Development and Application of an International Vehicle Emissions Model

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ABSTRACT

Vehicle growth in developing nations is increasing rapidly, making it necessary for these nations to address the transportation and environmental impacts of on-road mobile sources. To estimate the air quality impact of their fleet, many nations have adopted modified versions of U.S.- or European-based emissions models or factors. In most cases, these models can lead to significant errors in emissions estimates. To address this problem, a new on-road mobile source emissions model designed for use in developing countries has been developed, called the International Vehicle Emissions (IVE) Model. The IVE model was developed jointly by researchers at the International Sustainable Systems Research Center and the University of California at Riverside. The IVE model uses local vehicle technology distributions, power-based driving factors, vehicle soak distributions, and meteorological factors to tailor the model to the local situation. In addition, an intensive two-week field study was designed to collect the necessary fleet and activity data to populate the model with critical local information. The IVE model along with the field study process have proven to be highly effective in providing an improved estimate of mobile source emissions in an urban area and allows the effective analysis of local policy options. The studies have served to transfer tools and knowledge on the process of creating and improving mobile source inventories in an efficient manner. The rational behind the development of the model, development and application of the field studies, overview of the results to date, and planned next steps are described in this paper.

1. INTRODUCTION

Worldwide vehicle growth rates have risen rapidly in the past few years, and are projected to continue at this pace for some time *(1, 2, 3)*. With this exponential growth it is necessary to have an accurate understanding of the transportation and environmental impact of the current and future fleet. In Los Angeles beginning in the 1960s, it was observed that transportation was a major contributor to the air quality problem. However, the existing infrastructure and mindset of the community limited the changes to primary technological improvements. Over thirty years later, stringent rules and regulations have drastically reduced the emissions burden in spite of the rapid growth rates, but not without a major effort.

Recognizing the imminent transportation issues and their resource limitations, many developing nations have begun using modified versions of U.S.- or European based emissions models and factors in the absence of readily available local information to predict their vehicle fleet's emissions. While these approaches provide a baseline estimate of on-road emissions, there are many disadvantages of modifying these highly region-specific models and data to outside regions. U.S. emission factors are conventionally based on model year of the U.S. make and specific emission standards, and are tested only on U.S. fuels and driving cycles. This can lead to significant error in the overall emissions calculations when extrapolated to other areas with differing vehicles, emission standards, fuels, and driving activity. With EPA funding, the International Sustainable Systems Research Center (ISSRC) and the University of California at Riverside (UCR) have developed the International Vehicle Emissions (IVE) Model. The IVE model, along with corresponding field studies to improve the understanding of the vehicle fleet, activity, and emissions, enable informed decisions to be made about the regulations and choices for future transportation.

This paper highlights:

- The development of an emission modeling approach that allows for better transportation-related air quality decision making in developing countries;

- The development and application of effective data collection methods and associated equipment that can be carried out with limited resources normally available to developing countries in support of transportation modeling; and

- A summary of the results and implications of the research conducted to date, and a discussion of ongoing and next steps to provide an improved understanding of the status of transportation around the world.

2. MODELING MOBILE SOURCE EMISSIONS IN DEVELOPING NATIONS

An emissions inventory is essential for assessing and predicting air quality and for evaluating policy choices. Typically, the mobile source portion of the inventory is developed through the use of an on-road vehicle emission model. Several countries (such as Europe and the U.S.) have developed sophisticated vehicle emissions models that can predict emission based on local fuel specifications, vehicle types, emission standards, inspection and maintenance programs, and driving behavior *(4, 5, 6)*. These models are highly complex and have evolved over decades to meet the intricacies of technology and policy changes. In both Mexico and Hong Kong, U.S. EPA's MOBILE model and the California EMFAC model, respectively have been modified to predict emissions in these other areas *(7, 8, 9)*. Adapting these models for a different location requires extensive modification to the existing model. Even after such modifications, the code is such that future modifications will take additional structural changes. At the other end of the spectrum, many nations exist that have minimal resources and do not have the capacity to modify an existing model. Some of these countries have simply adopted the US AP-42 emission factors and applied these to their own fleet to develop their mobile source emissions inventory *(10)*. The AP-42 lists emissions for various model year vehicles and was developed to represent the base emission rates from U.S. vehicles in the 1980s. This approach can lead to highly unreliable results since driving and start patterns can vary from location to location and the insertion of local vehicle technology distributions into the model year based fleet information can be highly uncertain.

2.1. Model Design

For improving the current state of mobile emissions modeling in developing nations, a versatile and easy-to-use modeling tool called the International Vehicle Emissions (IVE) Model was created. The IVE model is a java-based stand-alone computer model that estimates vehicle emissions for any area, given three types of inputs. These inputs consist of: 1) the engine technology and add-on control distribution in the vehicle fleet (as well as maintenance); 2) driving behavior of the different types of on-road vehicles traveling on local roadways; and 3) vehicle emission factors specific to the local vehicles. The IVE model, similar to the U.S. and European models, is highly complex and incorporates many factors, vehicles, and fuel types (Figure 1a, 1b). It can be used to estimate emissions from virtually any fleet, at any scale (micro to macroscale). It can also be used to predict future emissions given changes in the fleet, fuel, and vehicle flows and congestion. The model can be downloaded from the Internet at no charge from http://www.issrc.org. Also available on this website is a complete User's Manual and a lengthy discussion of the theory of operation of the model that is too great to be included in this paper *(11)*.

