Kazakhstan Vehicle Activity Study

Conducted May 18 - 30, 2003

University of California at Riverside

Global Sustainable Systems Research

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I. Introduction

Almaty, Kazakhstan was visited from May 19, 2003 to May 30, 2003 to collect and analyze data related to on-road transportation. The study effort was designed to support estimates of the air pollution impacts of on-road transportation in Almaty 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 cities in Kazakhstan to support environmental improvement efforts in the other cities as well. The data collection effort was a partnership between Almaty local and regional governments, universities, and non-government officials, the USEPA and USAEP offices, staff from Global Sustainable Systems research, and the University of California at Riverside. In all, about thirty persons participated in data collection activities over an approximate two week period.

The study was designed:

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

The technology distribution of vehicles was developed using a combination of two approaches. Vehicles were video taped on a variety of streets and the video tapes were reviewed to count the numbers of the various types of vehicles plying Almaty streets. Typically in the field studies, parking areas are also surveyed to collect specific technology information about vehicles operating in the local area. However, Almaty officials had already collected similar information, so this activity was not performed in this study.

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

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

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

II. Vehicle Technology Distribution

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

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

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

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

It is not possible using the video taping process to determine the exact nature of the vehicle technologies observed. The video taping allowed the determination of the fractions of trucks, buses, passenger vehicles, 2-wheelers, 3-wheelers, and such operating on the roadways of interest. To understand the specific technologies of local vehicles, parking survey data are used. Normally, the team members conduct this parking lot survey as part of the field testing program with help from local mechanics, government, and University officials. Parking surveys allow careful inspection of vehicles so that the engine technology, model year, control equipment, and fuel type can be established. The parked vehicle surveys are used to estimate the more specific natures of the general vehicle classifications determined from the video tape studies. Figure II.2 illustrates a parking lot survey process in Nairobi, Kenya.

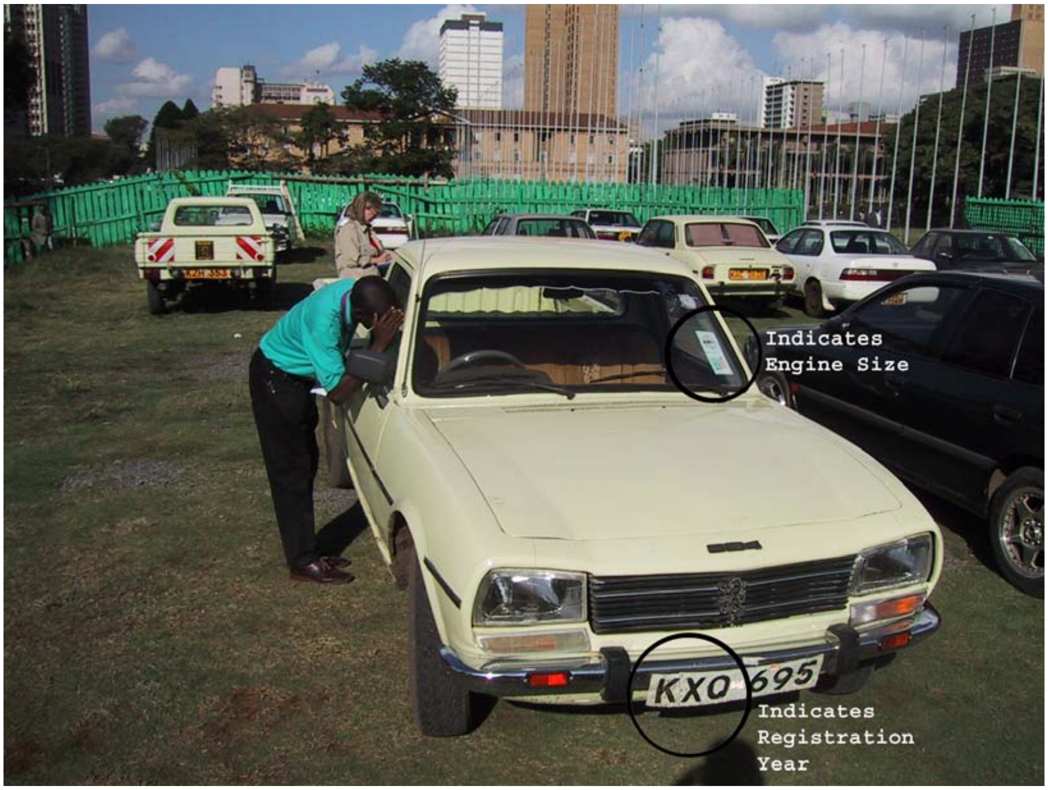

Figure II.2: Parking Lot Survey in Nairobi, Kenya

In the case of this field study, Almaty officials conducted a vehicle owner survey instead of the typical parking lot survey normally performed by the field team. The Almaty officials conducted this survey prior to the arrival of the field team and independent from the University and GSSR, but the data provided in the appendix detailing the logistics and datasheets used for recording the data were used in the development of the altered survey. The results from the vehicle owner survey will be presented and used in this report instead of the parking lot survey data. There is one cautionary note about using a vehicle owner's recollection instead of having a local mechanic visually inspect the vehicle as is done in the parking lot survey. The error rate of a vehicle owner accurately reporting the odometer reading is potentially larger than a mechanic reading the odometer reading on the vehicle itself. Additionally, it was found in the owner survey that the owners did not accurately report whether their vehicle was equipped with exhaust control devices. Many owners reported that their vehicles were equipped with these devices when in fact they were not. For this reason, the owner's data on control devices was disregarded and the advice of the local mechanics was used to determine which vehicle types had controls.

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

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

Table II.1 Video Locations Surveyed in Almaty, Kazakhstan

Street Type	Description	Date and Hour of Surveys
Highway-A1	Highway in South Almaty near foothills	Mon, May 26/14:00; Mon, May 26/17:00; Mon, May 26/20:00; Wed, May 28/08:00; Wed, May 28/11:00
Highway-B1	Highway in West Almaty outskirts	Tue, May 27/16:00; Tue, May 27/19:00; Thu, May 29/07:00; Thu, May 29/10:00; Thu, May 29/13:00
Highway-C1	Highway in North East Almaty	Mon, Tue, Wed or Thurs: 07:00; 09:00; 11:00; 13:00; 15:00; 17:00; 19:00;
Arterial-A2	Arterial roadway in South East Almaty	Mon, May 26/15:00; Mon, May 26/18:00; Wed, May 28/09:00; Wed, May 28/12:00; Wed, May 28/13:00
Arterial-B2	Arterial Roadway in West Almaty	Tue, May 27/14:00; Tue, May 27/17:00; Tue, May 27/20:00; Thu, May 29/08:00; Thu, May 29/11:00
Arterial-C2	Arterial Roadway in North East Almaty	Mon, Tue, Wed or Thurs: 08:00; 10:00; 12:00; 14:00; 16:00; 18:00; 20:00;
Residential-A3	Residential Roadway in Central Almaty	Mon, May 26/16:00; Mon, May 26/19:00; Wed, May 28/07:00; Wed, May 28/10:00
Residential-B3	Residential Roadway in West Almaty	Tue, May 27/15:00; Tue, May 27/18:00; Thu, May 29/09:00; Thu, May 29/12:00

IIa. Video Analysis

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

Table IIa.1: Results of Analysis of Almaty Videotapes

Road Type	Area	Time	Vehicles/hour	Passenger Vehicle	Small Truck	Medium Truck	Large Truck	Small Bus	Medium Bus	Large Bus	2-Wheel
Arterial	A-2	9:00	1195	85%	2%	3%	0%	9%	1%	1%	0%
Arterial	A-2	12:00	1683	87%	1%	1%	0%	8%	1%	1%	0%
Arterial	A-2	15:00	1742	87%	1%	2%	0%	8%	1%	1%	0%
Arterial	A-2	18:00	1510	86%	1%	1%	0%	8%	2%	1%	0%
Arterial	B-2	8:00	695	64%	2%	0%	0%	24%	5%	5%	0%
Arterial	B-2	9:00	766	67%	1%	1%	0%	20%	4%	7%	0%
Arterial	B-2	11:00	791	71%	2%	2%	0%	16%	3%	5%	0%
Arterial	B-2	12:00	625	70%	3%	1%	0%	17%	3%	5%	0%
Arterial	B-2	14:00	839	83%	2%	1%	0%	12%	2%	1%	0%
Arterial	B-2	15:00	869	76%	3%	1%	0%	11%	4%	5%	0%
Arterial	B-2	17:00	835	82%	2%	0%	0%	12%	3%	1%	0%
Arterial	B-2	18:00	770	74%	1%	0%	0%	17%	2%	5%	0%
Arterial	B-2	20:00	874	79%	1%	0%	0%	14%	2%	4%	0%
Arterial	C-2	8:00	1873	87%	2%	1%	0%	7%	1%	0%	0%
Arterial	C-2	10:00	2200	83%	4%	4%	0%	7%	1%	1%	0%
Arterial	C-2	12:00	2254	82%	7%	3%	1%	7%	0%	1%	0%
Arterial	C-2	14:00	2356	87%	4%	3%	0%	6%	0%	1%	0%
Arterial	C-2	16:00	2008	84%	6%	2%	0%	6%	1%	1%	0%
Arterial	C-2	18:00	2283	86%	4%	1%	0%	7%	1%	0%	0%
Arterial	C-2	20:00	1755	90%	2%	1%	0%	6%	1%	1%	0%
Highway	A-1	7:00	193	86%	5%	3%	0%	5%	2%	0%	0%
Highway	A-1	8:00	1571	92%	2%	0%	0%	6%	0%	1%	0%
Highway	A-1	11:00	1396	90%	2%	1%	0%	5%	0%	1%	0%
Highway	A-1	14:00	1964	91%	3%	2%	0%	3%	0%	2%	0%
Highway	A-1	16:00	2027	92%	2%	0%	0%	5%	0%	0%	0%
Highway	A-1	20:00	1948	95%	2%	0%	0%	2%	0%	0%	0%
Highway	A-1	17:00	1984	87%	6%	2%	0%	4%	0%	0%	1%
Highway	B-1	7:00	812	82%	2%	1%	1%	9%	4%	1%	0%
Highway	B-1	8:00	1225	88%	1%	3%	0%	5%	2%	1%	0%
Highway	B-1	10:00	876	88%	2%	2%	0%	6%	2%	0%	0%
Highway	B-1	11:00	1112	83%	5%	4%	0%	6%	1%	1%	0%
Highway	B-1	13:00	1194	84%	2%	5%	0%	6%	1%	2%	0%
Highway	B-1	14:00	1128	85%	4%	6%	0%	4%	1%	1%	0%
Highway	B-1	16:00	1150	84%	3%	5%	1%	4%	2%	1%	0%
Highway	B-1	17:00	1282	85%	2%	5%	0%	4%	2%	2%	0%
Highway	B-1	19:00	1288	85%	3%	2%	1%	7%	1%	1%	0%
Highway	B-1	20:00	1078	93%	1%	1%	0%	4%	0%	1%	0%
Highway	C-1	7:00	677	76%	1%	1%	0%	18%	3%	2%	0%
Highway	C-1	9:00	1394	82%	4%	3%	1%	9%	0%	1%	0%
Highway	C-1	11:00	1336	82%	6%	1%	1%	9%	0%	1%	0%
Highway	C-1	13:00	1087	81%	3%	2%	0%	14%	0%	1%	0%
Highway	C-1	15:00	1507	86%	4%	1%	1%	8%	0%	0%	0%
Highway	C-1	17:00	1386	82%	3%	3%	0%	11%	1%	1%	0%
Highway	C-1	19:00	1382	85%	5%	0%	0%	8%	1%	1%	0%
Residential	A-3	10:00	513	89%	6%	2%	0%	1%	1%	0%	0%
Residential	A-3	13:00	487	92%	2%	0%	0%	5%	1%	0%	0%
Residential	A-3	16:00	466	85%	1%	6%	0%	7%	1%	0%	1%
Residential	A-3	19:00	415	93%	4%	1%	0%	1%	0%	0%	0%
Residential	B-3	7:00	143	56%	4%	2%	0%	26%	0%	12%	0%
Residential	B-3	9:00	189	67%	2%	3%	0%	17%	2%	10%	0%
Residential	B-3	10:00	228	71%	4%	4%	1%	13%	0%	7%	0%
Residential	B-3	12:00	208	70%	9%	0%	0%	15%	0%	6%	0%
Residential	B-3	1300	207	62%	7%	4%	0%	16%	0%	10%	0%
Residential	B-3	15:00	186	77%	2%	0%	0%	15%	0%	6%	0%
Residential	B-3	16:00	175	69%	0%	3%	0%	17%	0%	8%	2%
Residential	B-3	18:00	262	76%	2%	0%	0%	16%	0%	6%	0%
Residential	B-3	19:00	315	82%	2%	0%	0%	12%	0%	4%	0%
Overall Arterial	---	---	1396	80.52%	2.51%	1.38%	0.13%	11.20%	1.91%	2.31%	0.04%
Overall Highway	---	---	1291	85.96%	2.99%	2.18%	0.28%	6.72%	0.92%	0.92%	0.03%
Overall Residen.	---	---	292	76.16%	3.45%	2.08%	0.10%	12.48%	0.26%	5.29%	0.18%
Overall Almaty	---	---	---	81.84%	2.74%	1.69%	0.18%	9.92%	1.46%	2.13%	0.05%

The overall distribution shown in the last row shown of Table IIa.1 is a weighted distribution of the results of the three road types. The appropriate weighting factors can be calculated if the activity fraction on each of the roadway types is known and the relative lengths of each roadway is known. Because the exact length of roadways was not available, it was assumed by visual observation of maps of Almaty that 45% of the roadways in Almaty are arterial, 25% are highway, and 30% are residential. Based on this assumption and the measured average traffic volumes on each road type, it is calculated that 60.0% of overall travel in Almaty occurs on arterials, 28% on highways, and 13% on residential streets. These values were used to weight the travel and the fleet distribution values.

There are two existing reports that have estimated the fleet distribution of vehicles in Kazakhstan. For comparison purposes, these are displayed in Table IIa.2. The distribution observed in this study is fairly consistent with the data reported in other studies, except that there were more buses observed in this study. The majority of the buses observed in this study were minibuses. There may be some discrepancy in the definition of a truck and a bus from the studies referenced and the definition used in this study, which may account for some of this difference. A bus and a truck are defined in this study as a vehicles that weigh at least 9000 lbs. The primary importance of distinguishing between trucks and buses in this study is not for technology differentiation, but differences in activity. A bus is defined in this study as a vehicle that transports 8 or more people. The activity for a bus can be significantly different than a heavy duty truck.

Table IIa.2: Comparison of Fleet Distribution from Various Studies

Vehicle Type	Kazakh Report for Year 2000	Draft Inventory Report for Year 2001	Video Survey for Year 2003
Passenger Cars	87%	81%	81%
Trucks	8%	15%	5%
Buses	3%	4%	14%
Other	2%	0%	0%

IIb. Vehicle Owner Survey

The vehicle owner survey in Kazakhstan was conducted by NIIT officials instead of the parking lot survey. The goal of the survey was to identify the specific engine technologies, drive train, control technologies, air conditioning, total use, and model years of the vehicles surveyed. The focus was aimed at passenger vehicles, since the vast majority of the Almaty fleet are these vehicles. The survey was conducted at the entrance of malls and grocery stores as vehicle owners were on the way to their vehicles. The NIIT personnel asked the owner to recall their vehicle type, model year, odometer reading, and if the vehicle was equipped with exhaust controls. Approximately 1150 passenger vehicles were surveyed. Table IIb.1 indicates some of the general characteristics observed in the surveyed fleet. The exhaust control distribution in Table IIb.1 was obtained from the expert opinion of the local mechanics, not the vehicle owner's recollection. The results indicate the vast majority (93%) of the passenger vehicles are not equipped with a catalyst.

