Shanghai Vehicle Activity Study

Conducted June 6 - 18, 2004
April, 2005

Cheng Huang, the_light@sohu.com
East China Unversity of Science and Technology (http://www.ecust.edu.cn)
130 Meilong Rd., Shanghai 200237, P.R.China
Hansheng Pan, panhs@pku.org.cn
Shanghai Academy of Environmental Sciences (http://www.saes.sh.cn)
508 Qinzhou Rd.,Shanghai 200233, P.R.China
James Lents, jlents@issrc.org
Nicole Davis, ndavis@issrc.org
International Sustainable Systems Research (http://www.issrc.org)
21573 Ambushers St., Diamond Bar, CA 91765, USA
Mauricio Osses, maosses@ing.uchile.cl
University of Chile (http://www.uchile.cl)
Department of Mechanical Engineering, Casilla 2777, Santiago, Chile
Nick Nikkila, mail@gssr.net
Global Sustainable Systems Research (http://www.gssr.net/)
7146 Aloe Court, Rancho Cucamonga, CA 91739, USA

Table of Contents

EXECUTIVE SUMMARY

Shanghai, China was visited from June 6, 2004 to June 18, 2004 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 Shanghai 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 Chinese cities to support environmental improvement efforts in the other cities as well. The data collection effort was a partnership between Shanghai local and regional governments, Shanghai Academy of Environmental Sciences, non-government officials, and the International Sustainable Systems Research Center (ISSRC) in cooperation with the University of California at Riverside (UCR). Energy Foundation and International Sustainable Systems Research Center (ISSRC) provided technical and financial support. In all, more than thirty persons participated in data collection activities over an approximate two week period.

The study collected three types of information on vehicles operating on Shanghai streets: technology distribution, driving patterns, and start patterns. Each area is summarized below.

Vehicle Technology Distribution

Objective:
To develop a representative distribution of vehicle types, sizes, and ages of the operating fleet in the Shanghai area on various roadway types.

Methodology:
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 Shanghai streets. Simultaneous with this data collection process, parking areas were surveyed to collect specific technology information about vehicles operating in Shanghai.

Results:
The observed vehicle class fraction for the city overall, weighting various roadways and portions of the city is shown in Table 1. Significant variation between the vehicle class fractions on different roadway types and different portions of the city are observed. For example, the fraction of passenger vehicles observed on arterials is 44% compared to 33% on residential roadways. Additionally, the percentage of passenger cars in the on-road fleet in the northwest of Shanghai city (section A) is approximately 39% and in Shanghai city center (section B) it is 46%.

Table 1. Observed Vehicle Class Distributions in Shanghai, China

Type of Vehicle	Observed Travel, 2004
Passenger Car	37%
Taxi	19%
Motorcycle	4%
Moped	21%
Bus	8%
Truck	11%
Total	100%

In addition to observing the class distribution, a separate survey was conducted to determine the emissions control technology and engine type of the passenger fleet. Only 6% of the gasoline passenger vehicles have no catalyst, and approximately 94% have three way catalysts. The majority of passenger vehicles on the road are gasoline multi-point fuel injected vehicles.

Vehicle Driving Patterns

Objectives:
To collect second-by-second information on the speed and acceleration of the main types of vehicles operating in Shanghai on a representative set of roadways throughout the day.

Methodology:
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 measurements of vehicle speeds and altitude. GPS units were carried on nine selected routes. Data was collected from 07:00 to 21:00 to provide driving pattern information for different hours of the day.

Results:
Driving pattern data was successfully collected over 6 days from a number of passenger vehicles, taxis, buses and delivery trucks. Overall, except for passenger cars on highways, various road types and vehicle types have similar average velocities. Velocities of taxis and buses were higher than the passenger vehicles on arterials, which had the lowest velocity of all the vehicle types. The highest speeds occurred during the very early morning hours and the middle of the day, the lowest velocities occurred in the morning and afternoon. Mopeds always drive on the bicycle lanes in Shanghai, however driving patterns were not surveyed on mopeds. Buses and taxis have similar average speeds to passenger vehicles traveling on arterial and residential roadways. Taxis and passenger vehicles operating on the highway during the middle of the day and evening exhibit the highest occurrences of hard accelerations, due to congestion and high target velocities.

Vehicle Start Patterns

Objective:
To collect a representative sample of the number, time of day, and soak period from passenger vehicles operating in Shanghai.

Methodology:

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 VOCE units were placed in passenger vehicles and left there for a period of a week.

Results:
A total of sixty-eight passenger vehicles were equipped and used in the start survey over approximately six days each. Data was successfully processed for forty-nine of these vehicles for a total of 280 days of starting data. The results show that on average a typical passenger car is started 5.2 times per day. Approximately 20% of the starts occur between 6 am and 9 am, and another 20% occur between 3 pm and 6 pm. The second highest 19% occur between 9 pm to 12 pm. In the early morning hours, over half of the starts occur after having soaked over 12 hours. These long soaks leave the engine cold, which results in increased starting emissions.

Conclusions

The three types of data collected in this study have been used to compile a comprehensive analysis of the make-up and behavior of the current on-road mobile fleet in Shanghai. This data is pertinent for correctly estimating current mobile source emissions and projecting the impact of proposed control strategies and growth scenarios, because the vehicle type, speed profiles, and the number of starts and the soak period have a large impact on the mobile source emissions inventory.

The data collected in this study was formatted to allow vehicle emissions estimates using the International Vehicle Emissions Model (http://www.issrc.org/ive or www.gssr.net/ive). The IVE model was developed with USEPA funding to make emissions estimates under different technology and driving situations as found in various countries, and has been used extensively in several developing countries. Although up-to date vehicles activity and fleet information was collected in this study, no emissions measurements were made. All emission estimates have been calculated using the IVE model's default emission rates. Shanghai specific emissions will be updated in the near future throughout on-road emission testing for in-use vehicles in Shanghai.

Overall, the results of this study have shown that driving in Shanghai is similar to other developing urban areas with some subtle but important differences. Of all the areas observed to date, Shanghai has the lowest percentage of passenger vehicles and the highest percentage of buses and trucks and a very large fraction of mopeds. The average age of the passenger fleet in Shanghai is quite low and average mileage accumulation also varies widely from city to city in the countries studied to date. Shanghai's relatively new passenger fleet is comprised of 6% non-catalyst vehicles, compared to 1% in the US; 20-30% in Mexico City, Santiago, and Pune; 90-100% in Almaty and Nairobi and 10% in Beijing.

A preliminary emissions analysis using the IVE model indicates that on the order of 3.5 metric tons of PM, 185 tons of NOx, 82.3 tons of VOC, and 965 tons/day of CO are emitted from on-road motor vehicles each day in Shanghai. By viewing the contribution of various vehicle types to the inventory, it was determined that to reduce PM, NOx and toxic emissions in Shanghai, buses and trucks must be controlled. Shanghai currently has the second and third highest emission rate respectively for PM and NOx on a per vehicle mile basis in comparing the fleets of Los Angeles, Nairobi, Santiago, Pune, Mexico City and Beijing, largely due to the lack of control technology on the trucks and buses operating in the area. The passenger vehicle emission rates per distance traveled on arterials and residential roads are much higher than on highways due primarily to changes in driving patterns from increased congestion.

It must be noted that the emissions analysis is subject to the appropriateness of the emission rates used in the IVE model. While the emission rates in the IVE model were designed to be loosely representative of emission rates worldwide, it will improve the accuracy of the estimate when specific emission rates from Shanghai. At the time of this report, no on-road emission rates existed for the current fleet in Shanghai. However, emission testing is being conducted in the Fall of 2004 and the test results will be used to update the emission rates used for this analysis at that time.

Several recommendations for additional study include conducting additional technology surveys to improve the specific technology and fuel type distribution of the Shanghai truck and moped fleet, , collecting driving pattern information on mopeds operating in the bicycle lanes and trucks operating during the evening hours, improving the emission factor database through the collection of on-board emissions testing of the Shanghai fleet, and improving the estimate of the overall daily vehicular travel (VKT) in Shanghai. Some of the recommendations listed here are already in process. Using the tools outlined in this report, it is recommended that a strategy for improving future air quality be developed. However, caution should be taken if the data collected in this study is to be extrapolated to suburban areas outside of Shanghai or other urban areas within China. In this study it was found that there are significant differences in the fleet and activity in Beijing and Shanghai, and it is known that the urbanized fleet is very different from the suburban areas. If this data is to be used for a regional emissions estimate, it is recommended that at least cursory data collection on the fleet and activity be collected throughout the area.

I. INTRODUCTION

The vehicle activity study conducted in Shanghai, China, was from June 6, 2004 to June 18, 2004. During this time, in cooperation with local academies and government officials, three types of information sets were collected. Subsequently, this data was processed into a format which can be used in the IVE model. There are four sections in this paper: the activity data, the collection process, comparisons with the studies in other regions, and emission results from the IVE model. The data collected in this field study has three purposes:

- To estimate the technology distribution of vehicles operating on Shanghai streets.
- To measure driving patterns for the various classes of vehicles operating on Shanghai streets.
- To estimate the times and numbers of vehicle engine startups for the various classes of vehicles operating on Shanghai 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 videotapes were reviewed to count the numbers of the various types of vehicles plying Shanghai streets. Simultaneous with this data collection process, parking areas were surveyed to collect specific technology information about vehicles operating in Shanghai.

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 measurements 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 21:00 to provide driving pattern information for different hours 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 (IVE) Model (http://www.issrc.org/ive or 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.

Each process and results are described in detail in the next sections.

II. VEHICLE TECHNOLOGY DISTRIBUTION

II.A. BACKGROUND AND OBJECTIVES

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. 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 correct estimate of the vehicular contribution to air emissions is made by determining the <u>operating</u> fraction of the various vehicle technology classes rather than the <u>static</u> distribution of vehicles registered in the region of interest.

The objective of this portion of the study is to determine the on-road fraction of each vehicle type operating in different areas within Shanghai. This requires information on both the fraction of vehicles in each class (passenger vehicles, taxis, mopeds, buses, or trucks) and the technology distribution within each class (engine size, vehicle age, and emissions control technology). To collect information on the former piece of data, video road surveys are conducted to identify the fraction of travel in each vehicle class. For the latter, parking lot surveys are conducted to determine the types of technologies within each vehicle class. The video survey allows a continuous picture of all lanes of a roadway where an accurate count of each class of vehicle can be conducted. The parking lot surveys allows for individual inspection of each vehicle to determine the odometer reading, engine size, drive train, control technology and model year. This data can then be combined to get an overall fleet travel distribution for each area in Shanghai.

II.B. METHODOLOGY

In order to insure that the most representative data is collected, both video-traffic and parked vehicle surveys were carried out from 07:00 in the morning to 21:00 in the evening over 6 days in three representative sections of the urban area. On-road video surveys were carried out on three specific types of roadways: a residential street, an arterial roadway, and a highway in each of the three sections to determine the fraction of travel of each vehicle class. The video surveys were conducted by setting up video cameras along the sides of the road or on the overpass and traffic movement taped. Figure II.1 illustrates this process on a freeway on the Outer Ring road in Shanghai, China.

Figure II.1: Video Taping Road Traffic in Shanghai, China

Parked vehicle surveys were conducted in each of the three regions as well to determine specific technology distribution in each vehicle class. For passenger vehicles and mopeds, public parking lots such as malls, grocery stores, and fueling stations were surveyed. For trucks, taxis, and buses, taxi stops, bus stops, and truck stops were surveyed in each of the three areas. Figure II.2 shows the three different areas where both parking lot and video taping activities were conducted. The red lines indicate highway roads; the blue lines indicate arterial roads; the green lines indicate residential roads; and the stars indicate the locations of video taping. Section A covers Pu Tuo district, which is one of the relative low income areas in Shanghai; Section B (Huang Pu district) indicates the commercial area and section C (Xu Hui districts) indicates a high income district.

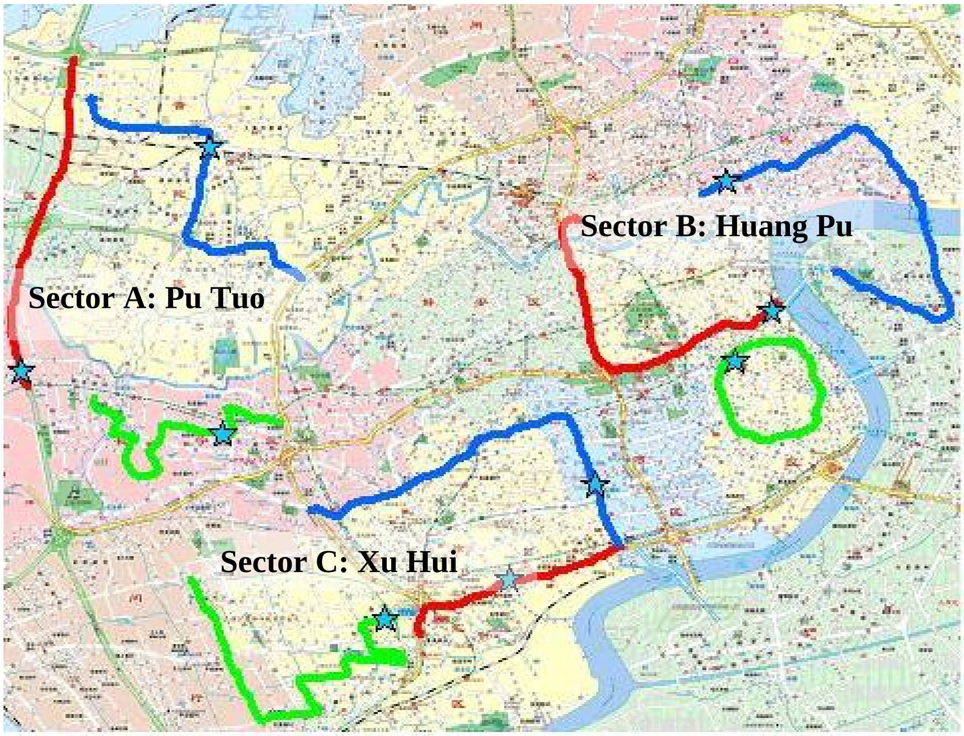

Figure II.2: Sectors where Activity Study was conducted in Shanghai, China

Figure II. 1 shows a graphical view of the general location where the video survey and parking lot surveys were conducted. Table II.1 lists the specific address in Shanghai where video surveys were completed. Parking surveys were completed at locations generally in the vicinity of the video surveys. These locations were determined by the SAES as representative of the general metropolitan area.

Table II.1 Video Locations Surveyed in Shanghai, China

Street Type	Location	Date and Hour of Surveys
Highway A1	Overpass of Bei Zhai Road and Outer Ring	Wed, Jun 9 @ 07:00, 10:00, 13:00 Fri, Jun 11 @ 14:00, 17:00, 20:00
Highway B1	East Yan An Road	Mon, Jun 14 @ 08:00, 11:00 Wed, Jun 16 @ 15:00, 18:00
Highway C1	7th floor of Xu Hui Education Institute	Thu, Jun 10 @ 09:00, 12:00 Tue, Jun 15 @ 16:00, 19:00
Arterial A2	Overpass of Jiao Tong Road and Zhen Bei Road	Wed, Jun 9 @ 08:00, 11:00 Fri, Jun 11 @ 15:00, 18:00
Arterial B2	Overpass of He Nan Road and Hai Ning Road	Mon, Jun 14 @ 09:00, 12:00 Wed, Jun 16 @ 16:00, 19:00
Arterial C2	Overpass of Zhao Jia Bang Road and Rui Jin No.2 Road	Thu, Jun 10 @ 07:00, 10:00, 13:00 Tue, Jun 15 @ 14:00, 17:00, 20:00
Residential A3	Intersection of Mao Tai Road and Gu Bei Road	Wed, Jun 9 @ 09:00, 12:00 Fri, Jun 11 @ 16:00, 19:00
Residential B3	Intersection of He Nan Road and Zhong Hua Road	Mon, Jun 14 @ 07:00, 10:00, 13:00 Wed, Jun 16 @ 14:00, 17:00, 20:00
Residential C3	East Tian Lin Road	Thu, Jun 10 @ 08:00, 11:00 Tue, Jun 15 @ 15:00, 18:00

Two cameras were placed along roads or on the overpass of the road where driving patterns were measured as described in Table II.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 collection period was 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 II.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.

The completed videotapes were analyzed in slow motion to insure the most accurate counts of vehicles, as it is shown in Figure II.3. 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 vehicle classes, i.e. the fractions of trucks, buses, passenger vehicles, 2-wheelers, and such operating on the roadways of interest.

Figure II.3: Video Tape Counting at SAES, Shanghai, China

There was a misunderstanding in the data collection schedule resulting in the failure of video data collection on certain hours. Information for these few hours was estimated from existing data in adjacent hours. Also, video counts from individual vehicle categories varied considerably from hour to hour due to the limited video taping time. To correct for this, overall vehicle flow was used, which was more consistent, and then the average vehicle category fractions were used to estimate typical vehicle flow for each vehicle category.

To determine the specific technologies in each vehicle class, 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 Atmospheric Environment Institute (AEI) of Shanghai Academy of Environmental Sciences (SAES) directed the parking lot survey in Shanghai. Three teams, nearly 9 students and staff members were used in the study. There was one person who was experienced in identifying vehicle technologies and in each team there were others experienced with the survey methodology. The three teams worked the three areas respectively each day (Table II.1). Figure II.4 illustrates the training process for the students at SAES, and Figure II.5 shows the actual parking lot survey process in Shanghai, China.

Figure II.4: Training for students participating in the Parking Lot Survey

Figure II.5: Parking Lot Survey in Shanghai, China

II.C. SURVEY RESULTS

II.C.1. Fleet Composition

Table II.2 below indicate the results of the fleet composition analysis. 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.

