on-road vehicle technologies are typically very tiring and dirty activities, data collection is held to about 7 hours each day. Since information is typically needed from 06:00 to 20:00 to understand the complete cycle of traffic flow, the driving times are set for 7 hours in the morning on one day of data collection and 7 hours in the evening the next day of data collection. Data collection is normally started at 06:00 and continues until shortly before 13:00 for the morning data collection and starts at 13:00 and goes to shortly before 20:00 for the afternoon data collection. If special circumstances exist in an area where data is desired at earlier or later times, this should be discussed in advance of the study period.

D. Collecting Other Related Data

Parking lot data is collected in the same parts of the city where on-road driving and technology data are collected. It is desirable to capture vehicle technologies that exist down to 1% of the fleet. To increase the probability of seeing the types of vehicles that exist at the 1% level and to improve the accuracy of vehicle use data, it is important to collect data on more than 800 randomly selected parked vehicles over the 6-day study period. Generally, it is attempted to collect data on 300 vehicles in each of the three selected sections of the urban area; however, vehicle availability in lower income sections often reduce the total collected data to 800-850 vehicles in the overall study.

In the case of the collection of start-up data, individuals are asked to carry small data collection devices in their vehicles. **It is important that the individuals selected for this portion of the study should be representative of the general driving population.** It would be best to study at least 300 persons, but lack of time and equipment does not allow this large of a study. As discussed later in this paper, it is more efficient to collect data over more days from fewer persons. In all, it is hoped that more than 100 persons will use the units for at least 3 days per person to provide 300 person-days of information.

III. On-Road Driving Pattern Collection Using GPS Technology

Collection of on-road driving pattern data will be conducted on the streets identified by local agencies as discussed in Section II. This data collection will be conducted using combined Global Positioning Satellite (CGPS) modules with microprocessors developed by CE-CERT and GSSR. The unit is placed on a vehicle that drives on predetermined street sections with the flow of traffic. The CGPS module collects information about the location, speed, and altitude on a second by second basis.

For areas with large passenger vehicle, bus, 2-wheeler, and/or 3-wheeler populations it is important to collect independent driving pattern data for all of these vehicles since they will likely operate differently. Eight CGPS modules will be provided for the study: three for passenger vehicles, one for a 2-wheeler, and two each for buses and 3-wheelers. An additional two units are brought as backup units. The collection procedure for each type of vehicle is described later in this section.

Figure III.2 shows a typical CGPS unit. They weigh about 5.5 kilograms each and can be strapped to the back of a 2-wheeler or placed on the seat of a passenger vehicle. An antenna is required. In the case of 2-wheelers, 3-wheelers, and buses some experimentation may be required to fina a suitable location for the antenna. The antenna is magnetic and will stick to the roof of automobiles easily. In the case of buses with fiberglass roofs, 2-wheelers, and 3-wheelers tape or other attachment means may be necessary. The antenna may be taped to the top of the CGPS box, the bus roof, or may be attached to the helmet of the 2-wheeler operator.

Figure III.2 CGPS Unit

A. Driving Pattern Collection for Passenger Vehicles and 2-wheelers

To collect general passenger vehicle driving patterns, the local partners for the study must arrange for three passenger vehicles and local drivers to drive for eight hours each day for 6 days. In addition, one CGPS unit will be dedicated to the collection of 2-wheeler data[4]. The local study

[4] The decision to collect data from 2-wheelers and 3-wheelers is dependent upon the size fraction of these types of vehicles in the fleet. In the case of studies in the United States and Chile it was determined that 2-wheelers and 3-wheelers were too small of a portion of the fleets to justify the collection of driving pattern data for these vehicles.

partners should identify up to six 2-wheelers and drivers to participate in this study[5]. Figure III.1 shows a passenger vehicle equipped with a GPS module as used in Santiago, Chile. The CGPS units do not require an operator or laptop computer. Thus, only the driver is necessary.