To create an adaptable tool for any international locale, over 700 technologies have been incorporated in the IVE model. These include vehicles with motors ranging from two wheelers to large trucks and buses, including alternative fuels and varying combinations of air/fuel control and after-treatment controls (Figure 1b). Each technology is assigned a base emission running factor and a base emission start factor. These factors are defaults in the model and have been developed from existing information mostly from the U.S., but also from some data collection activities from Thailand, China, and India. The model allows the user to enter in fleet and location specific information as shown in the yellow highlighted boxes in Figure 1a. Also allowed are modifications to the default emission rates in the model if the region has developed site-specific emission rates. The mechanics of the IVE model are simple and similar to other conventional models. The base emission rate for each technology is multiplied by the correction factors and the distance traveled to determine the overall emissions produced from each vehicle type. Once an area has collected information as outlined in the subsequent section, the IVE model can create a first order estimate of emissions for the entire fleet in the region.

2.2. Model Application

The importance of a tool such as the IVE model to a developing nation is paramount. The results of this model can easily be incorporated into a city or countrywide emissions inventory, where the air quality burden attributed to mobile sources can be assessed. Once a baseline inventory has been established, various policy decisions about transportation planning, vehicle growth, fuel changes, and emission control systems can be evaluated and weighted. The IVE model is unique in its ability to predict a whole range of emissions from criteria pollutants (i.e., CO, HC, NOx) to toxics to global warming pollutants. This allows for a complete assessment of the air quality impacts from potential regulatory and growth scenarios.

3. COLLECTING MOBILE SOURCE INFORMATION

One of the major hurdles in creating an accurate inventory is the availability of appropriate local data relating to vehicle emissions. The data requirements for an advanced mobile emissions model are large. This is why some areas use the data already developed, which may not be representative of their area. Even with a tool such as the IVE model, significant data inputs are required for accurate emissions prediction. Data are required in three areas:

- Fleet composition
- Vehicle Activity
- Emission rates (not discussed in this paper)

The authors have developed a data collection methodology to gather this information with the resources typically available to a developing nation. The field study is designed to collect a large amount of initial data in a six-day period. This information is useful to provide a first order estimate of the emissions in the specific region studied. Validation of the techniques and tools used to collect the fleet and activity information is important for the results to be used in a meaningful manner. It is imperative to collect unbiased data when the collection effort is targeted at relatively small data samples. Extreme caution is employed to ensure that a representative variety of routes and drivers be used to collect the vehicle activity information. Additionally, the days selected for the study are typical and do not occur during adverse weather conditions, holidays, or weekends. If an analysis of the effect of these variables is desired, more data collection would be required. It is also imperative that a log of the actual drivers, vehicles, weather conditions, and dates be documented. Any observations that may skew the data sample should be noted and included in the final data analysis, so they can be further investigated. A full description of the field study design and collection procedure can be found in the IVE documentation *(11)*.

3.1. Fleet Composition

Many regions in the world do not have accurate information on the make-up of the on-road fleet. Registration and inspection/maintenance data may exist, but many times it has errors, may be out-of-date, or only reflects a portion of the fleet. Even in the United States, recent registration data were found to differ significantly from a manual inspection of the true on-road fleet *(12, 13)*. As a result, techniques were developed to capture an accurate fleet profile as part of a two-week field study that can take place at the study location. The field study consists of two types of data collection: 1) video taping traffic on various roadways to collect the proportion of general vehicle types on road; and 2) parking lot, bus terminal, taxi stand, and trucking surveys to determine the technology distribution of passenger vehicles, buses, and trucks.

3.1.1. Vehicle Class Distribution

In each city, typically nine roads are videotaped on weekdays between the hours of 07:00 and 21:00.The nine roads are selected with the assistance of the local agencies to be representative of three parts of the city of interest and can include residential streets, arterials, and highways. These videotapes are reviewed to determine the fraction of passenger vehicles, taxis, buses, trucks, motorcycles, three-wheeled vehicles, and other vehicles observed on the selected city streets. The hourly traffic volumes are also determined. The requirements for the video taping process include a high-speed, high-resolution digital video camera, possibly a guard for safety purposes, and a student trained in operation of the video camera. The videotapes are manually reviewed by trained students to count the various vehicle types. This method has been used effectively in many cities (e.g., the Los Angeles region, Nairobi, Santiago, and Shanghai) and provides very accurate results in the areas of interest when compared to other methods such as roadway monitors and automated decoders *(13, 14)*. In these validation exercises, it is demonstrated that the fleet mix observed on the nine roads selected can be extrapolated throughout the city of interest without biasing results. However, it is not accurate to extrapolate this information to other cities or areas outside of the specific metropolitan region studied because large fleet differences are typically observed that are not captured when looking only within the metropolitan area. This video capture approach requires no specific infrastructure requirements such as embedded monitors or the assumption of proper lane behavior. Figure 2a shows a picture of a roadway being video taped, and Figure 2b shows a local student viewing and categorizing the vehicle class information from the tape.