Table II.2: Results of Analysis of Shanghai Videotapes

Road type	Area	Time	Vehicles /hour	Passenger Car	Taxi	Small Truck	Medium Truck	Large Truck	Small Bus	Medium Bus	Large Bus	Motor-cycles	Mopeds
Highway	A1	7:00	2997	46.2%	2.0%	9.1%	20.5%	17.7%	2.1%	2.3%	0.0%	0.0%	0.0%
Highway	A1	10:00	4080	51.1%	1.3%	11.6%	23.8%	8.5%	3.2%	0.4%	0.1%	0.1%	0.0%
Highway	A1	13:00	3435	47.9%	2.4%	13.1%	23.1%	10.0%	2.4%	1.0%	0.0%	0.0%	0.0%
Highway	A1	14:00	3570	52.1%	2.9%	11.9%	21.0%	8.5%	2.8%	0.6%	0.0%	0.2%	0.0%
Highway	A1	17:00	3366	59.4%	2.8%	5.7%	21.9%	4.3%	4.2%	1.8%	0.0%	0.0%	0.0%
Highway	A1	20:00	2394	50.3%	4.0%	9.1%	24.9%	8.6%	2.1%	0.8%	0.1%	0.0%	0.0%
Highway	B1	8:00	2238	75.5%	20.2%	0.0%	0.0%	0.0%	2.8%	1.5%	0.0%	0.0%	0.0%
Highway	B1	11:00	1989	77.4%	18.1%	0.3%	0.0%	0.0%	3.5%	0.8%	0.0%	0.0%	0.0%
Highway	B1	15:00	2265	70.2%	27.7%	0.0%	0.0%	0.0%	1.6%	0.5%	0.0%	0.0%	0.0%
Highway	B1	18:00	2061	69.4%	24.0%	0.0%	0.0%	0.0%	4.2%	2.3%	0.0%	0.0%	0.0%
Highway	C1	9:00	4257	73.9%	19.7%	0.1%	0.2%	0.0%	4.2%	1.9%	0.0%	0.0%	0.0%
Highway	C1	12:00	3345	77.8%	15.4%	0.4%	0.0%	0.0%	4.8%	1.5%	0.0%	0.0%	0.0%
Highway	C1	16:00	3804	82.4%	12.1%	0.2%	0.0%	0.0%	3.2%	2.0%	0.0%	0.0%	0.0%
Highway	C1	19:00	4248	74.0%	18.4%	0.1%	0.2%	0.0%	4.7%	2.5%	0.0%	0.0%	0.0%
Arterial	A2	8:00	2841	34.5%	2.1%	3.3%	5.5%	0.6%	2.1%	5.1%	0.0%	1.3%	45.5%
Arterial	A2	19:00	1908	32.7%	10.5%	5.0%	8.3%	0.6%	2.4%	4.6%	0.0%	10.4%	25.5%
Arterial	A2	15:00	2166	33.0%	11.1%	5.0%	6.9%	1.8%	3.0%	7.6%	0.0%	9.6%	22.0%
Arterial	A2	18:00	1896	34.8%	14.2%	1.9%	6.0%	1.9%	2.7%	5.2%	0.0%	9.5%	23.7%
Arterial	B2	9:00	1110	48.6%	32.4%	3.8%	2.2%	0.5%	1.6%	10.8%	0.0%	0.0%	0.0%
Arterial	B2	12:00	1494	32.1%	31.1%	3.8%	2.0%	0.0%	0.6%	5.2%	0.0%	0.0%	25.1%
Arterial	B2	16:00	1275	49.4%	34.4%	3.8%	3.1%	0.0%	0.9%	8.5%	0.0%	0.0%	0.0%
Arterial	B2	19:00	948	34.5%	41.5%	0.6%	0.3%	0.0%	0.6%	7.9%	0.0%	0.0%	14.6%
Arterial	C2	7:00	2220	46.4%	20.0%	1.5%	0.3%	0.1%	3.0%	11.4%	0.9%	0.1%	16.4%
Arterial	C2	10:00	2619	47.3%	28.6%	1.9%	1.7%	0.5%	1.1%	5.4%	0.7%	0.1%	12.6%
Arterial	C2	13:00	2286	49.3%	30.1%	2.1%	1.2%	0.1%	2.4%	5.2%	0.5%	0.0%	9.1%
Arterial	C2	14:00	2031	69.1%	18.9%	4.1%	1.2%	0.0%	1.0%	4.9%	0.7%	0.0%	0.0%
Arterial	C2	17:00	2706	54.2%	32.5%	1.1%	1.0%	0.0%	3.0%	6.3%	0.8%	0.6%	0.6%
Arterial	C2	20:00	1422	50.2%	38.2%	1.5%	2.7%	0.0%	0.2%	5.9%	1.3%	0.0%	0.0%
Residential	A3	9:00	942	34.4%	24.5%	1.0%	0.6%	0.0%	1.0%	1.0%	0.0%	3.5%	34.1%
Residential	A3	12:00	498	28.3%	35.5%	2.4%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%	32.5%
Residential	A3	16:00	444	46.6%	37.2%	0.7%	0.0%	0.0%	2.0%	4.1%	0.0%	5.4%	4.1%
Residential	A3	19:00	507	34.9%	37.9%	0.0%	0.6%	0.0%	0.6%	0.6%	0.0%	1.8%	23.7%
Residential	B3	7:00	285	30.5%	28.4%	2.1%	0.0%	0.0%	3.2%	32.6%	0.0%	3.2%	0.0%
Residential	B3	10:00	801	21.0%	31.1%	1.1%	1.1%	0.0%	1.5%	11.6%	0.0%	5.2%	27.3%
Residential	B3	13:00	735	18.0%	30.2%	0.8%	1.2%	0.0%	1.2%	11.8%	0.0%	4.1%	32.7%
Residential	B3	14:00	711	30.4%	23.6%	1.3%	0.4%	0.0%	0.0%	11.4%	0.0%	3.8%	29.1%
Residential	B3	17:00	765	25.9%	15.3%	0.8%	0.0%	0.0%	0.4%	12.5%	0.0%	3.5%	41.6%
Residential	B3	20:00	315	29.5%	34.3%	0.0%	1.0%	0.0%	1.0%	20.0%	0.0%	3.8%	10.5%
Residential	C3	8:00	1092	39.6%	11.8%	1.1%	0.0%	0.5%	0.0%	3.6%	0.0%	3.8%	39.6%
Residential	C3	0:00	813	31.0%	28.4%	3.3%	3.7%	0.0%	2.2%	2.2%	0.0%	2.2%	26.9%
Residential	C3	15:00	822	44.5%	33.2%	1.1%	3.3%	0.0%	1.5%	2.2%	0.0%	0.0%	14.2%
Residential	C3	18:00	708	45.3%	30.9%	0.8%	0.8%	0.0%	1.3%	4.7%	0.0%	1.7%	14.4%
Overall Highway			3146	64.6%	11.4%	4.7%	10.2%	4.3%	3.4%	1.5%	0.0%	0.0%	0.0%
Overall Arterial			1923	44.3%	22.7%	2.8%	3.1%	0.5%	1.9%	6.5%	0.4%	2.4%	15.4%
Overall Residential			674	33.0%	27.1%	1.2%	1.0%	0.1%	1.1%	6.9%	0.0%	3.0%	26.6%

From this data, an overall average technology distribution can be developed for each road type in the general metropolitan area (see the last three rows in Table II.2). The weighted averages are based on the vehicle counts and the observed technology distributions on the various types of streets. The observed mix on the three roadway types can be combined to a single overall composite roadway in Shanghai, using the following values (see section V for details): 55% of overall driving is on highways, 33% on arterials, and 12% on residential streets. It is important to underscore that mopeds have been considered in this study, which were not allowed to drive on the vehicle lanes. Shanghai government is trying to limit the growth of the vehicle population allowing only a small number of Shanghai license plates by auction. Licenses are very expensive, so motorcycles and mopeds are very popular now in Shanghai. Figure II.6 illustrates the traffic flow on arterial (A2) and highway (A1) in Shanghai. It is indicated that there are many mopeds driving on the bicycle lane on A2 and many trucks driving on two lanes on A1. Of all the areas observed to date, Shanghai has the highest percentage of passenger vehicles and the lowest percentage of large buses. On the overall highway roads, especially on the Outer Ring road, trucks have much higher percentage than the other road types. That is partially because trucks are not allowed into the city center in Shanghai during the day.

Figure II.6: Traffic flow on the Outer Ring road in Shanghai

Table II.3: Comparison of Observed Fleet Mix in Urban Areas Worldwide

City	Passenger Vehicles	Motor Cycles	Taxi	3-Wheel Carriers	Small Buses	Medium / Large Buses	Small / Medium Delivery Trucks	Large (18 Wheel Type) Trucks	Non-Motorized
Almaty, Kazakhstan	83%	0%		0%	9%	3%	5%	0%	1%
Los Angeles, USA	95%	0%	0%	0%	0%	1%	1%	3%	0%
Mexico City, Mexico	74%	2%	15%	0%	2%	1%	4%	1%	0%
Nairobi, Kenya	88%	2%	1%	0%	2%	2%	4%	1%	1%
Pune, India	12%	55%	0%	13%	0%	1%	1%	0%	17%
Santiago, Chile	79%	1%	8%	0%	0%	6%	5%	1%	0%
Lima, Peru	52%	1%	3%	0%	15%	3%	5%	1%	0%
Beijing, China	70%	0%	24%	0%	1%	3%	2%	0%	High
Shanghai, China	**37%**	**24%**	**19%**	**0%**	**2%**	**7%**	**9%**	**2%**	**High**

Compared with other cities shown in Table II.3, Shanghai has a quite low fraction of passenger cars mainly because of the high number of 2 wheel vehicles (mopeds, scooters and bicycles). An important number of motorized 2-wheel carriers (mopeds and scooters) were not counted during the video tape readings because these vehicles usually drive on the bicycle lanes. Considering static databases from vehicle registration in Shanghai, it is expected that this type of motorized 2-wheel vehicles represent 21% of the total vehicle counts, which have been added to the column "motorcycles" on Table II.3.

II.C.2. Passenger Vehicle Technology Distribution

A total of 1200 passenger cars were surveyed in Shanghai and 919 of them were used in this study (blank and unreliable data was filtered out). Nearly 230 vehicle surveys had no odometer data or had digital odometers, and 56 vehicle surveys were without reasonable odometer data (too high or too low considering vehicle age). In addition to this, more than 70 vehicles did not have information on the air/fuel control or exhaust control. Table II.4 presents some of the general characteristics observed in the surveyed fleet.

Table II.4: General characteristics of the surveyed Passenger Cars

Type of Fuel	Air Conditioning System	Type of Transmission	Catalytic Converter (CC)
98.5% Gasoline	96% with A/C	55% Mechanic Trans.	94% with CC
1.5% Diesel	4% without A/C	45% Automatic Trans.	6% without CC

The IVE Model defines 1328 technology classifications based on fuel type, engine technology, and control technology plus 45 user defined technologies. A list of the six most common technology types for gasoline passenger vehicles is shown in Table II.5.

Table II.5: IVE Technology Fractions of the Gasoline Passenger Cars

Passenger Vehicles	Fraction of Passenger Vehicles
Gasoline, 4-stroke, Carburetor, No Catalyst	5.04%
Gasoline, 4-stroke, Carburetor, 3-way Catalyst	0.12%
Gasoline, 4-stroke, Single Point Fuel Injection, 2-way Catalyst	9.38%
Gasoline, 4-stroke, Single Point Fuel Injection, 3-way Catalyst	7.03%
Gasoline, 4-stroke, Multipoint Fuel Injection, No Catalyst	0.70%
Gasoline, 4-stroke, Multipoint Fuel Injection, 3-Way Catalyst	77.73%

The engine size of the Shanghai vehicle fleet was generally midsize (1500-2900cc) and most of the passenger vehicles in Shanghai were low use (<80,000 km). Table II.6 indicates the engine size and use distribution of the passenger vehicle fleet.

Table II.6: Size and Use Characteristics of the Surveyed Passenger Car Fleet

Vehicle Engine Size	71% Low Use (<80 K km)	19% Medium Use (80-160 K km)	10% High Use (>160 K km)
1% Small (<1500 cc)	1.11%	0.27%	0.00%
88% Medium (1500-2900 cc)	63.23%	16.00%	8.49%
11% Large (>2900 cc)	7.24%	2.32%	1.34%

Information in Table II.5 must be combined with information in Table II.6 along with the video collected data in Table II.2 to produce the passenger vehicle fleet information for estimating emissions.

Figure II.7 illustrates the model year distribution for active passenger vehicles in three types of the areas in Shanghai. The average age of passenger vehicles surveyed during the parking lot activity was 3.61 years. According to the survey done by Shanghai City Comprehensive Transport Planning Institute (SCCTPI, vehicle population 2003), new passenger cars began to be purchased mostly from private users since 2001. The growth rate of private passenger cars came up to 73% in 2002 in Shanghai.

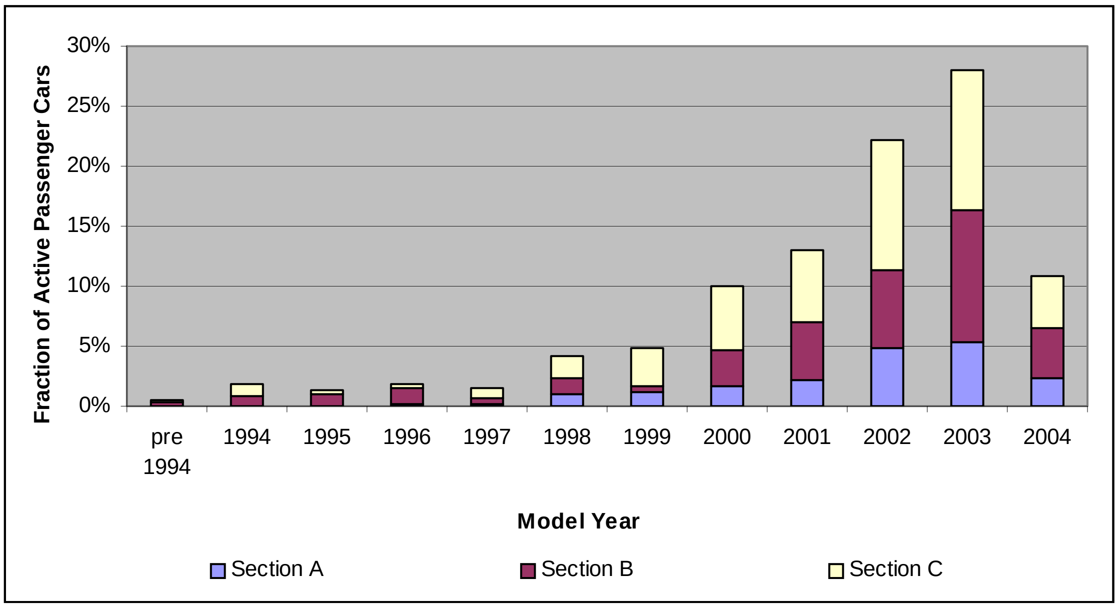

Figure II.7: Model Year Distribution in the Shanghai Passenger Vehicle Fleet

Table II.7 illustrates the fraction of air/fuel control and exhaust control on passenger vehicles. Most of the passenger vehicles now use fuel injection in Shanghai, second only to Los Angeles, USA. 90% of the passenger cars have catalyst and only 6% have no catalyst. Los Angeles, Beijing and Shanghai have the three highest fractions of 3-way catalyst vehicles, while Almaty and Pune have mostly non-catalyst vehicles.

Table II.7 Current Passenger Vehicle Technology Distributions around the World

	Air/Fuel Control		Catalyst		
Location	**Carburetor**	**Fuel Injection**	**None**	**2-Way Catalyst**	**3-Way Catalyst**
Almaty, Kazakhstan	45%	51%	89%	0%	7%
Los Angeles, USA	6%	94%	1%	3%	96%
Mexico City, Mexico	18%	82%	20%	0%	80%
Nairobi, Kenya	60%	32%	100%	0%	0%
Pune, India	42%	32%	29%	35%	11%
Santiago, Chile	17%	80%	17%	3%	77%
Shanghai, Peru	44%	56%	53%	6%	40%
Beijing, China	11%	89%	7%	4%	89%
Shanghai, China	**5%**	**93%**	**6%**	**9%**	**84%**

II.C.3. Passenger Vehicle Use

Odometer data was obtained from the parking lot surveys. Thus, some approximation of the use of passenger vehicles can be made and this can be extrapolated to make approximations of total vehicle use for Shanghai.

Figure II.8 shows the passenger vehicle use taken from vehicle odometers. In this figure, we only used the first eleven years because too little data was available on the vehicles older than 11 years. In total, data from 831 vehicles have been considered out of 919 surveyed cars. The data was fit with a quadratic polynomial growth trend (Figure II.7). Average driving for a 4-year old vehicle is 80,000 kilometers. When the vehicle age reaches 9 years, the passenger cars in Shanghai have traveled an average of 160 thousand kilometers.

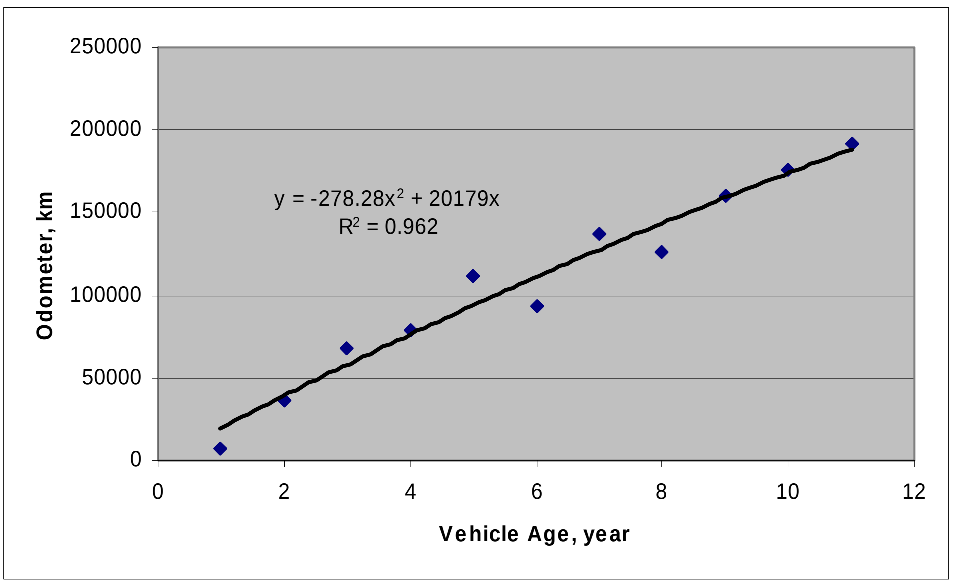

Figure II.8: Passenger Vehicle Use during the first eleven years of age

As is typical for the United States and all other countries studied so far, vehicle use decreases with vehicle age. Using the age distribution illustrated in previous Figure II.6, the average passenger car age in Shanghai is calculated to be 3.61 years.

Figure II.9 illustrates the average age of the on-road vehicle fleet in different cities where the IVE methodology has been conducted. Compared with the other countries, on-road passenger cars in China are much younger than most of the other cities. Especially in Shanghai, the average age was only 3.61 years. This young average passenger vehicle age is due to shift where families have only recently begun purchasing passenger vehicle in Shanghai.

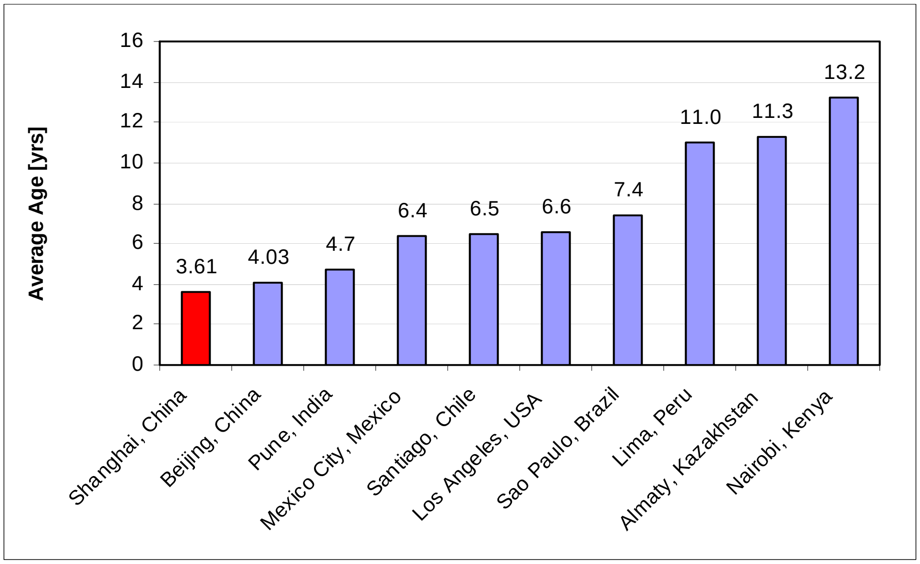

Figure II.9: Comparison of Average Vehicle Age in different cities

Figure II.10 illustrates the average daily passenger vehicle use in the countries studied to date. As can be seen, Shanghai, and the other Chinese city Beijing has a quite high daily use, second only to Los Angeles, USA. Considering the previous figure, passenger vehicles in Shanghai and Beijing are very new, and it can be assumed that the passenger cars in Shanghai and Beijing are more frequently used than the other cities. Moreover, cooperation-owned passenger cars in Shanghai were higher than private passenger cars by almost 4 times. Cooperation-owned passenger cars usually have higher daily use than the private cars.

