Measurement of In-Use Passenger Vehicle Emissions in Almaty, Kazakhstan

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I. Abstract

Second by second emissions of CO, CO2 and NO were measured for 94 gasoline fueled passenger vehicles over a two week period in Almaty, Kazakhstan. The measurements included a vehicle cold start and about 30 minutes of driving. A circular driving route was selected with a variety of driving situations including low speeds on congested arterials and higher speeds and accelerations on highways. A Sensors SEMTECH-G portable emissions monitor and exhaust flow measurement system was used for the on-road emission and position, speed, and acceleration measurements providing in-use emissions information for vehicles operating in the three study areas. Subsequent analysis of the data provided second by second vehicle power demands in association with the measured emissions. By normalizing this data, it is possible to obtain estimates of emissions that would have occurred on an LA-4 cycle. These calculated emissions were used to improve the performance of the International Vehicle Emissions (IVE) model in conjunction with fleet and activity information previously collected to create an on-road emissions inventory for Almaty. This study comes to improve the information obtained in Mexico City, Sao Paulo and Nairobi in a previous report.

II. Background

On-road vehicles are responsible for a significant and rapidly increasing portion of the air pollution in the urban areas of developing nations. Many nations have recognized the health and environmental degradation from the use of these vehicles and have begun efforts to control the amount of emissions from their fleets. The process of reducing vehicular emissions is not straightforward; in general consisting of a combination of implementing stricter emission levels on new vehicles, tighter fuel standards, and implementing behavioral policies such as limiting driving in certain areas or days. While it is easy to conclude that these efforts should improve the situation, it is unclear to what extent these decisions have actually reduced in-use emissions, and what additional efforts will be needed to adequately address the urban air pollution problem. To provide answers to these types of questions, a complex and accurate vehicular emissions model is needed for estimating vehicular emissions, its contribution to the total inventory and air pollution, and forecasting emission reductions under various policy implementations. This model requires significant data inputs on the specific fleet of interest, including the type and quantity of vehicles, their behavior and amount of use on the roadways, and their in-use emissions under various conditions. Existing or easily obtainable information on the fleet and its emissions (for example, the registration database or emissions certification values) have shown to be exceptionally inadequate for this purpose. Both the development of a model and gathering necessary fleet information require significant financial and time investment that is not readily available in many locations. Moreover, the need for this information sooner rather than later is important, since even a few years delay in implementing emission reduction strategies could have a catastrophic impact on the air quality for years to come.

In response to this situation, the International Sustainable Systems Research Center (ISSRC) has developed a study process to gather the information and build the tools and capacity to properly estimate and predict vehicular emissions in any location worldwide. This process has several parts. First, the US EPA international offices funded the development of the International

Vehicle Emissions (IVE) model that can be applied to any area to estimate emissions. This model is designed with the flexibility to accommodate a wide variety of vehicle types, fuels, and driving behavior. The model is available free from the internet and requires minimal training to use. However, information specific to each local area is still needed to accurately estimate emissions using the model. In recent years, the US EPA, the Hewlett, and the Energy Foundations have funded ISSRC to collect information on the type, quantity, and driving behavior of the fleet in 11 cities worldwide. More information on these studies can be found on the ISSRC website (www.issrc.org/ive). The last required piece of information is the actual in-use emissions from the specific vehicle fleet. This report documents the procedure and results of collecting in-use light duty gasoline emissions in the city of Almaty, Kazakhstan and applying this information to the IVE model.

III. Study Design

III.A. Overview

The core purpose of the study was to collect real-world second by second emissions data from a representative sample of on-road gasoline fueled vehicles under a wide variety of driving conditions, including cold and hot starting conditions. A previous study by ISSRC (www.issrc.org/ive) established typical driving patterns in each city between the hours of 07:00 and 21:00. Thus, there was no need in this study to attempt to collect typical driving patterns. Instead, the goal was to collect vehicle emissions data from as large a variety of driving situations as might occur in the city within the constraints of safety, road conditions, and congestion. Clearly, since the study involved actual on-road driving, the test vehicle driving patterns will vary from vehicle to vehicle as traffic congestion changed throughout the test period. In order to compare measurements from the different vehicles, second by second vehicle speed and road altitude data was collected using GPS technology simultaneous with the emissions measurement. Altitude information can be used to estimate road grade and combined with vehicle speeds the power demand per unit weight, denoted VSP, on the vehicle can be determined. VSP is one of the best predictors of emissions variation with changes in driving behavior and speed. (Figure 1). With a complete map of emissions versus VSP collected, this information can be used to recreate emission estimates from any driving patterns. To enable the collection of cold-start conditions, the vehicles were procured the day before they were to be tested so that they could soak overnight

III.B. Route Selection

The driving route selected needed, of course, to begin at the test setup location and to return the vehicle to the test setup location in order to remove the test equipment to the next vehicle. In addition, a driving route that exercised the vehicle under many different driving conditions, including slow, steady driving, fast speeds, and hard accelerations was required. Thus, the driving route needed to include opportunities for driving in congestion as well as opportunities for driving in high speed situations. It is difficult in urban to find a route that would allow many high speed opportunities due to the ubiquitous traffic congestion. The route also needed to be completed in 30-45 minutes depending upon the traffic situation at the time of testing. The route selection is further compromised due to the need to be located near a secure place to park the vehicles overnight. These routes allowed a significant, although not complete variety of driving patterns for the vehicles tested. In general, a reasonable range of driving patterns was collected as will be shown in the data analysis section.

III.C. Vehicle Procurement

The intent of the study was to test a variety of vehicle technologies found in the city of Almaty. It was not intended to develop an exact representation of the local light-duty gasoline fleet. However, the vehicle procurement process did result in a fairly typical light-duty gasoline fleet. A combination of ads placed in a few periodicals and newspapers and word of mouth was used to find vehicle donors. A US$50 payment was paid to the vehicle donor to drive their vehicle to the test location and leave it for 24 hours and then pick it up. The owner was required to sign a waiver that the vehicle had liability and collision insurance and to agree that the maximum liability of ISSRC for each tested vehicle was US$1,000.

Each vehicle was inspected upon arrival and was rejected if it did not appear to be safe to operate for the test or if the exhaust had leaks. For example, some vehicles had tires with large bulges that could contribute to a blow-out and at least one vehicle had significant steering and brake problems. The vehicles were randomly selected from the volunteered fleet and therefore should be somewhat representative of the real-world fleet.

Table III-1 Overview of Light Duty Gasoline Vehicles Successfully Tested in Almaty

Vehicle Air/Fuel System	Vehicle Emissions Control Technology	Range of Model Years	Number of Vehicles
Carburetor	None	2000-2006	35
Multipoint Fuel Injection	None	1986-2004	26
Multipoint Fuel Injection	3-Way Catalyst and EGR	1986-2005	33
Average Age of Vehicle Fleet Tested		**MY 1996 (9 yrs)**	**94**

III.D. Emission, Speed, and Altitude Measurements

A SEMTECH-G portable emissions test unit was used to make emission measurements. This unit, shown in Figure III-1, weighs 40 kilograms equipped for testing (http://www.sensors-inc.com/semtech.htm). A separate flow measurement device manufactured by Sensors, Inc. that integrated with the SEMTECH-G unit was used in order to make mass emissions measurements. This unit weighed about 5 kilograms. An integrated Garmin GPS unit was used to estimate vehicle speeds and altitude. The SEMTECH-G unit also contained a temperature and humidity measurement device that was placed on the exterior of the vehicle to proved information concerning the vehicle intake air. A 100 amp-hour, 12 volt lead acid battery was used to power the system during on-road testing. Combined, the test equipment and battery added about 70 kilograms of weight to the vehicle, which is similar to an extra passenger. Thus as tested, the vehicles were transporting the rough equivalent of two persons counting the vehicle operator.

Figure III-1 SEMTECH-G Portable Emission Measurement Unit

The SEMTECH-G uses an NDIR for CO and CO_2 measurement, a NDUV for NO measurement, and an electrochemical O_2 sensor. There were no measurements of THC because the FID gas didn't make it to Almaty. Further information on the exact specifications for the measurement technology can be found in Appendix A of this report.

Its important to the analysis of this report to establish that the calibration gases didn't arrive to the test site at Almaty, the campaign was carry out without calibration during the campaign. When the equipment get back to the ISSRC headquarters a Span procedure was made to verify the offset of the measurement.

IV. Data Analysis Process

IV.A. Time alignment

The time alignment between the vehicle speed, tailpipe flow measurement, and gas concentrations is critical for producing accurate second by second emission estimates. Vehicle speed was estimated using a GPS unit attached to the vehicle that was supplied by Sensors. Flow measurements were made by a pitot tube flow measurement device provided by Sensors, Inc. (http://www.sensors-inc.com/semtech.htm). The time alignment was initially established by observing the flow measurements and comparing them to concentration and vehicle speed measurements. This allowed an approximation of the appropriate time alignment between the speed, flow, and concentration measurements. The time alignment was further refined by comparing the total carbon out of the tailpipe with the power demand (VSP) determined by the GPS unit. The total carbon relates to fuel use and should correlate with the power demand on the vehicle. Delay times were refined by selecting the values that gave the best total carbon to vehicle power demand correlations.