Table IIb.1 General Characteristics of the Surveyed Passenger Car

Passenger Vehicle Technology	Fraction of Passenger Vehicles
Carburetor, No Catalyst, No EGR	44%
Carburetor, Catalyst, No EGR	0%
Fuel Injection, No Catalyst	43%
Fuel Injection, Catalyst	7%
Diesel, Pre-Injection	3%
Diesel, Improved	2%

The Kazakhstan passenger vehicle fleet is generally of medium engine size (1301-2000 cc) with more than 160,000 kilometers of use. Table IIb.2 indicates the engine size and use distribution of the passenger vehicle fleet.

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

Vehicle Engine Size	Low Use (<80 K km)	Medium Use (80-161 K km)	High Use (>161 K km)
Small (<1301 cc)	3%	5%	6%
Medium (1301-2000 cc)	15%	23%	31%
Large (>2000 cc)	4%	7%	5%

Figure IIb.1 illustrates the model year distribution for active passenger vehicles in Almaty obtained from the vehicle owner survey. This distribution is more evenly distributed and has a higher fraction of older vehicles than is observed in many other developing nations, and is similar to a distribution seen in areas with a saturated market or slow vehicle growth. The absence of significant numbers of 2003 vehicles in the Almaty fleet is predominately due to the fact that the survey was taken during the first quarter of 2003. It is likely that the fraction of 2003 vehicles in the fleet will ultimately at least approximate the 2001/2002 fraction.

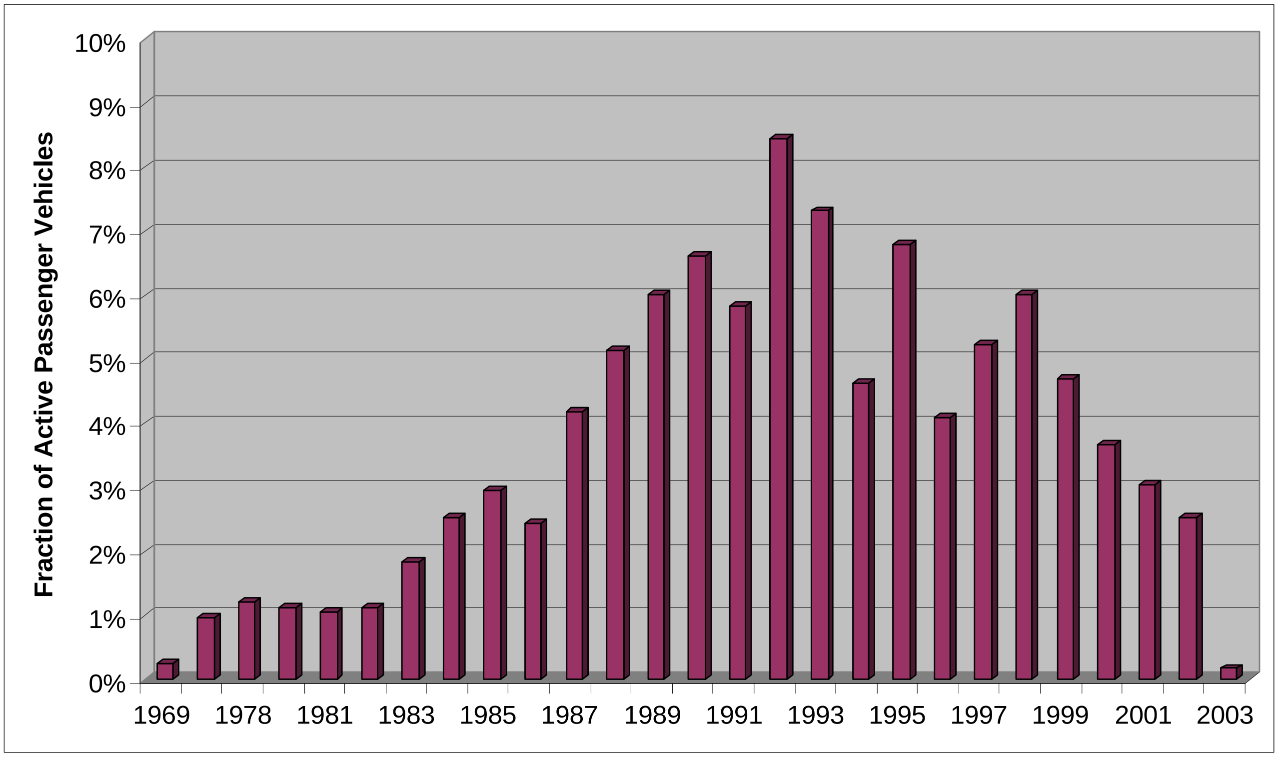

Figure IIb.1: Model Year Distribution in the Almaty Passenger Vehicle Fleet

The age distribution data is extremely different than the age distribution reported by the Agency for Statistics for passenger vehicles in the calendar year 2000 [1] (Table II.b.3). Some of the discrepancy may be explained because the data are from three years earlier, but that should not account for all of the difference. This age distribution is an important component of estimating emissions and even modest discrepancies can have significant effects of the uncertainty in emissions estimates. The Agency's data is what is expected from a region where recently vehicle sales have increased significantly in recent years, like is seen in other developing nations. However, other data from the Agency indicates that in Almaty there has been only modest and perhaps even negative vehicle growth in Almaty in the past five years [1]. If the latter data is reflective of the true conditions in Almaty, then the older fleet distribution measured in this study may be reasonable.

Table IIb.3: Age Distribution Comparison [1]

Age Group	Current Study, 2003	Agency of Statistics, 2000
10+ years	52%	8%
<8 years	36%	80%

IIc. Vehicle Use

Odometer data was recorded during the vehicle owner surveys for passenger vehicles. Two reports are available for Almaty that have data on vehicle use for trucks and buses, and overall vehicles operating in Almaty [1,2]. Thus, some approximation of the use of vehicle types can be made and this can be extrapolated to make approximations of total vehicle use for Almaty. There is an unknown error associated with the odometer data collected in the vehicle owner survey, as there is in all surveys where a person is asked to recall data, but it is reasonable to assume this error is relatively small and unbiased since most owners know the mileage on their vehicle within a couple thousand kilometers.

Figure IIc.1 on the next page shows the passenger vehicle use taken from vehicle odometers. The figure also includes a second order least square fit to the data. As is typical for the United States and all other countries studied so far, vehicle use decreases with vehicle age. A new passenger car in Almaty will be driven about 18,000 kilometers per year, whereas a very old vehicle is only driven about 10,000 kilometers per year. Using the age distribution illustrated in previous Figure IIb.1, the average passenger car age in Almaty is 11 years. This translates to an average daily driving of 41 kilometers of driving per day or about 15,000 kilometers per year. The scatter in the data for the high use years is due to the small numbers of vehicles observed with higher ages and the fact that the odometers themselves become unreliable. The equation shown in Figure IIb.1 will produce unreasonable results if extrapolated beyond 25 years due to the uncertainty in the odometer readings for older vehicles. It may be more appropriate to replace the second order term in the vehicle use equation with a value that is similar in a relative sense to those measured in other countries.

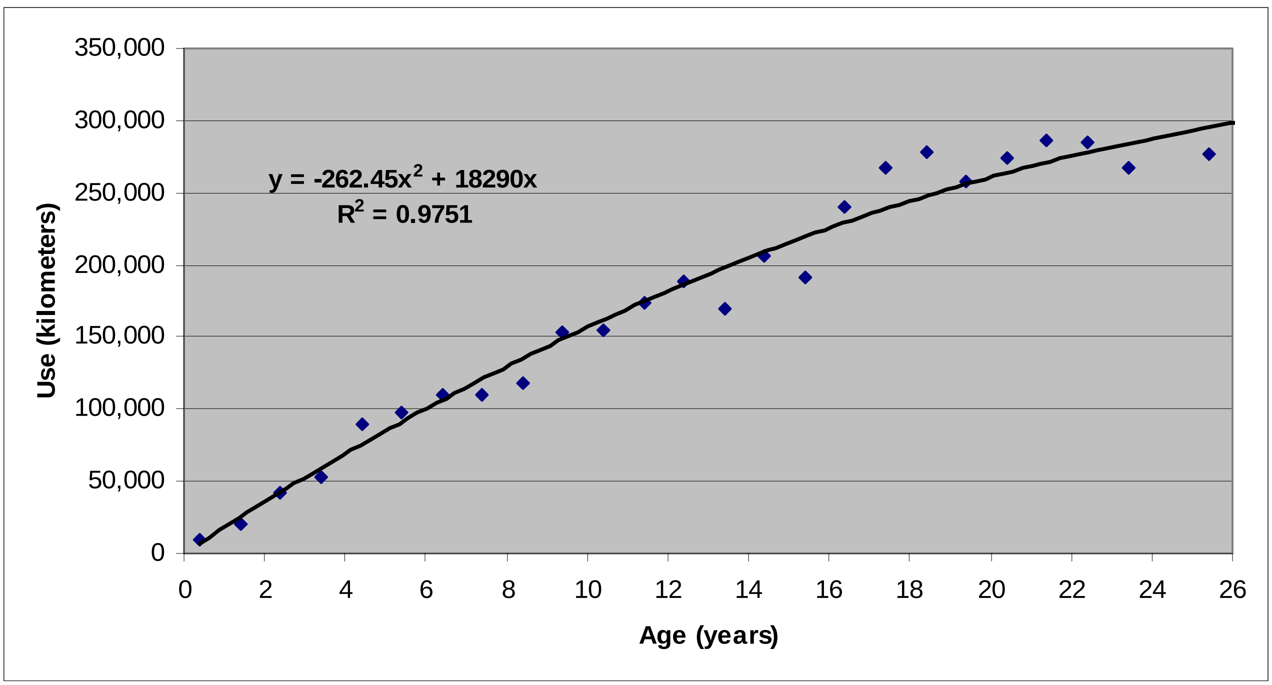

Figure IIc.1: Passenger Vehicle Use During the First Twenty Five Years of Age in Almaty

There are two other sources of vehicle use data besides the surveyed odometer data in this study. This data is shown in Table IIc.1. The last column shows the data used to estimate the vehicle use in this study. The survey data was used for passenger vehicles, and the average of the data from the other two studies was used for the Truck and Bus use data.

Table IIc.1: Average Vehicle Use from Parking Lot and other Data Sources (km/day) [1,2]

Vehicle Type	Kazakh Report for Year 2000	Draft Inventory Report for Year 2001	Parking Lot Study for Year 2003	Values Used in this Report for Year 2003
Passenger Cars	70	26	41	41
Trucks	122	85	--	103.5
Buses	122	110	--	116

The overall number of vehicles operating in Almaty was not measured in this study. Only one source of information from the Agency for Statistics was available for the total number of vehicles in Almaty. This number was 190,982 in the year 2000. This number should be prorated for vehicle growth in the year 2003 for use with this data set. However, although there has been overall vehicle growth in the past ten years, the Agency's data indicates there has been no growth over the past five and a decline in the number of vehicles from 1997 to 2000. While it is not probable that vehicles are declining in numbers over the past few years, no growth rate was applied to the 2000 number. This is considered a conservative estimate but reasonable in light of no other growth data available. Additional research should investigate the actual growth rate of the passenger and overall fleet in recent years.

Simple algebra can be used to demonstrate that the total amount of driving in the region by the use per vehicle and the total number of vehicles (equation IIc.1). The numbers of vehicles in each category are apportioned from the overall fleet distribution as shown in Table II.a.1. Table IIc.2 below provides the estimated total driving based on measurements made in this study. The values in bold are the data that has been calculated from the input data of the vehicle use and numbers, and the percentage of travel observed from the video data.

$$\text{Total Driving in Almaty (km/day)} = \sum_i (N_i * U_i) \qquad \text{IIc.1}$$

Where
N_i = total number of vehicles in Almaty in Category i
U_i = average use (km/day) of vehicles in Almaty in Category i

Table IIc.2: Estimation of Total Driving in Almaty, Calendar Year 2003

Category	Number of Vehicles in Almaty	Vehicle Use km/day/vehicle	Overall Travel km/day
Passenger Cars	**176,318**	41	**7,229,025**
Trucks	**3,942**	104	**408,019**
Buses	**10,629**	116	**1,232,926**
Total	190,889	--	**8,869,969**

The values shown in Table IIc.2 should only be treated as approximations, but they should be in the ballpark of the true total driving occurring in Almaty in 2003.

III. Vehicle Driving Patterns

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

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

Figure III.2 presents an example of the velocity profile on different road types as measured by the GPS unit for about 2 minutes around 07:00.

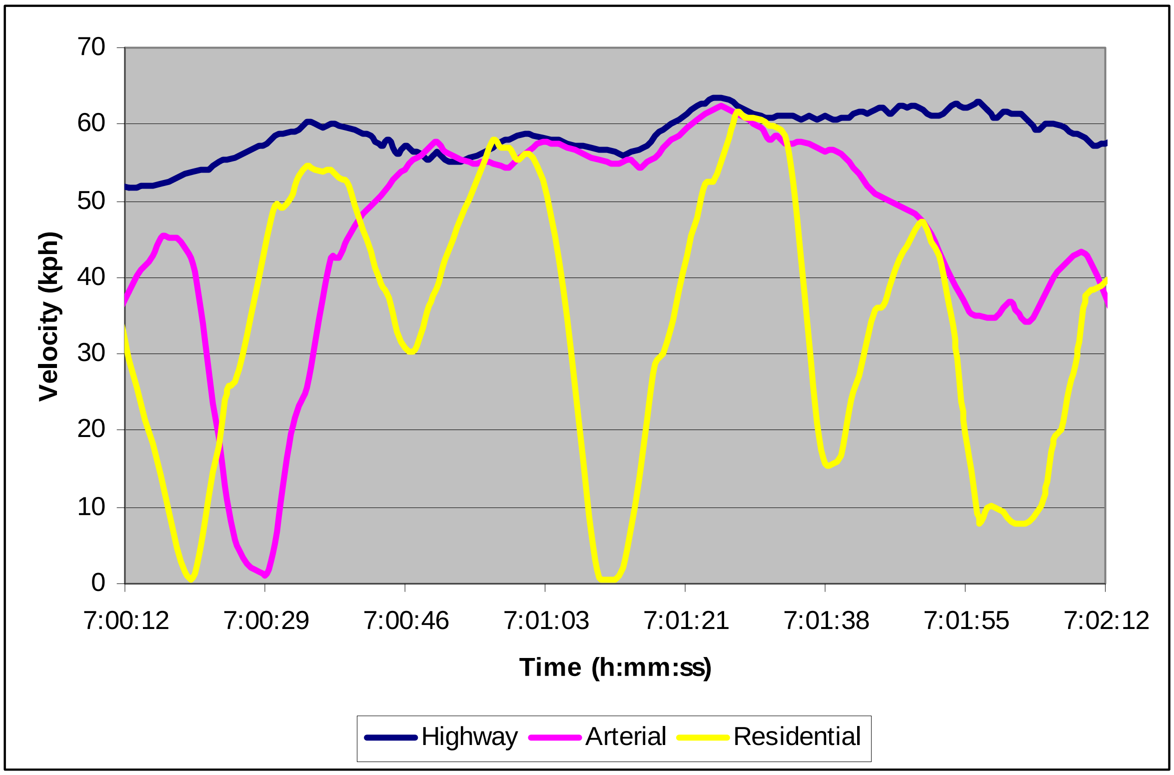

Figure III.2: Example of Residential, Arterial, and Highway Driving at 07:00 in Almaty

Figure III.3 presents an example of altitude recorded while driving on an arterial over a 15 minute drive. As noted earlier, the altitude measurement is the least accurate of the GPS determinations.