Figure III.1: GPS Instrumented Vehicle in Santiago, Chile

These drivers are asked to operate their vehicles on the nine designated street-sections (see Section II for a discussion of street-sections) over the course of the study. The purpose of the instrumented vehicle is to collect representative data concerning local passenger vehicle driving patterns. To accomplish this the vehicle is operated on the selected street-sections in accordance with normal traffic at the time they operate. It is important that the drivers duplicate typical driving patterns for the study area. Each day, one of the instrumented vehicles is assigned to a different selected area of the city (see Section II for a discussion of the general test areas of the urban area). The vehicles will operate in their section of the urban area for two days before moving to the next selected area of the city. The first day they will operate their vehicles in the morning timeframe and the second day they will operate their vehicles in the afternoon timeframe. Each vehicle will operate on a selected street-section for 1 hour and then move to another of the selected street-section in a predetermined pattern. Since there are three street sections in an area, after the third section is reached, the driver will return to the first street section and repeat the process until the end of the 7-hour test period. Table III.1 shows the driving circuits for the three passenger vehicles and 2-wheeler. It is important that the drivers adhere strictly to the defined street-section order to insure that all times of the day are covered. The 3 parts of the urban area designated for study are denoted as Area A, Area B, and Area C. The 3 street-sections selected in each area are designated as street-section 1, 2, or 3. Thus the highway street-section in Area A is designated as Street-Section A.1 and similarly for the others.

[5] It should be okay to use as few as three 2-wheelers over the course of the study. It is important to get a cross section of 2-wheeler types that represent different engine sizes. The use of 6 2-wheelers will reduce driver fatigue during the course of the study. One 2-wheeler could operate each day through the 6-day study.

Table III.1 Passenger Vehicle and 2-Wheeler Driving Circuits

Start	End	Passenger Vehicle 1	Passenger Vehicle 2	Passenger Vehicle 3 & 2-wheeler
Day 1				
06:00	07:00	Street-Section A.1	Street-Section B.1	Street-Section C.1
07:00	08:00	Street-Section A.2	Street-Section B.2	Street-Section C.2
08:00	09:00	Street-Section A.3	Street-Section B.3	Street-Section C.3
09:00	10:00	Street-Section A.1	Street-Section B.1	Street-Section C.1
10:00	11:00	Street-Section A.2	Street-Section B.2	Street-Section C.2
11:00	12:00	Street-Section A.3	Street-Section B.3	Street-Section C.3
12:00	13:00	Street-Section A.1	Street-Section B.1	Street-Section C.1
Day 2				
13:00	14:00	Street-Section A.1	Street-Section B.1	Street-Section C.1
14:00	15:00	Street-Section A.2	Street-Section B.2	Street-Section C.2
15:00	16:00	Street-Section A.3	Street-Section B.3	Street-Section C.3
16:00	17:00	Street-Section A.1	Street-Section B.1	Street-Section C.1
17:00	18:00	Street-Section A.2	Street-Section B.2	Street-Section C.2
18:00	19:00	Street-Section A.3	Street-Section B.3	Street-Section C.3
19:00	20:00	Street-Section A.1	Street-Section B.1	Street-Section C.1
Day 3				
06:00	07:00	Street-Section B.2	Street-Section C.2	Street-Section A.2
07:00	08:00	Street-Section B.3	Street-Section C.3	Street-Section A.3
08:00	09:00	Street-Section B.1	Street-Section C.1	Street-Section A.1
09:00	10:00	Street-Section B.2	Street-Section C.2	Street-Section A.2
10:00	11:00	Street-Section B.3	Street-Section C.3	Street-Section A.3
11:00	12:00	Street-Section B.1	Street-Section C.1	Street-Section A.1
12:00	13:00	Street-Section B.2	Street-Section C.2	Street-Section A.2
Day 4				
13:00	14:00	Street-Section B.2	Street-Section C.2	Street-Section A.2
14:00	15:00	Street-Section B.3	Street-Section C.3	Street-Section A.3
15:00	16:00	Street-Section B.1	Street-Section C.1	Street-Section A.1
16:00	17:00	Street-Section B.2	Street-Section C.2	Street-Section A.2
17:00	18:00	Street-Section B.3	Street-Section C.3	Street-Section A.3
18:00	19:00	Street-Section B.1	Street-Section C.1	Street-Section A.1
19:00	20:00	Street-Section B.2	Street-Section C.2	Street-Section A.2
Day 5				
06:00	07:00	Street-Section C.3	Street-Section A.3	Street-Section B.3
07:00	08:00	Street-Section C.1	Street-Section A.1	Street-Section B.1
08:00	09:00	Street-Section C.2	Street-Section A.2	Street-Section B.2
09:00	10:00	Street-Section C.3	Street-Section A.3	Street-Section B.3
10:00	11:00	Street-Section C.1	Street-Section A.1	Street-Section B.1
11:00	12:00	Street-Section C.2	Street-Section A.2	Street-Section B.2
12:00	13:00	Street-Section C.3	Street-Section A.3	Street-Section B.3
Day 6				
13:00	14:00	Street-Section C.3	Street-Section A.3	Street-Section B.3
14:00	15:00	Street-Section C.1	Street-Section A.1	Street-Section B.1
15:00	16:00	Street-Section C.2	Street-Section A.2	Street-Section B.2
16:00	17:00	Street-Section C.3	Street-Section A.3	Street-Section B.3
17:00	18:00	Street-Section C.1	Street-Section A.1	Street-Section B.1
18:00	19:00	Street-Section C.2	Street-Section A.2	Street-Section B.2
19:00	20:00	Street-Section C.3	Street-Section A.3	Street-Section B.3