IV.B. Running Emissions

Two approaches for analyzing running emissions were used in this study. First, the emissions as collected are reported directly. Second, the emission rates were corrected to represent emissions from a standard driving pattern (the LA4 driving cycle).

IV.B.1. Study Measured Emission Rates

With the limited testing time, this study did not attempt to replicate typical citywide driving patterns. Instead, driving in all types of conditions was attempted to be collected. Therefore, the raw emissions reported from each test will not be exactly the same emissions as would be observed for a daily typical operation in each city. To compare how similar the driving pattern from the emissions study is to the real world, Figure IV-1 presents the study's driving trace and the actual arterial driving pattern as determined in previous studies. As shown in the figure, the driving pattern used in the emissions study ('study') compared to the driving pattern measured on arterials in the activity data collection ('art') is fairly similar with the exception of Nairobi. Thus, there will be some small errors when assuming the average emissions data collected in this study is the same as the average emissions of a typical vehicle operating on road. The reader should note these small differences when reporting the directly measured values as typical emission rates for each area. However, the corrected and raw emission values should not be very different, and the raw emission values should give one a ballpark idea of actual gasoline fleet emissions in each area.

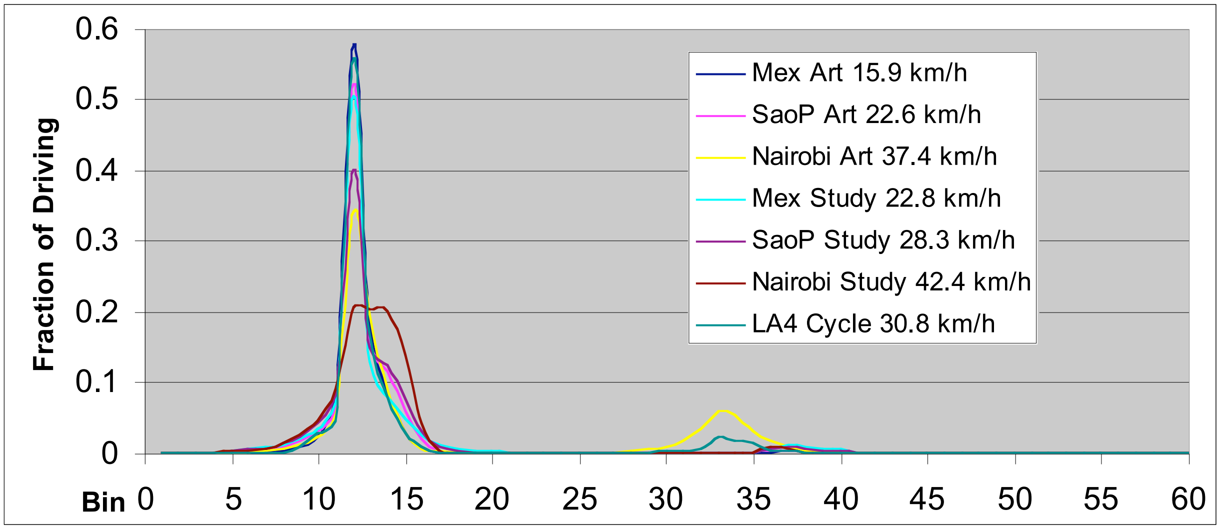

Figure IV-1 Distribution of Driving Among the 60 IVE Bins for a Typical Vehicle Compared to Daytime Distribution of Arterial City Driving

As can be seen in Figure IV-1, the driving was restricted primarily to the first 20 bins (power demand groupings) with only a small amount of driving in bins above 20. The bins above 20 are referred to as higher stress bins in the IVE model. The emissions study vehicles achieved a higher average speed than was observed in the original vehicle activity study but this was on purpose to gather as large a variety of data as possible. Even with the increased driving speeds there was still little data collected outside of bins 5 through 16, making it difficult to yield reliable emissions trends in these higher bins.

IV.B.2. Corrected Emission Rates for City Driving

The second approach used to analyze the running emission data is more complex. To estimate a more realistic on-road emission factor, the driving patterns of arterial, residential, and highway driving should be applied instead of the driving pattern during the limited emissions test. To extrapolate the collected emissions data to other driving patterns, the average emissions in each driving condition (termed 'bin') is determined. Once the emission rate for each individual bin is determined, emissions from any driving cycle can be recreated by multiplying the fraction of driving in each bin by the emission rate in each bin. The IVE model uses 60 bins to represent urban and rural driving. The emissions variation from bin to bin is what ultimately accounts for the variation in emissions from different driving patterns. There are default values for each pollutant built into the IVE model (named Driving Pattern Correction Factors). These corrections were developed based on second by second emissions data collected on a variety of US vehicles. Figure IV-2 - **Error! Reference source not found.** presents the variation in emissions for bins 1-20 for the IVE model and the data collected in each of the cities for multipoint fuel injected gasoline vehicles. From the figure, it indicates that the driving corrections in the IVE model are representative of the collected data for bins 1-15. After that, the IVE model correction factors are larger than the measured values for all pollutants. This indicates that the model is reporting larger emissions from driving in these high power bins. It is unknown whether this overestimation of the emissions during high power situations is a real phenomenon or not. Unfortunately, the numbers of data points in the three cities in bins 16-20 are very small compared to the number of data used in the development of the IVE model. Also, time alignment becomes very critical for gauging these higher bins and more work needs to be done to understand this impact. For this reason, the IVE bin corrections were not modified based on these results at this time. Additional studies to collect emissions data for the larger bins are planned in the future, and the results will indicate whether the IVE correction factors should be modified. At any rate, the fraction of actual driving occurring in these bins is a tiny portion of the driving (see Figure IV-1), and therefore making changes to the corrections would not result in a large change in overall emission rates.

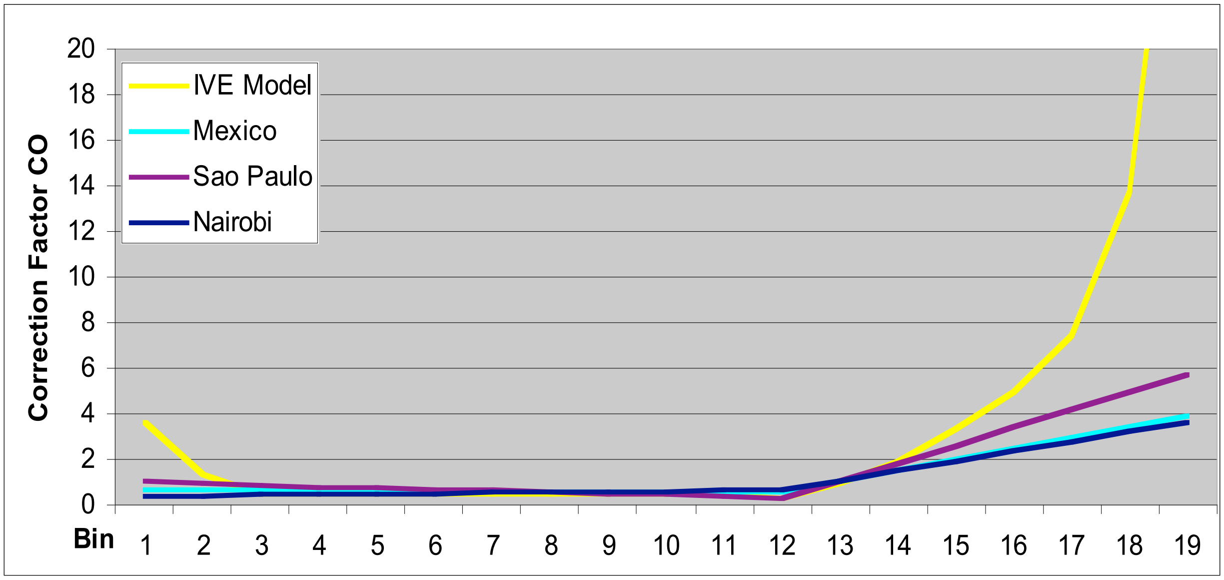

Figure IV-2 CO Corrections for the Driving Bins for the New Multipoint Fuel Injected Vehicle with a 3-Way Catalyst Observed in previous Study