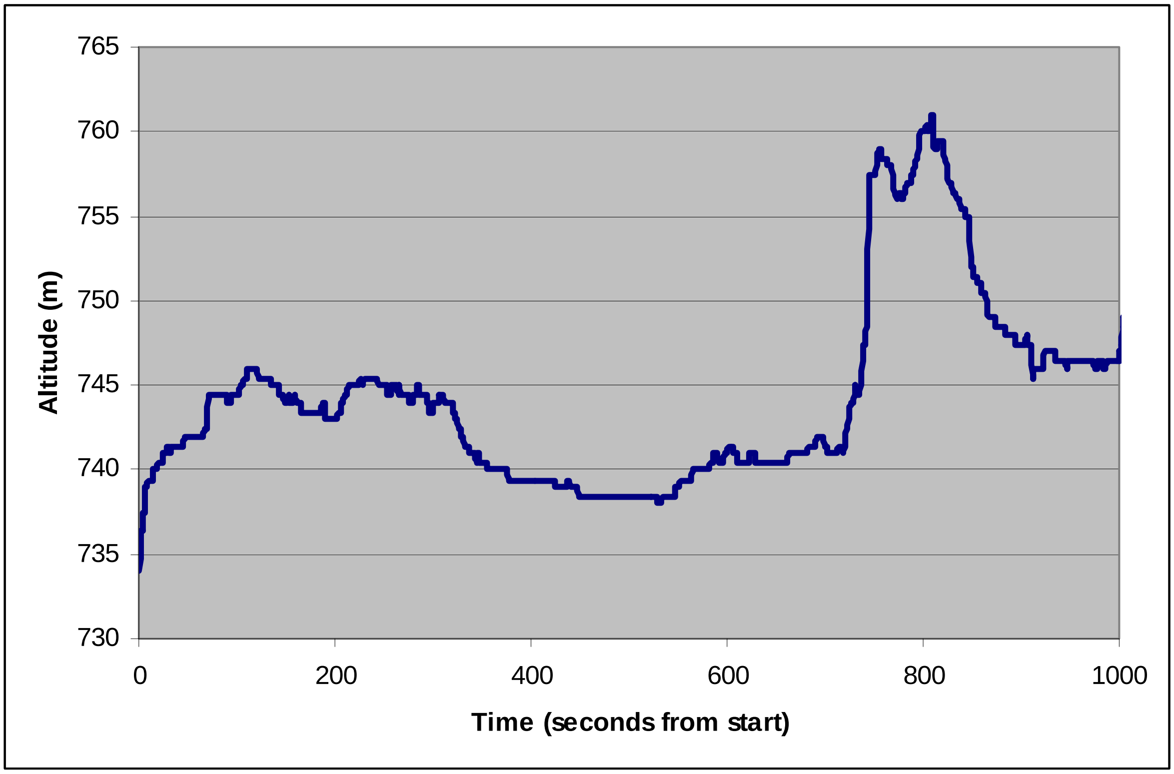

Figure III.3: Example of Altitude Recorded by GPS over 15 Minute Arterial Drive

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

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

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

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

IIIa. Passenger Cars

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

Table IIIa.1: Average Velocity of Passenger Vehicles on Almaty Roads

Time	Highway	Arterial	Residential Street
7:00	49.3	38.1	27.2
8:00	48.7	34.4	26.5
10:00	50.4	32.8	27.0
12:00	48.5	33.5	27.4
14:00	48.6	39.6	25.7
16:00	50.5	37.7	26.5
18:00	47.8	40.2	24.8
20:00	51.9	43.0	25.8

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

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

Table IIIa.2: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Highways Averaged Over All Hours (average speed: 49.51 km/hour)

Stress Group	Power Bins									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.06%	0.03%	0.07%	0.08%	0.22%	0.41%	0.80%	1.44%	2.28%	4.01%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Low	10.26%	23.91%	20.83%	18.21%	10.48%	3.30%	0.44%	0.09%	0.03%	0.03%
	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**
Med	0.01%	0.01%	0.00%	0.01%	0.01%	0.99%	1.33%	0.43%	0.10%	0.13%
	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**
High	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table IIIa.3: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Arterials Averaged Over All Hours (average speed: 38.77 kilometers/hour)

Stress Group	Power Bins									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.01%	0.01%	0.04%	0.07%	0.16%	0.38%	0.74%	1.52%	2.75%	5.27%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Low	11.73%	26.76%	21.20%	15.95%	7.95%	2.82%	0.65%	0.14%	0.02%	0.03%
	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**
Med	0.00%	0.00%	0.00%	0.00%	0.00%	0.66%	0.77%	0.24%	0.07%	0.06%
	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**
High	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table IIIa.4: Distribution of Driving into IVE Power Bins for Passenger Cars Operating on Residential Streets Averaged Over All Hours (average speed: 26.26 km/hour)

Stress Group	Power Bins									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.02%	0.01%	0.02%	0.06%	0.09%	0.18%	0.40%	0.85%	1.91%	4.35%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Low	11.21%	35.82%	23.91%	12.48%	5.39%	1.87%	0.41%	0.15%	0.03%	0.03%
	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**
Med	0.00%	0.00%	0.00%	0.00%	0.00%	0.21%	0.39%	0.13%	0.04%	0.03%
	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**
High	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 IIIa.2 through IIIa.4 that the times in the zero power bin, 12, (stopping and idling) increases from the highway case to the residential case. It is also noteworthy that the high stress, high power demand driving does not show up in passenger vehicle driving in Almaty.

IIIb. Buses

Table IIIb.1 indicates average bus velocities in Almaty. There is not much variation in the average velocity during different times of day. The maximum velocity occurs during the 14:00 to 16:00 time frame.

Table IIIb.1: Average Bus Speeds on Pune Roads

Time	Overall
10:00	25.9
12:00	27.6
14:00	29.3
16:00	24.9
18:00	25.4
20:00	26.5

Table IIIb.2 indicates the power bin distributions for a bus averaged over all hours. There is a large percentage of idle time for the buses which is expected since their routes include many stops. There is very little high stress and power demand from bus driving observed in this study.

Table IIIb.2: Distribution of Driving into IVE Power Bins Buses Averaged Over All Hours (average speed: 26.62 km/hour)

Stress Group	Power Bins									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	0.00%	0.00%	0.00%	0.00%	0.01%	0.02%	0.06%	0.14%	0.70%	2.68%
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Low	10.43%	43.86%	28.97%	11.31%	1.51%	0.18%	0.04%	0.01%	0.01%	0.01%
	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**
Med	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.02%	0.02%	0.00%	0.00%
	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**
High	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

IIIc. Summary of Driving Pattern Results

Figure IIIc. 1 compares driving speeds by hour for the four types of vehicles studied. There is no large velocity variation during the day, perhaps indicating that congestion is relatively constant or that changes in congestion are not affecting the average speed of the vehicles on the roadways studied. The average bus velocity is similar to a passenger vehicle traveling on a residential roadway. Travel on the highway has the highest average speed of around 50 kilometers per hour.

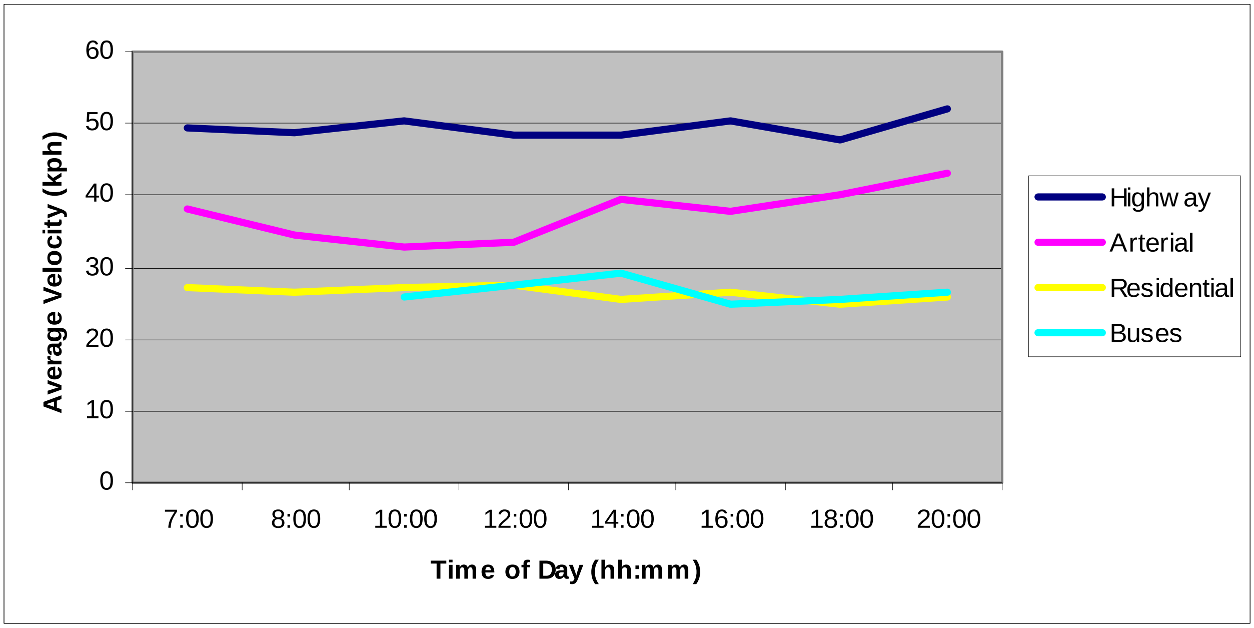

Figure IIIc.1: Average Speeds for All Road Types and Vehicle Classes in Almaty

Figure IIIc.2 illustrates the average driving pattern for the three road types in Almaty. The x axis represents the VSP and stress bins discussed earlier in this section. The residential has the highest percentage of idle or almost idle driving, followed by the arterial driving and lowest for freeway. There are no occurrences of high stress driving and very little of moderate stress driving.

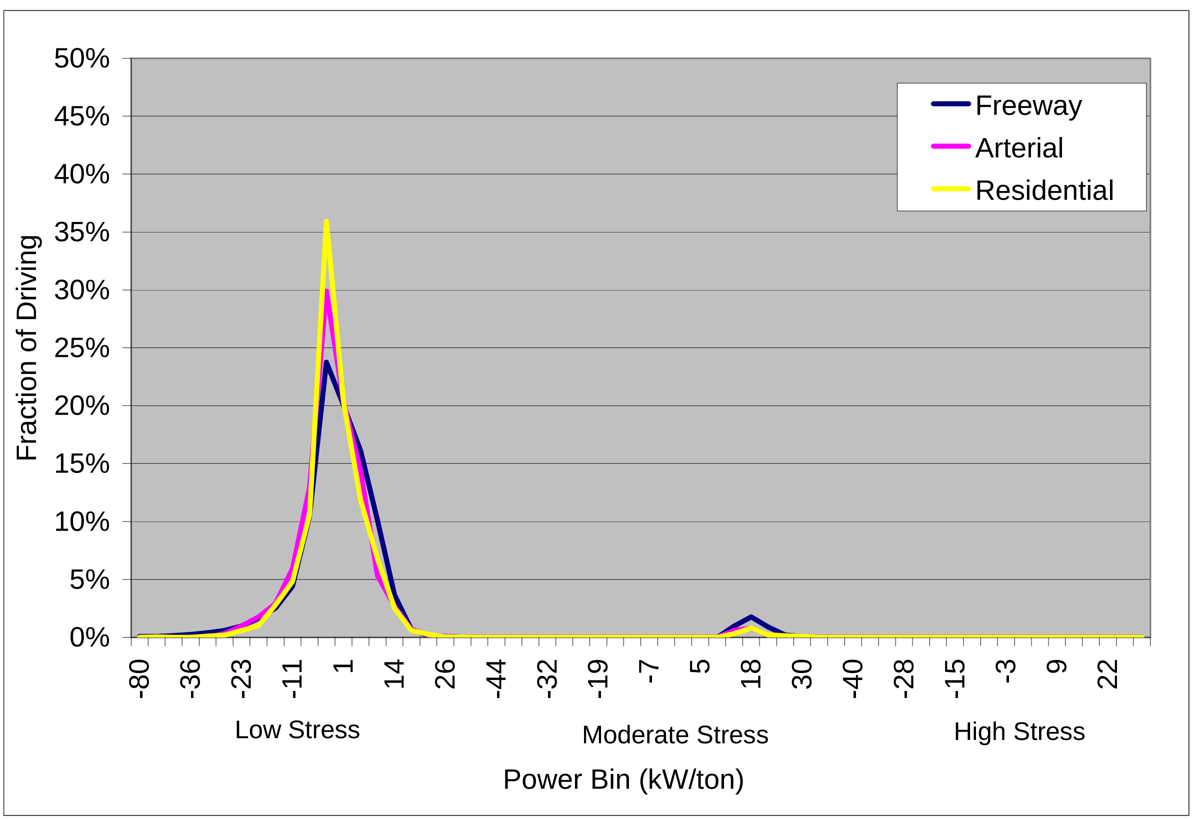

Figure IIIc.2: Average Driving Pattern for Road Types in Almaty

It is also useful to compare the driving pattern observed in Almaty with that in other areas. Figure III.c.3-5 compare the freeway, arterial and residential driving patterns observed in Almaty with Santiago, Nairobi, and Los Angeles. There is a higher percentage of medium stress driving in the freeways in other areas than in Almaty. The closest distribution to Almaty for freeway driving is Nairobi, which also has the closes average velocity. However, it is clear that the average velocity does not provide enough information to determine the driving pattern distribution. Notice that only Los Angeles, with the highest average speed of 88 kph, contains high stress driving.

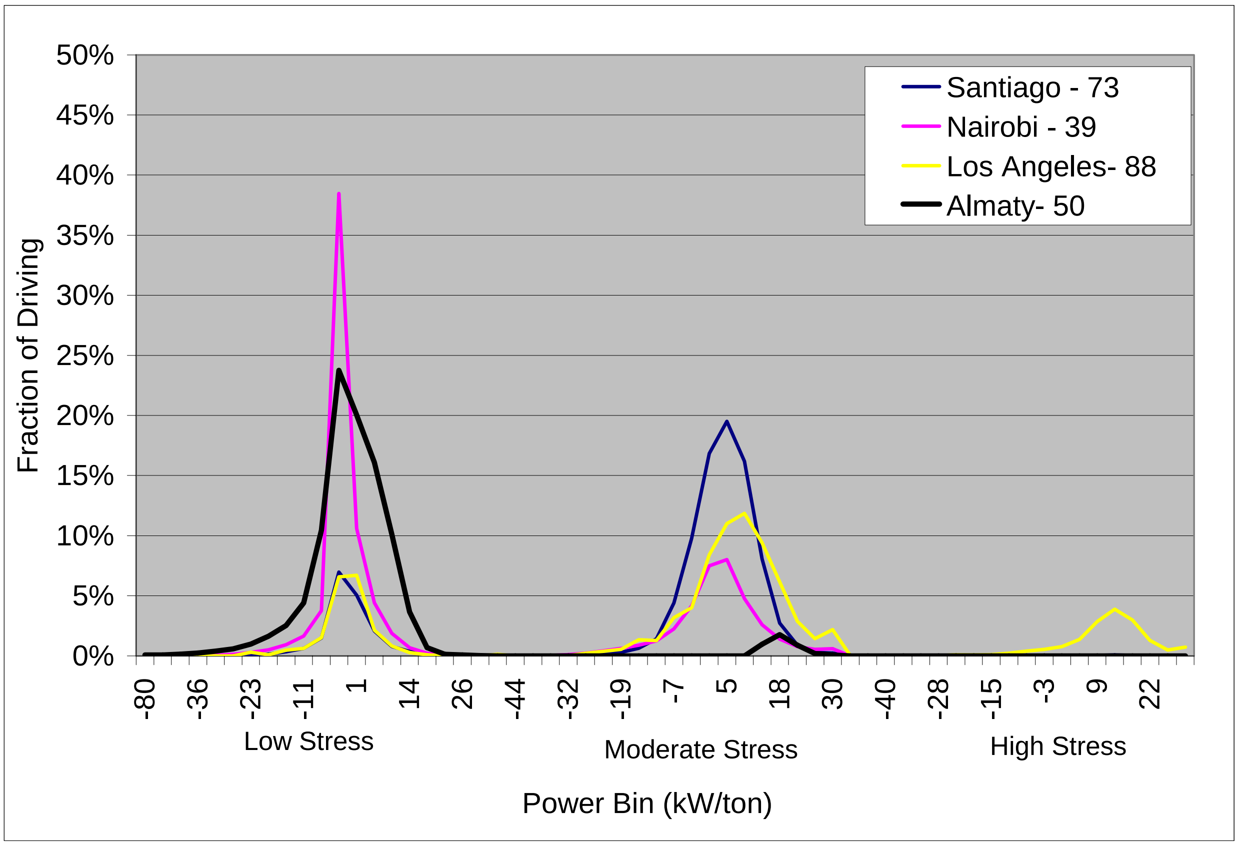

Figure IIIc.3: Freeway Driving Pattern Distribution in Several Locations (average velocities in legend in kph)

Similar to the freeway driving, Almaty experiences lower stress driving than other areas studied (Figure III.c.4). It also has the lowest average velocity on arterial roadways. If the driving patterns were to change in Almaty to look more aggressive, this would increase emissions per kilometer traveled.