3.1.2. Technology Distribution

Because of the wide variation in types of passenger vehicles, trucks, and buses that operate on the roadway, it is necessary to determine the percentage of vehicles that have catalysts, specific engine control technology, and other parameters to support vehicle emissions estimates. This information cannot be determined through the videotaping procedure. Thus, in addition to the videotaping process, parking lot surveys are carried out in each area where a local mechanic physically inspects each vehicle and records the model year, emission and engine control technologies, odometer reading, and presence of air conditioning. This methodology requires a mechanic who has local expertise (and possibly a guard or a local official to obtain permission to enter parking lots), and a method to record the data (on paper, then onto a computer; see Figure 3). To collect the technology distribution of the passenger fleet, public parking lots are canvassed throughout the day. Caution is employed to select a variety of parking lots that contain a proportionate mixture of passenger cars, for example shopping malls or grocery stores or gas stations in several different areas of the metropolitan region. Residential streets are avoided because residents tend to park their oldest vehicles on the street and newer vehicles in the garage. Business centers are also avoided because they tend to only have newer vehicles. To obtain the technology distribution of the rest of the fleet, including trucks, buses, and taxis, a process tailored to the local situation is used but typically includes surveying bus, taxi, and truck stops in lieu of parking lots. Alternatively, the government or several private companies may have adequate records of the types of buses and taxis in the fleet since these may have strict regulations and limited variety.

The process of determining the fleet mix was validated first in the United States *(13, 14)*. In other regions, existing data were compared with the observed field studies. As expected, some differences are common, mostly due to the fact that many registration data sets do not contain accurate scrappage rates and reflect the static, not dynamic fleet. Further, results from the field study many times indicate that odometer tampering and reporting rates may be a problem in many areas.

3.2. Vehicle Activity

Another important factor in estimating vehicle emissions includes: 1) the amount and type of driving that is performed, and 2) start events performed by the vehicles. As part of the two-week field study, equipment is placed in vehicles to get an understanding of the local driving conditions.

3.2.1. Driving Patterns

Passenger vehicles cars are operated with the flow of traffic on the nine selected routes to measure the driving patterns of passenger vehicles and motorcycles using global Global Positioning Satellite (GPS) technology. During this same time period, students are dispatched to ride a variety of buses, three-wheelers, and motorcycles (where applicable) operating on their normal routes to estimate their driving patterns. The nine roads for the passenger cars, as well as the bus, taxi, and truck routes, are selected to collect representative data at all times of day across a variety of urban settings. Specially-designed, highly-portable GPS units are used in these studies that log vehicle location, speed, and altitude on a second-by-second basis. The data are then processed to produce the second-by-second speed and acceleration profiles at various times of day. The GPS units are specifically designed to operate in any vehicle, and do not depend on any on-board computer information for successful operation (Figure 4a).

The methodology used in this study is based on a limited amount number of GPS units operated for a very brief period of time. Thus, it is extremely important to verify that the data collected can be extrapolated to represent the driving patterns of the entire metropolitan region. In the U.S., the GPS-derived velocity data have been compared against extensive continuous traffic monitors that record average traffic velocity *(15, 16)*. These experiments have shown excellent correlation between the GPS-based driving patterns and the local area-wide driving profiles. Caution should be taken to properly delineate the boundaries of a region and capture a variety of residential, arterial and freeway driving across urban, suburban, and rural zones. Data collected in one region cannot accurately be extrapolated to a different region.

It is also important to verify the accuracy of the equipment used to collect the driving pattern information. Ever since inexpensive, high-resolution GPS units became available a few years ago, this technique has been used by many organizations to measure driving patterns. It has been well documented that the use of 1-Hz GPS data is adequate for the purposes of determining second-by-second vehicle specific power. Additional studies at the University of California, Riverside compared the GPS units used in this field study (resolution of 1 Hz) side-by-side with two more expensive commercial GPS units (some capable of 10 Hz resolution) along with other vehicle velocity measurement techniques (e.g., on-board diagnostic data). It does appear that the first three seconds of a hard acceleration are slightly underestimated for the inexpensive 1-Hz reporting units; however, these variations were very rare and determined not to have a noticeable impact on the resulting driving pattern. Moreover, several on-road emissions companies offer a 1-Hz GPS unit for determining velocity, and the U.S. EPA and ARB are using GPS instruments of a similar resolution for determining their driving patterns. The binning methodology employed in creating the driving patterns eliminates the use of devising representative “driving cycles” that represent a certain type of driving. A similar binning methodology is now being used by the U.S. EPA in their newest MOVES model *(17,18).*

3.2.2. Start Distribution

To collect the vehicle start patterns, equipment is placed in volunteer’s vehicles, taxis, and trucks for a period of 5 to 7 days to record the engine start/stop patterns of the fleet (Figure 4b). These VOCE (Vehicle Operating Characteristics Enunciators) units report the time of day of each key-on/key-off and how long the vehicle has soaked before starting. Typically over 80 units are distributed that record a total of 400 days of operation. This information is critical for developing an accurate assessment of start emissions, which can constitute 30-50% of the overall emissions in some areas. The VOCE units are simple in design and have been verified by comparing actual numbers and times of starts on a variety of vehicles in the U.S. *(11).*

4. RESULTS AND IMPLICATIONS

The field study methodology described above has been applied in many areas of the world. This section briefly highlights some of the results of the field study from six areas of the world, and compares it to data from the Los Angeles, California region. A comprehensive analysis of the results from these studies is included in a separate paper *(19).* The six areas compared here are listed in Table 1 along with the dates and a summary of the amount of data collected. The times of the year were selected to avoid unusual climatic conditions or holidays that would produce non-representative data.

Figure 5 compares the general vehicle mix observed on city streets in the six cities studied and observations in Los Angeles, California. The vehicle technology distributions vary among cities, but there were some remarkable similarities. Most of the traffic on all cities is due to passenger vehicle travel. Passenger vehicles as used here include passenger cars, trucks, and SUVs. Los Angeles, CA has the highest fraction of passenger vehicle travel at 95.5% of all observed traffic, and Mexico City is the next highest at almost 89% when taxis are included. The lowest observed passenger travel is observed in Lima, where only about half of the traffic is from passenger vehicles, motorcycles, and taxis. Accordingly, Lima has the highest observed travel from public transit vehicles at almost 20%. Public transit vehicles include 3-wheel carriers, buses, and electric trolleys in Almaty and Mexico City. In comparison, the Los Angeles region has less than 1% of travel from public travel vehicles. Pune, India has over half of its travel attributed to motorcycles. Because the economy is improving in India, more and more people are purchasing two-wheelers and not riding buses. This trend is causing an enormous amount of congestion and pollution in the urban areas.