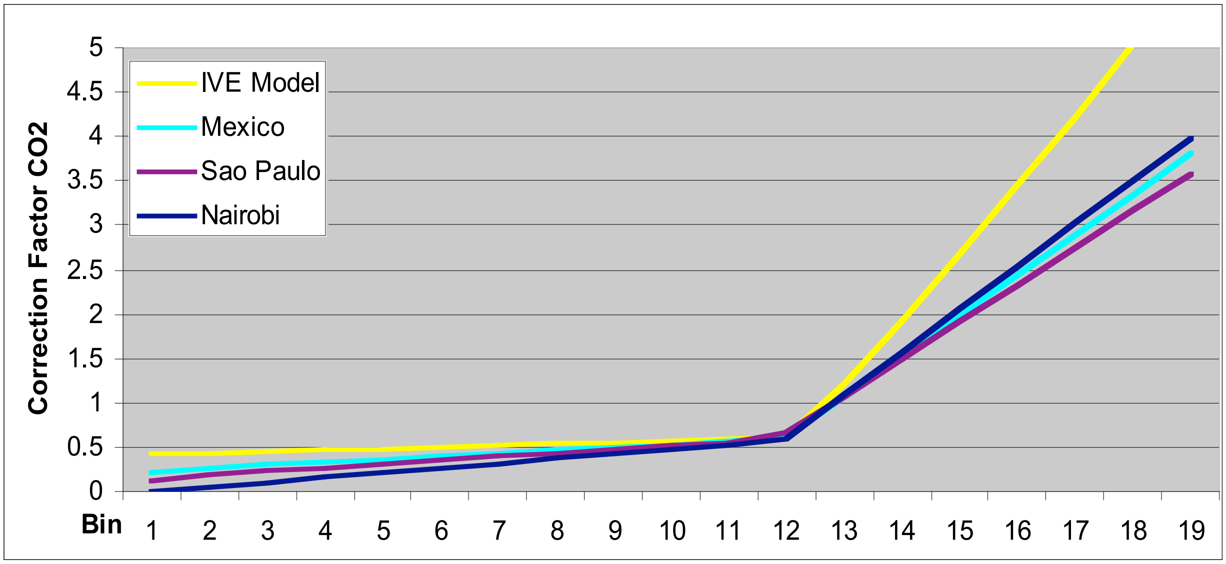

Figure IV-3 CO2 Corrections for the Driving Bins for the New Multipoint Fuel Injected Vehicle with a 3-Way Catalyst Observed in previous Study

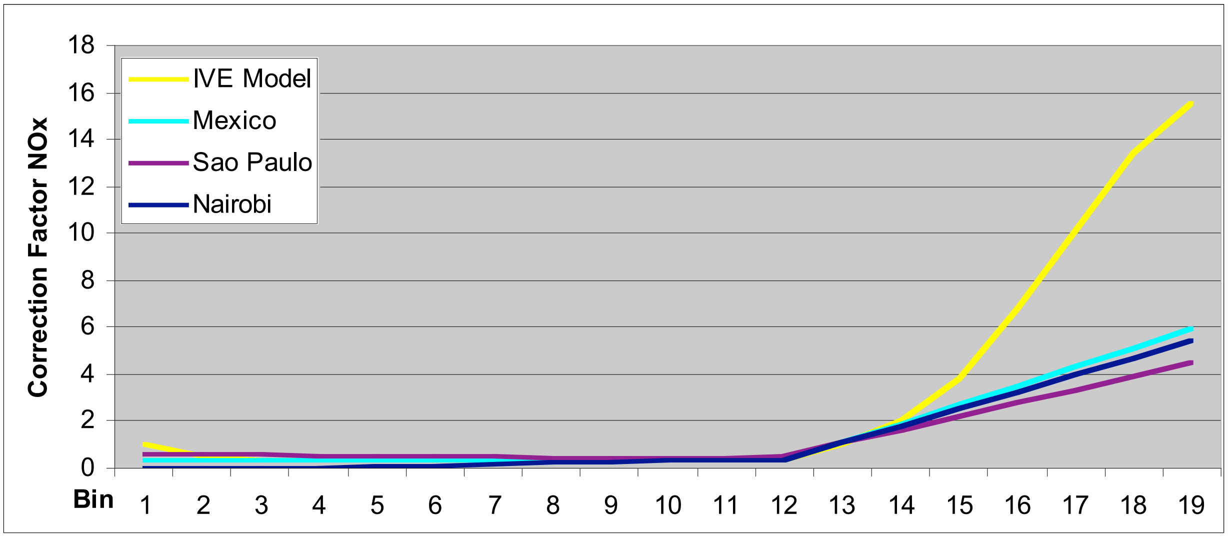

Figure IV-4 NOx Corrections for the Driving Bins for the New Multipoint Fuel Injected Vehicle with a 3-Way Catalyst Observed in previous Study

Due to traffic congestion during parts of the day, driving could not be achieved in all of the necessary running bins. Thus there were no emission estimates for these bins. In all cases, the bins missed were the bins were the smallest fraction of driving was taking place. Thus, an estimate of emissions for these bins would not produce a major change in the resulting emission estimates. A linear fit was made to the data in bins 0 to 11 (these are the bins were the vehicle is slowing down), and a second linear fit was made for bins 11-19 (these are the bins were the vehicle is accelerating or driving at a steady rate). Similar linear fits were made to the higher stress bins. These linear fits were used to fill in data where no driving was observed.

The LA4 test cycle, which represents the hot running portion of the FTP test procedure, is a standard test cycle used all over the world and is used in the IVE model to establish the base emission factors. It is easy to divide the driving trace of the LA4 cycle into the fractions of time spent in each of the 60 IVE VSP bins. The result is the LA4 driving pattern as shown in Figure IV-1. These fractions can be used in conjunction with the emission rates measured for the various IVE VSP bins (Figure IV-2) to determine the approximate emissions that would result had the tested vehicle been driven on the LA4 cycle. Thus, the emission rates for different vehicles can be normalized as if the vehicle had been tested on a LA4 cycle. This will not be a perfect conversion, and as noted earlier, the observed changes in emissions in the higher bins were not totally consistent with our U.S. results. Until this can be better understood a different approach to LA4 normalization will be used as described in the next paragraph.

In order to make comparisons with the base emission factors in the IVE model, and because of the inconsistency in higher bin emissions, a second normalization approach was used. In this approach, the IVE driving correction factors as illustrated in Figure IV-2 are multiplied by the fraction of observed driving illustrated in Figure IV-1. This process results in a driving correction factor that indicates the difference in emissions predicted by the IVE model from an LA4 cycle to the actual cycle used to measure the emissions. This value is divided into the measured running emissions from each test to obtain an estimate of the vehicle's emissions if it was driven over the LA4 cycle (the running base emission factor). This value is important for developing improved base emission factors for the IVE model. These results will be presented in the results section as the LA4 corrected emissions.

IV.C. Starting Emissions

Cold-Start emissions are defined to be the excess emissions that occur in the first 200 seconds after the vehicle sits for 12 or more hours. When the vehicle is started, there will be both starting emissions and running emissions for the first 200 seconds. The cold start emissions can be obtained by subtracting the running emissions that occur during the first 200 seconds from the total emissions that occur during that period. Similarly, Warm-Start emissions are defined to be the excess emissions that occur from an already warmed up vehicle in the first 200 seconds after the vehicle rests for 10 minutes.

The estimation of start emissions is not an exact exercise. The estimated running emissions that occurred during the start up phase can be a little too high or a little too low. Since the Cold-Start and Warm-Start emissions are calculated as the difference between two values, an error in the estimation of one of the values will exacerbate the error in the calculation of Cold-Start and Warm-Start emissions. However, when applied over several vehicles, the errors should average out to produce a representative emission rate depending upon the number of vehicles tested.

V. Results

V.A. Running Emission Rates for Individual Technologies

Table V-1 - **Error! Reference source not found.** lists the technologies that participated in the testing, the number of vehicles tested in that technology category, and the 90% confidence intervals for the vehicle categories where applicable. For example, for IVE category 0 in Almaty, there is a 90% probability that a similar vehicle tested would fall within ± 24% of the reported value for CO. The large range in the 90% confidence interval results from the fact that similar vehicles can have a large spread in actual emissions. This fact emphasizes the point that many vehicles need to be tested to fully understand vehicle emissions in an area, and further studies need to be completed in all of the urban areas where we worked. Appendix B contains the numerical values for the measured emissions from each vehicle as well as the FTP corrected values.

Table V-1 Description of Vehicles Tested in Almaty and the 90% Confidence Intervals for Average Values Computed for each IVE Class

IVE Category	IVE Description	# Tested	CO	CO2	NOx	THC
0	light carb low mi	11	24%	8%	13%	n/a
1	light carb med mi	20	17%	4%	12%	n/a
2	light carb high mi	4	23%	19%	33%	n/a
99	light mpfi low mi	4	54%	22%	45%	n/a
100	light mpfi med mi	14	28%	4%	8%	n/a
101	light mpfi high mi	4	61%	2%	13%	n/a
103	med mpfi med mi	2	38%	15%	16%	n/a
104	med mpfi high mi	8	66%	9%	35%	n/a
107	heavy mpfi high mi	1	n/a	n/a	n/a	n/a
117	light mpfi 3w low mi	1	n/a	n/a	n/a	n/a
118	light mpfi 3w med mi	6	13%	2%	32%	n/a
119	light mpfi 3w high mi	2	n/a	6%	7%	n/a
120	med mpfi 3w low mi	1	n/a	n/a	n/a	n/a
121	med mpfi 3w med mi	5	31%	9%	96%	n/a
122	med mpfi 3w high mi	9	48%	13%	34%	n/a
124	heavy mpfi 3w med mi	1	n/a	n/a	n/a	n/a
449	heavy carb/mixer 3w high mi	1	n/a	n/a	n/a	n/a
	All Vehicles	94	15%	3%	8%	n/a

As noted earlier, these data show a clear indication of the need to collect larger samples of vehicles to have an improved confidence in the results of the testing. Although data was successfully retrieved from over 100 vehicles at the location, very few vehicles were left in a technology group by the time it was categorized. A combination of the innate nature of the variation in emissions from vehicle to vehicle and the limited number of tests render quite large confidence limits in many cases. Overall, the Almaty data set contains the best confidence, probably due to the larger quantity of vehicles within each grouping, and the less complicated control technology. There are only 16 different vehicle types tested in Almaty, compared to 26 in Sao Paulo Mexico City in previous study. Looking at all vehicles combined, the confidence interval improves somewhat and looks similar between cities. Confidence intervals for CO2 remained 3-4%, ranged from 15-30% for CO and THC, and 7-15% for NOx. Almaty remain in the low part of the range.