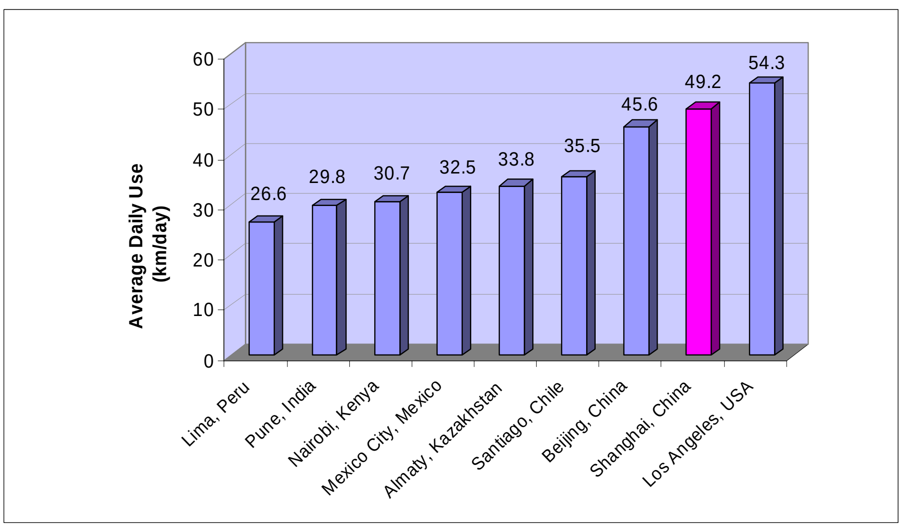

Figure II.10: Comparison of Average Vehicle Age in different cities

Considering this data and the odometer analysis of the passenger cars, it is possible to estimate an overall average travel for Shanghai passenger cars equals to 17,958 km/year, thus, an average daily driving of 49 kilometers of driving per day over the year (assuming 365 days/year).

Based on the statistics done by SCCTPI, the total number of passenger vehicle in Shanghai is 371,000. According to the truck and bus information survey conducted in June 2004, the average bus and truck travel are 120 to 130 km per day and 90 km per day respectively, and taxis around 300 km per day in Shanghai. Thus, the current travel from all vehicle classes is estimated to be approximately 39,957,200 kilometers per day in the Shanghai Metropolitan Area[1]. This estimate is used in the IVE analysis to project emissions for the whole city. Table II.8 below provides the estimated total driving for each vehicle class based on measurements made in this study.

Table II.8: Observed Travel Distribution by vehicle type in Shanghai

Type of Vehicle	Number of Vehicles in Region	Average Driving per Day (km/day)	Fraction of Observed Travel 2004	Estimated Travel (1,000 km/day)	All Travel (1,000 km/day)
Passenger Car	371,000	49	37%	18,253	49,332
Taxi	47,500	300	19%	14,250	75,000
Motorcycle	125,000	12	4%	1,500	37,500
Moped	633,000	12	20%	7,600	38,000
Bus	32,300	130	9%	4,199	46,656
Truck	57,000	90	11%	5,130	46,636
Total	1,265,800	**Overall Average**		50,928	

The values shown in Table II.8 should only be treated as approximations, but they should be in the ball park of the true total driving occurring in Shanghai in 2004.

A final issue of interest is to compare Shanghai driving with other areas. Figure II.11 illustrates the total driving per vehicle for the countries studied to date. As can be seen, passenger cars are driven the most in Los Angeles and the least in Pune, India. The mileage passenger cars traveled in Shanghai was in high growth trend second only to Los Angeles, USA and similar to Beijing. So the vehicle use in Shanghai is relatively high compared most of the cities in the world and higher than Beijing, China.

[1] Fleet estimates are based on vehicle population data in 2002 provided by Shanghai City Comprehensive Transport Planning Institute (SCCTPI), the data is available on the website: www.scctpi.com.

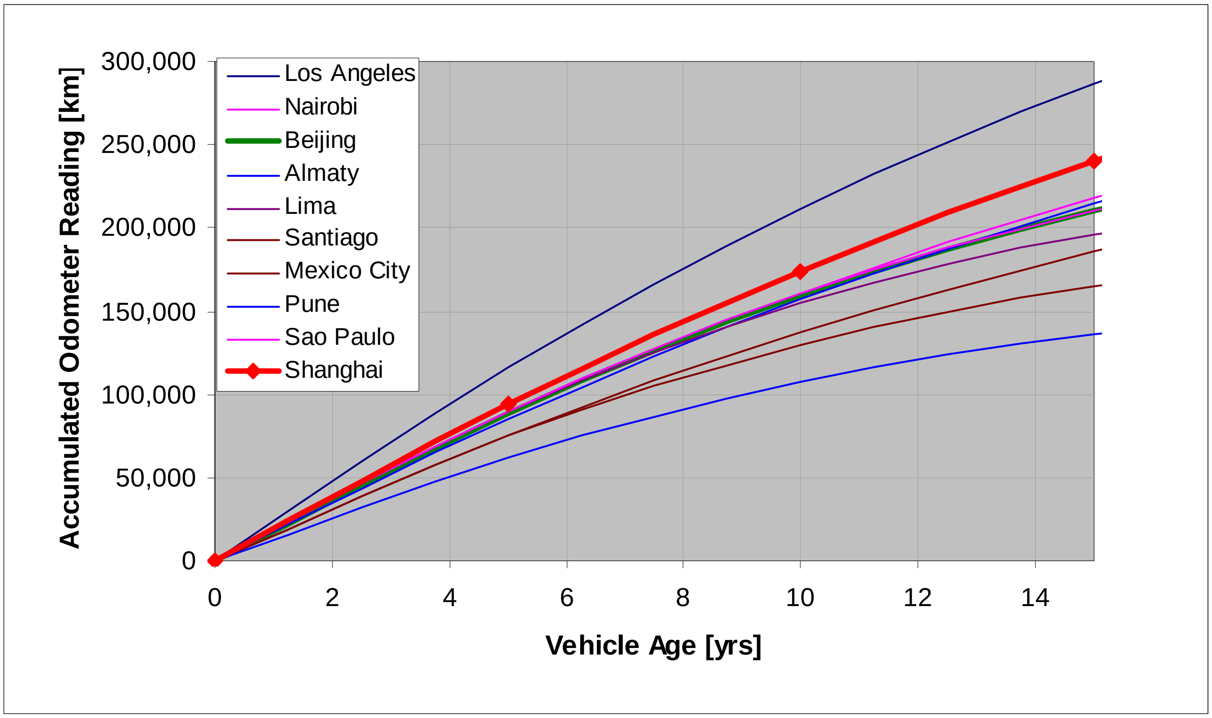

Figure II.11: Comparison of Passenger Vehicle Use in different cities

II.C.4. Taxi Technology Distribution

Technology information was gathered from the three largest taxi companies in Shanghai, China on 140 vehicles (Table II.9). More than half of the taxis in Shanghai are single-point petrol cars with 3 way catalysts. Nearly 26% of the taxis were retrofitted to LPG as fuel in Shanghai.

Table II.9: IVE technology fractions of the Taxis

Fuel	Air/Fuel Control	Exhaust Control	Fraction
Petrol	Carburetor	None	2.2%
	Single Point Fuel Injection	3 Way	54.0%
	Multi-Point Fuel Injection	3 Way	17.3%
LPG	Fuel Injection	3 Way	26.5%

Taxis in Shanghai are used frequently. According to the survey, taxis in Shanghai usually travel more than 300 km per day. Most of the taxis were generally midsize (1500-2900cc) on the engine size. Table II.9 indicates the engine size and use distribution of the taxi fleet.

Table II.10: Size and Use Characteristics of the Surveyed Taxi Fleet

Vehicle Engine Size	9% Low Use (<80 K km)	6% Medium Use (80-160 K km)	85% High Use (>160 K km)
98.56% Medium (1500-2900 cc)	7.19%	5.76%	85.61%
1.44% Large (>2900 cc)	1.44%	0.00%	0.00%

Figure II.12 illustrates the model year distribution in the Shanghai taxi fleet. Most of the taxis were 3 to 4 years old in 2004. Because of the high use of the vehicles, the taxis accumulate a higher overall use in a shorter time period compared with passenger vehicles. At a use of 500 thousand kilometers, generally equivalent to 5 or 6 years old, the vehicle is scrapped. Therefore, there were virtually no taxis greater than 6 years old observed in the on-road fleet.

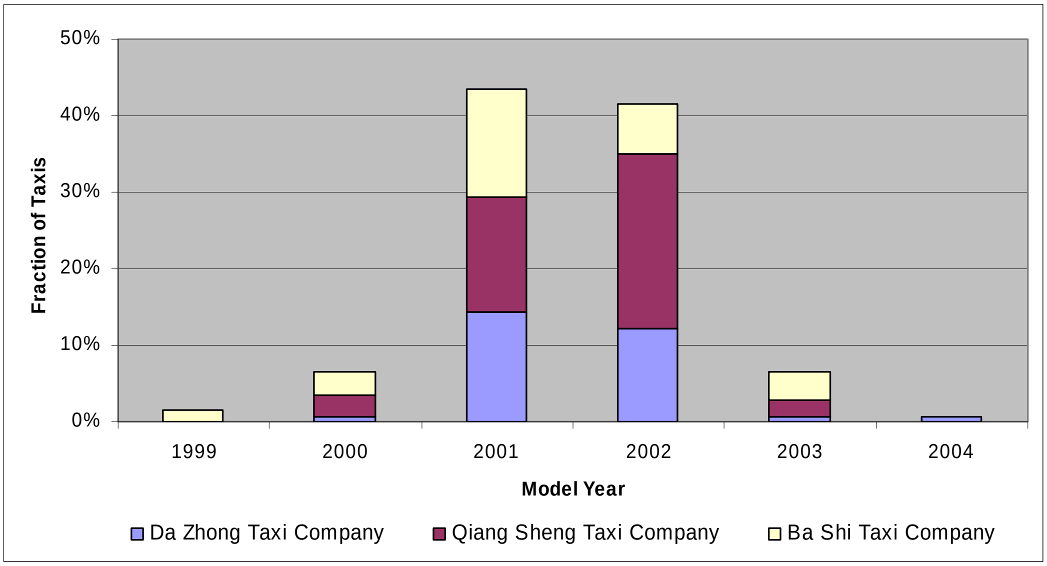

Figure II.12: Model Year Distribution in Shanghai Passenger Vehicle Fleet

II.C.5. Bus Technology Distribution

A survey with the Number One Bus Company was conducted in June 2004, which is the third largest bus company in Shanghai. The fleet of this company was assumed to be representative of the on-road buss fleet in Shanghai. It is recommended that at least two more bus companies should be surveyed to confirm this assumption. Table II.11 indicates the IVE technology fractions in the surveyed fleet. The fraction of petrol buses was 24% and diesel buses accounted for 76%. More than 72% of the buses meet the Euro I emission standards.

Table II.11: IVE Technology Fractions of the Buses

Fuel	Air/Fuel Control	Exhaust Control	Fraction
Petrol	Fuel Injection	None	6.0%
	Fuel Injection	Euro I	18.1%
Diesel	Direct Injection	Improved	21.5%
	Direct Injection	Euro I	54.4%

Buses in Shanghai travel about 120-130 km per day. Almost all buses are scrapped before they travel more than 160,000 km. Most of the buses were generally midsize (14,001 to 33,000 lbs GVWR). Table II.12 indicates the engine size and use distribution of the bus fleet.

Table II.12: Size and Use Characteristics of the Surveyed Bus Fleet

Vehicle Engine Size	25% Low Use (<80 K km)	75% Medium Use (80-160 K km)	No High Use (>160 K km)
3.2% Light (9,000 to 14,000 lbs GVWR)	3.2%	0.00%	0.00%
84.7% Medium (14,001 to 33,000 lbs GVWR)	63.5%	21.2%	0.00%
12.1% Large (>33,001 lbs GVWR)	9.1%	3.0%	0.00%

II.C.6. Truck Technology Distribution

A comprehensive survey of specific truck technologies was not conducted in this field study. Therefore, information from experts at a local university provided some assumptions on the distribution of truck technologies. The breakdown uses assumes 70% of trucks use diesel and 30% use petrol. Only 10% of the trucks meet the Euro I standard. Table II.13 indicates the assumed IVE technology fractions in the truck fleet.

Table II.13: IVE Technology Fractions of Trucks

Fuel	Air/Fuel Control	Exhaust Control	Fraction
Petrol	Carburetor	None	27%
	Fuel Injection	Euro I	3%
Diesel	Direct Injection	Improved	63%
	Fuel Injection	Euro I	7%

Trucks in Shanghai travel approximately 80-100 km per day. Almost no trucks were large size (>33,001 lbs GVWR). Half of the trucks were small size (9,000 to 14,000 lbs GVWR) and half of the trucks were medium size (14,001 to 33,000 lbs GVWR). Most of the trucks had been used for many years and are categorized in the 'high use' classification. Table II.10 indicates the engine size and use distribution of the truck fleet.

Table II.10: Size and Use Characteristics of the Surveyed Truck Fleet

Vehicle Engine Size	10% Low Use (<80 K km)	20% Medium Use (80-160 K km)	70% High Use (>160 K km)
50% Light (9,000 to 14,000 lbs GVWR)	9.5%	9.00%	31.50%
50% Medium (14,001 to 33,000 lbs GVWR)	9.5%	9.00%	31.50%
0% Large (>33,001 lbs GVWR)	0.00%	0.00%	0.00%

II.C.7. Motorcycle Technology Distribution

Not enough motorcycle data was collected, therefore the technology distribution of motorcycles in Pune, India served as the basis of the Shanghai fleet. It is believed there may be significant error in this assumption because the Pune motorcycle fleet is older than what has been observed in Shanghai.

Mopeds consist of a significant portion of the vehicle fleet in Shanghai, making it necessary to include in the inventory. A specific moped technology survey was not conducted during this field study. For the IVE fleet distribution of mopeds, it was assumed almost all of the mopeds were LPG, 4 cycle carburetors and without catalyst. In order to verify and improve the technology distribution for motorcycles and mopeds in Shanghai, it is recommended that physical surveys of the technology distribution on the roads be conducted in the future.

III. VEHICLE DRIVING PATTERNS

III.A. BACKGROUND AND OBJECTIVES

The main objective of this section is to collect second-by-second information on the speed and acceleration of the main types of vehicles operating in Shanghai on a representative set of roadways throughout the day.

III.B. METHODOLOGY

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. Three representative sections of the city were selected for the IVE study in Shanghai. The areas selected should represent a generally lower income area, a generally upper income area, and a commercial area of the city. Figure II.5 and Table III.1 show the sectors and streets selected in this study.

Table III.1 Streets selected for vehicle driving in Shanghai, China

Street Type	Location
Highway A1	Outer Ring Road – Pu Tuo District
Highway B1	East Yan An Road – Huang Pu District
Highway C1	South Zhong Shan Road 2 – Xu Hui Distrist
Arterial A2	Zhen Nan Road – Pu Tuo District
Arterial B2	Han Ning Road – Hong Kou District
Arterial C2	Huai Hai Road – Xu Hui District
Residential A3	Mao Tai Road – Pu Tuo District
Residential B3	Zhong Hua Road – Huang Pu District
Residential C3	Tian Lin Road – Xu Hui District

Figure III.1 illustrates the location data was collected from one of the CGPS units installed on a passenger car driving over Sector A in Shanghai. Roads A1 (Outer Ring Road), A2 (Zhen Nan Road) and A3 (Mao Tai Road) can be correlated with the drawings in Table III.1.

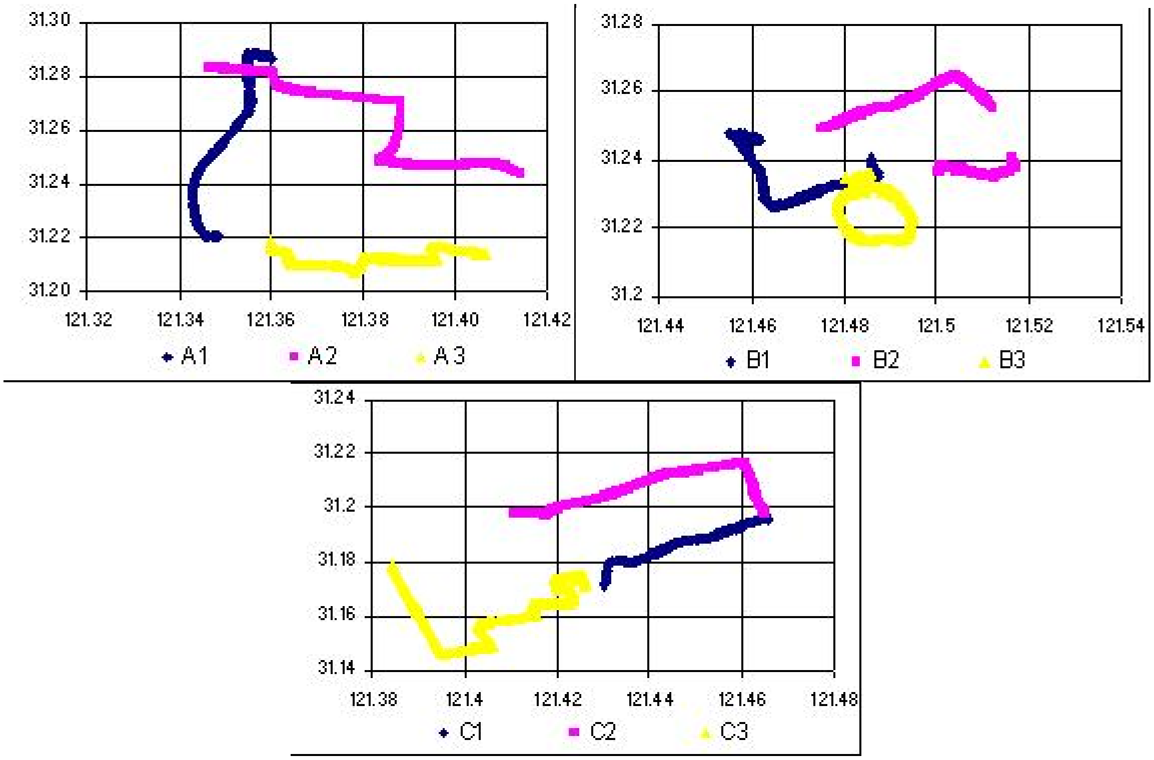

Figure III.1: CGPS output from Sector A, B,C, Shanghai

III.C. RESULTS

Figure III.2 presents an example of speeds as measured by the GPS unit for about 180 seconds around 16:00 driving a passenger car (Sector A, Pu Tuo District).