It is important that the passenger vehicle and 2-wheeler operators keep a record of the times when their driving should not be included in the analysis due to their taking a rest or leaving the study area. It is also important that the drivers note any unusual traffic conditions that would invalidate the data. Each driver is to be supplied with a writing tablet and pen in order to make records of unusual traffic situations. The CGPS unit will record information on where the driver operated the vehicle and how it was operated. Thus, data analysis will indicate if the proper driving routes were followed.

B. Measurement of Bus and 3-Wheeler Driving Patterns

In the case of 3-wheelers and buses, student participants will be asked to take passage on suitable buses and 3-wheeler vehicles operating on the street sections of interest. Four units are dedicated to this purpose. Two units will be used for 3-wheelers and two units will be used for buses[6].

<u>Care should be taken to select likely bus routes and 3-wheeler routes to be used before the study begins in order to avoid lost time once CE-CERT personnel reach the study area.</u>

[6] The reserve CGPS units could also be used if the local partners are willing to provide additional 2-wheelers or students to collect bus and 3-wheeler data. Of course, if a CGPS unit fails the reserve units will have to be moved to replace the failed unit.

IV. On-Road Vehicle Technology Identification Using Digital Video Cameras

Two digital video cameras are set up on the roadside or above the road to capture images of the vehicles driving by. This data is later manually reviewed to determine the number, size and type of vehicle. It is important to set the cameras at an appropriate height in order to have a good view of traffic on one side of a roadway. Useful data can be captured with the cameras located at the roadside, but on busy roads it is best to have the cameras elevated 1 to 3 meters above the street level when possible. Figure IV.1 shows videotaping in Santiago, Chile on a residential street. In this case due to the low traffic volume and small street size, videotaping could be carried out at street level. Figure IV.2 shows videotaping from an overpass of a freeway in Los Angeles, California. In this case due to the high traffic volume and the multiple lane roadway, data is best collected from directly above the street.