The vehicles tested in each city should roughly represent a random selection of the light duty passenger fleet as found in each city. Thus, the overall results should provide a reasonable estimate of the light duty fleet emission rates, but again caution should be employed when looking at individual classes with few vehicles tested.

Table V-2 lists the average running emissions for all vehicles tested in Almaty operating over the LA4 cycle. Because the LA4 cycle could not be replicated for every vehicle tested since this was an on-road experiment, the IVE model was used to adjust the actual emissions to emissions from an LA4 cycle as explained in the data analysis section.

Table V-2 Mexico City Average Running FTP Emissions Rates for each Technology Type Tested[1]

IVE Category	IVE Description	CO (g/km)	CO2 (g/km)	NOx (g/km)	THC (g/km)
0	light carb low mi	38	249	2.8	n/a
1	light carb med mi	48	234	2.8	n/a
2	light carb high mi	48	211	3.1	n/a
99	light mpfi low mi	23	243	2.6	n/a
100	light mpfi med mi	22	230	3.2	n/a
101	light mpfi high mi	22	221	3.5	n/a
103	med mpfi med mi	20	363	4.7	n/a
104	med mpfi high mi	20	281	2.9	n/a
107	heavy mpfi high mi	12	302	2.2	n/a
117	light mpfi 3w low mi	11	200	1.9	n/a
118	light mpfi 3w med mi	4	183	0.2	n/a
119	light mpfi 3w high mi	4	172	1.6	n/a
120	med mpfi 3w low mi	15	229	0.9	n/a
121	med mpfi 3w med mi	6	278	1.3	n/a
122	med mpfi 3w high mi	12	284	2.7	n/a
124	heavy mpfi 3w med mi	34	276	0.6	n/a
449	heavy carb/mixer 3w high mi	10	103	1.6	n/a
Average of All Light Duty Vehicles Tested		27	242	2.6	n/a

[1] The measured emissions values were normalized to the FTP cycle using the IVE model for comparison purposes. It should be noted that the FTP referred to here includes only the running part of the FTP cycle (bags 2 and 3). The value was not normalized for altitude, fuel, temperature, humidity; although, the temperature and humidity were somewhat close to those called for in the standard FTP testing cycle on the days of testing.

From the previous table, it is clear that the emissions follow the expected trend when looking on a gross scale, but there are not enough tests to see the expected trends on the disaggregated scale in all cases. For example, in Table V-3, you would expect the class 101 with high mileage to have higher CO emissions than class 100, but it does not. Because the vehicle to vehicle variability is large compared with sample sizes, it is necessary to take into account and average effects until more data can be collected.

Table V-3 are similar to the previous table in that it shows the running emissions from all vehicles tested, but these have not been corrected to be for the LA4. Instead, this is the result of the actual driving cycle at the time each vehicle was tested. Therefore, no two driving cycles are alike, and will affect emission rates differently for each vehicle, which makes it difficult for exact comparison between vehicles and classes. However, it is useful to observe the actual emissions, and these emissions should more closely represent real-world conditions than the LA-4 corrected emission rates, and be similar to what would be used in an emissions inventory. Note that in most cases, the actual on-road emissions are larger than the LA4 corrected emission rates shown in

Table V-2. This is expected since the LA4 is considered to be a non-aggressive cycle that does not represent real-world driving conditions.

Additionally, these emissions are for the cycles that operated during testing, which is slightly different than the cycles operating within the city on a daily basis. Emissions corrected for the cycle is discussed in the next section.

Table V-3 Almaty City Average On-Road Running Emissions Rates for each Technology Type Tested

IVE Category	IVE Description	CO (g/km)	CO2 (g/km)	NOx (g/km)	THC (g/km)
0	light carb low mi	59	249	2.8	n/a
1	light carb med mi	76	234	2.8	n/a
2	light carb high mi	76	211	3.1	n/a
99	light mpfi low mi	38	243	2.6	n/a
100	light mpfi med mi	39	230	3.2	n/a
101	light mpfi high mi	32	221	3.5	n/a
103	med mpfi med mi	34	363	4.7	n/a
104	med mpfi high mi	29	281	2.9	n/a
107	heavy mpfi high mi	22	551	3.5	n/a
117	light mpfi 3w low mi	17	200	1.9	n/a
118	light mpfi 3w med mi	14	183	0.2	n/a
119	light mpfi 3w high mi	6	172	1.6	n/a
120	med mpfi 3w low mi	25	229	0.9	n/a
121	med mpfi 3w med mi	12	278	1.3	n/a
122	med mpfi 3w high mi	25	284	2.7	n/a
124	heavy mpfi 3w med mi	208	276	0.6	n/a
449	heavy carb/mixer 3w high mi	17	103	1.6	n/a
Average of All Light Duty Vehicles Tested		45	242	2.6	n/a

V.B. Running Emissions by Technology Groups

It can be useful to group emissions from similar classes together to observe trends and to increase sample size and minimize random error. For comparisons between classes, vehicles in more than a single IVE class were aggregated for a larger sample size between comparable vehicle types. For this section of the analysis, the vehicles from the following classes were aggregated into five general technology and age classes (Table V-4).

Table V-4 Almaty Grouped IVE Classes for Technology Comparisons

Description	# of Vehicles	IVE Classes
Carb low mi	11	0
Carb med mi	20	1
Carb high mi	4	2
Mpfi 3w	26	117,118,119,120,121,122,124,449
Mpfi No 3w	33	99,100,101,103,104,107

Figure V-1 shows the FTP corrected running emissions for the technology groups shown in Table V-4. The FTP corrected emissions were used because they provide a fairer comparison between vehicles because the actual emissions have been normalized to the same driving trace. In the actual tests, the vehicles are not constrained to specific driving patterns and thus can produce a variety of emissions depending upon the traffic situation at the time of testing.

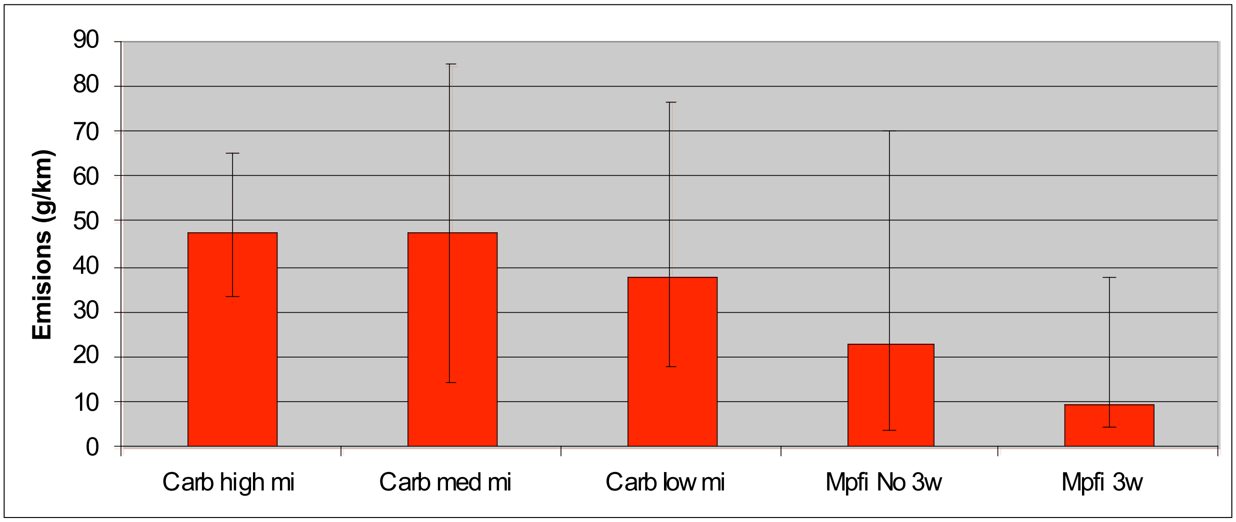

Figure V-1 Comparison of FTP corrected carbon monoxide emission values for the predominant Almaty vehicle technologies

