The Roadmap for Clean Air: A Mobile Source Emissions Inventory for Istanbul, Turkey

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ABSTRACT

Istanbul is a megacity with a population of 15 million and is the leading city in Turkey in financial, commercial, and industrial activities as well as in cultural and educational services. Rapid urbanization with fast economic growth in Istanbul has created enormous stress on its transportation infrastructure and other services. Traffic congestion and air pollution have become major concerns for economic managers and city planners. Opinion surveys reveal that traffic congestion is the number one public concern followed by environmental problems.

The International Vehicle Emissions (IVE) model was developed to better estimate mobile source emissions in developing countries with an objective to overcome many of the problems associated with adopting emission inventory models from other countries. A methodology was developed in association with the IVE model to collect vehicle activity and emissions data needed for the model. This system was implemented to estimate emissions from on-road transport in Istanbul, Turkey. The study revealed that, excluding truck emissions, on the order of 5,200 metric tons of PM, 138,000 tons of NO_X, 38,500 tons of VOC, 270,000 tons of CO, and 9,500,000 tons of CO_2 are emitted from on-road motor vehicles annually in the Istanbul Metropolitan Region.

Introduction

Istanbul is a megacity with a population of approximately 15 million [1] and is the leading city in Turkey in financial, commercial, and industrial activities as well as in cultural and educational services. Rapid urbanization coupled with fast economic growth in Istanbul has created enormous stress on its transportation infrastructure and other services. As a result traffic congestion and air pollution have become major concerns for economic managers and city planners. Opinion surveys reveal that traffic congestion is the number one public concern followed by environmental problems [2].

Vehicles are considered to be an important contributor to carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), and particulate matter (PM) emissions, especially in urban areas [3-6]. Much research has been conducted in Turkey to quantify the contribution of vehicles to air pollution [7-14]. However, in all these efforts, ambient air and/or soil monitoring data were used to estimate the contribution of vehicle emissions. In other studies [15, 16], vehicle emissions models developed in and for Europe or North America, such as MOBILE6 or COPERT III [17-19], were used. As stated in [20], this creates a problem since "these models are highly complex and have evolved over decades to meet the intricacies of technology and policy changes" in these countries. Although the United States Environmental Protection Agency's MOBILE model and California Air Resources Board's (CARB) EMFAC model were modified for use in Mexico and Hong Kong, [21, 22], in general adapting these U.S. models for different countries is very difficult and often inaccurate since it requires extensive modification to the existing model as well as additional data collection to represent the vehicle fleet of that country. Therefore for many developing countries, attempts have been made to estimate emissions using simplified U.S.- or European-based emissions models and factors directly. As stated in [23], results obtained using these models are highly uncertain since these conventional models are region specific and are based on specific vehicles and emission standards of those regions and significant errors in the overall emissions calculations are possible when they are extrapolated to other areas with differing vehicles, emissions standards, fuels, and driving activity.

In order to quantify on-road transport emissions, in addition to the characteristics of the vehicles, it is also critical to understand how these vehicles are being operated. For developing countries, collecting accurate data related to vehicle activity has always been a challenge. The International Vehicle Emissions (IVE) model was developed to better estimate mobile source emissions in developing countries with an objective to overcome many of the problems associated with adopting emissions models from other countries [20, 23-26] as well as developing a methodology to collect vehicle activity data. This system was implemented to estimate emissions from on-road transport in Istanbul, Turkey. Specifically, the main objectives of this study were to: (1) set up an emission factor database for both diesel and gasoline vehicles in Istanbul, based on on-road testing; (2) collect comprehensive data on vehicle activity and fleet composition; and (3) estimate annual on-road vehicle emissions in Istanbul.

Methodology and Results

The measurement side of this study consisted of three different components: i) activity/fleet composition data collection; ii) gasoline vehicle emissions measurements; and iii) diesel vehicle emissions measurements. Activity data collection focused on three types of information on vehicles operating on Istanbul streets: vehicle technology distribution, driving patterns, and start patterns. Gasoline and diesel vehicle emissions measurements focused on collecting real-world second-by-second emissions data from a representative sample of on-road gasoline- and diesel-fueled vehicles under a wide variety of driving conditions. Fuel quality analyses were also conducted to find out the contents of the fuel used in gasoline and diesel vehicles.