Data is collected on the same roads and at the same times when driving patterns are being collected. This allows driving speeds and patterns determined from the CGPS units (discussed earlier in this paper) to be correlated with traffic counts taken from the digital video cameras. Thus, selection of roadways, as discussed in Section II, should consider the video taping requirements as well.

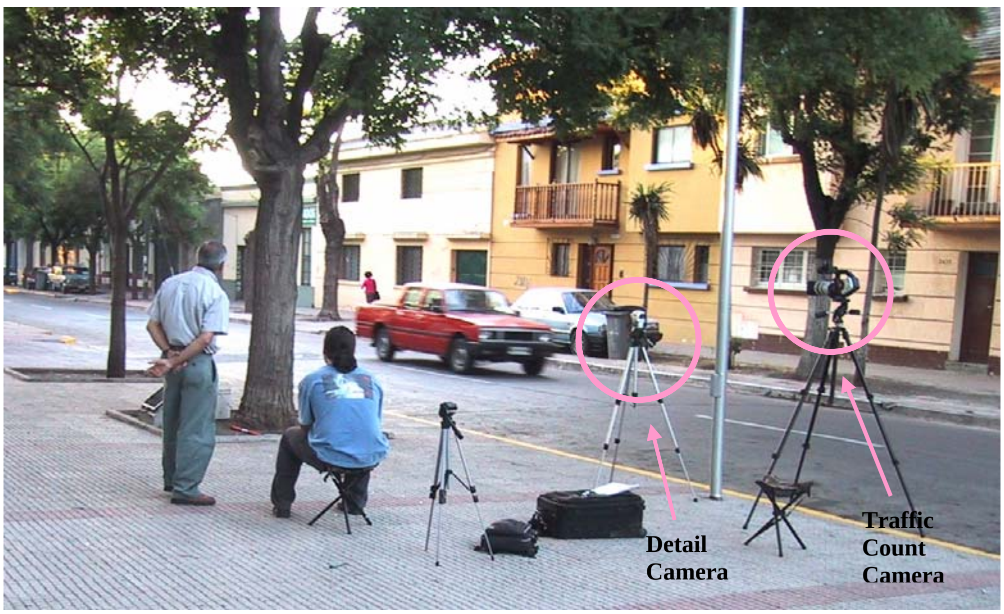

Figure IV.1 Cameras Collecting Data on a Residential Roadway in Santiago, Chile

Camera Setup on the Overpass

Picture of the Freeway Below

Figure IV.2 Camera Collecting Data from a Freeway Overpass in Los Angeles, California

The digital video cameras and the two operators usually travel with one of the instrumented vehicles to their desired location. Videotapes for analysis are collected for at least 20 minutes out of each hour and preferably for 40 minutes of each hour.

Local citizens passing the cameras often have questions and upon occasion, the police become concerned about the operation of the cameras. **It is important to provide a local person to explain the purpose of the data collection effort to avoid raising local concerns.** It should also be noted that working along side the street for up to 7 hours a day could expose the video taping crew to considerable dust and other pollutants. It is recommended that the camera operators have good quality dust masks for cases where the dust levels are high.

Each day about 3.5 hours of videotapes are collected. These videotapes are analyzed the following day by student workers and CE-CERT staff to develop the needed data for establishing on-road fleet fractions. CE-CERT will provide two videotape readers and laptop computers to support analysis of the data during the data collection process.

V. On-Road Vehicle Technology Identification Using Parked Vehicle Surveys

The on-road technology identification process using digital video cameras does not collect all of the information required to completely identify the vehicle. Therefore, it is important to supplement this data by visual inspection of parked vehicles using on-street and parking lot surveys. Figure V.1 shows data collection in a Nairobi parking lot. By use of an experienced mechanic recruited from the local area, model year distributions, odometer (distance traveled) data, air conditioning, engine air/fuel control, engine size, and emissions control technology can be estimated for the local fleet using this type of survey technique. Studies in Los Angeles indicate that the technology distributions found in parking lots and along the street closely mirror the on-road vehicle fleet.