The average vehicle age of the passenger fleet was also measured in the field studies. The results indicate that the Pune fleet is the youngest with the average age of less than 5 years, and Lima, Almaty, and Nairobi having the oldest average vehicle age of 11 years or older. In Los Angeles the average passenger vehicle age is around 7 years. The coupling of the new age of the fleet and the typical pace of introducing low emission vehicles and motorcycles could have long-lasting implications for areas such as Pune, unless policy-driven restrictions are implemented. This is because the current vehicles will be on the road for many years, and any new lower emitting technology may take longer to infiltrate the fleet.

It is well known that vehicles pollute significantly more when placed under high load conditions such as in accelerations and high speed driving. Thus, the actual in-use emissions that result from vehicles can vary considerably depending upon how vehicles are operated. Using velocity profiles gathered in the field, average power demand per unit weight can be estimated. Figure 6 indicates the average power demand per unit weight required of vehicles in the different cities studied.

It was found that the average power demand was highest in Los Angeles by a factor of two. The lowest is in Pune where congestion slows driving and accelerations down so much that average power demand is 1/7th of that found in Los Angeles. When engine size is considered, the actual overall energy use in Los Angeles will be about 11 times that of Pune if engine technologies were the same. Figure 6 also compares overall average driving speeds in the cities studied to date. As can be seen, average driving speed is similar to average power demand, but not directly related. The average power demand is lower in Pune compared to Nairobi even though average speeds are higher. The level of congestion in Pune compared with smaller overall engines resulted in lower acceleration rates and thus reduced average power use in Pune compared to Nairobi.

Based on the data collection conducted in these cities, some of the key findings are:

- With the exception of Pune, India, passenger cars represent about 85% of VKT (vehicle kilometers traveled).
- The average age of the passenger fleet in Los Angeles, Santiago, and Mexico City is about the same.
- The U.S. is using the most modern engine and control technology.
- Of the six international areas studied, three have a passenger fleet with predominately non-catalyst vehicles; The other three have about 20% of travel from non-catalyst vehicles. Los Angeles has less than 1%.
- Mexico City and Los Angeles have the largest passenger car engines.
- The greatest amount of driving per vehicle occurs in the U.S.
- Fuel quality and catalyst poisoning is wide-spread in some areas.
- Los Angeles drivers place the greatest power demand on their vehicles while Mexico drivers place the least (due to unrelenting traffic congestion).

5. CONCLUSIONS AND NEXT STEPS

A method for international cities has been developed to allow analysis of the impacts of fleet technology improvements, traffic flow improvements, and fuel modifications on criteria pollutants, toxics, and global warming gases. This process has been carried out in seven urban areas worldwide. Additional fieldwork is ongoing in Bogotá, Shanghai, and Beijing to collect fleet and activity data. At the conclusion of this process, local universities and government officials are educated in the use of the IVE model, the rational and techniques of data collection, and the importance of using the proper methods of estimating mobile source emissions. The process has proven to be highly successful in producing an initial mobile source inventory for these urban areas, along with guidelines and identified (sometimes substantial) data gaps for improving the inventory. The field analysis and application in the IVE model have shown that there are significant similarities with respect to mobile sources in a wide variety of cities. However, there are also key differences among developing countries that must be considered.

Policy makers in Chile, Nairobi (primarily the UN), India, Kazakhstan, Mexico, Brazil, Peru, Georgia, Columbia, and Thailand are now using the IVE model to do analysis, help create an overall inventory, and support decisions for urban areas in their countries. The process has also been helpful in fostering communication within areas of expertise in modeling, policy, industry, and local and national government organizations. After a successful field study in Pune, India in 2003, the India and US governments recognizing the usefulness and importance of these data gaps, hosted a training seminar to transfer the tools and methods for collecting adequate vehicle fleet and activity information. This training exercise was conducted in August of 2004 and attended by several universities, government agencies, and private companies of India. This equipment and training has now allowed India to independently collect this type of information in seven cities nationwide to help improve the data for a baseline emissions inventory development. Also underway in India are plans to purchase on-board vehicle emissions monitoring equipment to improve the in-use emission factors of the real world fleet. India will use the IVE model as a tool to assess the emissions benefits of outlawing specific technologies, such as two-stroke vehicles, and introducing alternative-fueled vehicles, and provide a scientific basis for assessing the value of potential policy decisions.

The studies in Almaty, Kazakstan, and Nairobi, Africa have demonstrated the drawbacks of using leaded fuel in portions of the cities, rendering catalysts ineffective for the duration of their lifetime. The effects on criteria emissions are clearly illustrated in the figures above. The effects are not only in the present, but will affect the region for decades to come.

In Mexico, the vehicle activity and fleet data collected in this field study are being used to update and justify changes in the Mobile5Mexico mobile source emissions inventory update currently underway. Also in Mexico, an on-board emissions study was conducted in October and November of 2004 on 100 vehicles to determine the local on-road emissions from the fleet and improve emissions inventory estimates in the IVE model. The IVE model relies on base emission factors and emission adjustments collected in the United States in most cases. It is likely that similar technologies will produce similar emissions. However, field studies are recommended in each local area to improve the emission factors. As was recently conducted in Mexico, emissions testing will be carried out in Shanghai, China, Sao Paulo, Brazil, Nairobi, Kenya, and Almaty, Kazakhstan between September, 2004 and May, 2005 to improve the emissions database in the IVE model for specific regions.