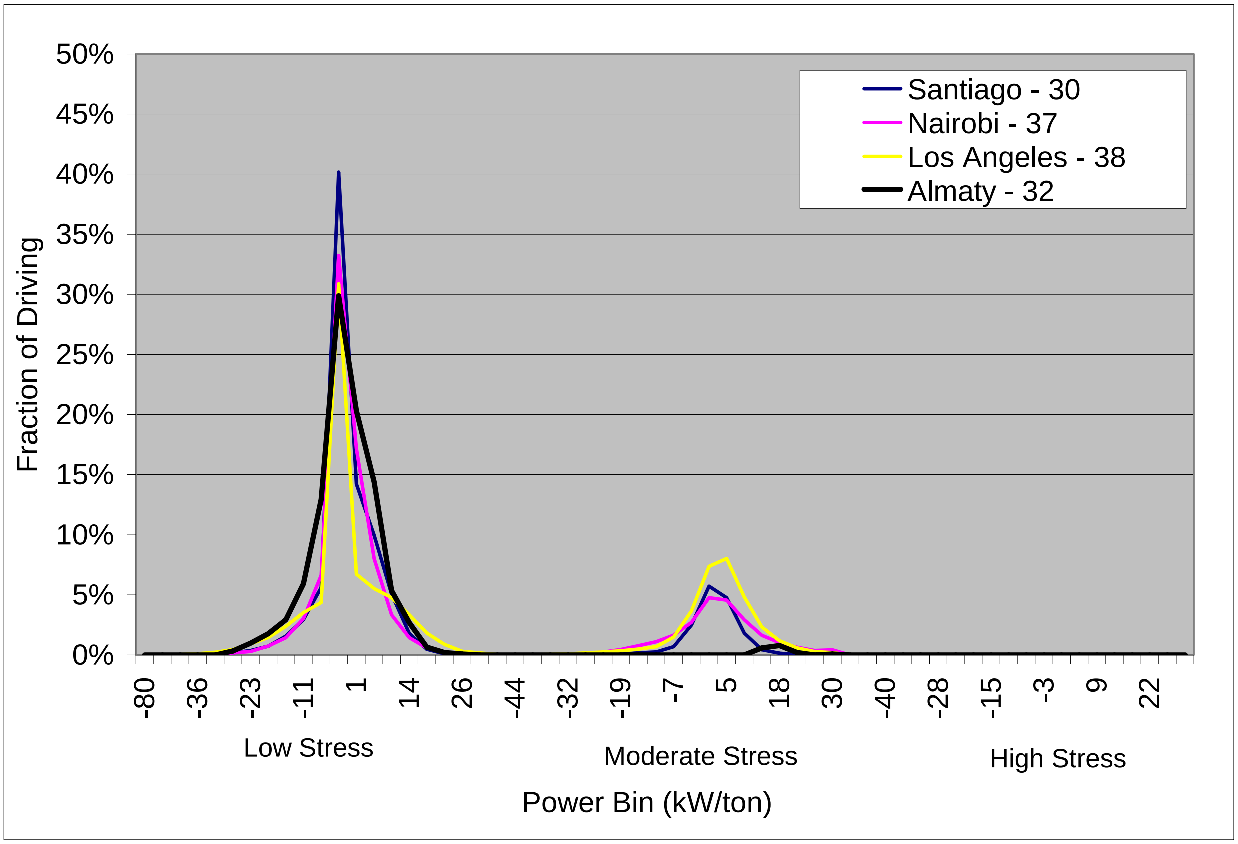

Figure IIIc.4: Arterial Driving Pattern Distribution in Several Locations (average velocities in legend in kph)

In contrast to highway and arterial driving, the driving pattern for residential area is quite similar than in other locations (Figure IIIc.5). It has been observed that the residential driving distribution is very similar and not very sensitive to moderate congestion changes, times of day, location, or average velocity.

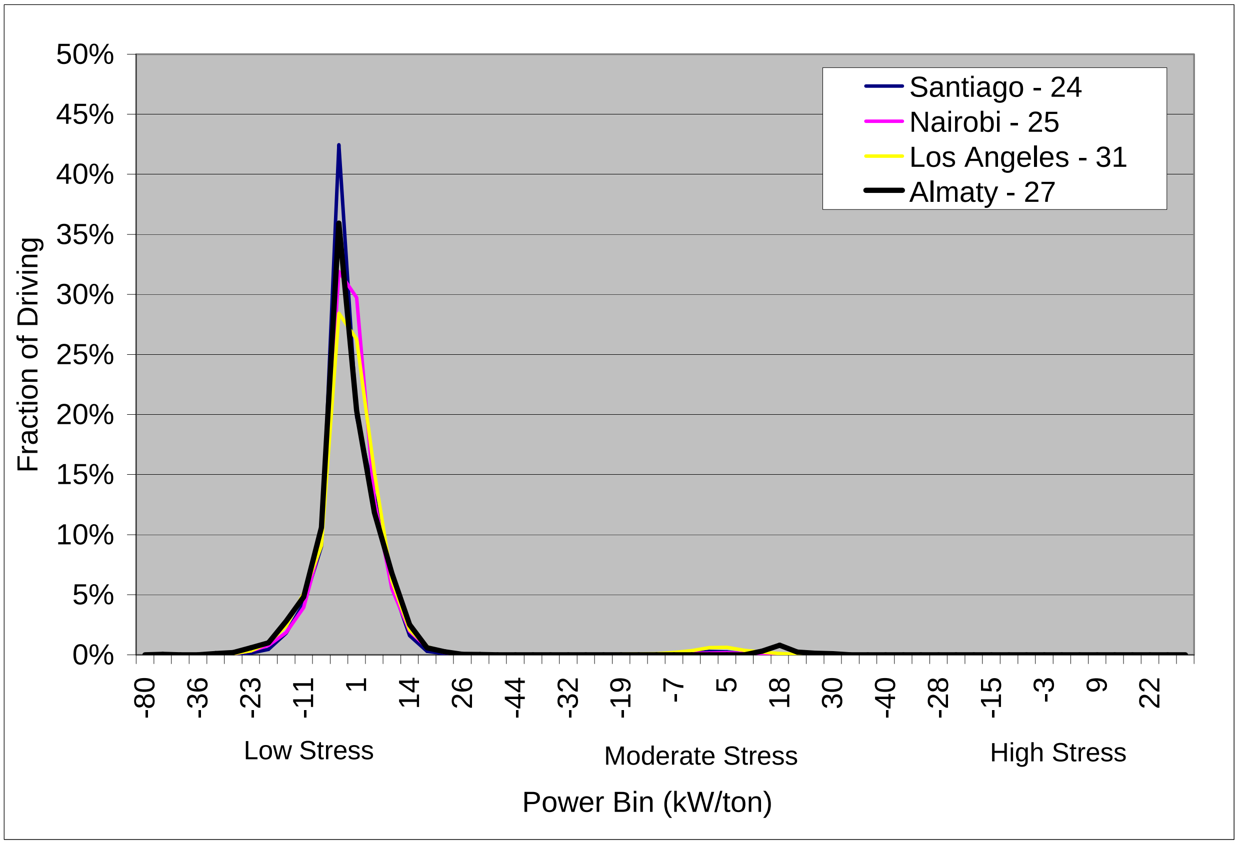

Figure IIIc.5: Residential Driving Pattern Distribution in Several Locations (average velocities in legend in kph)

IV. Vehicle Start Patterns

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

Table IV.1 indicates the measured start and soak patterns for passenger vehicles in Almaty. Data was successfully collected from about 32 passenger vehicles over about 3 days for each vehicle. This provides about 100 vehicle days of data. While this amount of information is significant, it was felt that hour by hour data would include too few events and would thus not be meaningful. Thus, the data was lumped into 3 hour groups.

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

Soak Category (hours)	5-7 AM	8-10 AM	11 AM-1 PM	2-4 PM	5-7 PM	8-10 PM	11PM - 4 AM	Daily Average
0-.08	21%	22%	13%	18%	10%	33%	0%	18%
.08-.25	14%	28%	27%	20%	15%	6%	13%	22%
.25-.5	14%	16%	15%	21%	8%	17%	0%	15%
.5-1	4%	11%	22%	8%	28%	11%	0%	13%
1-2	2%	13%	10%	10%	18%	0%	0%	10%
2-4	1%	4%	6%	12%	15%	11%	13%	7%
4-6	0%	1%	2%	6%	1%	0%	0%	2%
6-9	5%	0%	3%	3%	1%	6%	19%	3%
9-12	11%	0%	0%	1%	1%	0%	25%	3%
12+	28%	4%	2%	1%	3%	17%	31%	8%
Events	**137**	**208**	**147**	**139**	**79**	**18**	**16**	**744**
Fraction	**18%**	**28%**	**20%**	**19%**	**11%**	**2%**	**2%**	**100%**

Overall, Almaty passenger vehicles were started 7.46 times per day. This is typical of what is observed in other urban areas that have been studied. Starts per day vary from 6-8 for passenger vehicles in the urban areas studied to date.[1] As expected, most starts occur in the 07:00 to 10:00 time frame. The highest number of starts after an 8 or more hour weight occurs in the very early morning as would be expected. These long soak times leave the engine cold and result in much greater start emissions. The soak distribution varies during the time of day, with the early morning time having a greater number of starts where the engine has been soaking overnight. The midmorning through afternoon starts have a greater fraction of starts where the engine has been soaking for only a few minutes or hours. This is expected if it is believed that the majority of vehicle users park their vehicle overnight, start the vehicle in the early morning, and then do a variety of starts and stops during the day.

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

V. Results

The total daily driving in Almaty is around 9 million kilometers based on the estimation process indicated in Table IIc.1. The fraction of driving per hour can be estimated using traffic counts shown in Table IIa.1 and averaged according to the fraction of driving on each type of street discussed in Section IIa. The results are shown in Table V.1. Since no data was collected between 21:00 and 6:00 these values were estimated using fractions observed in other urban areas. Starts were estimated from the VOCE data collected in this study. It was assumed that the number and distribution of starts from buses and trucks were similar to the starts from passenger vehicles, since no data specifically on trucks and buses were available. Research to determine the exact amount and distribution of starts from trucks and buses should be conducted in the future. Approximately 191,000 vehicles in Almaty were assumed to be in operation in 2003, with an average of 7.5 starts per day.

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

Hour of Day*	Percent of Daily VMT	VMT (kilometers)	Percent of Daily Starts	Number of Starts
6:00 AM	2%	202,377	6%	87,383
7:00 AM	3%	269,836	7%	103,011
8:00 AM	5%	448,390	8%	118,638
9:00 AM	5%	477,680	9%	134,266
10:00 AM	7%	636,955	8%	120,903
11:00 AM	6%	575,891	8%	107,540
12:00 PM	6%	532,741	7%	94,177
1:00 PM	6%	532,741	6%	92,480
2:00 PM	6%	558,220	6%	90,783
3:00 PM	6%	557,963	6%	89,086
4:00 PM	7%	631,439	5%	76,360
5:00 PM	7%	588,289	4%	63,633
6:00 PM	6%	528,152	4%	50,906
7:00 PM	5%	485,002	3%	37,765
8:00 PM	5%	476,568	2%	24,623
9:00 PM	5%	457,032	1%	11,481
10:00 PM	4%	337,294	1%	8,927
11:00 PM	2%	202,377	0%	6,372
12:00 AM	1%	101,188	0%	3,818
1:00 AM	0%	33,729	0%	3,818
2:00 AM	0%	33,729	0%	3,818
3:00 AM	0%	33,729	0%	3,818
4:00 AM	1%	67,459	2%	31,604
5:00 AM	1%	101,188	4%	59,391
All Day	100%	8,869,969	100%	1,424,600

*times in italics were estimated from data collected in other areas since data was not collected at these times in Almaty

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

The general emission factors developed for the IVE study were used in conjunction with the activity data collected in this study to provide an estimate of vehicular emissions in the Almaty region. The general emission data was used in this study because there is no information available on the in-use exhaust emissions in Almaty [3]. With no Almaty-specific information, other Kazakhstan studies have used data from the Netherlands and Sweden. This regional data appears to be significantly different to the emission factors currently used in the current IVE model, especially for heavy duty diesel vehicles. Because of the amount of testing and vehicles used to develop the IVE emissions database, it is believed that IVE model contains the most up-to-date regional emission factors. However, it is important that local emissions data be added into the IVE database to ensure that the emissions are representative of this area. Recent technological advances have enabled on-road testing of vehicles via affordable portable emissions measurement systems. A program to test the on-road emissions from the Almaty in-use fleet is being planned and will be conducted by GSSR and the University team in the next two years. This data will provide useful emissions information for use in the IVE and other emissions models. Until this data is available, the default emission factors from the IVE model are used in the estimates below.

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

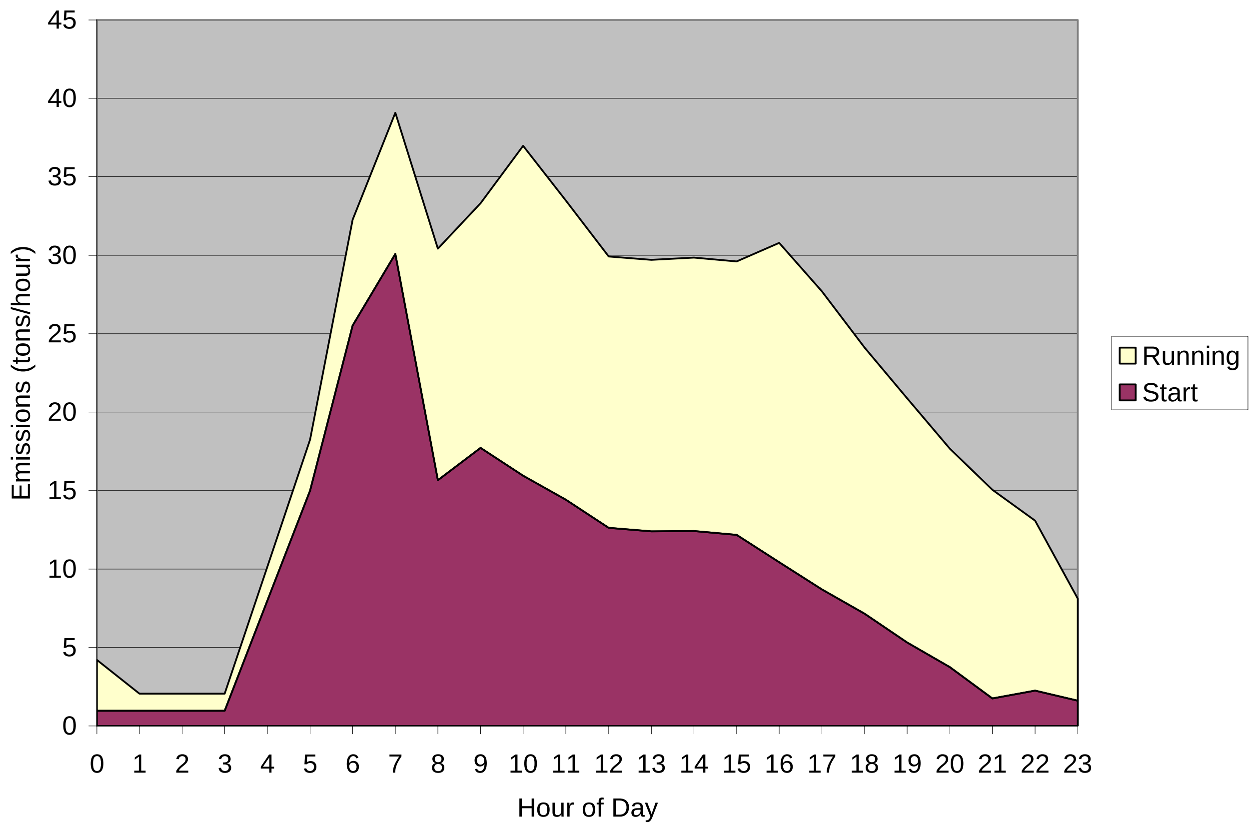

Figure V.1: Overall Almaty Carbon Monoxide Emissions

The peak CO emissions are occurring mid-morning. The dip in start emissions from the 7 to 8 o'clock hour is not due to the number of starts decreasing; instead it is due to the change in soak distribution, discussed later in this chapter. As expected, emissions are very low from midnight to

05:00. It is also valuable to note the importance of start emissions in Almaty. Most of the time, starts represent almost half of vehicle CO emissions. Overall, Figure V.1 reflects a total of 520 metric tons of CO emitted per day into the air over Almaty or an overall daily average emission rate of 58 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.