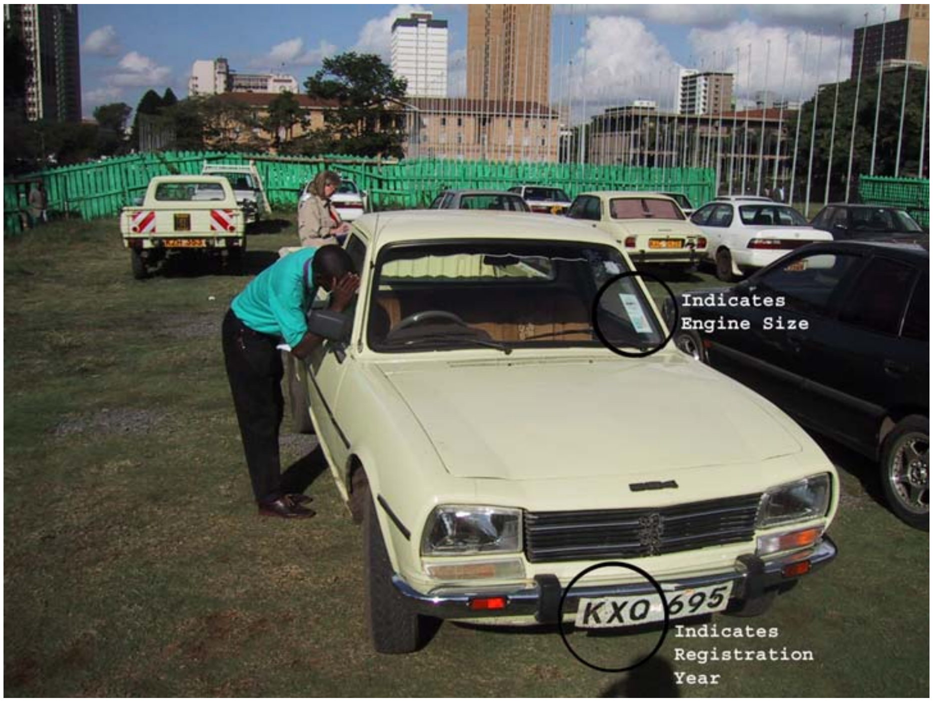

Figure V.1: Parking Lot Data Collection in Nairobi, Kenya

The determination of the needed data involves looking inside of parked vehicles. This process can alarm vehicle owners and the police upon occasion**. It is important that a local person participate in the parking lot survey that can explain the purpose of the study and resolve concerns of local law enforcement officials.**

Surveys are conducted in the same general areas where the vehicle driving patterns are collected. The parked vehicle survey team typically rides to their daily study area with the second instrumented vehicle (the first instrumented vehicle carries the on-road camera crew). The second instrumented vehicle leaves the parked vehicle survey team at a suitable location where sufficient numbers of parked vehicles can be found. This instrumented vehicle returns at the end of the study to pick up the surveyors.

As noted earlier it is desirable to collect data on more than 800 vehicles. Thus, the daily goal for the parking lot survey crew is 150 vehicles.

VI. Vehicle Start-Up Patterns by Monitoring Vehicle Voltage

As noted earlier, vehicles pollute more when they are first started compared to operations when they are fully warmed up. The colder the vehicle when started, the typically greater emissions. It is thus important to know how often vehicles are started in an urban area and how long a vehicle is off between starts to make an accurate estimate of start-up emissions. CE-CERT will bring 56 Vehicle Occupancy Characteristics Enumerator (VOCE) units to measure the times that vehicles are started and how often. These VOCE units will also give us information on how long vehicles are typically operated at different hours of the day. Figure VI.1 shows one of the units in a typical application. It is normally plugged into the cigarette lighter in the vehicle and left there for up to a week at a time, collecting data all the while.