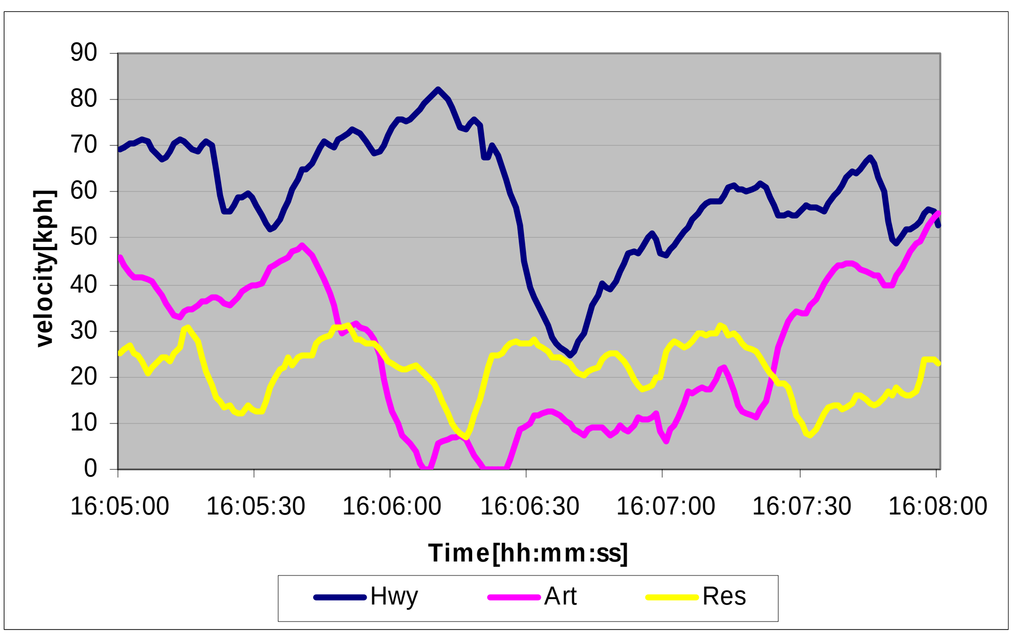

Figure III.2: Example of Residential, Arterial, and Highway Driving at 16:05pm in Shanghai

Figure III.3 presents an example of altitude and velocity recorded from passenger car over a 30 minute drive. The altitude reading is the least certain of the data collected by a GPS unit, but it is still useful after filtering and averaging for estimating road grade.

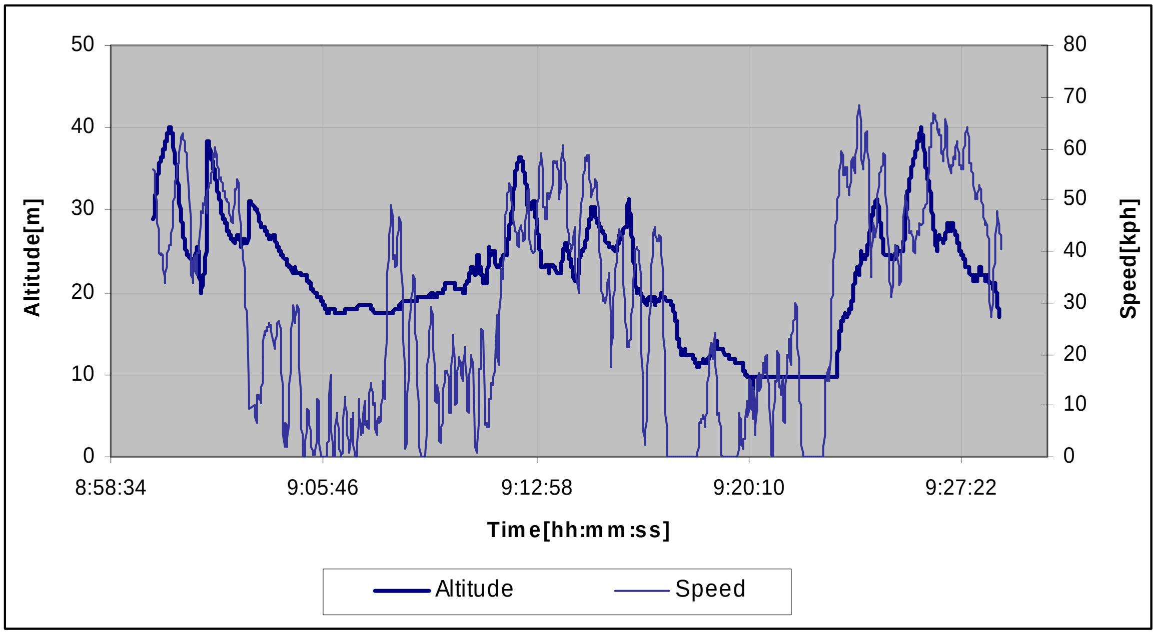

Figure III.3: Example of Altitude and Speed Recorded by GPS over a 30 Minutes Drive

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). VSP is the best, although imperfect, indicator of vehicle emissions given only vehicle velocity and position as inputs. Equation III.1 presents the VSP equation.

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

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.

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

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 separated 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.

III.C.1. Passenger Cars

Data on passenger car driving was collected in three parts of Shanghai (see Table II.1) over six days. GPS data in Shanghai started from 7:00 AM and ended at 21:00 PM. The driving data was allocated into 1-hour group. Table III.2 indicates the average speed for each type of road studied for each 1-hour group.

Table III.2: Average Passenger Car Speeds on Shanghai Roads

Time	Highway	Arterial	Residential Street
7:30	39.86	16.46	17.83
8:30	30.13	11.04	15.32
9:30	26.14	11.27	16.53
10:30	30.28	12.14	15.45
11:30	38.78	12.88	16.12
12:30	42.51	16.53	19.52
13:30	38.83	19.62	21.79
14:30	28.56	8.63	22.66
15:30	37.62	12.03	19.94
16:30	25.98	10.36	16.35
17:30	34.29	9.68	13.72
18:30	17.56	12.86	13.61
19:30	37.10	13.34	18.21
20:30	46.01	20.15	21.70

All of the GPS files over 6 days have been used here. Because of poor signals on the residential street of the commercial area (Section B3), nearly 20% of the data was lost on residential streets, while 8% and 5% of the data was lost on highway and arterial roads respectively.

Speed alone is not a good indicator of vehicle power demand. Vehicle acceleration consumes considerable energy and is not indicated by average vehicle speed. Tables III.3 to III.5 below provide the power bin distribution for the driving on Shanghai Highways, Arterials, and Residential streets respectively averaged over all hours.

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 III.3: Distribution of driving into IVE Power Bins for passenger cars operating on Highways averaged over all hours (average speed: 31.97 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.01%	0.03%	0.04%	0.07%	0.15%	0.37%	0.78%	2.36%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	9.35%	42.88%	22.83%	12.68%	5.33%	1.57%	0.12%	0.04%	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%	0.01%	0.01%	0.55%	0.56%	0.19%	0.03%	0.02%
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 III.4: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Arterials Averaged Over All Hours (average speed: 12.61 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.04%	0.01%	0.01%	0.01%	0.02%	0.01%	0.04%	0.20%	0.57%	1.76%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	5.84%	69.91%	12.13%	6.19%	2.26%	0.60%	0.13%	0.04%	0.02%	0.03%
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%	0.05%	0.06%	0.02%	0.00%	0.02%
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 III.5: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Residential Streets Averaged Over All Hours (average speed: 17.11 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.02%	0.01%	0.01%	0.01%	0.04%	0.08%	0.25%	0.75%	2.38%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	8.06%	57.83%	17.54%	8.03%	3.05%	1.03%	0.27%	0.06%	0.03%	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**
	0.00%	0.00%	0.00%	0.00%	0.00%	0.14%	0.22%	0.09%	0.01%	0.03%
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%

It is clear looking at Tables III.3 through III.5 that the percentages in the zero power Bin 12, (stopping and idling) on arterials are more than the other two. This, coupled with the fact that arterial roads have the lowest average speed, is an indication that there are many problems with traffic management on the arterial roadways in Shanghai. It is also noteworthy that the high stress, high power demand driving is not seen (fast accelerations from stops on less crowded streets).

III.C.2. Taxis

Two taxis were equipped with the GPS units and allowed to drive their normal daily routes for 6 days. The 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 within the Shanghai Metropolitan area. Table III.6 shows the average speeds recorded for the taxis by time of day.

Table III.6: Average Taxi Speeds on Shanghai Roads

Time	Overall
7:30	19.53
8:30	18.25
9:30	14.58
10:30	15.88
11:30	30.70
12:30	26.07
13:30	21.42
14:30	25.92
15:30	22.16
16:30	16.75
17:30	14.00
18:30	16.94
19:30	21.37
20:30	23.37

The taxi speeds are, as expected, similar to a combination of highway and arterial driving from passenger vehicles. Similar congestion patterns are observed in the taxi driving patterns as the passenger vehicles. There all were relatively high speed in the early morning and night. Most of the congestion and low velocities occur in the morning and afternoon. The minimum speed occurred at 9:30 and 17:30 and the maximum speed occurred at noon. Table III.7 presents the power-binned data for the taxis averaged over all hours.

Table III.7: Distribution of Driving into IVE Power Bins for Taxis Averaged Over All Hours (average speed: 20.48 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.02%	0.01%	0.01%	0.03%	0.05%	0.11%	0.23%	0.47%	1.03%	2.45%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	6.37%	57.19%	16.30%	8.66%	4.17%	1.28%	0.14%	0.05%	0.02%	0.05%
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%	0.02%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	0.02%	0.03%	0.03%	0.05%	0.06%	0.39%	0.51%	0.18%	0.05%	0.03%
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%

III.C.3. Buses

Table III.8 indicates the average bus speeds in Shanghai. The maximum speed is in the early morning and late afternoon. There are some low velocities during the middle of the day, however, buses do not have as drastic of a congestion effect as for the passenger vehicles and taxis.

Table III.8: Average Bus Speeds on Shanghai Roads

Time	Overall
7:30	15.90
8:30	13.99
9:30	16.93
10:30	17.38
11:30	15.36
12:30	13.89
13:30	15.44
14:30	17.12
15:30	13.55
16:30	13.90
17:30	12.24
18:30	14.08
19:30	20.85
20:30	15.28

Usually the bus driving patterns are expected to be similar to arterial from the driving pattern of passenger vehicles. In this study, average speed of buses in Shanghai was higher than the average speed of passenger vehicles on the arterial roads. It may be that bus driving is more similar to the combination of arterial and residential roads in Shanghai. Table III.9 indicates the power bin distributions for the buses averaged over all hours.

Table III.9: Distribution of Driving into IVE Power Bins Buses Averaged Over All Hours (average speed: 15.42 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.01%	0.02%	0.02%	0.04%	0.08%	0.14%	0.43%	1.51%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	5.33%	63.25%	21.62%	6.22%	0.95%	0.20%	0.05%	0.04%	0.02%	0.03%
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%	0.02%	0.01%	0.01%	0.00%	0.02%
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%

III.C.4. Trucks

Table III.10 indicates average truck vehicle speeds in Shanghai. The maximum speeds occur in the morning and afternoon. In the very early morning and late afternoon the average velocity is significantly lower. The average speed of the trucks is much higher than the other vehicle types and routes except for the highway driving patterns. The higher truck velocities can be explained by the fact that more trucks operate on the Outer Ring roads, which are far away from the city center and heavy congestion in Shanghai. Table III.11 indicates the power bin distributions for trucks averaged over all hours.

Table III.10: Average Delivery Truck Speeds on Shanghai Roads

Time	Overall
7:30	16.00
8:30	20.34
9:30	25.47
10:30	26.42
11:30	20.93
12:30	26.15
13:30	26.19
14:30	23.65
15:30	14.24

Table III.11: Distribution of Driving into IVE Power Bins Trucks Averaged Over All Hours (average speed: 23.61 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%	0.02%	0.04%	0.08%	0.26%	0.70%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	2.63%	55.48%	34.21%	5.94%	0.48%	0.07%	0.02%	0.01%	0.00%	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%	0.00%	0.01%	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%

III.C.5. Motorcycles

Table III.12 indicates average motorcycle speeds in Shanghai. One GPS unit was equipped on a motorcycle for 6 days. Because of technical problems, the last day's data was not used. The maximum speed is in the early afternoon. In the morning and late afternoon the average velocity is significantly lower.

Table III.12: Average Delivery Truck Speeds on Shanghai Roads

Time	Overall
7:30	10.44
8:30	4.36
9:30	13.12
10:30	20.70

11:30	8.51
12:30	10.77
13:30	24.79
14:30	16.84
15:30	15.07
16:30	10.82
17:30	14.63
18:30	15.61

Table III.13 indicates the power bin distributions for motorcycles averaged over all hours.

Table III.13: Distribution of Driving into IVE Power Bins Motorcycles Averaged Over All Hours (average speed: 13.46 km/hour)

Stress Group	Power Bins									
Low	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.01%	0.01%	0.01%	0.02%	0.04%	0.08%	0.08%	0.21%	0.60%	1.73%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	5.89%	64.08%	19.32%	5.74%	1.26%	0.36%	0.16%	0.12%	0.04%	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%	0.02%	0.01%	0.02%	0.00%	0.01%	0.01%	0.01%	0.03%	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%	0.00%	0.00%	0.00%

The same driving cycle used for motorcycles was applied to mopeds. This assumption should hold valid for the mopeds operating on the normal roadways, however, it is expected that a different driving pattern would be observed for the mopeds traveling in the bicycle lanes.

III.C.6. Summary of Driving Pattern Results

Figure III.4 compares driving speeds by hour for the five types of vehicles studied. In general, congestion lowers the average velocity during the daytime hours by 30 to 60 percent of free flow velocities. It was assumed that the early morning and late evening velocities were similar to the late evening and 7 am data because no data was collected between 10 pm and 5 am and traffic flow is expected to be free flow during this entire time period. Truck data was collected only between 7:00 am and 16:00 pm. Therefore it was assumed that early morning and late afternoon and evening velocities for trucks were similar to the 8 am and 14 pm.

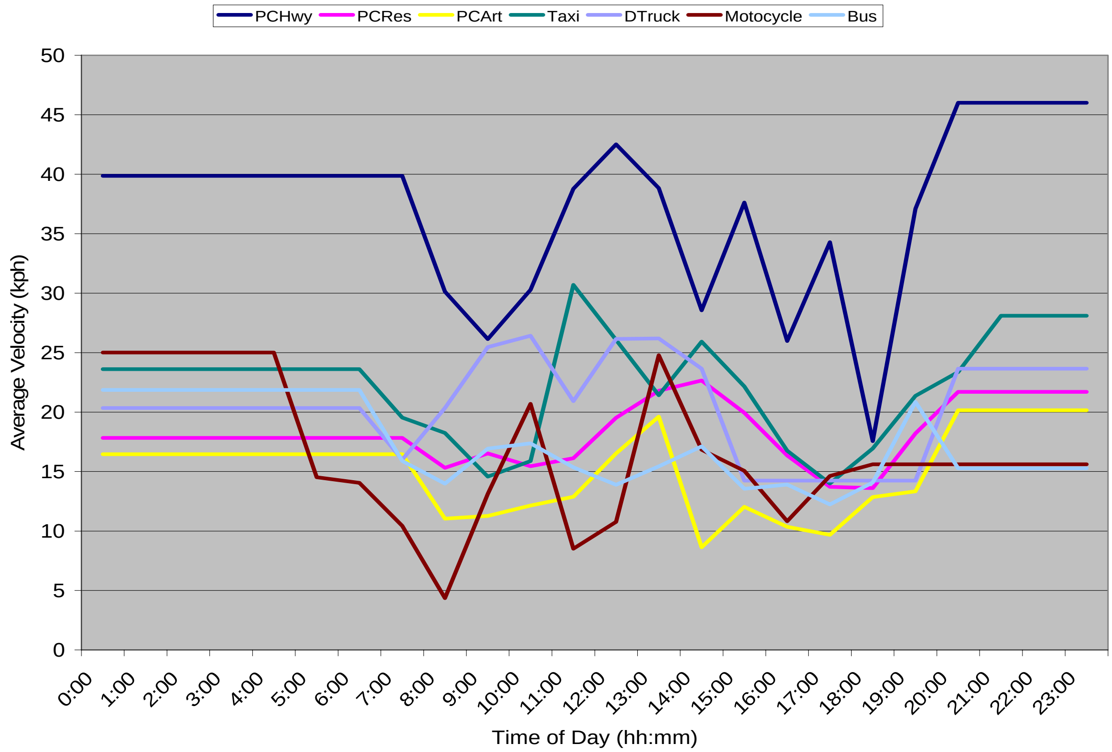

Figure III.4: Average Speeds for All Road Types and Vehicle Classes in Shanghai

Overall, the fastest velocities occur on the highways and the lowest velocities occur on arterials. The highest speeds occur during the noon and the very early morning hours. The lowest velocities occur in the morning and afternoon. Passenger cars on arterials maintain a relatively low average velocity throughout the day due to constant congestion. Buses and taxis have similar average speeds to passenger vehicles traveling on arterial and residential roadways.

Figure III.5 shows the distribution into driving bins for four of the main classes of driving at 08:30. There is little to distinguish the driving patterns between passenger vehicles, and buses at this time of the morning. All vehicles driving on similar roadways experience similar driving styles. The 2-Wheel vehicles and passenger vehicles are using slightly more relative power (i.e. accelerations) in driving under free flow conditions.

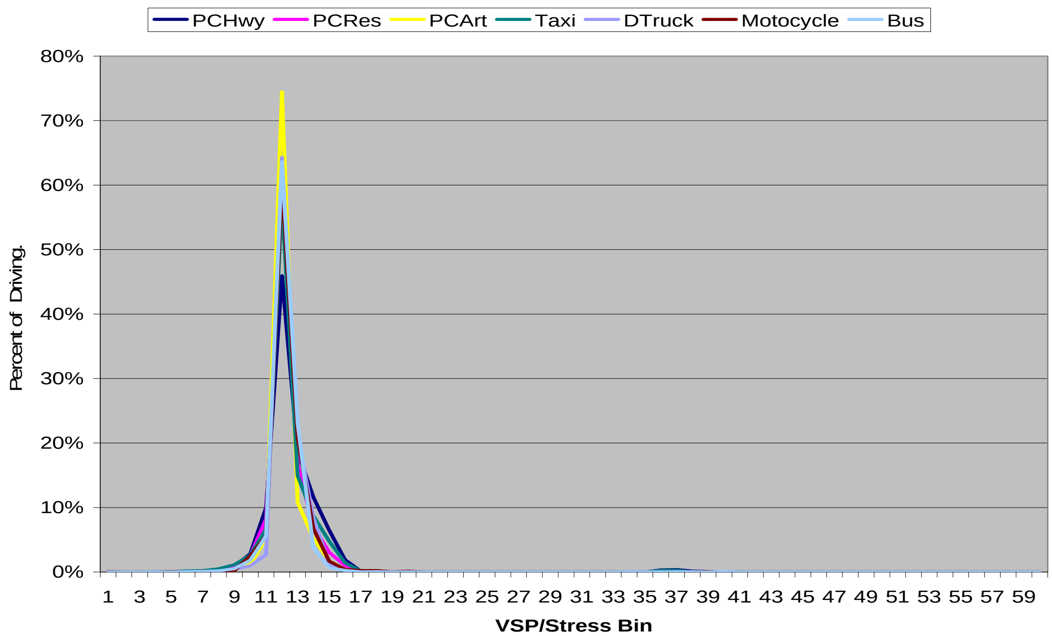

Figure III.5: Comparison of Driving Patterns for Four Major Vehicle Classes for 08:30

Figure III.6 represents driving at 12:30. In this case, the highway passenger vehicles and taxi driving look very similar and contain some higher power driving (bins above 20) which is caused by hard accelerations. The highway driving contains the lowest percentage of idle and low stress driving. All driving patterns are significantly different and contain less idle time than the early morning driving patterns.