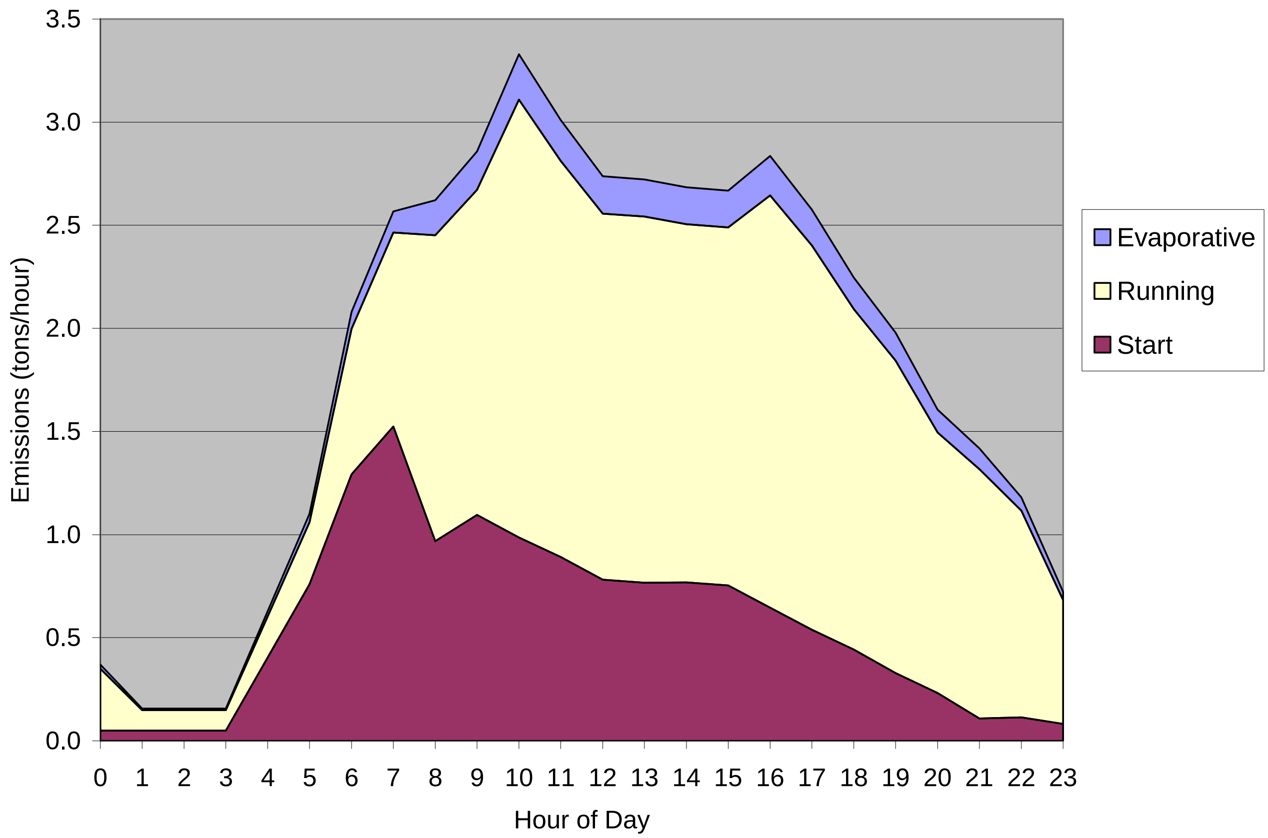

Figure V.2: Overall Almaty Volatile Organic Emissions

The peak VOC emissions are occurring midmorning in Almaty, which could facilitate ozone formation in the afternoon. Start emissions are not as great a percentage of emissions as is the case for CO, but they are still large. Evaporative emissions are important as well. Figure V.2 reflects a total of 44 metric tons per day of VOC emissions going into the air over Almaty or an overall daily average emission rate of 5 grams/kilometer including starting, running, and evaporative emissions.

Figure V.3 shows the modeling results using the data developed or estimated from this study for Nitrogen Oxides (NOx). The top line reflects start and running emissions added together. Start emissions are much lower in this case although still large. As is the case for CO and VOC, the largest emissions occur during midmorning and late afternoon, in a somewhat diurnal distribution. Figure V.3 reflects a total of 36 metric tons per day of NOx going into the air over Almaty or an overall daily average emission rate of 4.1 grams/kilometer including starting and running emissions.

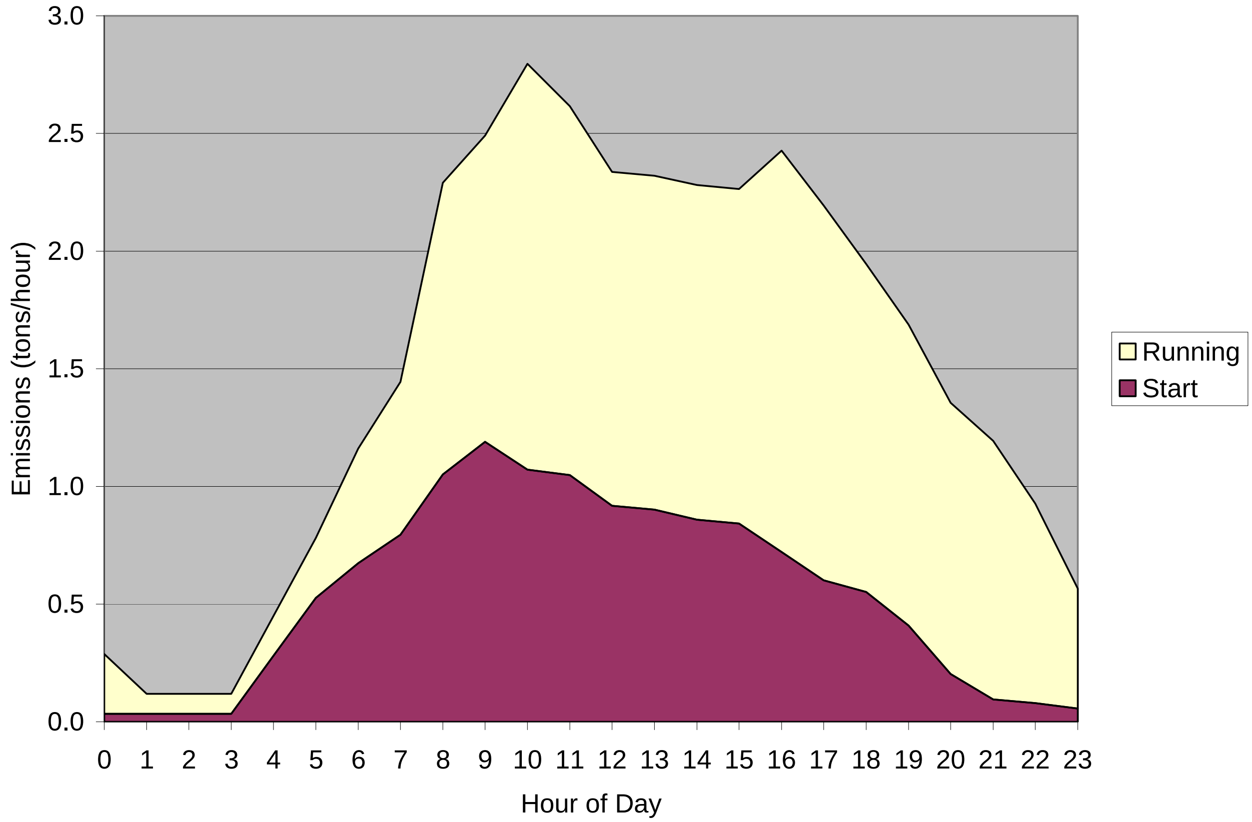

Figure V.3: Overall Almaty Nitrogen Oxide Emissions

Figure V.3 shows the modeling results using the data developed or estimated from this study for Particulate Matter (PM) of 10 microns or less in diameter. The top line reflects start and running emissions added together. The diurnal pattern for particulate matter is very similar to that of NOx, with slightly less of the emissions resulting from start emissions. Figure V.4 reflects a total of 0.4 metric tons per day of PM10 going into the air over Almaty or an overall daily average emission rate of 0.04 grams/kilometer including starting and running emissions. This is relatively a small overall fleet emission rate for particulate matter, and is due to the fact that the vast majority of the fleet is petroleum fueled passenger vehicles.

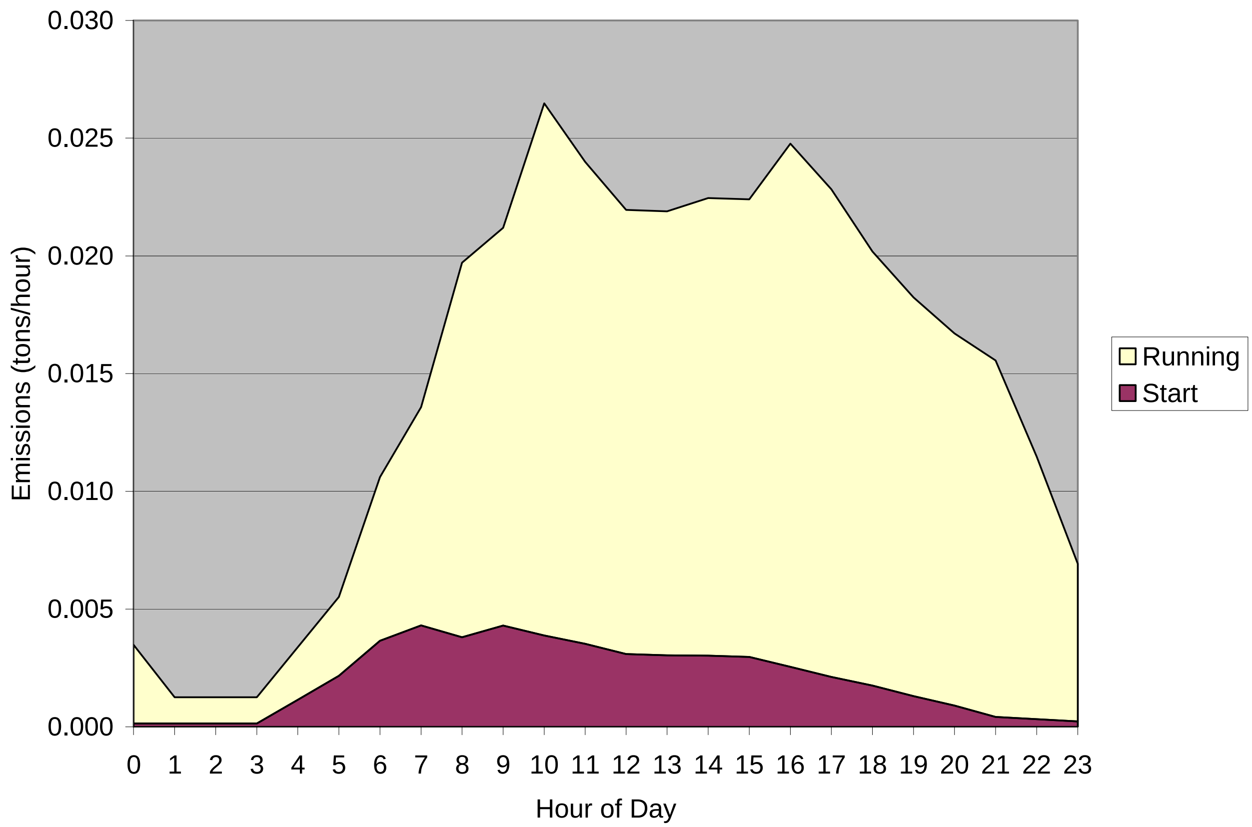

Figure V.4: Overall Almaty Particulate Matter Emissions

Figures V.1-V.4 were calculated based on a total daily driving of approximately 10,000,000 kilometers and a fleet of 191,000 vehicles. The emission numbers will of course have to be modified if the total kilometers per day measured in Almaty are different than the assumptions in this study.

Effect of Soak Distribution on Emissions:
One of the complicating factors in determining start emissions is that the amount of emissions depends on how long an engine has been resting before it is started. For most pollutants, the amount of emissions decreases as the soak time (the time the engine has been off) increases. This is because the engine and catalyst takes longer to heat up to its normal operating temperature. By design, emissions are lowest at the normal operating temperature of the engine. However, tests in the United States have indicated for NOx emissions, an opposite effect is seen. It is unclear why this effect is observed, but it is thought to be a real effect and is reflected in the IVE model at this time. Figure V.5 shows the correction factor applied to a cold start depending on its soak period for NOx and CO. *(There are different correction factor curves for different vehicle types, this curve is weighted approximately for the vehicle types seen in the Almaty Fleet).* For an example, if an engine has been shut off for 120 minutes and is started, you would multiply the cold start emission rate for CO by roughly 0.3 and the cold start NOx emission rate by approximately 2.3.