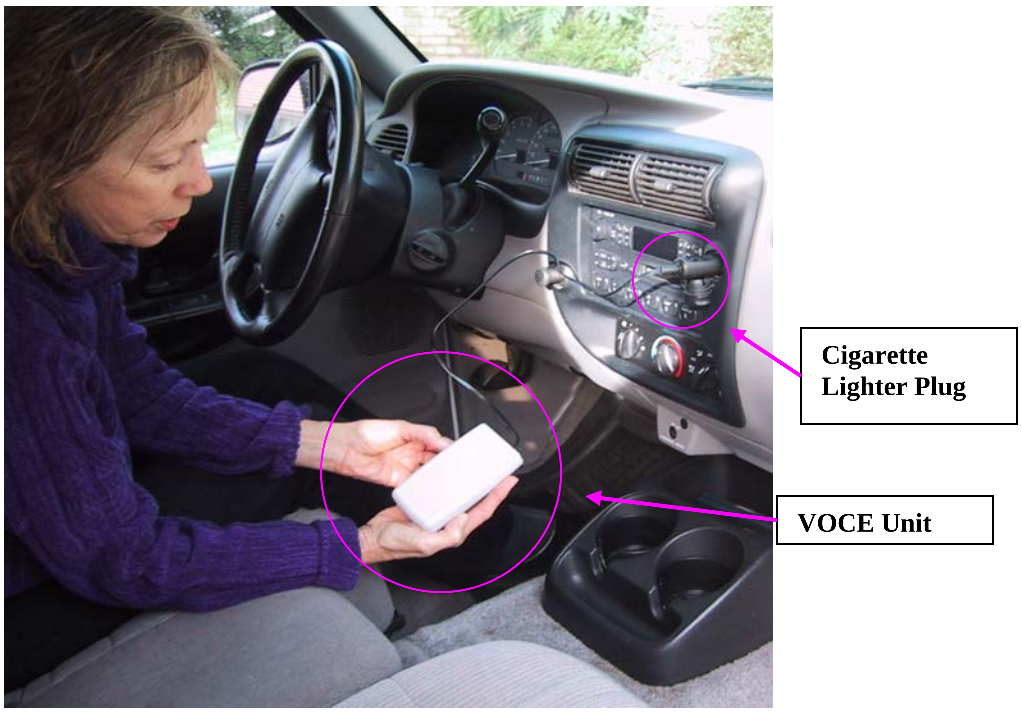

Figure VI.1 VOCE Unit for Collecting Vehicle Start Information

The VOCE units operate by simply recording vehicle voltage on a second by second basis. The voltage rises when the vehicle is operated. Software has been developed to download and interpret data from the units. In cases where there are no cigarette lighters, clamps are available to directly clamp the VOCE units to the vehicle battery or other suitable location to capture system voltage.

During the study, 50 of the VOCE units will be distributed to local vehicle owners and attached to their vehicles for four days. The units are then retrieved, the data downloaded, and given back out to 50 different vehicle owners for another four days. **To complete this part of the study, 100 participants must be identified by the local partners to use the units by the time the CE-CERT team reaches the location**. The VOCE units are distributed within the first 24 hours after arrival of the CE-CERT team. At the end of 4 days, the units are retrieved, the data downloaded over night, and the units re-distributed the next day for another 4 days. This will give us 400 person days of information. In some cases when a weekend intervenes, the units are left for more than four days with the vehicle owners and weekend data is collected. The VOCE units are capable of operating and collecting data for more than a week if necessary. There will be 6 extra VOCE units that can be used to replace units if they become faulty.