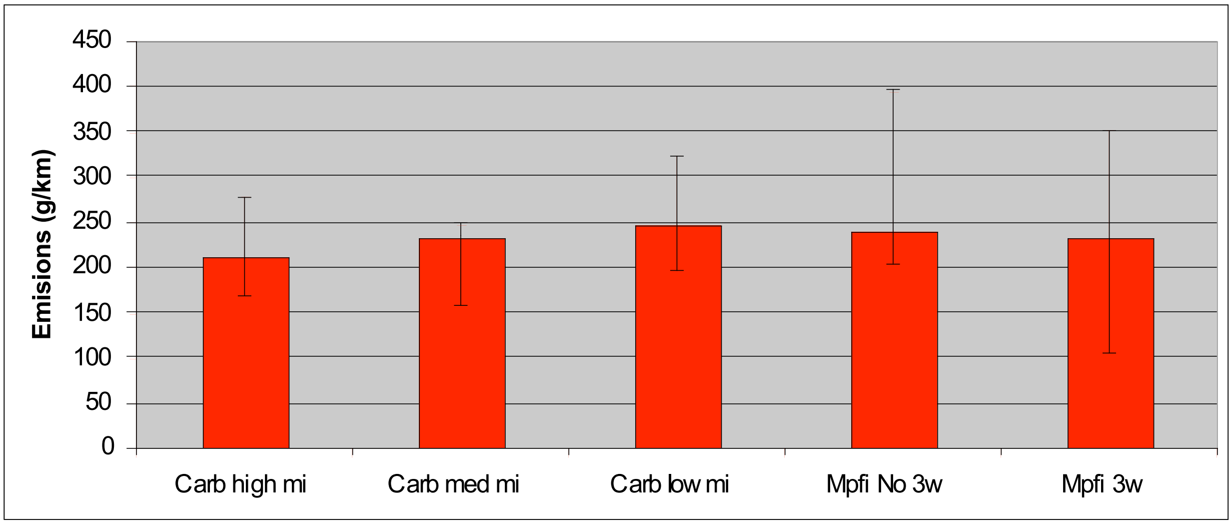

Figure V-2 Comparison of FTP corrected carbon dioxide emission values for the predominant Almaty vehicle technologies

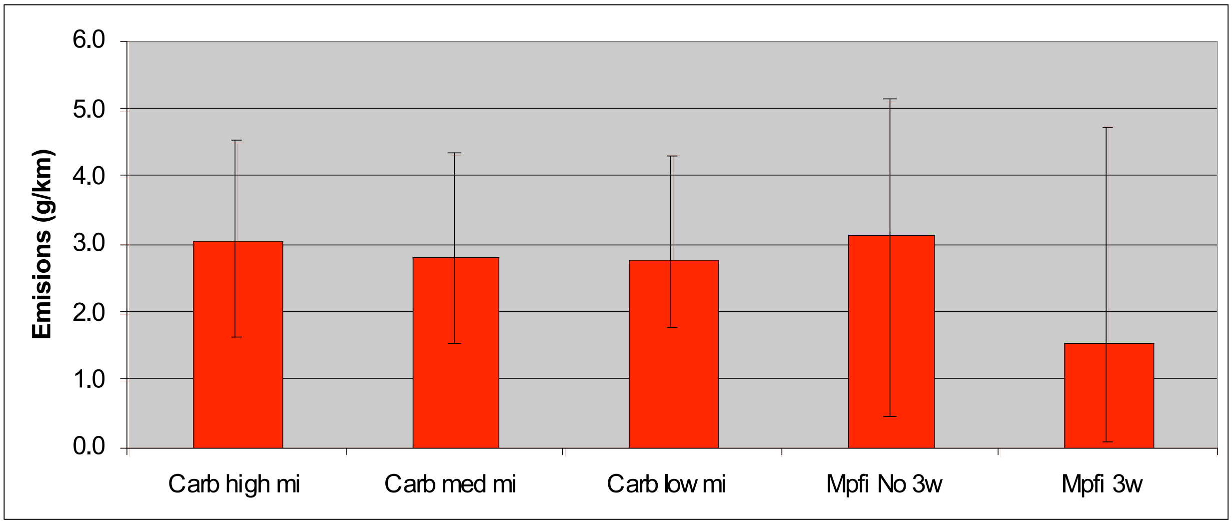

Figure V-3 Comparison of FTP corrected nitrogen oxide emission values for the predominant Almaty vehicle technologies

In general the emission rates observed from the fleet followed the predicted trend. One standard deviation is shown in the error bars to illustrate the variation in the dataset. Some of this variation is due to mixing IVE classes (i.e. categories 100 and 101 should have similar but different emissions); some is due to the variations within each vehicle class. In general, the variation is reduced for the newer vehicles, which behave more consistently (in terms of emissions) from vehicle to vehicle than the older aged vehicles. For CO2, all emission rates are similar between the classes. This indicates that there is not a clear trend in fuel efficiency between these classes. (There is a trend seen with CO2 and size of vehicle, as expected). For CO and NOx, the carbureted, non-catalyst vehicles (Categories 0, 1 & 2) generally have the highest emissions. The older multi point fuel injected non-catalyst vehicles also have high emissions. The lowest emissions are from the fuel injected catalyst vehicles. Within the same technology type, there is not a clear difference between the newer and older aged vehicles, and also between the vehicles with many miles and those with not very many miles. While the datasets show expected trend in emissions, there is still a large error and more vehicles should be tested to improve the confidence levels.

V.C. Emissions Variations by Model Year within a Technology Class

One observation made in viewing the test results were that emissions varied by model year for several of the technologies, also from the results it can be seen that there isn't any regulation in the Almaty region, older vehicles trend to be cleaner than new ones.

In the tested sample we found that the older vehicles have catalyst converter but new ones doesn't, this is the main explanation for the lower emission on older vehicles.

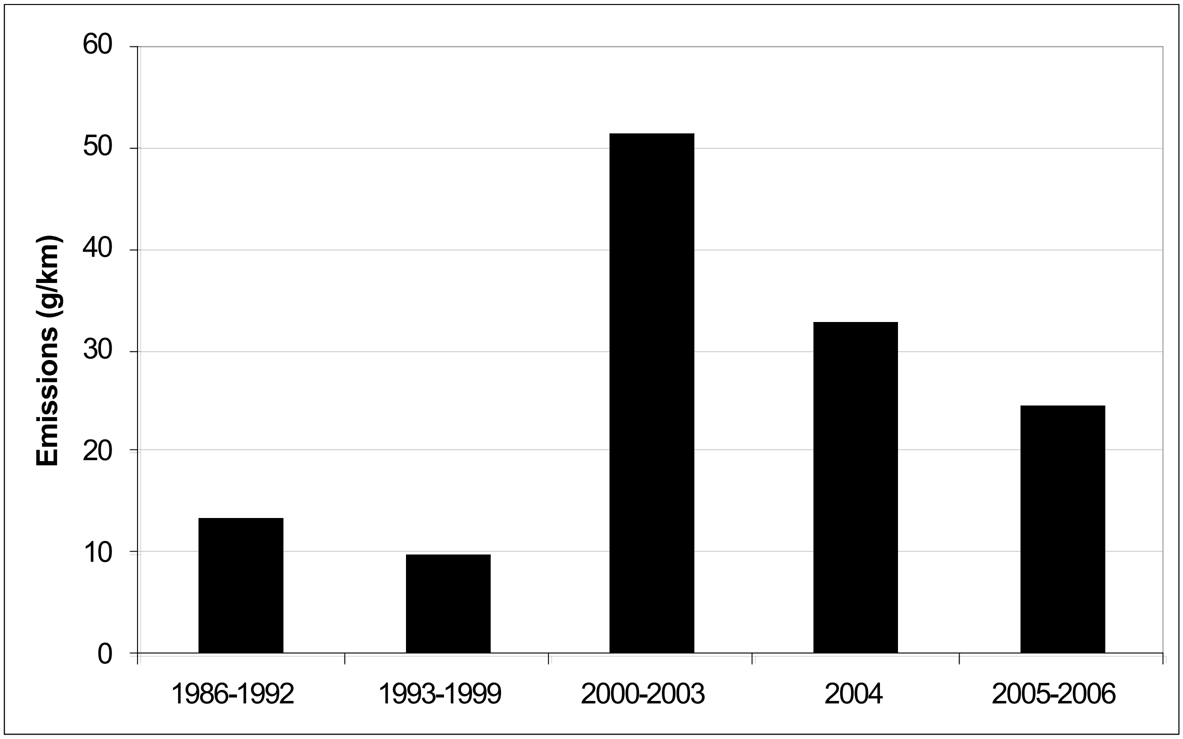

Figure V-4 Almaty Comparison of carbon monoxide emission values for select IVE Classes by Model Year