Using available local information and minimal field studies, the IVE model can provide a useful mechanism for estimating current mobile emissions of criteria, toxic, and global warming pollutants. The model has been designed as a policy tool and can easily assess future scenarios of varying technology types, fuel type and quality, and driving behaviors.

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REFERENCES

1. World Resource Institute 1998-1999, The Global Commons: Proceed with Caution. Growth in the Global Motor Vehicle Fleet. http://www.wri.org/wr-98-99/autos.htm Accessed July 29, 2004.

2. Asian Development Bank, Reducing Vehicle Emissions in Asia. Policy Guidelines for Reducing Vehicle Emissions in Asia, Publication Stock No. 110202 Copyright 2003. pp. 9-11.

3. United Nations (U.N.) Population Division, *World Population Prospects 1950-2050: The 1996 Revision*, Annex 1: Demographic Indicators (U.N., New York, 1997), pp. 11-45

4. CARB, California Air Resources Board EMFAC model, see www.arb.ca.gov/msei.html. Accessed on July 30, 2004.

5. EPA, MOBILE6 Vehicle Emissions Modeling Software. http://www.epa.gov/otaq/m6.htm Accessed on July 30, 2004.

6. European Environment Agency, COPERTII Computer Programme to Calculate Emissions from Road Transport – Methodology and Emission Factors. Technical Report 6. October 25, 1999. http://reports.eea.eu.int/TEC06/en/tab_abstract_RLR Accessed July 30th, 2004.

7. Rivero, D.M., H.L. Fonseca. Motor Vehicle Emissions Inventory for Mexico City, 1998. Emission Inventory: Living in a Global Environment. Proceedings of the EPA Emissions Factor and Inventory Group and Air Pollution Prevention and Control Division. New Orleans, Louisiana 1998

8. Cuatecontzi, D.H. Trends and Uncertainties in Mexico City Metropolitan Area Mobile Sources Emission Inventory. Proceedings of the 11th CRC On-Road Vehicle Emissions Workshop. San Diego, California 2001

9. Wong, C.K.L., Adaptation of EMFAC Model in Hong Kong. Poster Presentation at the 14th CRC Workshop. San Diego, 2004

10. Taiwan EPA, System Development for Air Pollution Control Plan and Standard Procedure for Emission Inventory Establishment, EPA-88-FA31-03-1059, Taipei (1999).

11. IVE Model. User's Guide, Model and Data Files. http://www.issrc.org Accessed July 30th, 2004.

12. Granell, J.L., R. Guensler, and W.H. Bachman. Using Locality Specific Fleet Distributions In Emissions Inventories: Current Practice, Problems, and Alternatives. TRB Paper number 02-3334.

13. Malcolm, C., T. Younglove, J. Tietjen, M. Barth, N. Davis, and J. Lents. Understanding Real-World Vehicle Activity Patterns and Vehicle Fleet Distributions in the SoCAB. Proceedings of the 12th CRC On-Road Vehicle Emissions Workshop, San Diego, 2002.

14. Younglove, T., C. Malcolm, G. Scora, and M. Barth. Observed On-Road Vehicle Fleet Differences and Their Effect on Emissions. Proceedings of the 12th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 2002.

15. Barth, M., E. Johnston, and R. Tadi. (1996) Using GPS technology to relate macroscopic and microscopic traffic parameters, *Transportation Research Record No. 1520*, pp. 89-96, Transportation Research Board, National Academy of Science.

16. Barth, M., C. Malcolm, T. Younglove, N. Davis, and J. Lents. (2002) Developing Link Emission Factors In The Southern California Air Basin, *Proceedings of the 12th CRC On-Road Vehicle Emissions Workshop*, San Diego, CA, April, 2002.

17. Beardsley, M. (2004) MOVES Model Update, *Proceedings of the 14th CRC On-Road Vehicle Emissions Workshop*, Hyatt Islandia, San Diego, California, March 29-31, 2004.

18. Koupal, J. et al., (2002) Draft Design and Implementation Plan for EPA's Multi-Scale Motor Vehicle and Equipment Emission System (MOVES), *U.S. EPA Technical Report #420-P-02-006*, October 2002.

19. Lents, J.M., M. Osses, N. Davis, and N. Nikkila. (2004) Comparison of On-Road Vehicle Profiles Collected in Seven Cities Worldwide. Proceedings of 13th International Symposium Transport and Air Pollution. September 13-15. Boulder, Colorado.