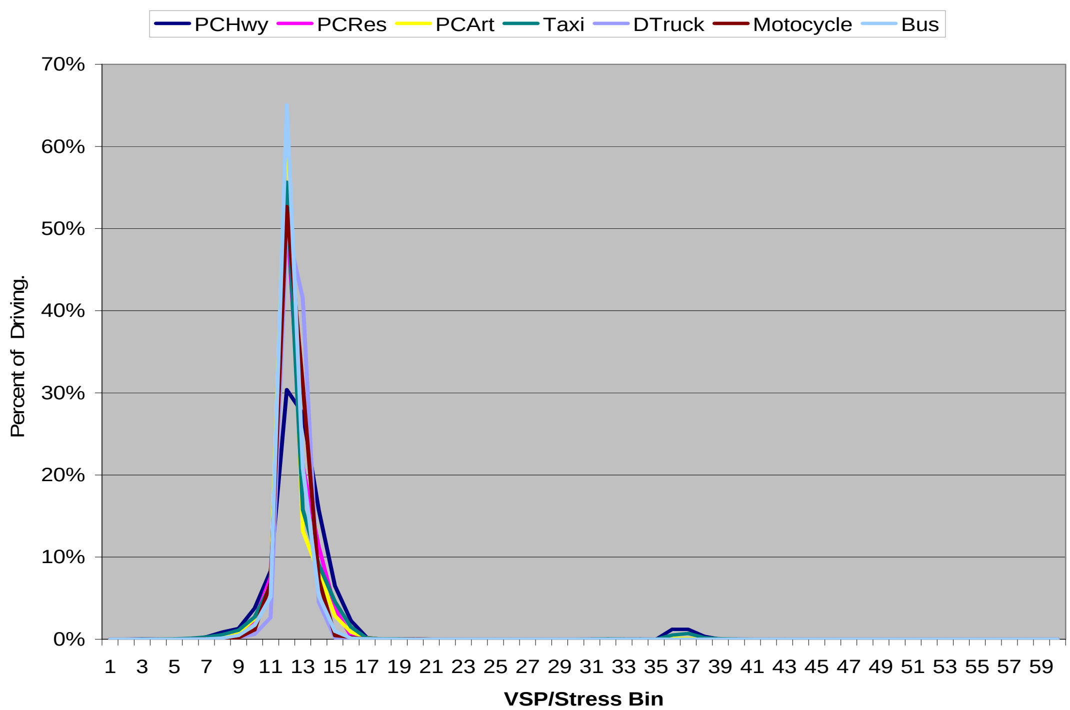

Figure III.6: Comparison of Driving Patterns for Four Major Vehicle Classes for 12:30

Figure III.7 represents the 17:30 time frame. This hour of the day represents the most uniform driving among the various vehicle classes. Very little high stress driving is seen here. Both the 08:30 and the 17:30 driving contain much larger proportions of low stress and idle driving.

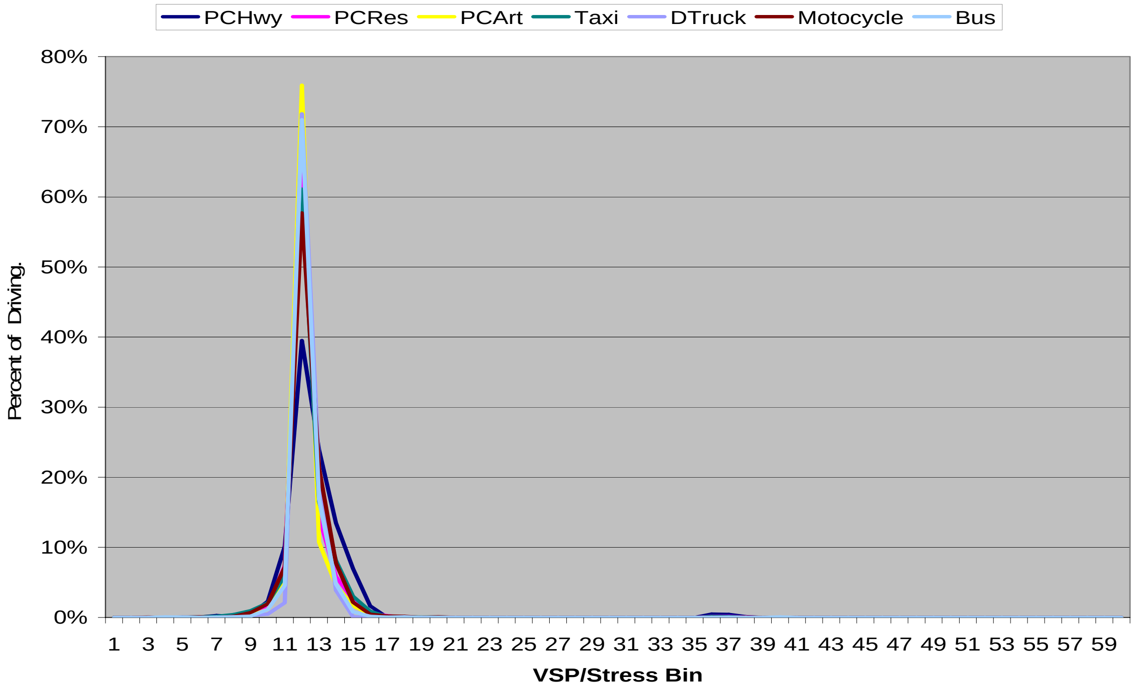

Figure III.7: Comparison of Driving Patterns for Four Major Vehicle Classes for 17:30

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

IV.A. BACKGROUND AND OBJECTIVES

Between 10% 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 vehicle's 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 main objective of this task is to collect a representative sample of the number, time of day, and soak period from passenger vehicle starts in Shanghai.

IV.B. METHODOLOGY

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 VOCE units were placed in a variety of passenger vehicles and collected data for a week.

IV.C. RESULTS

Table IV.1 indicates the measured start soak patterns for passenger vehicles in Shanghai. A total of 68 passenger vehicles were equipped with VOCE units. Data from 49 vehicles were successfully processed. The vehicle starts recording procedure was over about 6 days for each vehicle. This provides about 280 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 Shanghai

Soak Time (hrs)	Overall PC	PC 06:00-08:59	PC 09:00-11:59	PC 12:00-14:59	PC 15:00-17:59	PC 18:00-20:59	PC 21:00-23:59	PC 00:00-2:59	PC 03:00-05:59
0.25	24%	23.73%	26.69%	25.75%	26.88%	24.85%	18.80%	32.96%	20.27%
0.5	11%	10.06%	19.45%	9.90%	12.95%	8.37%	6.55%	7.70%	8.87%
1	13%	6.55%	16.97%	12.63%	11.02%	16.20%	10.10%	14.28%	11.39%
2	13%	4.85%	13.46%	19.21%	14.33%	19.05%	18.80%	7.70%	8.88%
3	9%	1.04%	5.29%	8.00%	7.95%	9.54%	13.80%	5.50%	16.41%
4	3%	0.16%	0.87%	6.74%	4.83%	2.29%	5.80%	0.00%	2.51%
6	6%	0.52%	0.52%	6.14%	3.94%	3.72%	10.90%	14.28%	6.28%
8	3%	2.94%	0.17%	2.12%	5.55%	1.77%	1.45%	2.20%	5.10%
12	7%	14.18%	2.46%	1.26%	8.59%	8.99%	5.05%	10.98%	7.62%
18	12%	35.97%	14.12%	8.23%	3.95%	5.22%	8.75%	4.41%	12.66%
Events	1426	289	284	238	289	174	184	46	40
Fraction		20%	20%	17%	20%	12%	5%	3%	3%

Overall, Shanghai passenger vehicles were started 5.2 times per day. This is a little lower than other urban areas that have been studied. Starts per day vary from 6-8 for passenger vehicles in the urban areas studied to date.[2] As expected, most starts occur in the 06:00 to 09:00 and 15:00- 18:00 time frame. The second highest number of starts is in the 9:00- 12:00 time frame, and the third in the 12:00 – 15:00 time frame. The highest fraction of starts after an 8 or more hour weight occurs in the early morning to morning time frame as would be expected. These long soak times leave the engine cold and result in much greater start emissions.

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

V. IVE APPLICATION AND EMISSIONS RESULTS

The total daily driving in the Shanghai Metropolitan Area is estimated to be on the order of 50,928,200 kilometers based on Table II.8. 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 II.A. Based on the observed number of vehicles on the different road types and the total length of each type of road in Shanghai, it was estimated that 40% of overall driving in Shanghai is on arterials, 18% on highways, and 42% on residential streets.

The resulting diurnal driving and start distributions for all vehicle in Shanghai is shown in Table V.1. Since no data was collected between 0:00 and 06:00 and between 21:00 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. A total of approximately 1.4 million vehicles were assumed to be in daily operation in 2003 in the Shanghai Metropolitan Area. Since we only have the starts data for passenger cars, this data was applied to the other vehicle classes for this study.

Table V.1: Estimated Fraction and VMT and Starts By Hour in Shanghai Metropolitan Area

Time of Day	Estimated Driving Fractions in Each Hour	Total Estimated Driving by Hour (kilometers)	Fraction of Starts in Each Hour	Total Estimated Starts by Hour
0:00	1%	509282	1%	93410
1:00	1%	509282	1%	93410
2:00	1%	509282	1%	43112
3:00	0%	203713	1%	43112
4:00	1%	305569	1%	79039
5:00	1%	509282	1%	79039
6:00	2%	1018564	6%	431122
7:00	3%	1456771	6%	431122
8:00	10%	5292456	8%	596385
9:00	10%	4786255	8%	596385
10:00	6%	2813074	6%	416751
11:00	6%	3087266	6%	416751
12:00	4%	2082907	6%	395195
13:00	4%	2210273	6%	395195
14:00	7%	3616810	6%	409566
15:00	8%	4483887	6%	409566
16:00	7%	3057885	7%	524531
17:00	7%	3315409	7%	524531
18:00	7%	3932589	5%	352083
19:00	5%	2614714	5%	352083
20:00	3%	1557238	2%	172449
21:00	3%	1527846	2%	172449
22:00	2%	1018564	1%	86224
23:00	1%	509282	1%	86224
	Total	50,928,200		7,185,360

(Data in red had to be estimated from data collected in other urban areas since these times were not observed in Shanghai)

The calculations shown above are considered to be approximations and more extensive measurements should be completed in Shanghai to improve the estimate of total daily driving in Shanghai and hourly driving outside of the hours measured in this study.

Several assumptions were made in the technology survey, it is recommended that the technology distribution of the bus and truck fleets in Shanghai should be further improved. Motorcycle technology distribution was quoted directly from Pune data. Moped technology also needs to be surveyed in Shanghai.

Figure V.1 shows the modeling results using the data developed from this study for carbon monoxide (CO). The top line reflects start and running emissions added together.

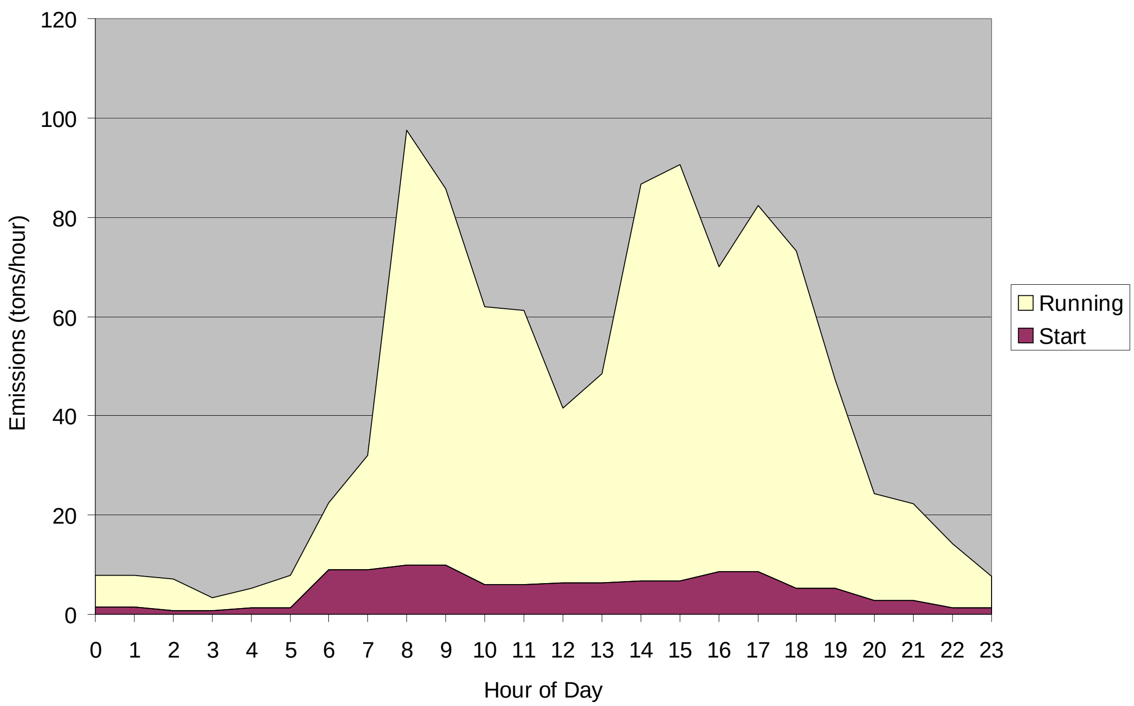

Figure V.1: Overall Shanghai Carbon Monoxide Emissions

The peak CO emissions are occurring around 08:00, 15:00 and 17:30. The minimum during the day occurs around 12:00. Off course, emissions are very low from 21:00 to 05:00. It is also valuable to note the contribution of start emissions in Shanghai. Overall, Figure V.1 reflects a total of 1009 metric tons of CO emitted per day into the air over Shanghai or an overall daily average emission rate of 19.8 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.

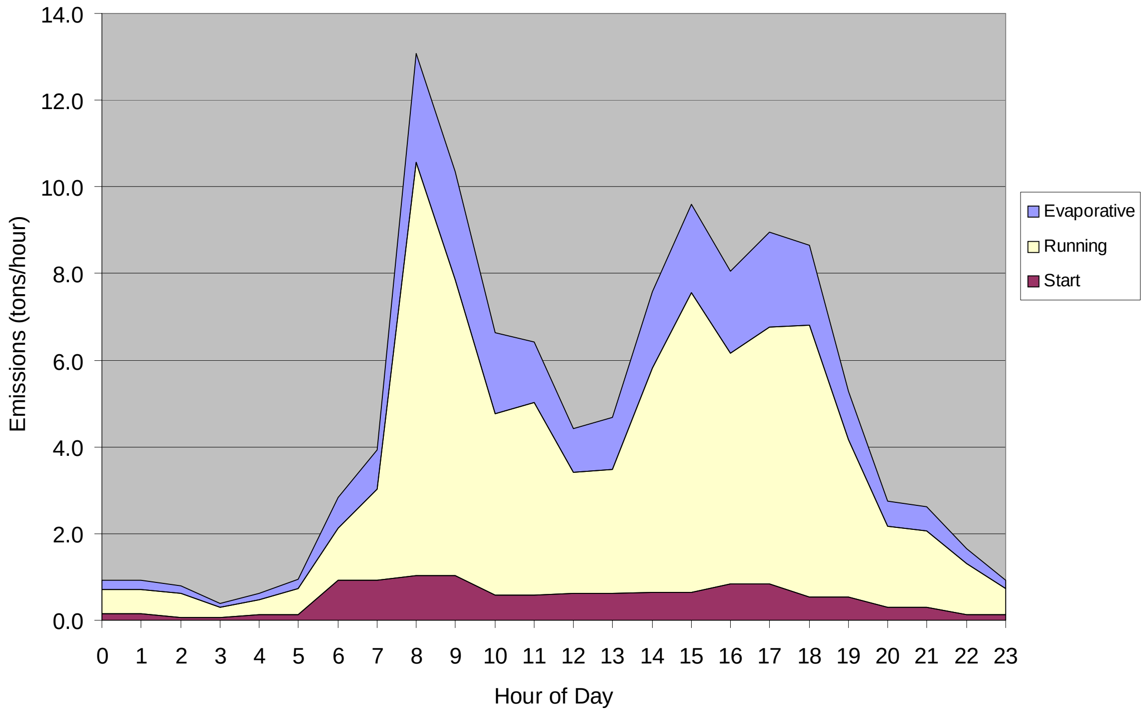

Figure V.2: Overall Shanghai Volatile Organic Emissions

There are two VOC peak emissions, one occurring in the morning, which could facilitate ozone formation. Since motorcycle and mopeds make up a large portion of the travel, VOC emissions are quite high. Both start and evaporative emissions contribute to the overall VOC emissions as well. Figure V.2 reflects a total of 113 metric tons per day of VOC emissions emitted over Shanghai or an overall daily average emission rate of 2.2 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. As is the case for CO and VOC, there is a bimodal distribution of emissions with the largest peaks occurring in the morning and the afternoon. Figure V.3 reflects a total of 189 metric tons per day of NOx going into the air over Shanghai or an overall daily average emission rate of 3.7 grams/kilometer including starting and running emissions.

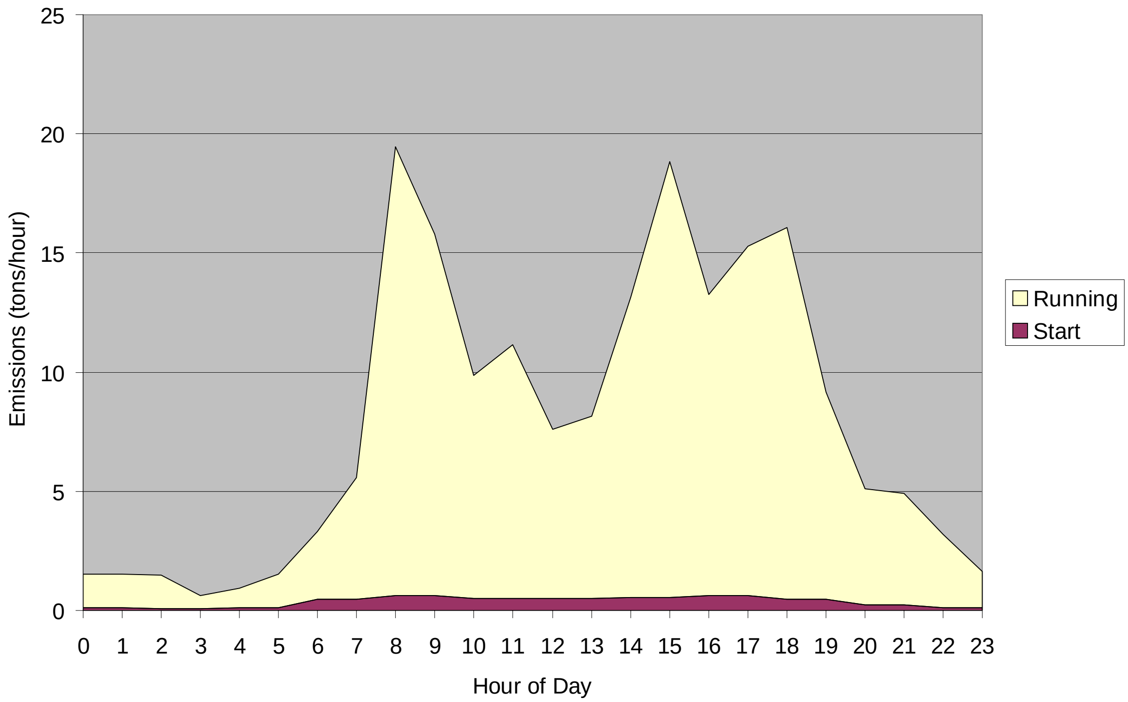

Figure V.3: Overall Shanghai Nitrogen Oxide Emissions

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 significant. Figure V.4 reflects a total of 3.6 metric tons per day of PM going into the air over Shanghai or an overall daily average emission rate of 0.07 grams/kilometer including starting and running emissions.