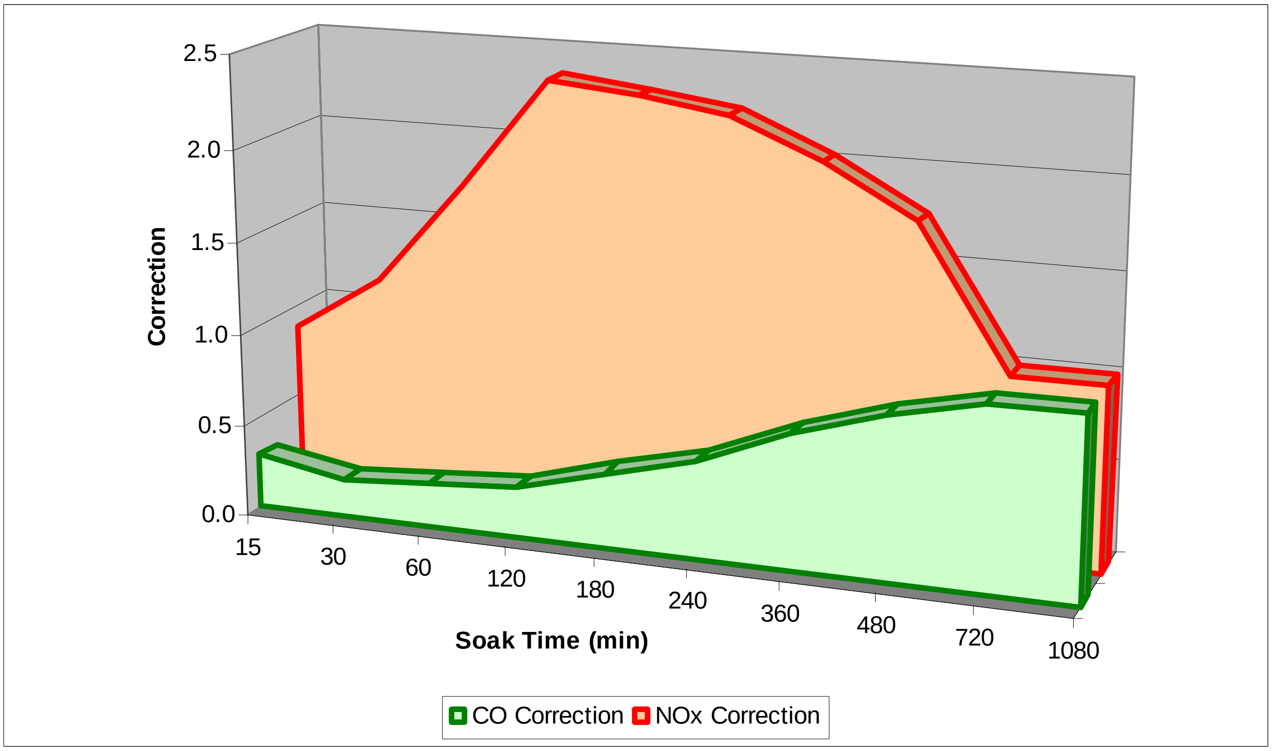

Figure V.5: Soak Correction for CO and NOx Used in the IVE model

As the time of day changes, the number of starts in each of these soak categories changes. The fraction of starts in each soak category is called a soak distribution. Figure V.6 shows the measured soak distribution of the 7 AM and 8 AM hour collected using the VOCE units. When looking at the soak distribution for these two hours, you may notice that the majority of starts in the 7 AM hour have a very long soak period of greater than 480 minutes. The 8 AM hour soak distribution measured in the 8 AM hour, however, has a majority of very short soak periods, with most starts occurring when the engine has been shut off an hour or less. Conceptually, this makes sense if you think the majority of the drivers start their vehicle after it has been off all night in the 7 AM hour, drive somewhere, and then do an errand or two during the 8 AM hour.

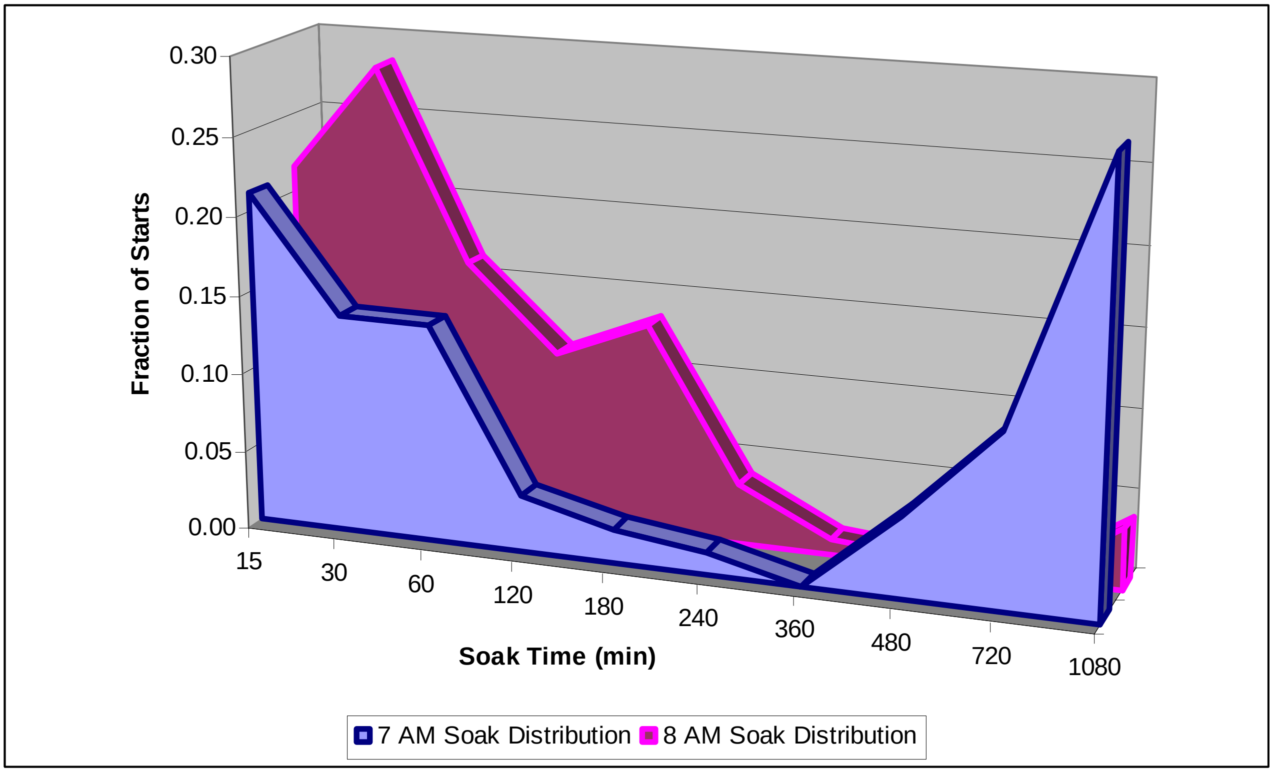

Figure V.6: Soak Distribution for the 7 AM and 8 AM hour as Measured in Almaty

The correction can be calculated by simply multiplying the fraction of starts in each soak bin with the correction in that bin (Figure V.5 multiplied by Figure V.6), and then each of these can be added together. This sum is the soak correction factor applied to each pollutant for that time period. The overall soak correction factor for CO and NOx for the hours of 7 AM and 8 AM is shown in Table V.2. There are two useful things to note from these values: 1) the CO emissions from both the 7 AM and 8 AM soak distributions are less than that from a cold start (the correction factor is less than 1) while the NOx emissions are greater than a cold start and 2) The CO emissions go down from 7 AM to 8 AM while the NOx emissions go up.

Table V.2: Effect of Soak Distribution on CO and NOx for Two Soak Distributions

Time of Day	Correction Factor		Start Emissions (tons)	
	CO	NOx	CO	NOx
7:00 AM	0.58	1.24	30.1	0.79
8:00 AM	0.32	1.54	15.7	1.05

This effect of the soak distribution on overall emissions can be observed in the hourly tonnage plots shown earlier in this chapter. In looking at Figure V.1, the 7 AM hour has higher CO start emissions than the 8 AM hour, despite a small increase in the number of starts for that time period. This same soak distribution results in a decrease in the overall NOx start emissions from the 7 AM to the 8 AM hour, despite an increase in the number of starts per hour.

This demonstration is reviewed to illustrate the importance of collecting accurate activity information. Even though the soak distribution measured in this study follows common sense, the data was only collected on approximately 100 vehicle days of data and less than 50 overall vehicles.

Therefore, it is recommended that this soak distribution be investigated on a broader vehicle base, including some soak activity data collection on trucks and buses. The results may have a significant impact of the temporal and overall emissions.

Contribution by Roadway Type:
It is useful to know the emissions variation by road type for spatial allocation as input to air quality modeling and for estimation of exposure rates to toxic substances. The data presented here is only a gross dissagregation by the three road types, but using road maps and a GIS database, it is possible to allocate these emissions to a finer resolution. The travel and start contribution for each road type is shown in Figure V.6. In Figures V.7-8, the emissions from each road type and activity are shown for four pollutants. Highway driving, by definition, does not contain any starts. The majority of the starts occur in the arterial portion. The number of starts was weighted by the travel contribution to arrive at the .83/.17 weighting seen in Figure V.6. In general, arterial emissions account for approximately 68% of total emissions, and highway accounts for roughly 15% of overall emissions.

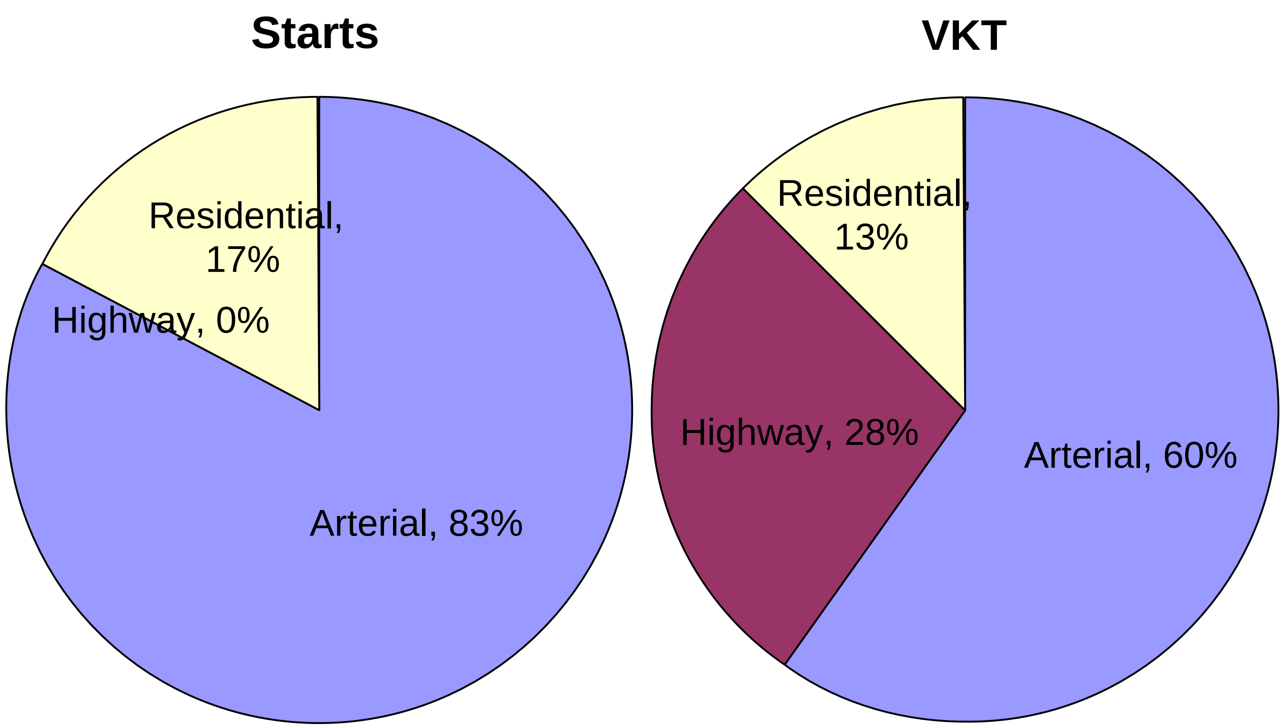

Figure V.6: Contribution of Starts and VKT in Almaty

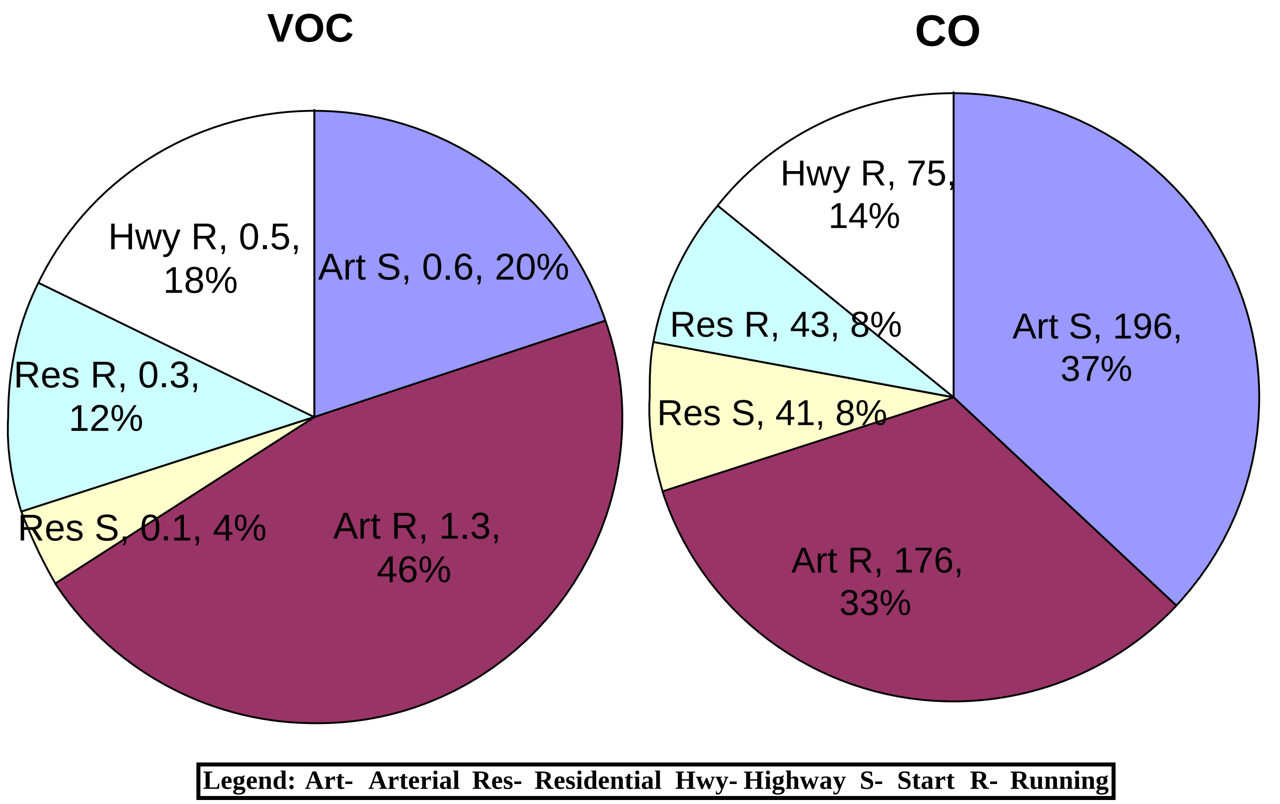

Figure V.7: Roadway Distribution of VOC and CO Emissions in Almaty (Metric Tons/day)