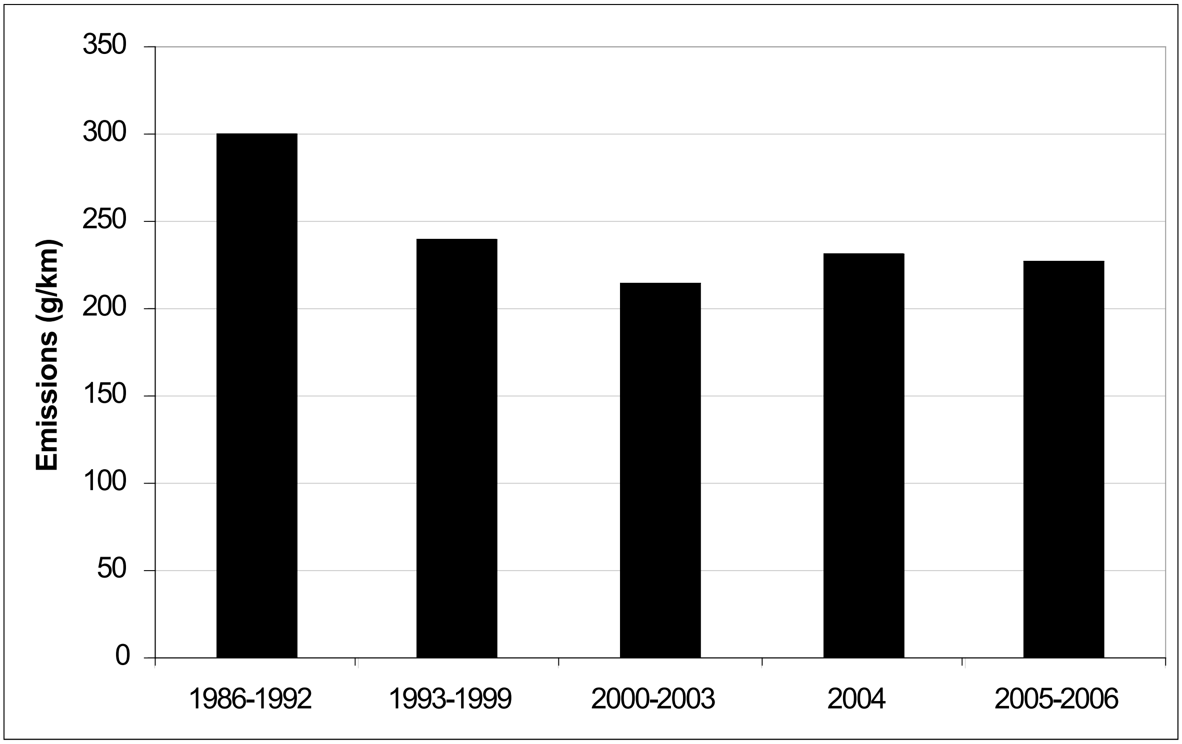

Figure V-5 Almaty Comparison of carbon dioxide emission values for select IVE Classes by Model Year

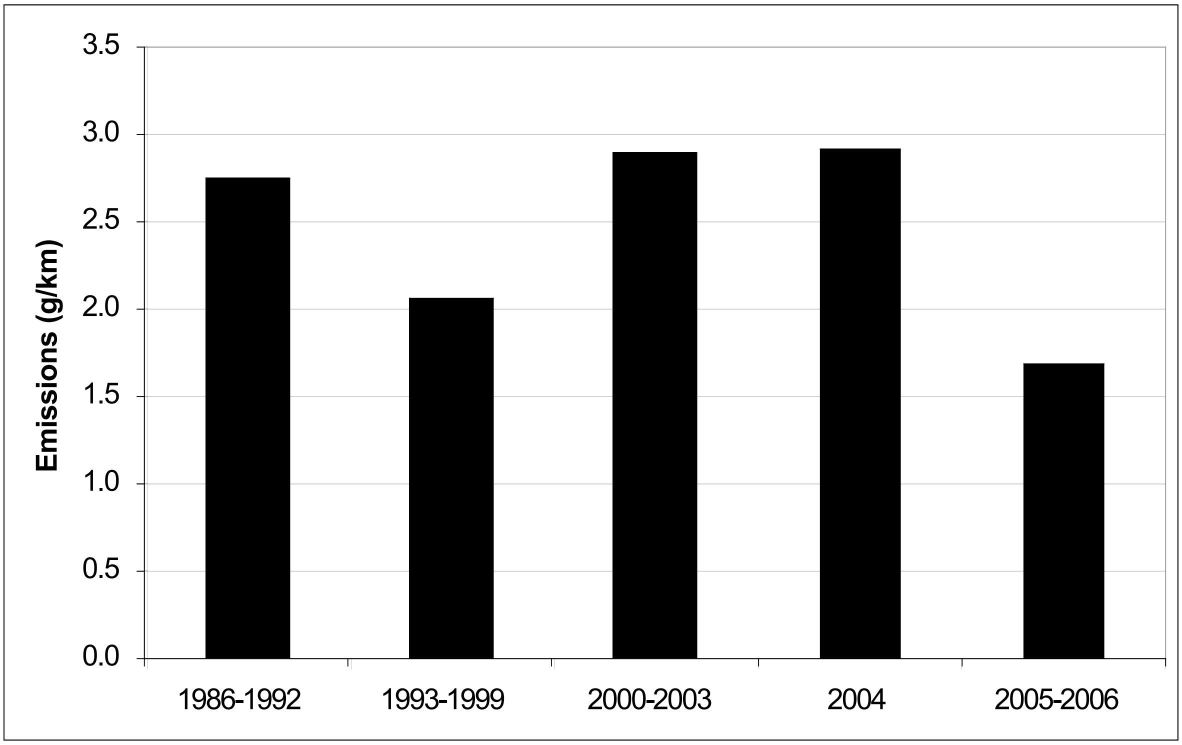

Figure V-6 Almaty Comparison of nitrogen oxide emission values for select IVE Classes by Model Year

V.D. Comparison between Cities

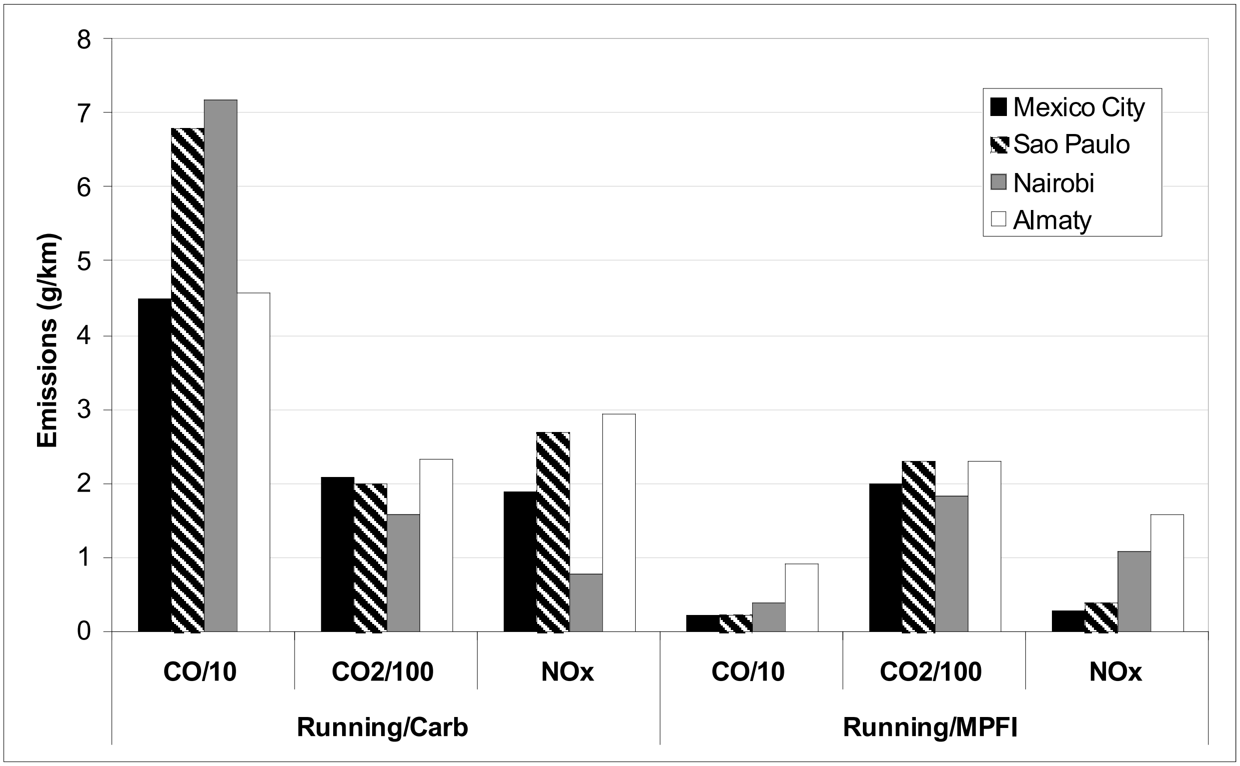

Figure V-7 summarizes average emissions for all cities and the light duty fleet average emissions when normalized to the LA4 cycle. Overall, these results indicate that the carbureted vehicles pollute the most, followed by multipoint fuel injection vehicles, although there is variability between cities, due to technology differences and different mixes of technologies. For all pollutants except CO2, Almaty has the highest fleet-wide emissions and Mexico City has the lowest. This is expected since the Almaty fleet is largely non-catalyst and the Mexican fleet has a mixture of low emissions alternative fueled technologies. For CO2, it appears the Nairobi fleet has the lowest emissions and the Almaty fleet has the highest. This is also expected from the size of the fleet, where Nairobi does not have any larger passenger vehicles while Almaty has no fuel efficient vehicles.