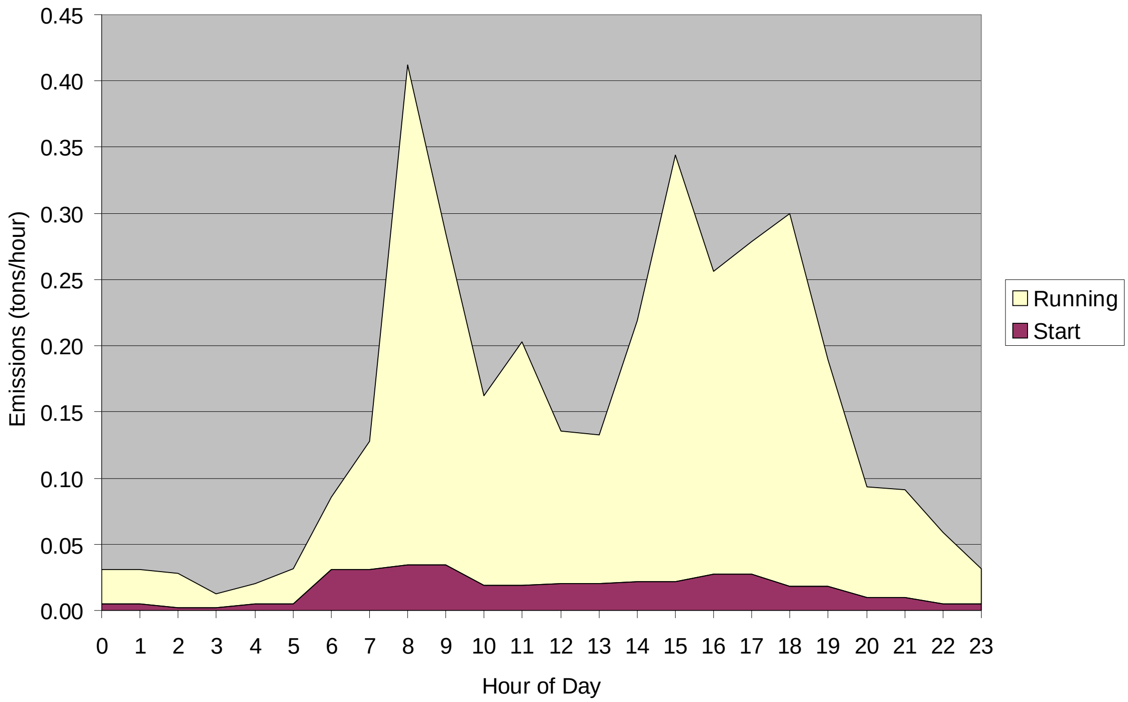

Figure V.4: Overall Shanghai Particulate Matter Emissions

Figures V.1-V.4 are calculated based on a total daily driving of 50 million kilometers and a fleet of 1.3 million vehicles. The emission numbers will of course have to be modified if the total kilometers per day measured in Shanghai are greater than 50,000,000 and/or if the number of vehicles actually operating daily is different from 1.3 million.

Driving behavior plays a very important role on vehicle emissions. Table V.2 indicates the emission rates of different vehicle pollutants from passenger cars on three road types. As can be seen, passenger cars on arterials had lowest velocity of 12.61 km/hr and highest fraction of BIN 12, so the emission rates per distance traveled for each pollutant is much higher than on other roadways. And passenger cars on highways, which had the highest velocities and lowest BIN 12, resulted in an emission rate that is half of that on other roadways. Obviously, driving activity has an important effect on the vehicle emission rate, indicating that traffic management techniques applied in Shanghai may be a useful method for reducing emissions.

Table V.2 Comparison of Emission Rate of Passenger Vehicles on Every Road Types

	Average Velocity	BIN12	Emission Rate, g/km				
Results	km/hr	%	CO	VOC	NOx	PM	CO2
PCHighway	31.97	42.9	6.26	0.53	0.94	0.006	263
PCResidential	17.11	57.8	13.99	1.20	1.60	0.012	432
PCArterial	12.61	69.9	15.79	1.50	1.83	0.014	547

To better understand the emissions created from the Shanghai vehicle fleet, it is useful to look at the contribution of each type of vehicle class. For Shanghai, the major vehicle categories include light duty passenger vehicles and trucks (PC), two wheeled vehicles (2w), mopeds (mopeds), taxis (taxis), buses (Buses), and trucks (Truck). The overall estimated on-road emission rate, including start and evaporative emissions, for each type of vehicle is shown in Figure V.5.

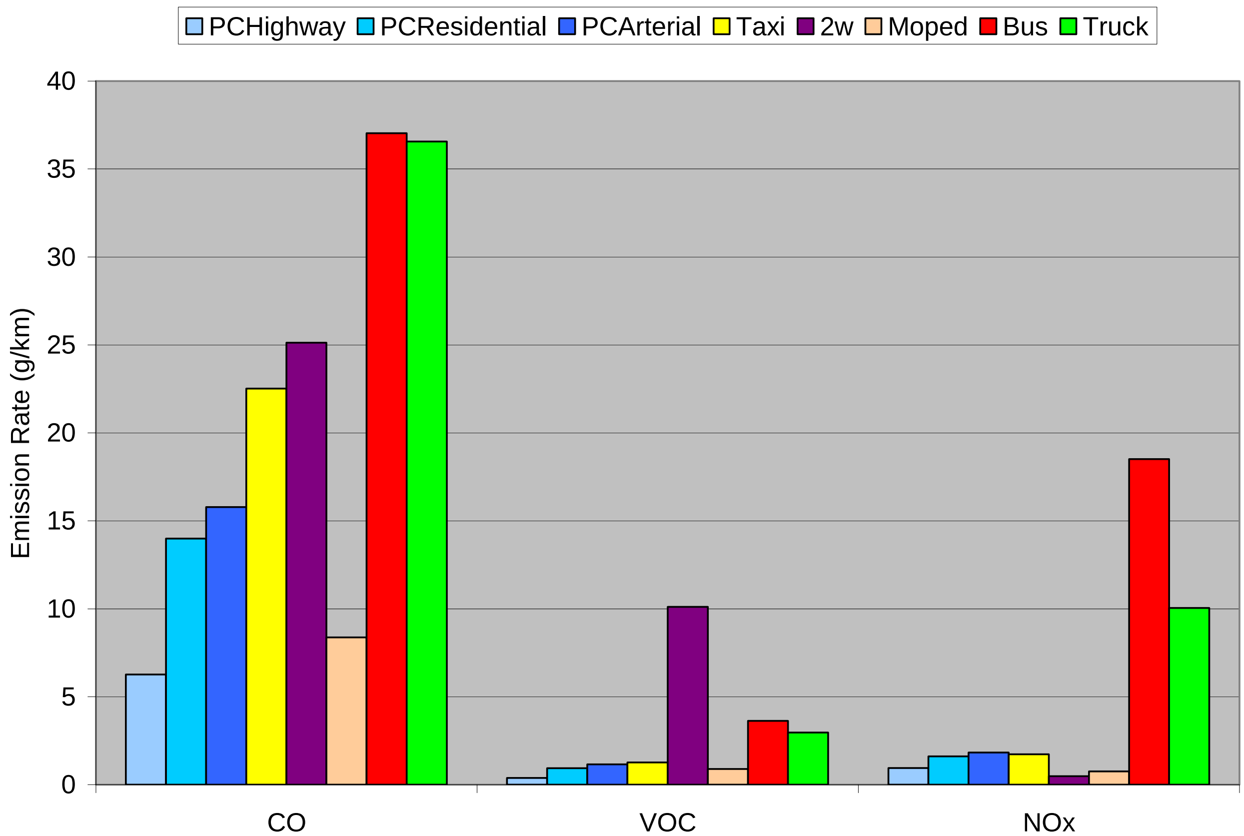

Figure V.5 Emission Rate for each Type of Vehicle in Shanghai

The overall emission contribution to the mobile source inventory can be considered using the emission rate from each vehicle type and the travel fractions of each vehicle type. The fraction of travel from each vehicle type is shown in the last column of Figure V.6. The percent contribution each of these vehicle types to vehicular CO, VOC, NOx, and PM emissions is also shown in Figure V.6. Passenger vehicles, taxis and mopeds represent the majority of the travel in Shanghai. The majority of vehicular CO is from light duty passenger vehicles and taxis. Coincidentally, all of the vehicle types have the same overall VOC emissions even though their emission rates are very different. Because of their high emission rate, buses and trucks and 2 wheelers create most of the NOx and PM emissions.

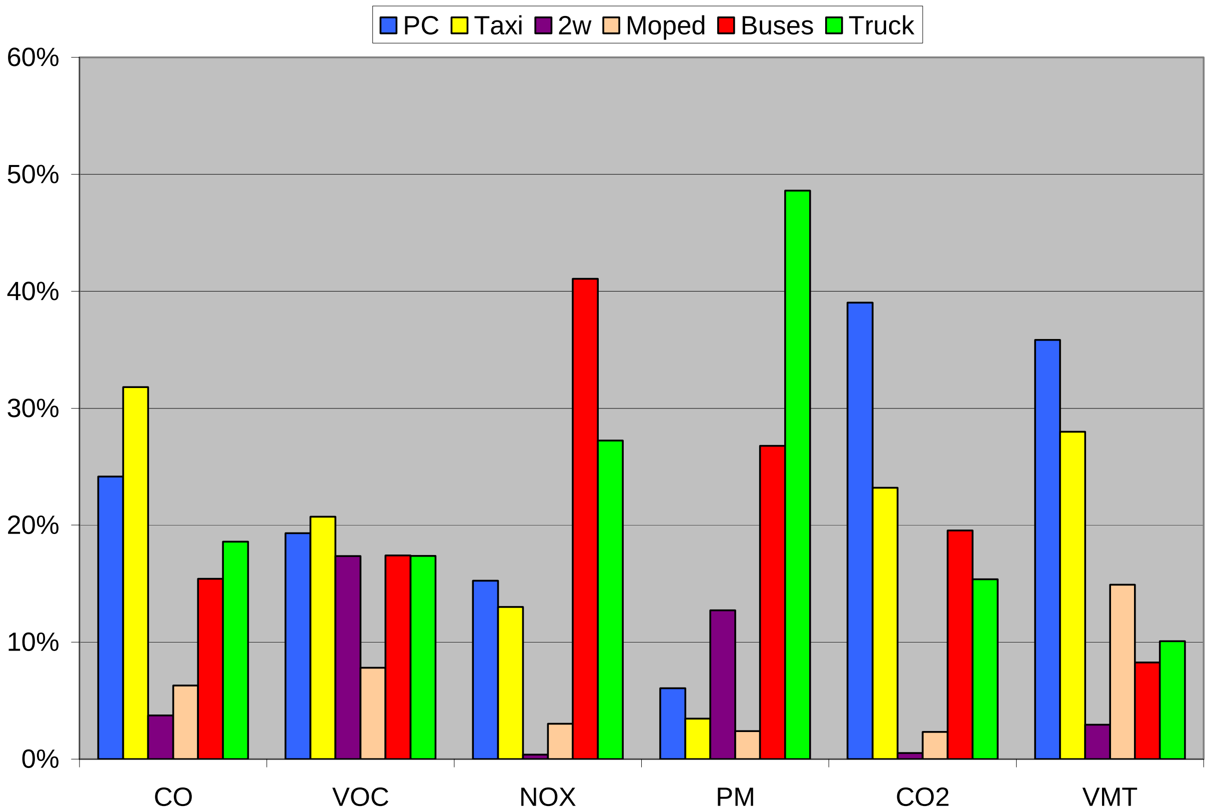

Figure V.6 Emission and VMT Contribution of Each Vehicle Type in Shanghai

Clearly, to reduce PM emissions in Shanghai, buses and trucks must be controlled. To reduce NOx, buses, trucks, and passenger vehicles must be further controlled. Since many mopeds in Shanghai have been retrofitted to be cleaner than before, the emissions from mopeds were much lower than motorcycles. With the development of economy in Shanghai, more private passenger cars are replacing mopeds. This will greatly influence the travel distribution in the various vehicle categories, and move the profile to one similar to Beijing's travel distribution. Figure V.7 provides an illustration of a scenario where all moped travel is replaced by additional passenger cars travel , while keeping the overall VMT the same. In this scenario, because the emission rate of passenger vehicles is higher than that for mopeds, CO, VOC and NOx emissions will increase nearly 1.3-1.4 times, PM will increase 1.1 times.

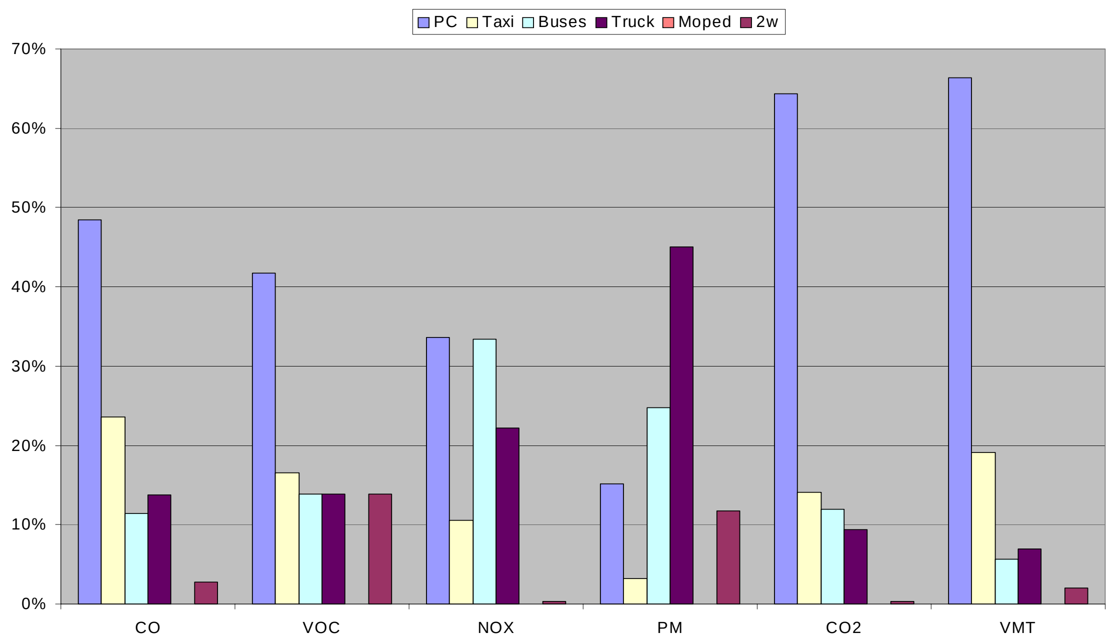

Figure V.7 Emission Contribution of Each Vehicle Type (Modified) in Shanghai

Another calculation of interest is the overall per kilometer emissions of Shanghai vehicles compared to vehicle fleets in cities of other countries. Figure V.8 compares Shanghai with Los Angeles, Santiago, Mexico, Nairobi, Pune and Beijing. These locations have a very different profile of vehicle fleet, fuel type, and driving patterns.

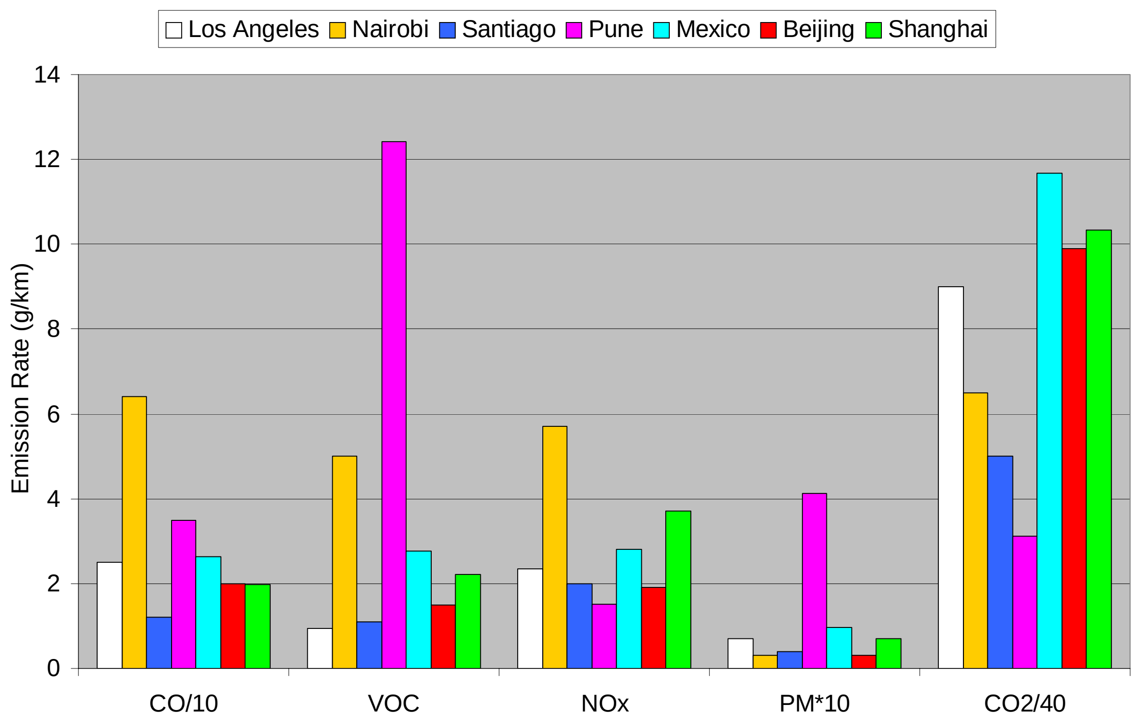

Figure V.8: Comparison of Daily Average Emission Rates in Countries Studied to Date

The Shanghai fleet has the second lowest emissions of CO because of the low fraction of passenger cars, but relative high emission of PM, NOx and CO2 from the heavy duty vehicles like buses and trucks. The high PM emissions are particularly troubling because they suggest a high emission rate of toxics. Figures V.6 and V.8 illustrate the possibilities that if emission rates were lowered, significant emissions reductions could be achieved in the Shanghai area. Compared with Beijing, only CO emission are lower, because Beijing has much higher percentage of passenger vehicles than Shanghai. Since more than 19% of travel is from heavy duty vehicles (buses and trucks) in Shanghai while Beijing only had 7%, NOx, PM and CO2 were all higher in Shanghai. The high fraction of travel from motorcycles contributes to the high emission rate of VOCs.

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

1. To improve the vehicle emissions from the vehicle fleet in Shanghai, additional surveys on the technology distribution of trucks, motorcycles and mopeds, which take up nearly half of the fraction of vehicle population, should be conducted.

2. Investigate the variation of the fleet, activity and fuel quality on areas beyond Shanghai if extrapolations are to be made to the entire metropolitan area.

3. Improve emission factors for in-use vehicles. Local emission studies are needed to verify the operating emissions of passenger vehicles, motorcycles, mopeds, buses and trucks in Shanghai to insure that the best emission factors are being used. Some in-use vehicle emissions are being tested by an on-board vehicle emission test unit, the Semtech-D, in September to October in Shanghai. However, a more extensive emissions testing study including passenger vehicles, motorcycles, and mopeds is highly recommended.

4. Improve the estimate of total VMT for the entire Shanghai region to support overall emission estimates.

5. Directly measure toxic emissions from these vehicles to better quantify the toxic emission rates from these sources.

6. 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 Shanghai database.

Appendix A

Data Collection Program Used in Shanghai

International Vehicle
Emissions Model

Field Data Collection Activities

Table of Contents

A.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 cShanghaitic 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 A.1.