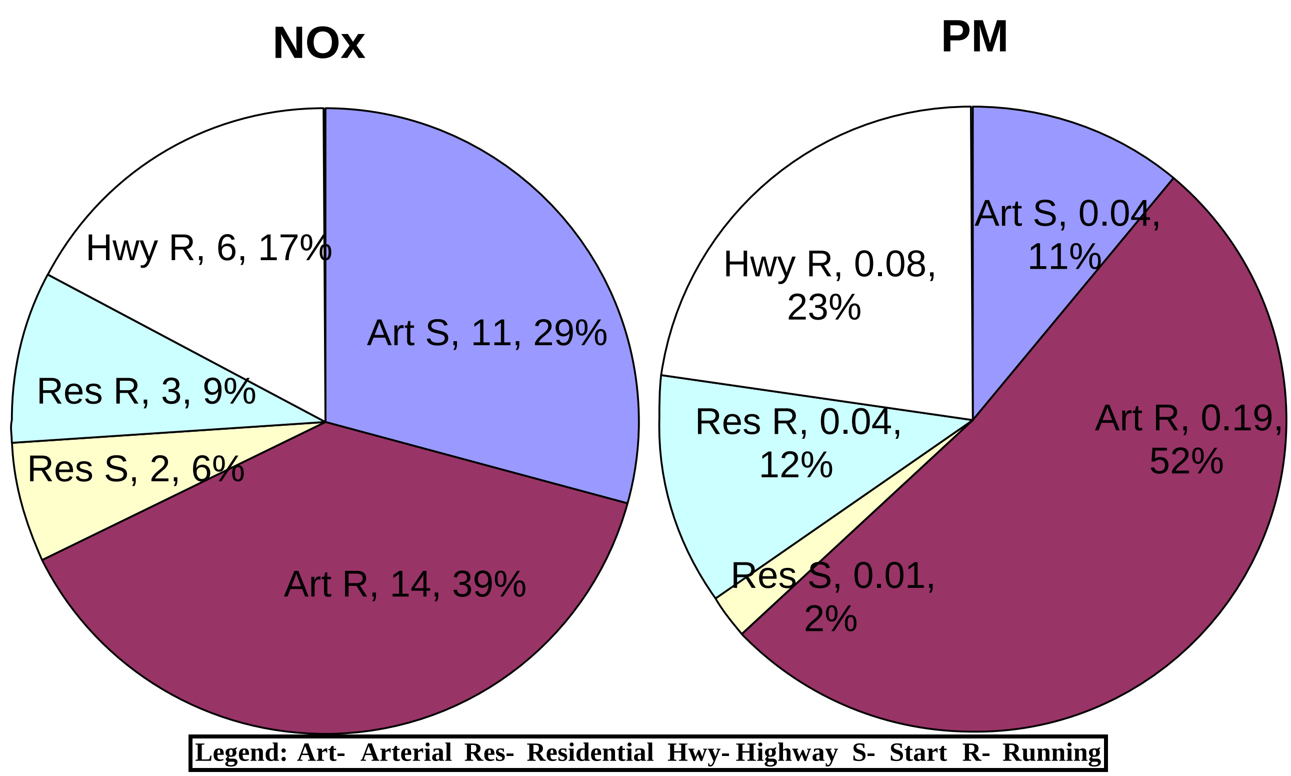

Figure V.8: Roadway Distribution of NOx and PM Emissions in Almaty (Metric Tons/day)

Emission Contribution by Vehicle Type:
To better understand the emissions created from the Almaty vehicle fleet, it is useful to look at the contribution of the two main vehicle classes in Almaty, passenger vehicles, and heavy duty trucks and buses. The fraction of travel from these two types of vehicles is shown in Figure V.4. The percent contribution each of these vehicle types to vehicular CO, VOC, and NOx emissions is shown in the columns to the right of the travel fraction. These results indicate roughly a quarter of the vehicular CO and NOx and 30% of the PM are from trucks and buses, while 18% of the travel and only 8% of the fleet is comprised of trucks and buses. It is usually the case that heavy duty vehicles have a larger contribution to both the travel and emissions (especially for PM) than they do in terms of their numbers. In areas with strict control and advanced technology light duty vehicles, trucks and buses can represent an even larger proportion of these emissions even when they contribute a relatively small percentage of the travel. Clearly, to reduce the criteria emissions in Almaty, both passenger vehicles and trucks and buses must be controlled.

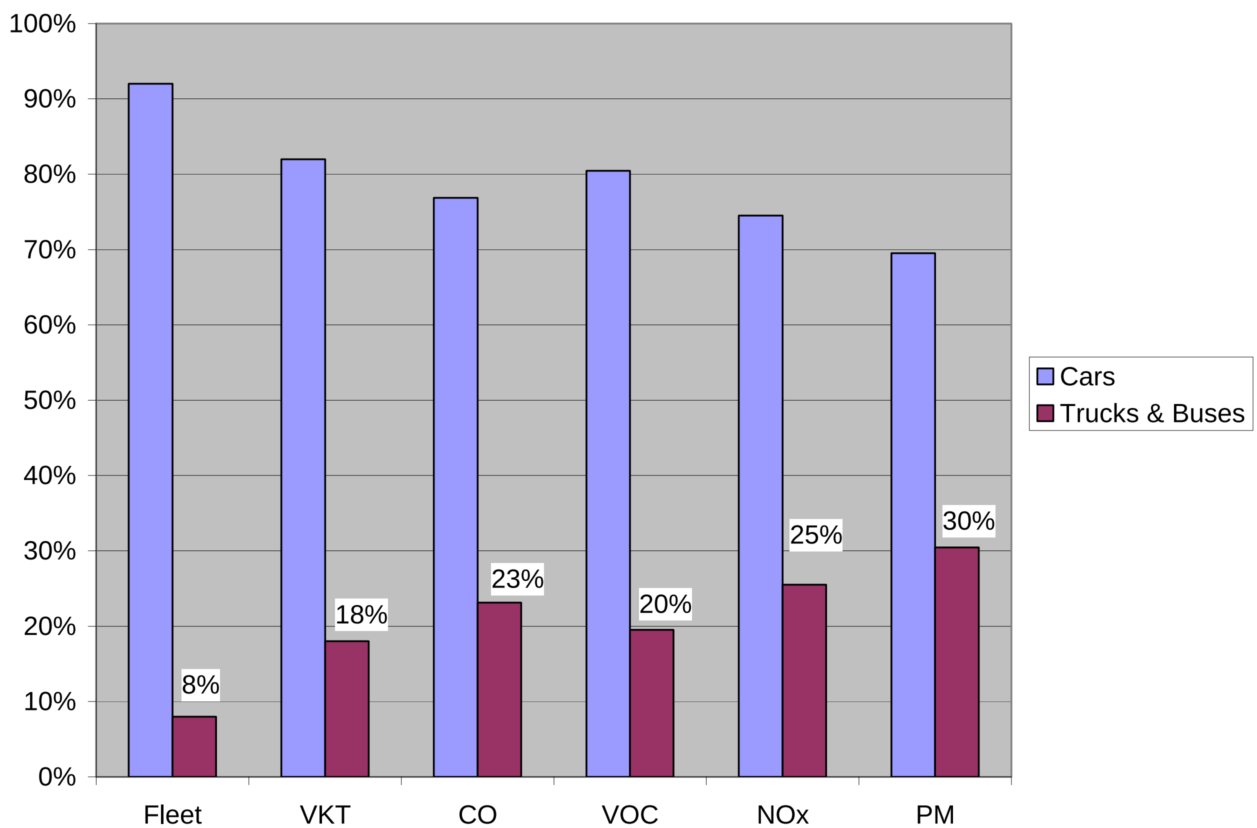

Figure V. 9 Travel and Emission Contribution of the two main Vehicle Types in Almaty

Another calculation that is of interest is the average emissions per vehicle from Almaty vehicles compared to vehicle fleets in cities of other countries. Figure V.9 compares Almaty with Los Angeles, Santiago, Nairobi, and Pune. It should be noted that the emissions shown in Figure V.9 and later in Figure V.10 include start and evaporative emissions that were prorated over the daily driving for all fleets shown.

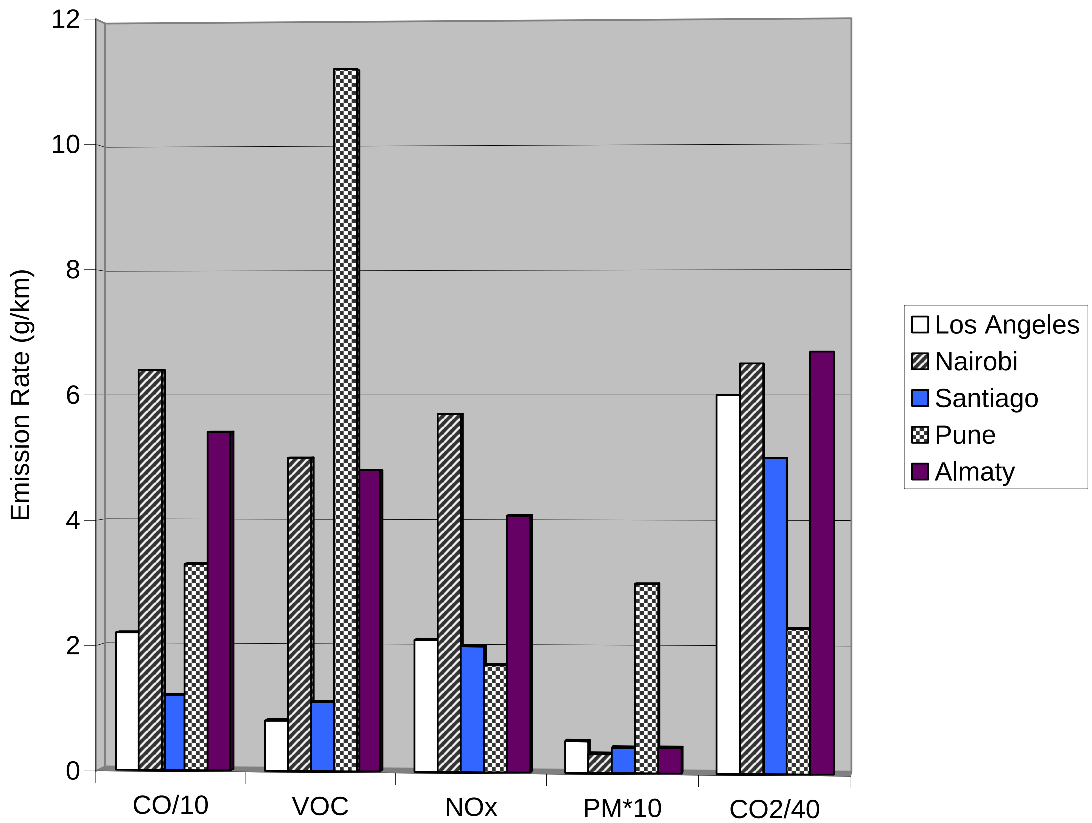

Figure V.10: Comparison of Daily Average Emissions in Countries Studied to Date

The Almaty fleet emissions of CO, VOC, and NOx are in the upper-middle range compared with measurement from other countries. It is in the lower range for PM, most likely because it has a small fraction of buses and trucks compared to other areas. It is the highest per vehicle producer of CO_2. This may be partly due to the fact that there are a very small fraction of small engine vehicles which have very high fuel economy, and a higher percentage of gasoline powered vehicles than in other areas. The toxic trend is consistent with the VOCs shown in the figure above.

A comparison with another estimate of vehicle emissions in Almaty is shown in Figure V.11. This comparison comes from the GHG emissions inventory report for road transport and coal mining [1]. For this report, CO2, CH4, and N2O emissions were estimated using a top-down and a bottom-up approach, and estimates for CO, NOx, VOC, and SO2 were estimated using the data from the bottom up approach and national emission factors. The emission factors were developed by the Kazakh Research Designing Institute of Energy Industry based on "Russian Guidelines for estimation of road transport emissions to be used in calculation of city air pollution". All vehicles were assumed to have no control technologies, which is a reasonable assumption for this situation. It is not clear what fuel assumptions, deterioration, or driving behavior effects, if any were used in the development of these emissions factors. The range of the emission factors reported by the guidelines are in the general range of the emissions measured in the IVE study, except for SO2. SO2 g/km emission factors were in general an order of magnitude higher than used in the IVE study.

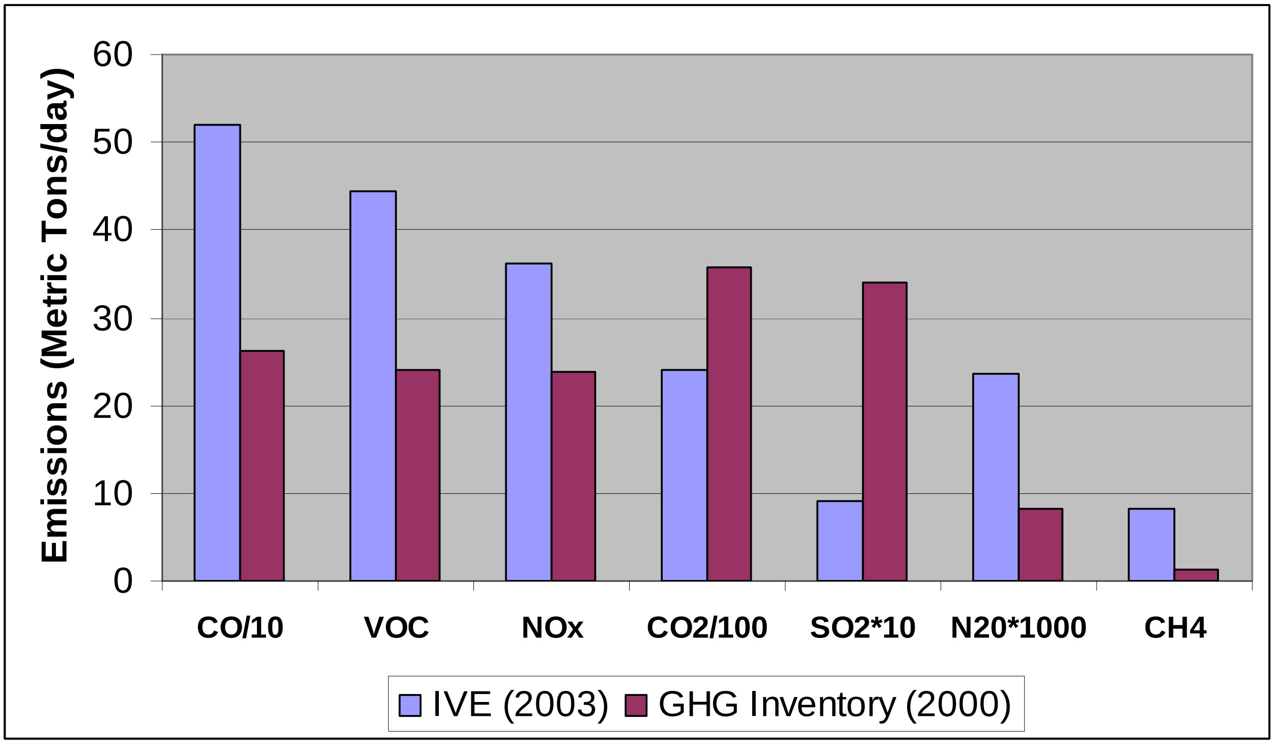

Figure V.11: Comparison of Emissions Prediction from the IVE study and the GHG Inventory

There are two factors that are most likely contribute to the majority of the differences seen in Figure V.11 for CO, VOC, NOx and CO2. The first is the on-road fleet mix, in particular the ratio of the trucks and buses to the passenger vehicles, in terms of travel. The IVE field study collected the VKT fraction on the road so is expected to be more accurate than using the registered vehicle data used in the other studies. However, the field study only observed the VKT fraction on nine different roadways. If desired, a more robust data collection effort could be conducted to see if this travel fraction is consistent throughout the rest of Almaty streets. Additionally, more work should be done to identify the annual average travel from buses and trucks. The second factor contributing to the differences in the emission estimates is most likely a result of the driving pattern distribution. As shown in this report, the mode of driving a vehicle is operating in can change emissions by several orders of magnitude. The Tacis report also notes the variation in emissions from driving behavior is similar, and varies thousands of times from idle to high acceleration modes. The significance of this variation is that understanding the real-world driving patterns is critical to accurately predicting emissions. It is common for standard driving cycles to be much less aggressive than real world emissions, and for most models to underpredict real-world emissions for this reason. The driving data collected from the passenger vehicles and buses in this study provided useful information for identifying the real world driving conditions. The use of this data in the IVE model is likely one of the main reasons for the difference in emissions from the IVE model and the other reports.

SO2 emissions are solely a factor of the sulfur content of the fuel input, and do not vary with changes in driving behavior. The differences seen for SO2 in Figure V.11 is most likely due to the assumed gasoline sulfur content, along with variations in the VKT ratio of passenger vehicles to heavy duty vehicles. Currently, the highest input for sulfur emissions for gasoline vehicle in the IVE model is 600 ppm. The Tacis report indicated the upper limit for Kazakhstan fuel is 1000 ppm [2].

The sulfur level listed for diesel fuel was 5000 ppm. This level was used in the IVE model. Performing some fuel analysis on the sulfur content of the fuel instead of simply relying on the upper limit of the environmental fuel specifications would be useful for determining the exact in-use fuel sulfur content.