Vehicle Activity Study

The vehicle activity portion of the emissions inventory project was designed specifically to: i) define the on-road fleet composition by vehicle class, engine size, emissions technology, fuel type, vehicle age, etc.; ii) understand the traffic flow using GPS data (second by second speeds, accelerations, etc); iii) understand vehicle use, including start patterns; and iv) observe driver behavior.

Five representative sections of the city were selected for the vehicle activity study, shown in Figure 1. The areas selected were chosen so that they would represent the overall fleet makeup and general driving taking place in the city. Three different observation teams were assigned to the same neighborhood, where they concurrently conducted the vehicle driving pattern measurements, the video surveys and parking lot surveys. Conducting all three studies in the same neighborhood provided a snapshot of the neighborhood for the given day and time. The neighborhoods selected for the study were felt to be representative of their respective portion of the city based on the recommendations of local city planners.

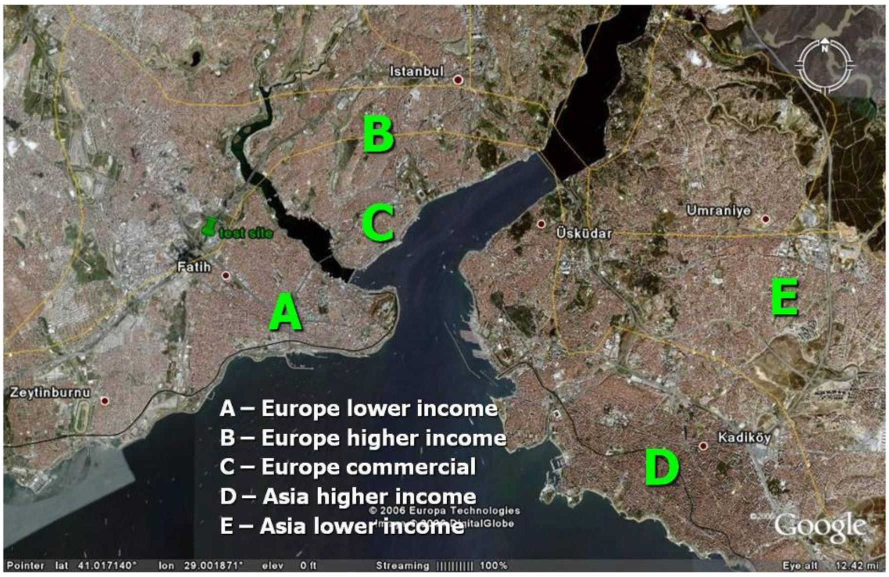

Figure 1 Areas of the Vehicle Activity Study in Istanbul

One of the most critical elements of on-road vehicle emissions analysis is the nature of the vehicle technologies that operate on the roadways in the region of interest. Different vehicle technologies can produce considerably different rates of emissions [3, 5, 6]. All cities/urban areas have some form of vehicle registration system and this database can be used to provide information regarding the registered vehicle fleet. However, the fractions of various vehicle types in the registered fleet are not necessarily the same as the fleet that is operating on the city's roadways on a daily basis. This difference occurs because some classes of vehicles are operated considerably more than other classes of vehicles. Therefore, the most accurate estimate of vehicular 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.

On-road driving varies by time of day, by day of the week, and by location in an urban area. To account for this, activity data were collected at different times of the day and in different locations. The technology distribution of vehicles was developed using a combination of two approaches. First, vehicles were videotaped on a variety of roadways and were reviewed by expert Istanbul Metropolitan Municipality (IMM) personnel who counted the numbers of the various types of vehicles driving on Istanbul's roads. Whereas videotaping allows the determination of the fractions of trucks, buses, and passenger vehicles operating on the roadways of interest, it is not possible to use the videotaping process to determine the exact nature of the vehicle technologies observed. To understand the specific technologies of passenger vehicles, a team of three people conducted parking lot surveys in Istanbul. This team surveyed the same locations and used the same schedules as those of the videotape recordings. In order to insure that the most representative data were collected, both videotaping of traffic and the surveys of parked vehicles were carried out from 07:00 in the morning to 16:00 in the afternoon over eight days in 13 representative sections of the city.