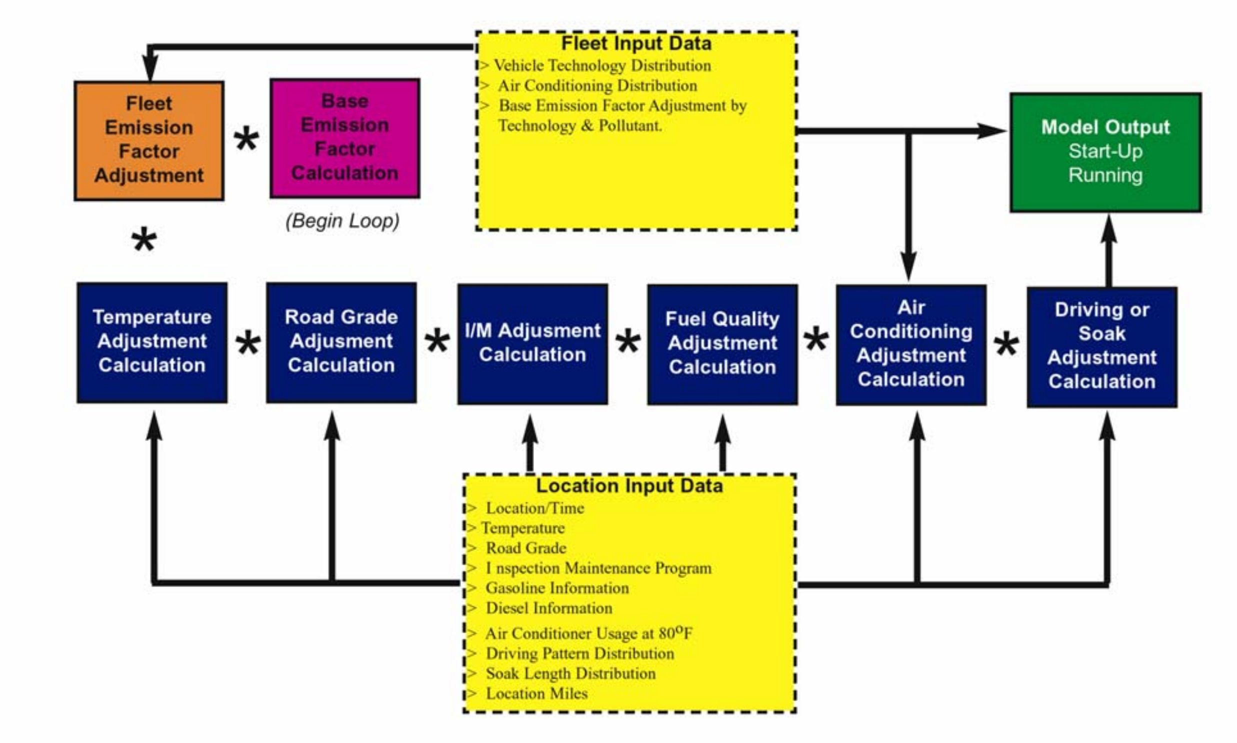

FIGURE 1a Illustration of the IVE model components

Light Duty Gasoline Vehicles	**Light Duty Diesel Vehicles**	**Light Duty Vehicles (Ethanol, Natural Gas, Propane, retrofits, etc)**	**Heavy Duty Gasoline Vehicles**	**Heavy Duty Diesel Vehicles**	**Heavy Duty Vehicles (Ethanol, Natural Gas, Propane, etc)**	**Gasoline,Ethanol, Natural Gas, Propane 2 and 3 Wheelers**
Carburetor	Pre-Chamber Inject.	Carburetor/Mixer	Carburetor	Pre-Chamber Inj	Carburetor	Carburetor
Single-Pt FI	Pre-Chamber Inject.	Single-Pt FI	FI	Direct Injection	FI	FI
Multi-Pt FI	Direct Injection	Multi-Pt FI	none	FI	None	None
None	FI	None	2-Way	None	2-Way/EGR	Catalyst
2-Way	None	2-Way	2-Way/EGR	Improved	3-Way/EGR	High Tech
2-Way/EGR	Improved	2-Way/EGR	3-Way	EGR+	3-Way/EGR	2 cycle
3-Way	EGR+	3-Way	3-Way/EGR	PM		4 cycle
3-Way/EGR	PM	3-Way/EGR	EuroI	PM/NOx		
LEV	PM/NOx	ZEV	EuroII	EuroI		
ULEV	EuroI		EuroIII	EuroII		
SULEV	EuroII		EuroIV	EuroIII		
EuroI	EuroIII		EuroV	EuroIV		
EuroII	EuroIV			EuroV		
EuroIII	Hybrid			Hybrid		
EuroIV						
Hybrid						