In past studies, the vehicle owners have installed the units themselves since they normally only have to be plugged into the vehicles cigarette lighter and left there for the four days of data collection. In cases where the vehicle does not have a cigarette lighter, CE-CERT personnel and local partners may have to help the vehicle owner to install the unit. **It is important that none of the VOCE units are lost because they are each hand built and can not be easily replaced.**

To complete this part of the operation, one local person is normally required to spend most of their time during the testing program to first identify 100 participants in advance and then to give out and retrieve the units. Vehicle owners often forget to bring the VOCE units back when they are supposed to or have a problem that keeps them from coming to work to return the units. Thus, while simple in concept, identification, deployment and retrieval of 50 units in the proper timeframe can be a complicated and tedious process. **Finally, in selecting vehicle owners to use the VOCE units it is import to select persons that represent a cross section of drivers in the urban area of interest**.

VII. Research Coordination and Local Support Needs

In order to properly carry out the data collection and processing outlined in this paper, both CE-CERT and local support are needed. CE-CERT will provide 5 persons to work on the project. It is requested that the local partners supply 17-23 persons. 7-14 of these people can be students. Table IV.1 below outlines the needed CE-CERT and local support requirements.

Table IV.1 Study Support Requirements

CE-CERT Support	Local Support - Staff	Local Support - Student
Prior to Start of the Test		
Obtain needed Visas, test and pack equipment, review streets selected by local partners.	Obtain permission to bring test equipment into the country. Identify 100 persons to participate in vehicle start pattern data collection. Identify road sections for vehicle technology and driving pattern measurement. Identify support staff including students, mechanics, motorcycle owners, and chase vehicles and drivers.	
On-Road Driving Patterns		
Researcher A: Provide training in use of GPS in chase car situations. Support data analysis as data is collected.	3 local drivers with vehicle to collect on-road passenger car driving patterns	1 student to support data analysis process.
Researcher B: Provide training in use of GPS on 2-Wheeler, 3-Wheeler, and Buses. Support data analysis as data is collected.	3-6 motorcycle operators for one or two days each (could be students).	3-4 students to ride in 3-Wheeler and Bus to collect driving pattern data.
On-Road Vehicle Technology Identification		
Researcher C: Setup and operate video camera and help determine best locations for videotaping.	1 person to help setup equipment and answer questions of local citizens and police.	
Researcher D: Support tape analysis and data entry as video data is collected.		2 students to review tapes and record technology information.
Parking Lot Technology Surveys		
Researcher D: Provide training on parking lot surveys. Support data analysis as data is collected.	1-2 expert vehicle mechanics to support identification of model year and engine technology	
Researcher A/E: Support data entry and analysis process.	1 person to answer questions and get permission to collect data in parking lots and on the street.	1 student to support entry of data into the computer and early analysis of data.
Vehicle Start Pattern Measurement		
Researcher E: Support distribution and retrieval of VOCE units and down loading data.	1-2 persons to identify 100 vehicle owners to use VOCE units in advance of start of study and to support distribution and retrieval of the VOCE units.	
Researcher B/D: Support data analysis.		
Total Personnel Requirements		
5 CE-CERT personnel	10-15 persons to support field operations	7-8 students to support data review and entry.

As noted earlier, the typical daily schedule is from about 06:00 to 13:00 on 3 of the 6 data collection days and 13:00 to 20:00 on 3 of the 6 data collection days. The students involved in data analysis will be requested to work each day after fieldwork is conducted. A specific test schedule will be supplied for each location based on the dates of arrival of the CE-CERT team members and intervening weekends.

Table IV.2 below provides a checklist of equipment being brought into the country. **The local partner must make arrangements with customs so that this equipment can be easily brought into and out of the country.**

Table IV.2: List of Equipment Brought Into and Out of the Country

Equipment	Use	Number
GPS Speed, Altitude, and Location Measurement Device	To measure traffic patterns of vehicles operating on urban streets.	10 units
VOCE Start-Up and Driving-Time monitor	To measure the typical times vehicles are started and operated in the urban area.	56 units
Portable Computer	To record data and carry out data analysis processes.	5 units
Portable Printer	To print out reports	1 unit
Video Camera	To record vehicle activity on selected streets.	2 units
Video Tape Reader	To read tapes and display pictures on computer screens.	2 units
Commercial GPS Device	To check operation of the main GPS testing units.	1 unit
Soldering Iron	To repair equipment as needed.	1 unit
Electrical Meter	To check and repair equipment as needed	1 unit
Commercial AA batteries	For use in the VOCE units	200 units