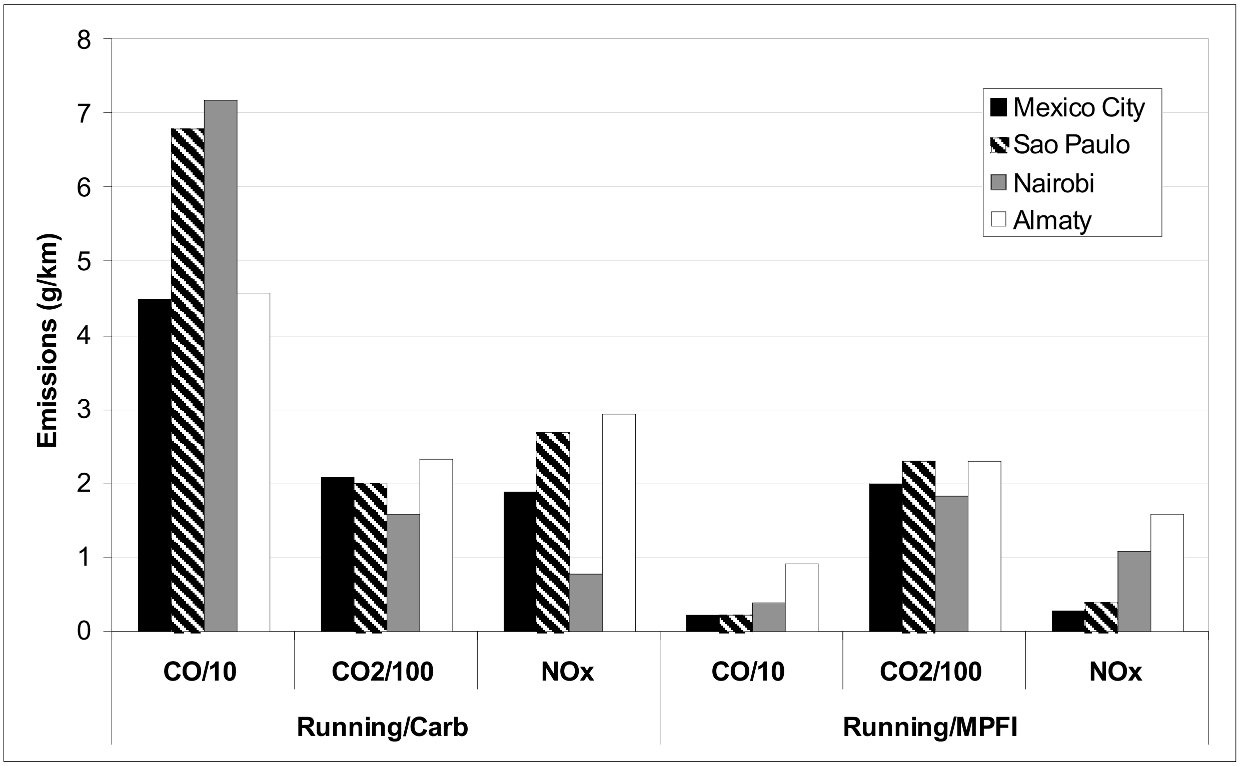

Figure V-7 Comparison of LA-4 Emission Rates in four cities for Carbureted running emissions

V.E. Running Emission Corrections to the IVE Model

One of the main purposes of collecting this on-road data in these cities is to improve the current emissions database and the resulting emissions modeling. Currently, emission rates in the IVE model and other models have not had the opportunity to utilize actual emissions data from the local fleet. However, with the 100 emissions tests conducted in this study, current data can be edited to obtain a more realistic estimate of the true on-road emissions. Additional emissions data will be collected in the near future and incorporated into these corrections as well.

The method for correcting for locally specific emissions in the IVE model is simple. The ratio of the measured emissions on the LA4 cycle to the IVE default emissions are input into the model for each technology available. A ratio of 1.0 indicates that the measured and IVE projected values are equal. A value less than 1.0 indicates that the IVE model is predicting values greater than actually measured, and a value greater than 1.0 indicates that the IVE model is under predicting emissions compared to measured emissions. A value different than 1 is expected in most cases, since it is believed that the fleet in other areas is not the same as the fleet used to derive the IVE model (mostly US vehicles). However, a value grossly different than 1 is not usually anticipated since it is believed that similar technologies should have similar emissions, no matter where they are built or used.

Figure V-8 compares the FTP corrected hot running emissions from the tests with the rates projected by the IVE model for the various technology types for the altitude and temperatures in Almaty observed during this testing. Because of the variability in the dataset and small sample size of many of the IVE Classes, similar classes were combined and compared with IVE predicted emissions values of the same combination. This method enables a general trend to be observed for the different groups.

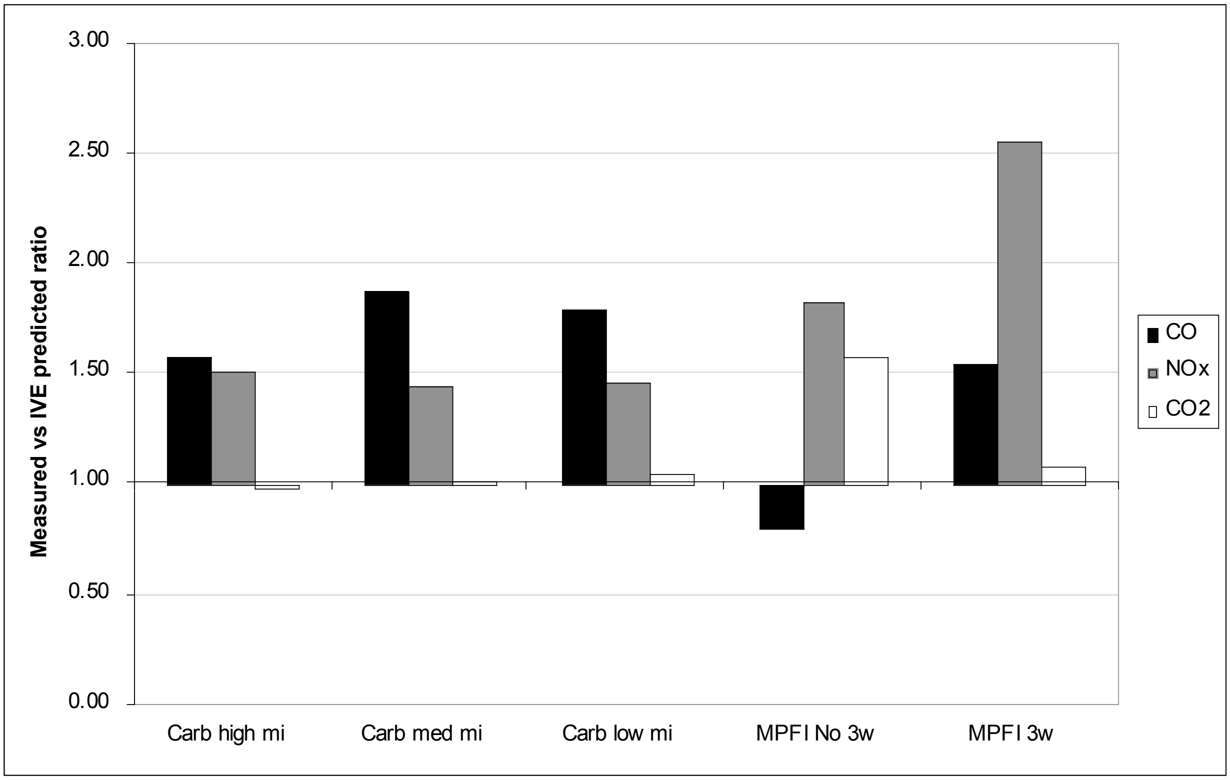

Figure V-8 Almaty measured running emissions compared to IVE projected emissions for General technology types

For Almaty, the running CO ratio of measured to IVE predicted values ranges from 0.88 to 1.88. So in general, actual measurements of CO were around 52% higher than predicted from the model. The CO2 emissions values are generally over the IVE predicted values, ranging from 0.98 to 1.58. For NOx, the ratio ranged from 1.47 to 2.56 depending on technology type. The IVE model significantly under predicted NOx emissions for all vehicles.

While this data is not from a large sample set, some adjustments to the IVE factors and other groups of similar vehicles are warranted for Almaty. Additional measurements planned in the future will clarify whether these trends are still observed with a larger sample set.

Table V-5 Almaty Corrections to the IVE Model

Categories	CO	NOx	CO2
Carb high mi	1.58	1.51	0.98
Carb med mi	1.88	1.45	1.02
Carb low mi	1.79	1.47	1.04
MPFI No 3w	0.81	1.83	1.58

MPFI 3w	1.54	2.56	1.08

VI. Summary and Conclusions

On-road tailpipe emissions of CO, NOx, and CO2 were successfully measured from a total of ninety four light duty vehicles in Almaty, Kazakhstan. The measurement system used in each city was a Sensors SEMTECH gasoline unit and flow meter that collected real-time flow rates, vehicle position, and ambient temperature and humidity in addition to the pollutants. Calibration and quality assurance procedures were conducted on a routine basis to ensure accurate data collection. A cold start and roughly 30 minutes of running emissions over a variety of speed and acceleration conditions were collected for each vehicle. It was determined, in previous studies, by testing that the hot (10 minute soak) starting emissions were in the noise of the measurement system and therefore were considered to be close to zero.

These data were used to gain an understanding of the light duty passenger vehicle emissions in this area. Confidence intervals of ± 20% or greater are common, due to this variability, it is recommended that additional testing be conducted in each city to improve the estimates. However, even with the large variability, general trends were observed in each fleet and some corrections can be applied to improve the emissions estimates. It must also be mentioned that this study did not include measurements of 2 and 3 wheeled vehicles, buses, or heavy trucks. In areas where these vehicles are an important component of the inventory, it is recommended that emissions testing be conducted on those vehicle types.