Table A.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. ISSRC will work with the urban area to suggest ways to make such assessments.

A.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 are 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[3]. 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.

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.** ISSRC 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.**

[3] 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.

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[4] 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 A.1 shows an example of three street-segments designed for an upper-income area in Los Angeles, California.

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

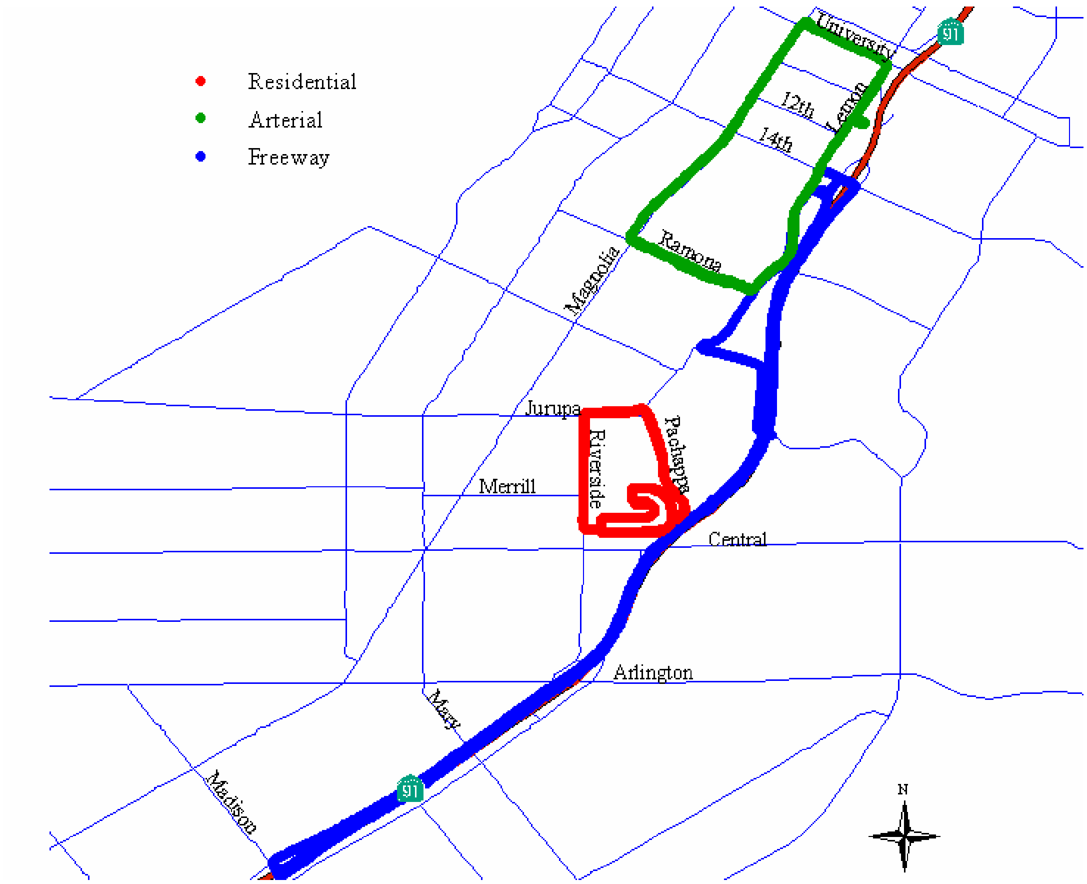

Figure A.1 Example of a Residential, Arterial, and Freeway Street-Segment Selected for a Single Study Area

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.** ISSRC will review the nine selected street sections and make recommendations as necessary.

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.

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.

A.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 A.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 A.2 CGPS Unit

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[5]. The local study

[5] 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[6]. Figure A.3 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 A.3: 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.

---

6 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 A.2: 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.

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[7].

<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 ISSRC personnel reach the study area.</u>

[7] 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.

A.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 A.4 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 roadways, 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 A.4: Cameras collecting data on a residential roadway in Santiago, Chile

Camera Setup on the Overpass

Picture of the Freeway Below

Figure A.5: 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 ISSRC staff to develop the needed data for establishing on-road fleet fractions. ISSRC will provide two videotape readers and laptop computers to support analysis of the data during the data collection process.

A.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.

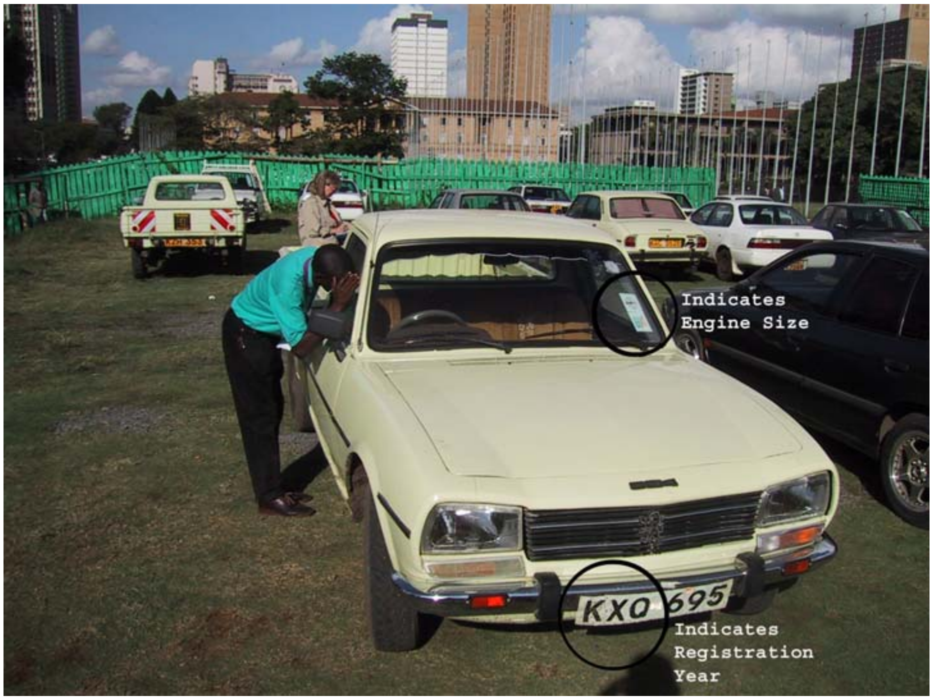

Figure A.6: Parking Lot Data Collection in Nairobi, Kenya

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.

A.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. ISSRC 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.

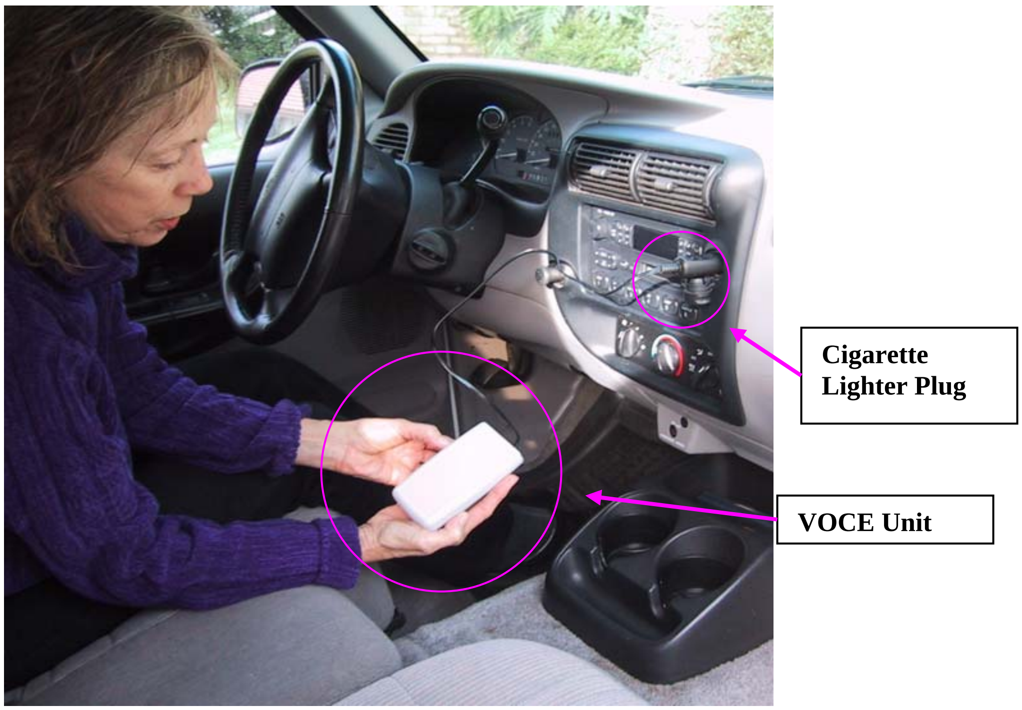

Figure A.7: VOCE Unit for Collecting Vehicle Start Information

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 ISSRC team reaches the location**. The VOCE units are distributed within the first 24 hours after arrival of the ISSRC 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, ISSRC 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**.

A.VII. Research Coordination and Local Support Needs

In order to properly carry out the data collection and processing outlined in this paper, both ISSRC and local support are needed. ISSRC will provide 2 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 A.3 below outlines the needed ISSRC and local support requirements.

Table A.3: Study Support Requirements

ISSRC 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 A: 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 B: 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 B: 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 B: 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/B: 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 A: 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 A/B: Support data analysis.		
Total Personnel Requirements		
2 ISSRC 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 ISSRC team members and intervening weekends.

Table A.4 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 A.4: 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@issrc.org
or
Nicole Davis
1-909-781-5795
ndavis@issrc.org

Example of the 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.

Example of the 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.						

Appendix B

Daily Log of the Data Collection Program Conducted in Shanghai

Shanghai IVE Vehicle Activity Study – Daily Log

Day One (Saturday, June 5, 2004)

Arrived at the Shanghai airport and, after a phone call to Professor Chen, connected with Haikun and one other student who had a vehicle and driver to take us to the hotel. Nick had a short meeting with Professor Chen in the evening. All seems to be progressing well. Arranged to meet at the Academy at 1:30 pm on Monday to provide a training session to the participants in the study. Nick indicated he wanted to visit the routes and video taping locations to make sure everything would be fine. Professor Chen indicated it shouldn't be necessary.

Day Two (Sunday, June 6, 2004)

A day off. Went shopping in the old town district of Shanghai. Dr. Matt Barth arrived in the late afternoon.

Day Three (Monday, June 7, 2004)

Visited an area similar to the silk market in Beijing. Met at the Academy with Professor Chen and the participants in the study. The office spaces provided for the study are very nice. The roof of the building should be a good place to acclimate the CGPS units. Again, discussed the need to look at the routes and video-taping locations in advance of the start of the project. Professor Chen indicated no one would be available on Tuesday to do that because they would be involved in giving out the VOCE units. We arranged to bring the VOCE units to the Academy at 8 am on Tuesday and then insert the batteries and reset the clocks. We should then be in a position to provide them with the VOCE units by around 9 am. Got back to the hotel and Haikun and another student came to say they needed 5 VOCE units to give to trucks. Nick put in the batteries and reset the clocks (see VOCE reset log). Two units that had not worked in Beijing appeared to be working fine and will be used for the Shanghai study.

Day Four (Tuesday, June 8, 2004)

Dr. Jim Lents left to return to the U.S. at about 6 am. Four CGPS batteries (No.s 1,2,3, and 4) were put on to charge at 7:20 am. Matt and Nick took the 76 VOCE units (4 units remain out of service – No's 5, 24, 27, and 126) to the Academy at 8:00 am and put batteries in them and reset their clocks. The reset times are recorded in excel format in the Shanghai VOCE Reset file. A young lady (Lily) from another university will be shuttling two CGPS units between the academy and a trucking company. Her university is much closer to the location of the truck company. We agreed to provide her with two CGPS units in the afternoon/evening. She will take them to her university and, the next morning, will take them to the truck company. The battery will be disconnected and she will be shown how to connect the battery and acquire satellites to make sure everything is working properly at the start of the day. After calling the truck company, the young lady indicated that the trucks stop working around 4 or 5 pm. She can collect the CGPS units then and bring them back to the academy. Nick and Matt will then download the data and reset the CGPS memory and put in a fresh battery so she can, again, take the unit to her university for the night. Professor Chen came in with a friend and said he would ride a motorcycle so we could collect motorcycle data. It was decided that one of the prototype units would be used for this purpose. The person was instructed to bring a backpack and wear a helmet. This person will then drive during seven hour periods each day on a variety of roadways in a variety of areas of the city. Batteries 1,2,3, and 4 were taken off the charger at 11:25 am and Batteries 5, 6, 7, and 8 were put on the charger at 11:40 am. Matt and Nick carried the CCGPS units over to the academy along with batteries 1, 2, 3, and 4. Units batteries 3 and 4 were placed in CCGPS units 9 and 10 and those units were taken to the roof of the academy building to acquire satellites while Nick and Matt ate lunch (provided by Professor Chen). Once the units had acquired satellites, Lily, the young lady who will shuttle the units between the academy and the trucks, was given a short lesson on how to operate the units. Following that, batteries 1 and 2 were used to power the rest of the CCGPS units (1, 2, 3, 5, 6, 7, and 8) while they acquired satellites. Haikun and Chang did most of the acquisition work. The plan is to leave at 2 pm to tour the routes and video taping locations. Batteries 5,6,7 and 8 were taken off the charge at 1:55 pm and Batteries 9, 10, 11, and 12 were placed on the charger at 2:00 pm. Matt and Nick and several of the students went in the van hired by the academy and drove the routes for the Residential-2 area (Area C). At the beginning, it was raining quite hard. Based on driving the routes in area C, it would not be surprising to see the freeway speeds to be slower than the speeds on the arterial and residential routes. The freeway section, which appears to be about 3 miles long, took 33 minutes to complete. The arterial route, which appears to be about 4.5 miles long, took 36 minutes to complete. The residential route took 30 minutes to complete. The video taping location for the freeway section is located in a building. They were apparently planning to video perpendicular to the flow of traffic across all the lanes in both direction. Matt advised that they film towards the NE so they only get the traffic in the lanes coming from the NE towards the SW. The videotaping location for the arterial route is on an overpass that overlooks an intersection. The first section of the arterial route is heavily tree covered with Sycamore trees that come completely over the road. However, the CGPS unit continued to receive satellite signals during the drive. The residential is residential, however, it is hard to distinguish it from an arterial route. It will be interesting to see how the speeds turn out between the two routes. Upon returning to the academy, the van driver said that she would provide Matt and Nick with a cell phone that they can use during their stay in Shanghai. When the phone was delivered, it had been equipped with a calling card and Nick reimbursed the driver 150 yuan for it. During the night, Nick will make sure the batteries are charged and will arrive at the academy at 5:45 am to put the batteries in the CCGPS units and to take them on the roof to make sure they acquire satellites. Matt will arrive at 6:00 am and will spend most of the day with the video taping team that will be working in Area A (Residential area 1). The Taxi's are scheduled to arrive at the academy at 6:30 am to receive their CCGPS units. All 76 of the VOCE units were reportedly given out during the day. Batteries 9, 10 11, and 12 were taken off the chargers at 6:00 pm. Batteries 1 and 2 were put back on the charger since they had been used to get the CCGPS units acclimated. Batteries 13 and 14 were also placed on the charger at 6 pm. Batteries 1 and 2 were removed at 9 pm. Batteries 15 and 16 were then put on the charger at 9:10 pm. The chargers were turned off at 10 pm.

Day Five (Wednesday, June 09, 2004)

Turned on battery chargers at 5:30 am. Nick took batteries to the academy and put them in the CGPS unit and then went on the roof and acquired satellites. Battery 1 was placed in Unit 1, 2 in 2, 9 in 3, 5 in 5, 6 in 6, 7 in 7, and 8 in 8. All 7 units (1,2,3,5,6,7,8) quickly acquired. Matt and the video taping crew left at 6:00 am. The bus riders had not been at the training session and Mr Chan gave them information on the CGPS use. Nick demonstrated how to use the Velcro tape in the event the roof on the bus is not metal. They were given CCGPS units 7 and 8. At approximately 7:30 am, one of the bus riders called Professor Chen to tell him he was concerned because the light was blinking. After speaking with Nick, Professor Chen let him know that it was okay and the light should be blinking. Nick was informed that 4 of the 5 VOCE units that had been given to the taxi's had been returned because the taxi's did not have cigarette lighters. Cars 1, 2, and 3 arrived and were given units 1, 2, and 3, respectively. Nick was told the two taxi's would be late because today is a very special day when all of the students are taking a very important test (probably the test that determines their future educational status) and the cabs are busy taking them to the test locations. Professor Chen went out front of the academy and called in two taxi's off of the street. He talked to them and they agreed to transport a CCGPS unit for the day. One agreed to carry one of the VOCE units. The two original taxi's then arrived. One of them agreed to carry a VOCE unit. A woman came by and picked up two VOCE units. Upon inquiry, Nick was informed the two units were for passenger cars and were not the two still remaining for taxi cabs. Nick was also informed that the motorcycle rider would be late because his wife had recently returned from the hospital and he needed to provide some care for her. At 9:30 Nick was informed the motorcycle rider was on his way. When he arrived, he did not have a back pack so, Nick provided the one from his luggage. The unit was turned on, acquired satellites, and the motorcycle rider departed at approximately 9:05 am. Professor Chen reported that all the VOCE units for the Taxi's had been given out to taxis. Nick went back to work in his hotel room and arranged to meet at 12:00 with Professor Chen. Batteries 13, 14, 15, and 16 were removed from the charger at 12:00. Batteries 17, 18, 19, and 20, were put on the chargers at 12:00. Following lunch, provided at the academy by Professor Chen, Nick took his computer to the academy to download CGPS data as the units are returned in the afternoon. The units from the passenger Cars, Buses, and Taxis arrived and were downloaded. Matt and the members of the video taping team arrived. Battery 7 became fully discharged immediately after the data for Bus 1 was downloaded. All of the other batteries continued to have a charge after the download. The data appears to be good. After Nick downloaded several of the CGPS units, the students downloaded the remainder. A copy of the data was then provided to the students so they could work on processing it. Professor Chen wishes to purchase a CCGPS unit and asked that he be given the very lowest possible price. Nick told him that the person he has hired to build the units in the past has now taken another job and may not be available to build any other units. Nick will check and let Professor Chen know by email if a unit can be built for him and, if so, how much it will cost. Batteries 17, 18, 19, and 20 were removed from the chargers at 4:30 pm. A student came to the hotel with 5 VOCE units and said that they could not place them in buses because the buses do not have cigarette lighters. Nick suggested that the five units be placed in passenger cars instead. The battery for Prototype CCGPS unit (Unit 13) was plugged in to charge at 4:30 pm. Batteries 1,2 5, and 6, were placed on the chargers at 4:40 pm. Within 3 or 4 minutes the charger for batteries 1 and 2 showed it had changed from the peak charging rate to the trickle charge rate suggesting that the batteries still had a high state of charge even after being used in Cars 1 and 2 for today's routes. At approximately 6 pm the CGPS units used for the trucks (Units 9 & 10) were returned. Downloading occurred without a problem. Batteries 3 and 4 were replaced with batteries 10 and 11 and the units were given back to Lily to provide to the trucks tomorrow. Lily was asked to try to get information on the trucks. Nick provided Lily with a copy of the CGPS and Raw data for Day One as well as the folder containing the software for down loading the CCGPS data. The battery pack for unit 13 was removed from the charger at approximately 9 pm. Batteries 1, 2, 5, and 6, were removed from the chargers at 9:55 pm.