FIGURE 1b Illustration of types of technologies included in the IVE model

FIGURE 2a Collecting Vehicle Class Information using Video Cameras

FIGURE 2b Downloading Vehicle Class Information using Digital Video Data

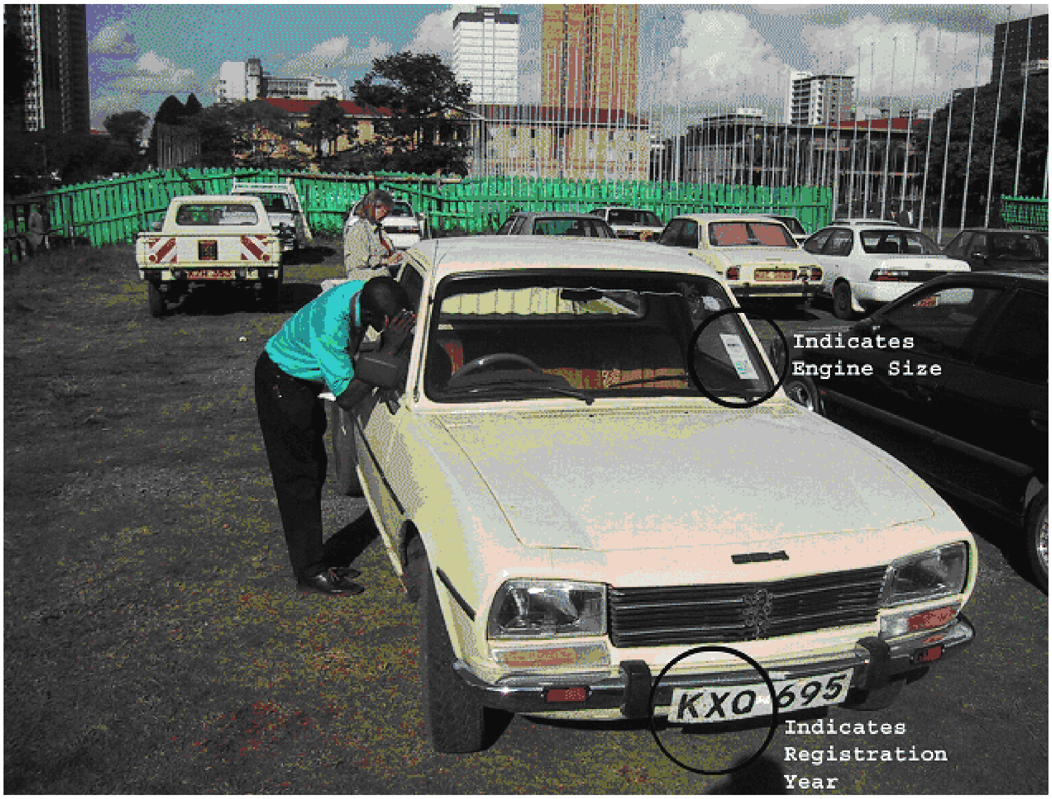

FIGURE 3 Parking Lot Data Collection in Nairobi, Kenya

FIGURE 4a Equipment Used in the Collection of Vehicle Driving Patterns

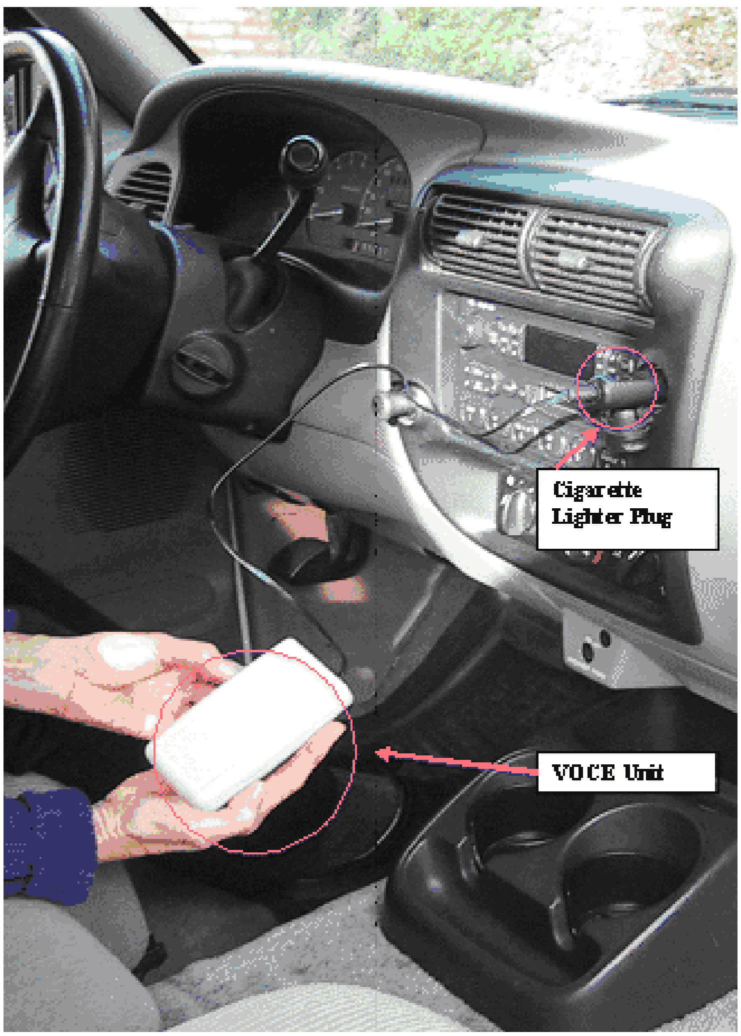

FIGURE 4b Equipment Used in the Collection of Vehicle Start Information

TABLE 1 Summary of Field Activity Studies Conducted in Six Locations

Location	Date	Hours of Video Tape Collected	Seconds of GPS Data Collected	Days of Vehicle Start Information	# of Vehicles Surveyed in Parking Lots
Almaty, Kazakhstan	May 2003	36	170,000	100	1150
Lima, Peru	December 2003	36	500,000	340	1422
Mexico City, Mexico	January 2004	36	684,000	340	n/a
Nairobi, Kenya	March 2002	36	336,000	104	865
Pune, India	March 2003	36	700,000	n/a	1154
Santiago, Chile	December 2001	36	224,000	n/a	814