On average, the Almaty passenger fleet has the highest CO, NOx and CO2 emissions (Figure VI-1). This is to be expected, since many of the vehicles in Almaty are used with high ranges of lead in the fuel. Mexico City has the lowest fleet emissions of the three cities measured. This is a combination of emissions regulations for newer model year vehicles and fleet control.

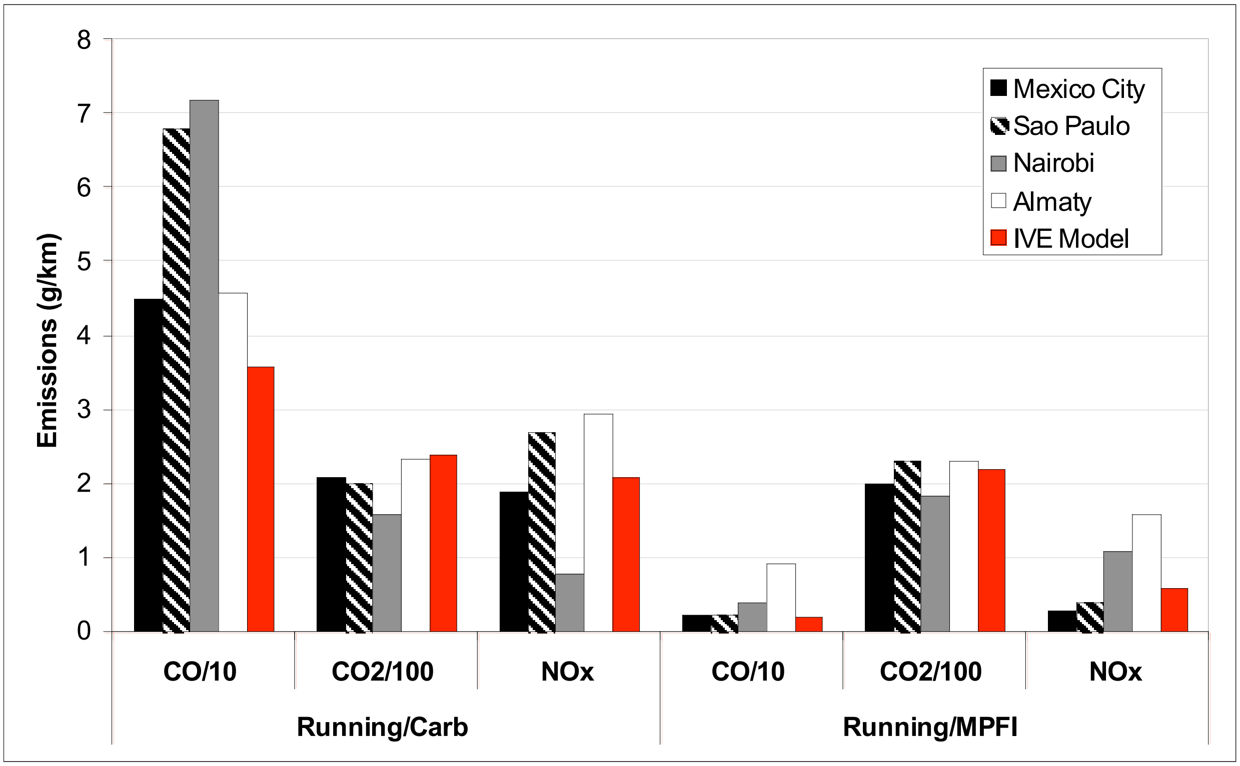

Figure VI-1 Fleet Average Emissions for the LA4 Cycle in Four Cities

One of the premises of the IVE model is that similar technologies will, in general, pollute similarly no matter where they are produced or operated. However, it was anticipated that some variation in emissions exist for same technologies in different cities, and therefore the collection of this data is necessary to update the emissions in each area to reflect these regional differences. The IVE model allows for the application of these locally specific emissions through the use of emission correction factors. There are correction factors allowed for start and running emissions for each technology and each pollutant.

In figure VI-1, the last (red) bar on refers to the base running emission rate used in the IVE model, which has been derived from emissions testing on US vehicles. In most cases, this emission rate falls in the mid range of the emissions measured from the various cities. Therefore, in a general sense, it is appropriate to assume that the IVE model emission rates are appropriate 'generic' emission factors to use if local emission data is not available. However, if local emission factors are available, like the four cities here, it is advised that correction factors be applied to account for this variability. If an area does not have any local emissions available to fine tune the emission factors, they can choose a region that is believed to be similar to one with available data. For example, another city in Africa would probably yield more accurate results if they used the Nairobi corrections instead of the IVE model default values alone.

The emissions data collected in each of the cities was analyzed and processed to yield correction factors for general technology classes. In the model, a different correction factor for every technology type and every pollutant is available; however, due to the variability and amount of data collected, the emissions were aggregated across similar groups. This process can be updated as more data is collected within each group. Figure VI-2 shows a summary of the average correction factors applied for three gasoline types, carbureted, older multipoint fuel injection vehicles without catalyst and newer multipoint fuel injected vehicles with 3 way catalysts. A correction factor of greater than 1 indicates the emissions in Almaty are greater than predicted by the default emission factors in the IVE model, and a value of less than one indicates the IVE model default rates are over predicting that vehicle type.

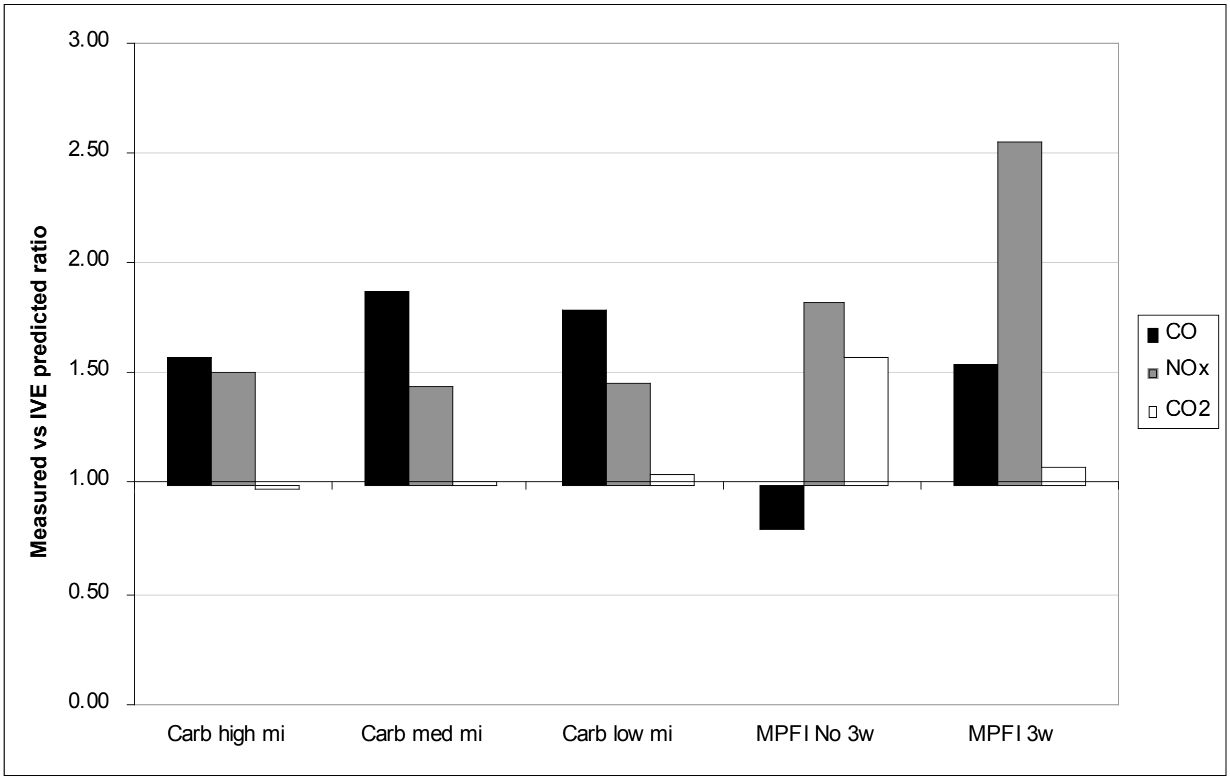

Figure VI-2 Summary of Running Emission Correction Factors In Three Cities

As can bee seen in Figure VI-2, for the Almaty fleet, most of the predicted IVE values are underestimating the emissions. The Multi point fuel injection vehicles without 3 way catalyst seem to have different results from the rest of the fleet, CO2 emissions are been underestimate for a 58%, and CO it been overestimate by the model on 19%. These behavior can be explained considering that there is large part of the fleet that is running with the catalyst completely dead, because of the leaded fuel, and the comparison is made between these kind of categories versus Non Catalyst manufactured vehicles from the USA, bigger and tuned to work without a catalyst.

Finally the main conclusion of this report is the next table with the values to correct the IVE model to use it in Almaty Kazakhstan.

Table VI-1 Almaty Corrections to the IVE Model

Categories	CO	NOx	CO2
Carb high mi	1.58	1.51	0.98
Carb med mi	1.88	1.45	1.02
Carb low mi	1.79	1.47	1.04
MPFI No 3w	0.81	1.83	1.58
MPFI 3w	1.54	2.56	1.08