Day Six (Thursday, June 10, 2004)

Placed batteries in the CCGPS units as follows: Unit 1-12, 2-13, 3-14, 5-15, 6-16, 7-17, 8-18. All the units, including the prototype (unit 13) quickly acquired satellites. Cars 1, 2, and 3 left on time. The video crew left by 6:30. By 7 am the only unit that had not been given out was unit 6 for Taxi 2. Mr Chan indicated the Taxi would be there shortly so Nick left the unit with him to install in the taxi and he returned to the hotel to have breakfast with Matt. Batteries 3, 4, 7, and 8 were placed on the chargers at 7:15 am. Matt and Nick met with the first pair of students who will view the videos from day one. They are using a number of counters to collect the data. A photo will be taken to show this technique. Nick worked on logs while Matt met with Professor Chen and worked more on the digital mapping. Matt learned that the team doing the parking lot surveys is having difficulties due to the number of vehicles with digital odometers and heavily tinted windows. Nick did a small survey in the parking lot of the academy and found that out of 5 vehicles there, he could only read the mileage on one of them. CGPS units began returning around 1:40 pm and Nick downloaded them. After all the units, except for those on the trucks, had been downloaded, Matt and Nick left the academy. They returned at 5:30 pm to await the arrival of Lily and the CGPS units from the two trucks. Professor Chen indicated that 170 vehicles had been surveyed today. The video taping of the license plates has not been working. Because of the video taping locations (high above the roadways) and the manner in which cars move across lanes, the license plates cannot be clearly seen on the highway and arterial routes. The camera operators are going to try to move the license plate camera to a more advantageous location instead of operating it side by side with the vehicle count camera. While waiting for Lily to arrive, Matt and Nick had the opportunity to discuss the issue of the parking lot surveys with Professor Chen. It turns out that during Day One and Day Two, the survey sheets do not reflect the vehicles that either had digital odometers that could not be read or tinted windows that prevented reading the odometer. Matt and Nick expressed concern that this might result in a bias in the data and the misimpression of the general age of the vehicle fleet. It is expected that the vehicles being missed are, in general, newer in age. Starting with Day Three, all vehicles will be recorded on the survey sheet and, if the odometer can not be read that space will be left blank with an indication of why. Professor Chen will be asked to insure the parking lot survey data is segregated by day when it is input into the computer. That way, Days Three, Four, Five, and Six can be used for determination of the age of the vehicle fleet. Lily arrived shortly after 6 pm and the two CCGPS units from the trucks were downloaded and the batteries were replaced with batteries 19 and 20. Batteries 3,4,7, and 8 were removed from the chargers at 8:00 pm.

Day Seven (Friday, June 11, 2004)

The battery pack for U13 was placed on the charger at 1:00 am and removed at 7:15 am. Batteries 9, 10, 11, and 12 were placed on the charger at 7:30 am. Nick went with Professor Chen and some of the parking lot survey team to survey vehicles near the People’s Square in the center of Shanghai. The parking lot is below ground which made it more difficult to see into the interior of the vehicles because of the heavy tinting. Even with flashlights it does not work very well. While the VIN numbers located at the front edge of the dash (just inside the windshield) often provide the model year, the numbers are often covered by things placed on the top of the dash. A significant number of the odometers are digital and only a few of those can be read. There were three teams of parking lot surveyors out today with one in each of the three areas. Nick left and returned to the academy arriving shortly after noon. He placed batteries in the CCGPS units in the following order: CCGPS unit 1 – 1, 2-2, 3-3, 5-5, 6-6, 7-7, and 8-8. Although the battery for U13 had charged for over 5 hours, the state of charge indicator showed the charge to only have a 60% charge. Matt then brought over the battery he had charged for the other Prototype CGPS unit and when connected to U13, it only showed a 40% state of charge. At this point, it is assumed the state of charge indicator is malfunctioning since it did that with another Prototype unit in an earlier study. U13 was assigned to the motorcycle using the battery that Matt had charged. All the other CCGPS units were given out to the vehicles in the same order as the previous two days. The driver for Car 2 said that they could not use the same car as they had used for the first two days and asked if it would be okay to use another vehicles. Thinking he meant another passenger car, Nick said that would be fine. However, when the vehicle arrived, it was a 16 passenger small bus. At that point, it was too late to find another passenger vehicle so it was sent out. The data may not be representative of how passenger vehicles are driven since the bus is more unwieldy and probably can't be maneuvered in traffic as well as a passenger vehicle. Nick discussed the need to collect data on the bus and truck fleet with Professor Chen. It will be discussed again on Monday. Batteries 9 and 10 were removed from the charger at 6:00 pm. Matt has developed a digitized map of Shanghai that will be workable for the activity study. Professor Chen indicated that each of the teams surveyed more than 400 vehicles today – many of which did not provide odometer readings. Nick and Matt got the impression that Professor Chen felt this concluded the parking lot survey effort. They will urge that more surveys be conducted since the first two days of surveying excluded vehicles for which odometer readings could not be obtained. Lily arrived at 6:50 pm. Downloaded the data from Trucks 1 and 2. Replaced the batteries with batteries 9 and 10 in CCGPS units 9 and 10 respectively.

Day Eight (Saturday, June 12, 2004)

Matt and Nick took the train to Hongzhou and spent the night there. Prior to leaving, the CCGPS units were locked up in the work room at the academy and the computer was locked up in a Pelican case in the hotel room. In addition, a copy of the data to date was kept in Matt's room.

Day Nine (Sunday, June 13, 2004)

Matt and Nick returned from Hongzhou at approximately 1 pm. Batteries 13, 14, 15, and 16 were put on to charge at 1:30 pm. Removed batteries 12, 14, 15, and 16 at 7:30 pm. Placed batteries 1, 2, 3, and 5 on chargers at 7:45 pm. Matt charged the battery pack for U13. Removed batteries 1,2,3, and 5 from chargers at 10 pm.

Day Ten (Monday, June 14, 2004_

A very hot and humid day. Placed batteries 3 and 5 back on charger along with 6 and 7 at 5:30 am. All CCGPS units quickly acquired satellites. Provided units to Mr. Chen to checkout to the proper vehicles. Mr. Chen had a new backpack for the motorcycle driver. Car 2 is back to being a passenger vehicle today. The video taping crew left at approximately 6:15 am. Nick, Matt, Professor Chen, and Lily had a discussion in regard to gathering data on the truck and bus technologies. Nick and Matt suggested that someone from the academy call several truck companies and try to set up times for meeting with each of them. Professor Chen thinks they will not want to meet and it is unclear if anyone is going to try to contact any trucking companies other than the one that Lily is working with to gather the CGPS data. It is also unclear what is going to occur in regard to the gathering of bus engine technology data. Batteries 3, 5, 6, and 7 were removed at 10:20 am. Batteries 17, 18, 19, and 20 were placed on the chargers at 1 pm. All of the CCGPS units were returned, with the exception of the two on the trucks, and were downloaded without a problem. A short video was taken of the students using the bank of counters to count vehicles in the video tapes. Later in the day, Professor Chen called and said that the truck company using the CGPS units has invited Nick and Matt to meet with them either this afternoon or tomorrow morning. Nick suggested that tomorrow morning might be the better time. Nick left the borrowed cell phone in a taxi cab when returning to the hotel in the afternoon. When Professor Chen called the cell phone number, it indicated that the cell phone was no longer in service. Professor Chen said that it is common for the cab drivers to pull the Sims card out of cell phones left in their cabs and all they have to do is put in a different Sims card and they have a working cell phone with a different telephone number. Nick had the receipt for the cab ride and it indicates the license number of the cab. Mr. Sun at the hotel is attempting to contact the cab company and see if they can get the phone returned. If not, Nick will purchase a new Nokia phone, along with a Sims card, to replace the borrowed phone. Matt and Nick arrived back at the academy to meet Lily at 6 pm. Professor Chen indicated she was delayed because the trucks were returning late. He left just before 7 pm indicating he would return in half of an hour and that Lily should be back by then as well. Batteries 17, 18, 19, and 20 were taken off the chargers at 7 pm. Batteries 1, 2, 4, and 8 were placed on the chargers at 7:05 pm. At a little after 8 pm, Professor Chen's voice was heard in his office. Nick asked him if he had heard from Lily. He indicated she was still at the truck company and the trucks had not yet returned. Nick and Matt decided to go out to eat supper since it would at least be another half of an hour before Lily would arrive. Lily arrived around 9:20 pm. Both units were downloaded without problem and batteries 19 and 20 were put into CGPS units 9 and 10 respectively. Professor Chen, Matt, and Nick had an opportunity to talk about the need for additional information on the Bus and Truck fleets. Citing the Shanghai Urban Transportation Management Bureau as his source, Professor Chen provided the following statistics: Shanghai bus fleet consists of 18,000 buses. 5,000 to 6,.000 buses are gasoline powered. 140 to 150 are powered by CNG. 200 are electric trolleys. The remainder are diesel powered. At this point, he does not have any statistics on the size of the engines and the average kilometers traveled. In further conversation, Professor Chen stated a belief that the sale of gasoline in Shanghai is on the order of 1.5 million tons per year. Nick arranged to meet with Professor Chen at 6:45 am to travel to the trucking company to gather information on the truck fleet. Batteries 1, 2, 4, and 8 were removed from the chargers at 11:00 pm.

Day Eleven (Tuesday, June 15, 2004)

A rainy and windy day. Nick met with Professor Chen at the academy at 6:45 am. They traveled by taxi to the Shanghai Chemical Trucking Transportation Company and met with Lily there. They then met with Mr. XuYong and two other managers from the trucking company. They were very hospitable and willing to take the time to talk with Professor Chen, Lily, and Nick. The company is one of 25 transportation related companies in the Shanghai Transportation Group. The company has 56 trucks which would be classified as medium trucks in size. The trucks are capable of hauling from 2 tons to 20 tons of fuel oil. 9 of the trucks are diesel – rated at 210 HP. Fuel injection was said to be "not electric injection, use high pressure." The remaining 47 trucks are gasoline powered and are rated at 135 HP. All of the gasoline trucks are carbureted. Over 80% of the gasoline trucks are "more than 9 years old.". When they reach 10 years of age, they are replaced. They are being replaced with diesel trucks. There are two manufacturers of the diesel trucks: JieFang and

DongFeng, DongFeng has two models – EQ140-2 and EQ4116-G. The JieFang trucks are three years old and the others are less than one year old. The trucks average 400,000 km over their 9 years of driving. It is estimated that "more than 50% of the driving is outside of Shanghai." The trucks are operated on Monday through Friday although, they occasionally work on weekends. The trucking company basically hauls residual oil for heating fuel to various businesses in and around the metro area. They thought there are approximately 100,000 trucks in the Shanghai vehicle fleet. Of that number, 4800 are haulers of hazardous materials. Fuel consumption is measured in liters per 100 ton-kilometers. The gasoline trucks average 42.6 liters per 100 ton-kilometers and for an unloaded truck it is about 26 liters per 100 ton-kilometers. When asked what they know about the other trucks in the group, they suggested that we talk to someone at the group office. Professor Chen then called a friend, Zhang Gu Feng, at the group office and arranged to meet with him. Professor Chen, Lily, and Nick then met with Mr. Zhang and Mr. Gu. They reported that there are 7,000 trucks and buses within their 25 companies. They have both passenger buses and trucks for hauling goods. There are 260 buses – all are diesel – that carry passengers on the highway to/from Nanjin, another city approximately 320 km west of Shanghai. The average age of the buses is 4 years. The engines run from 300 to 350 hp and are all direct injection. VKT is estimated to be 150,000 km/year. The buses consume 27-28 liters per 100 kilometers traveled. Some consume 30 liters per 100 kilometers. The buses, depending on their internal configuration, 41, 45, or 47 passenger seats. A few have a 30 seat capacity. Of the 6740 trucks in their fleet, approximately 1/3 are gasoline and 2/3 are diesel. The displacement of the engines ranges from 2L to 9L and, from 75 to >300 HP. 30% of the trucks are reported to be in the 2L size, another 30% in the 5L size range, and the remaining 40% in the 9L size range. It is estimated that 70% of the travel is done within the city of Shanghai. The trucks generally operate 7 days/week although less on weekends than weekdays. This transportation group is reportedly the largest one in Shanghai. When asked how large the Shanghai truck fleet is, Mr. Gu looked on the internet (www.jt.sh.cn) and said he believed there are more than 120,000 trucks. In response to queries regarding the VKT, it was stated that the Buses and Trucks combined average 42,000 km/year. The buses average 146,700 km/year and the trucks average 35,200 km/year. Batteries 13, 14, 15, and 16 were placed on the chargers at 1:00 pm. Peter Wonscott, the China Correspondent for The Wall Street Journal, arrived at 1:30 pm to learn about the study and to see if he could glean any information in regard to the current and projected environmental impact of China's rapid growth in vehicle population. During the discussion, Mr. Wonscott reported that China does not allow vehicles older than 10 years to be driven on its roadways (although there can be special exceptions). This would help to explain the lack of 1993 and older model year vehicles in the inventories from the parking lot surveys. Lily arrived at the academy at approximately 6:30 pm with the GPS units for the two trucks. They were downloaded and the batteries were replaced with batteries 17 and 18. Batteries 13, 14, 15, and 16 were removed from the chargers at 9:00 pm.

Day Twelve (Wednesday, June 16, 2004)

Matt met with Professor Chen, QianHua, DaiHaiXia, and other members of the parking lot survey team to conduct a final survey. They surveyed vehicles in a large underground parking lot very close to the academy. Approximately 250 vehicles were surveyed. Reportedly, approximately 30+% of the vehicles had digital odometers that could not be read. Nick charged the two battery packs for the prototype GPS units using the intellichargers. Nick and Matt took the batteries over to the academy and loaded them in the CGPS units. Mr. Chen checked them out to the drivers/riders. Taxi 1 left without having his CGPS unit (unit 5) turned on. After 15 or 20 minutes, he was contacted through the taxi company's dispatcher and he then turned the unit on. The motorcycle rider was equipped with both Prototype CGPS units since the battery for U13 is suspect. Three VOCE units have been turned in so far. Matt remained at the academy to work on a slide presentation and Nick returned to the hotel to start packing equipment and materials for the return trip to California. Lily brought in the two units from the trucks which were downloaded without problem. 17 VOCE units were returned and 16 were downloaded. Two displayed aperiodic voltage readings of 25.375 volts. 1 would not communicate with the computers. Most showed large clock deviations even though they were downloaded on the same computer that had been used to reset the clocks when the batteries were first inserted last week. The remainder of the CGPS units arrived and were downloaded. The battery in prototype CGPS unit 13 had apparently become depleted during the data collection period. It does not seem to accept a charge. Prototype CGPS unit 14 did appear to have collected data during the entire period. Professor Chen asked to be reminded tomorrow about the need to meet with the bus company representatives. Since several of the CGPS units were damp from all the rain, the cases were left open overnight in Nick's air conditioned hotel room.

Day Thirteen (Thursday, June 17, 2004)

Since the CGPS units will be stored in their cases for the next several weeks, Nick used the hotel's hair dryer to further dry out the CGPS units and cases. They were then packed in the appropriate cases as listed in the customs declaration. Matt is working on the exit presentation that will be given later in the day to the participants. Downloaded all but three VOCE units. They will be turned in tomorrow. Matt provided an exit presentation.

Had supper with Professor Chen and four of his students/colleagues. Met with Mr. Huang JiaLiang, Technical Services Manager at the Number One Bus Company. The Number One Bus Company is the third largest bus company in Shanghai. There are approximately 50 different bus companies in the city. The Pudong Bus Company is the largest and the Number Four Bus Company is the second largest. Mr. Huang confirmed that, in total, there are 18,000 buses in the Shanghai bus fleet. His company has 1,200 buses sized as follows:

Number of Seats	Passenger Capacity	Length (meters)	Number of Buses	Engine Size	Fuel Consumption (L/100 km)	Fuel Type
27		7	40	70 kW	16	Diesel
30	80-100	10	300	99 kW	28-30	Gasoline
34 w/AC 24 w/no AC	100	10-11	300	130 kW		Diesel
30	80 or 8 tons	11	250	150 kW		Diesel
36	70-80	12	150	169-192 kW		Diesel
30	70-80	11.5	200	160 kW		Diesel

On average, the buses travel 120-130 km per day, 7 days a week. Almost 98% of the fleet is in service at any point in time. 4 am to 11 pm are the normal operating hours. Additional buses are put on the streets during the peak hours. During the night hours there are 30 special routes the buses travel.

From memory, Mr. Huang stated that 300 buses are 7-8 years old, 530 are 4-6 years old, 12 buses are 3 years old, 45 buses were purchased in 2004, and the remainder are 2 years old. He then provided the following tables from existing records:

Bus Ages

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Number of Buses in use	55	66	270	189	286	90	15	72	130	27

Fuel Consumption

Bus Type	A/C	Fuel type	Age (Years)	Length (meters)	Fuel Consumption (L/100km)
CJ	N	G	5	10	32.85
KP	Y	G	7	10	32.59
5P	N	G	7	10	31.08
6P	N	G	8	10	27.74
DK	Y	D	8 months	10	36.77
Y02	N	D	2 months	10	31.68
CK	Y	D	5	12	37.45
3P	N	G	8	10	24.53
GC	N	D	8	10	23.92
YC	N	D	2	10	33.4
OK	Y	D	3	12	38.66
FK	Y	D	5	12	35.16
PD	N	D	5	11.5	30.36
P3	N	D	5	11.5	29.12
H4	N	D	4	10	34.00
HP	N	D	5	11.5	31.05
YZ	N	D	6	7	15.67
PK	Y	D	5	11.5	36.74
HK	Y	D	5	11.5	39.64
VK	Y	D	2	12	42.95
H3	N	D	4	10	32.08
JS	N	D	5	11	39.12
GK	Y	CNG	1	11	49.2
ZK	Y	CNG	1	11.5	56.18
JL	N	D	5	10	46.21

Mr. Huang reported that buses are replaced at 8 years of age. All the diesel engines are direct injection. He indicated the total number of CNG buses is 30 and they are 179 kW and 11.t meters in length.

The VKT for May, 2004 was provided as follows: 5,062,744 km

In discussion with the students while waiting for Mr. Huang, the following information was gleaned: Cars with licenses from other provinces cannot drive on highways in Shanghai between approximately 6:30-8:30 am and 4:30-6:30 pm. If you own a car with Shanghai license you have to pay 250 Yuan per month for road maintenance. For some people, this is a reason to obtain license plates from outside of the city. The government is trying to limit the growth of the vehicle population and only give out a small number of Shanghai license plates. Since vehicles with Shanghai license plates can be driven throughout the city, they are prized. The students report these plates are purchased through an auction system and can cost as much as 25 to 30% of the average cost of a vehicle. A Shanghai C license plate can be obtained much cheaper but, it only allows driving outside of the outer ring road and the vehicle cannot be driven into the city at any time.

Day Fourteen (Friday, June 18, 2004)

Nick and Matt met with Sabrina at 9 am and traveled to a phone store where Nick purchased a Nokia cell phone to replace the one he left in the taxicab. Nick then gave the phone to the van driver when he came to pick Matt up to take him to the airport. Nick then went to the academy at 10 am and downloaded the data from 2 VOCE units. At 2 pm, Nick met with Lily and Huang and went over the data they had collected from the bus company visit yesterday to make sure their notes coincided. The last VOCE unit (unit 29) arrived and was downloaded. Nick collected original copies of field notes and as the electronic data available at that time. Mr. Chen will email the VOCE tracking records to Nick next week. Ms. Dai will email Nick the complete set of parking lot surveys (translated into English) as soon as they are completed. 3 copies of the Shanghai IVE Activity Study were burned onto CD's and provided to SAES.