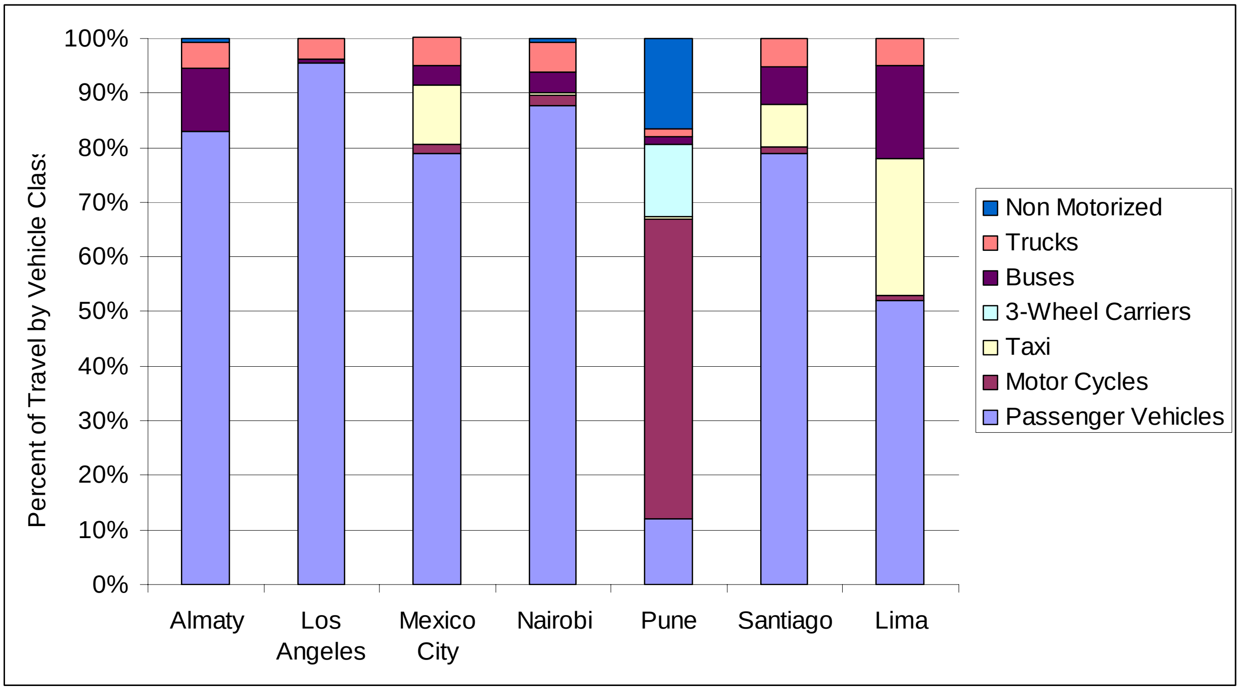

FIGURE 5 Distributions of Observed Vehicle Classes in Various Urban Cities Worldwide

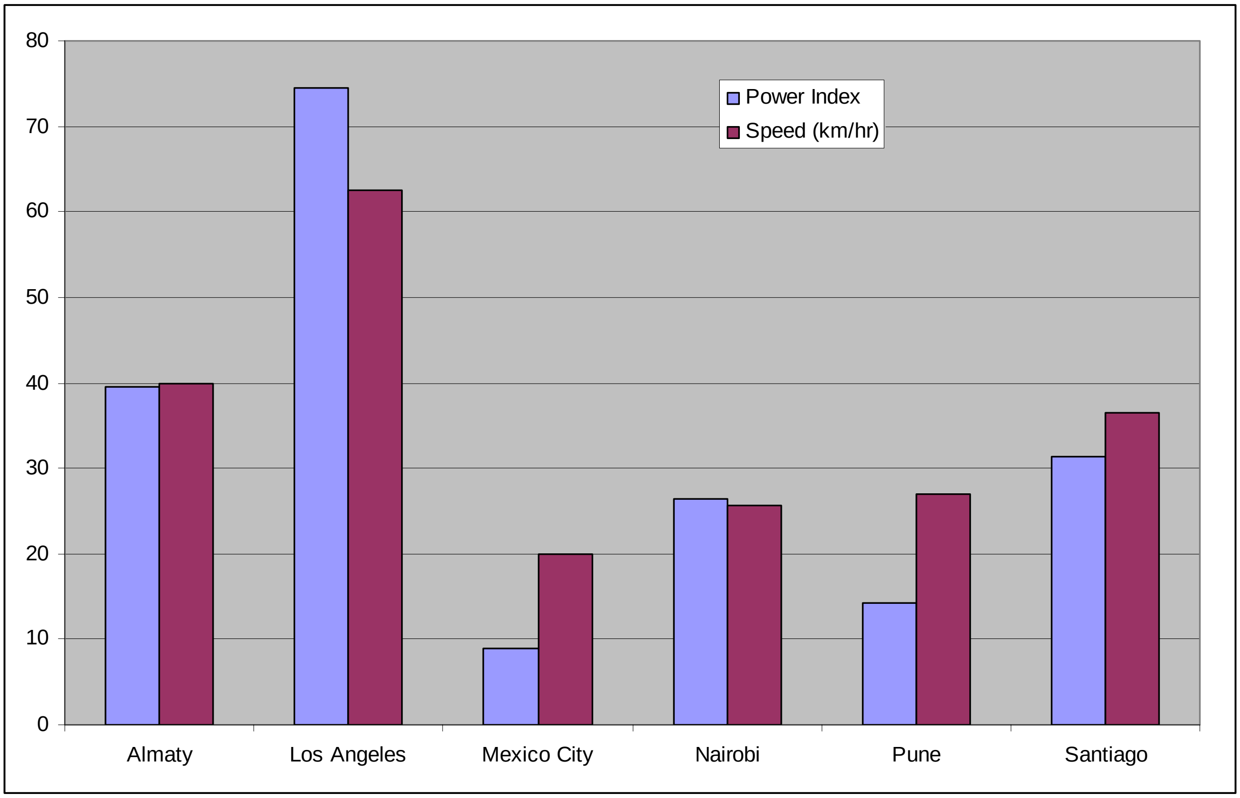

FIGURE 6 Average Driving Behavior Comparisons for Various Urban Areas Worldwide