Figure V.12 provides a view of a possible future emissions scenario in Almaty. To create Figure V.12, it was assumed that carbureted vehicles with no controls would be replaced by vehicles that meet Euro III standards and that all heavy duty gasoline and diesel vehicles were converted to LPG with catalysts and controls. This would, of course, require years to accomplish, and is only one of many possible future scenarios. It is also assumed that driving in Almaty doubles during the time the fleet is being improved, and that low sulfur fuel and a loaded mode Inspection and Maintenance (I/M) program are put into place. The result is emission rates that are significantly lower for all pollutants. Notice that PM has shown the least reduction of the pollutants, this is in part due to the fact that the emission rates for PM is already relatively low (Figure V.10). Figure V.12 is only intended to illustrate that significant improvement in local emissions can take place using today's modern vehicle technologies and improved fuel quality even with considerable growth in driving in Almaty.

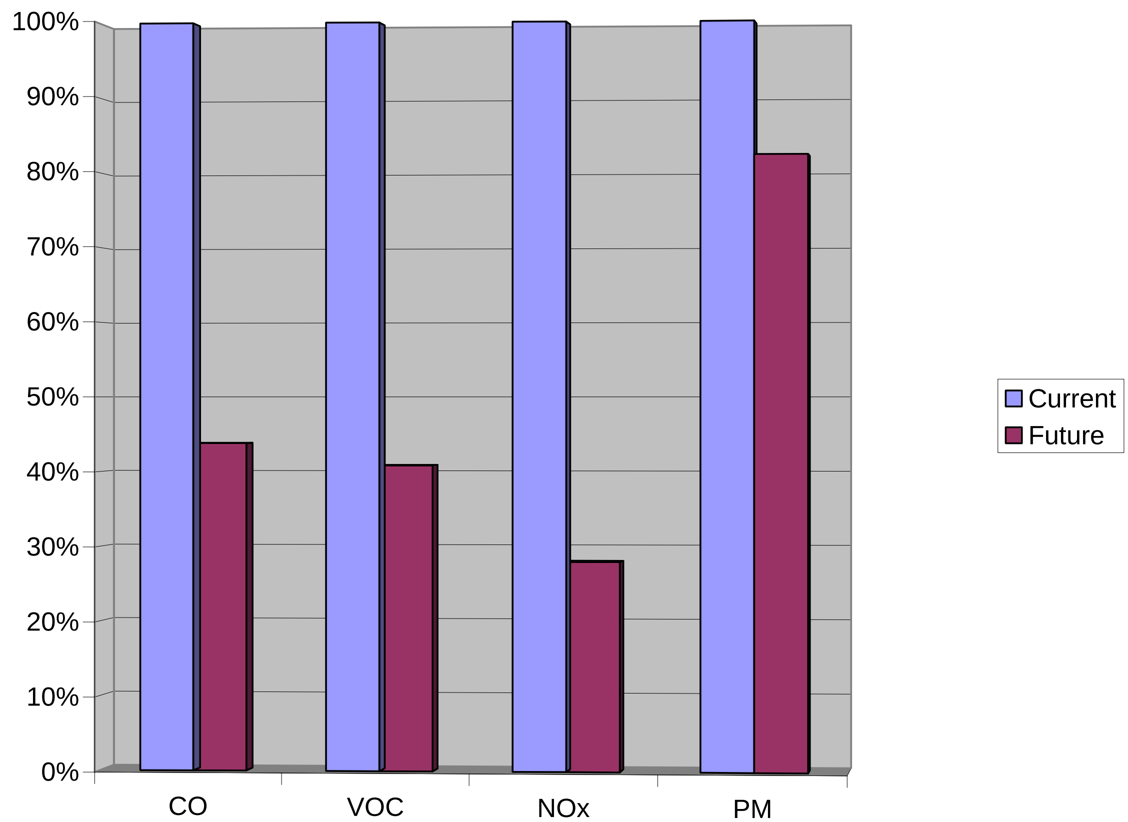

Figure V.12: Change in Emissions with an Improved Fleet in Almaty

The IVE emissions estimates presented in this report represent a compilation of the best available information to date in Almaty. It combines real-world fleet and VKT mix, age distribution of the fleet and numerous days of driving pattern data. In addition, the IVE model uses state of the art emission estimation techniques to correct for temperature changes, fuel quality, and differences in driving behavior. However, as always, there are steps that could improve these estimates. Additional data collection on other streets and other vehicles could improve activity estimates. Additionally, there is currently no account of the effect of the local emissions of the fleet in Almaty. Actual on-road testing of the Almaty fleet will be conducted by the field team in the next couple years. In spite of these data gaps, these estimates are believed to be the most accurate vehicular emissions estimate to date and should represent a reasonable emissions approximation, and provide insight into the emissions behavior and relevance of different types of vehicles in the fleet.

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

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

2. Collect additional information on the age of vehicles in the Almaty fleet, since there is a conflicting data for the age distribution of the passenger fleet and there is no data for the technology distribution of the heavy duty vehicle fleet.

3. Collect additional data on the soak distribution of passenger vehicles, taking care to identify a diverse and representative driver population. Also, expand start and soak distribution collection to heavy duty trucks and buses.

4. Improve emission factors for in-use Almaty fleet. Testing to collect this data will be performed by the GSSR and University staff over the next two years to fill this data gap.

5. Improve the estimate of total VMT for the current calendar year in Almaty to support overall emission estimates. Accurately identify future growth trends for the overall fleet in Almaty.

References:

1. Republic Stat Enterprise, Kazakh Research Institute for Environment Monitoring and Climate, "Kazakhstani GHG Emissions Inventory from Coal Mining and Road Transportation", Final Project Report Almaty July 2002

2. Agency? "Draft inventory report for road transportation as a contribution to the final project report", Contract# 355473-A June 6, 2003

3. DHV Consultants "First Interim Report: Support to the Ministry of Natural Resources and Environmental Protection of Kazakhstan. Almaty Urban Air Pollution Project" Almaty, October 2001 Tacis Programme, Eurpoean Commission

Appendix A

Data Collection Program Used in Almaty

International Vehicle
Emissions Model

Field Data Collection Activities

Table of Contents

I. Introduction

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

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

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

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

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

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

II. Collecting Representative Data

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

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

A. Selecting Parts of a City for Study

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

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

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

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

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

B. Selecting Driving Routes for Study

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

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

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

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

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

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

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

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

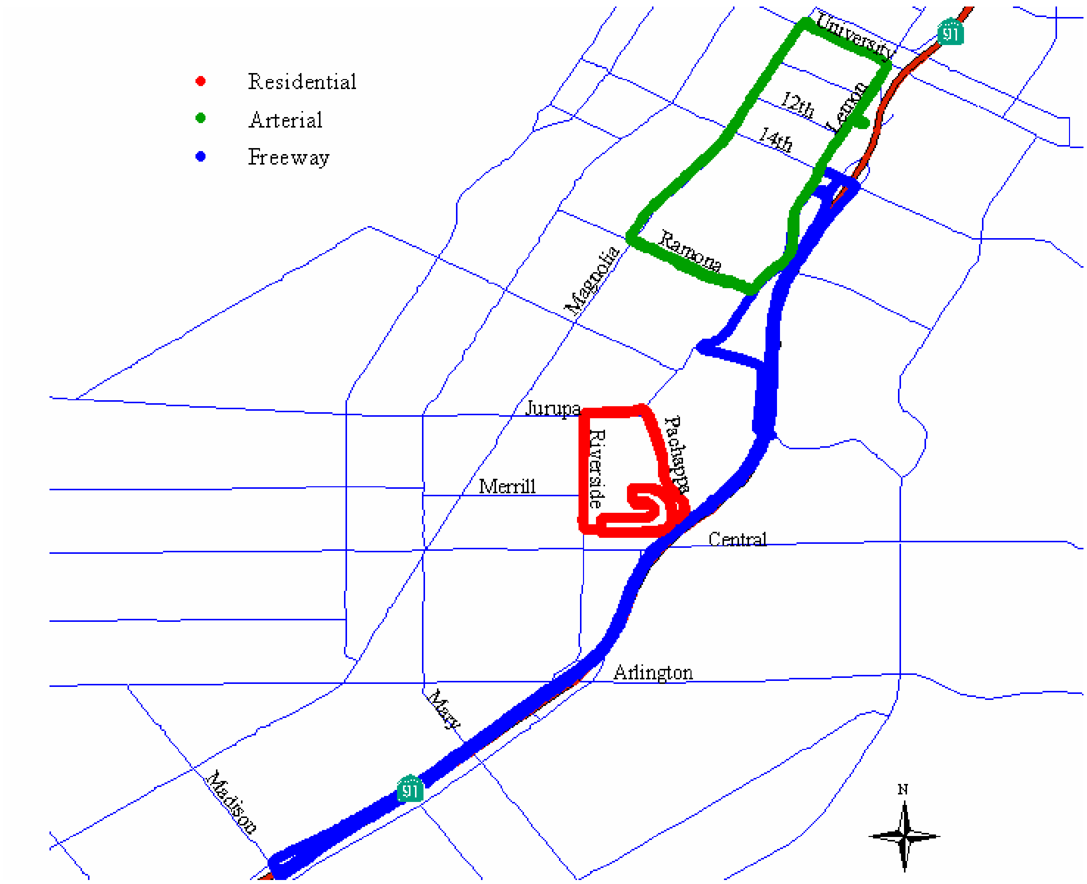

Figure II.1 Example of a Residential, Arterial, and Freeway Street-Segment Selected for a Single Study Area

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

C. Times of Data Collection

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

D. Collecting Other Related Data

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

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

III. On-Road Driving Pattern Collection Using GPS Technology

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

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

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

Figure III.2 CGPS Unit

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

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

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

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

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

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

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

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

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

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

B. Measurement of Bus and 3-Wheeler Driving Patterns

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

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

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

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

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

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

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

Camera Setup on the Overpass Picture of the Freeway Below

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

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

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

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

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

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

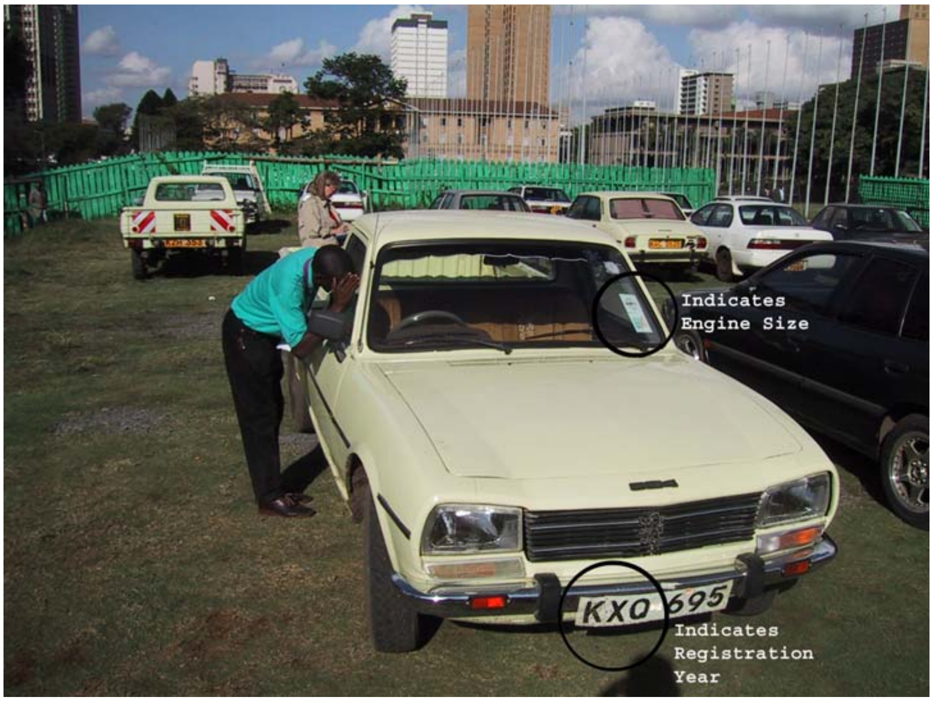

Figure V.1: Parking Lot Data Collection in Nairobi, Kenya

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

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

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

VI. Vehicle Start-Up Patterns by Monitoring Vehicle Voltage

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

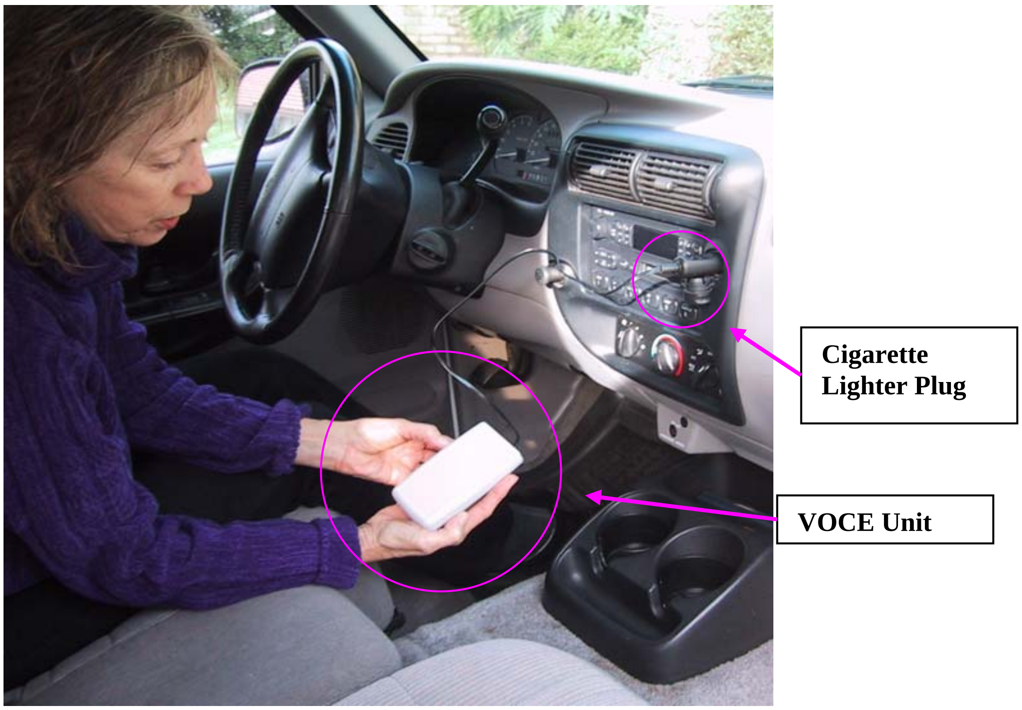

Figure VI.1 VOCE Unit for Collecting Vehicle Start Information

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

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

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

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

VII. Research Coordination and Local Support Needs

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

Table IV.1 Study Support Requirements

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

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

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

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

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

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Work Schedule for Almaty Kazakhstan*

May 18,2003	*May 19,2003*	*May 20,2003*	*May 21,2003*	*May 22,2003*	*May 23,2003*	May 24,2003
Sunday	***Monday***	***Tuesday***	***Wednesday***	***Thursday***	***Friday***	**Saturday**
Arrive	*No data collected*					
May 25,2003	**May 26,2003**	**May 27,2003**	**May 28,2003**	**May 29,2003**	**May 30,2003**	**May 31,2003**
Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
	VOCE Units distributed to 50 participants as early in day as possible. 1st day of on-road testing and video taping.	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. 2nd 50 VOCE units collected and data downloaded.	Meet at about 14:00 to review data collected and preliminary results of the study.

**the days in red italics were days that no data was collected due to unforeseen logistics issues. Extra data collection was conducted in the second week to compensate for the lost days of data collection. Additionally, vehicle owner surveys were conducted by local officials prior to the team's arrival in Almaty instead of the typical parking lot survey conducted by the team. The US team did not participate in this portion of the study except to provide this document with instructions and data collection procedure.*