If you have questions about the study please contact:

James M. Lents
1-909-781-5742
jlents@cert.ucr.edu
or
Nicole Davis
1-909-781-5795
ndavis@cert.ucr.edu

Work Schedule for Pune India

March 2,2003	March 3, 2003	March 4, 2003	March 5, 2003	March 6, 2003	March 7, 2003	March 8, 2003
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
					Depart Los Angeles for Mumbai, India	Arrive Mumbai, India at 23:35 and spend the night in Mumbai.
March 9, 2003	**March 10, 2003**	**March 11, 2003**	**March 12, 2003**	**March 13, 2003**	**March 14, 2003**	**March 15, 2003**
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Picked up by van at 12:30 and transported from Mumbai to Pune	Meet with Pune study group at about 10:00 to discuss study and use of equipment. VOCE units distributed to first 50 participants.	1st day of on-road testing, video taping, and parking lot surveys.	2nd day of on-road testing, video taping, and parking lot surveys. Begin processing collected data.	3rd day of on-road testing, video taping, and parking lot surveys. Process collected data.	4th day of on-road testing, video taping, and parking lot surveys. Process collected data.	
March 16, 2003	**March 17, 2003**	**March 18, 2003**	**March 19, 2003**	**March 20, 2003**	**March 21, 2003**	**March 22, 2003**
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
	No field data collection or processing. First 50 VOCE Units collected. Data downloaded in the evening.	5th day of on-road testing, video taping, and parking lot surveys. VOCE Units distributed to 2nd 50 participants as early in day as possible. Process collected data.	6th day of on-road testing, video taping, and parking lot surveys. Process collected data.	Process collected data.	2nd 50 VOCE units collected and data downloaded. Meet at about 10:00 to review data collected and preliminary results of the study. Depart by van for airport in Mumbai at about 5PM.	Depart Mumbai at 01:05 Saturday morning.

Work Schedule for Almaty, Kazakhstan

March 30,2003	March 31, 2003	April 1, 2003	April 2, 2003	April 3, 2003	April 4, 2003	April 5, 2003
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Depart Los Angeles for Almaty, Kazakhstan	Arrive Almaty, Kazakhstan late evening.	Meet with Almaty study group at about 14:00 to discuss study and use of equipment. VOCE units distributed to first 50 participants	1st day of on-road testing, videotaping, and parking lot surveys.	2nd day of on-road testing, videotaping, and parking lot surveys. Begin processing collected data.	3rd day of on-road testing, videotaping, and parking lot surveys. Process collected data.	
April 6, 2003	**April 7, 2003**	**April 8, 2003**	**April 9, 2003**	**April 10, 2003**	**April 11, 2003**	**April 12, 2003**
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
	No field data collection or processing. First 50 VOCE Units collected. Data downloaded in the evening.	4th day of on-road testing, videotaping, and parking lot surveys. VOCE Units distributed to 2nd 50 participants as early in day as possible. Process collected data.	5th day of on-road testing, videotaping, and parking lot surveys. Process collected data.	6th day of on-road testing, videotaping, and parking lot surveys. Process collected data.	Process collected data. 2nd 50 VOCE Units collected in the afternoon and data downloaded.	Meet at about 14:00 to review data collected and preliminary results of the study.
April 13, 2003	**April 14, 2003**	**April 15, 2003**	**April 16, 2003**	**April 17, 2003**	**April 18, 2003**	**April 19, 2003**
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
Depart from Almaty, Kazakhstan for Los Angeles in very early morning.						