Surveys of parked vehicles allowed for the careful inspection of vehicles. In this study, data pertaining to the vehicle manufacturer, model, fuel type, model year, license plate number, engine size and technology, add-on control technology, transmission type, and air conditioning equipment were collected.

Fleet Composition

A total of 780 minutes (13 hours) of digital video were recorded throughout the eight workdays of field work in Istanbul. As seen in Figure 2, passenger cars are the most dominant vehicle category for all roadway types (around 70% of the total on-road fleet). The percentage of taxis on residential streets is over 20%. Small buses and minibuses represent ~11% of the fleet, particularly on arterial roadways. It is important to note that the total number of large trucks is quite low (less than 1%) because most large trucks are banned from inner city roads during the daytime. Most of the traffic volume in the city (~64%) is found on highways. 29% of traffic is on arterial roads and 8% is on residential roads. Similar distributions are typical in most cities around the world. While the values shown in these figures should only be treated as approximations, they do serve as a good approximation of the true total driving occurring in the Istanbul Metropolitan Region in 2006.

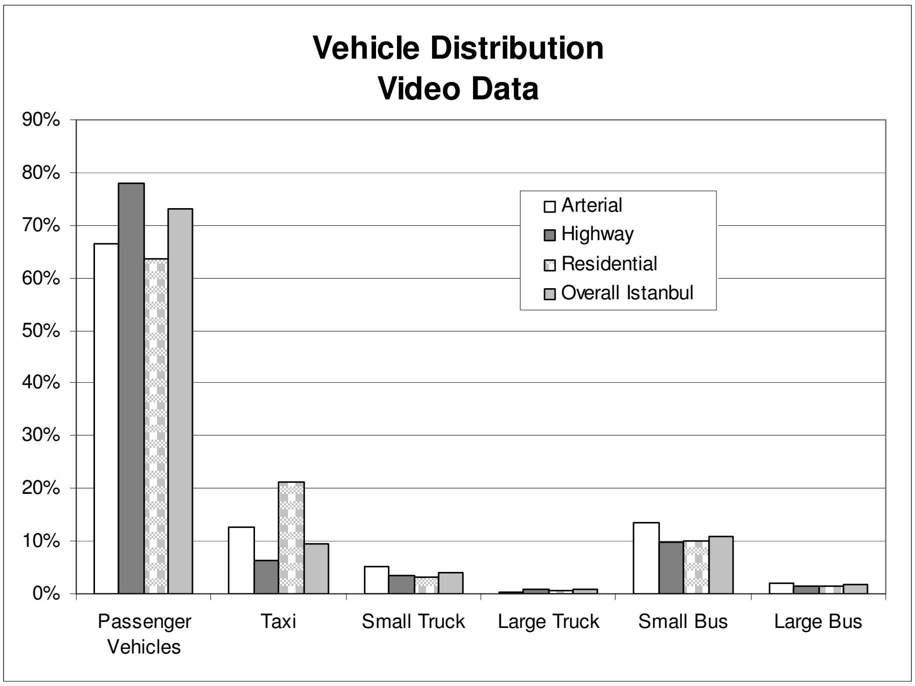

Figure 2 Vehicle Class Distribution in Istanbul: Videotape Analysis

In addition to the class of vehicle, the age of the fleet and the breakdown by model year is necessary to provide additional insight into the technology distribution in the fleet. Initially, in constructing the sample of vehicles to be tested, the official registration data maintained by the police department was used. However, the registered fleet and the actual on road fleet may (and usually do) differ.

Figure 3 is a comparison of the official registration data and the data collected from the parking lot surveys for the Istanbul fleet. The percentage of older vehicles identified in the parking lot surveys is lower than the percentage of older vehicles registered in the city, and the percentage of newer vehicles registered in the city is less than the percentage identified in the parking lot surveys. Thus, the fleet identified in the parking lots and on the streets is younger (average age 5.3 years) than the fleet that is officially registered in the city (average age 6.5 years). While this is a topic that merits further study, it is suspected that there are at least three reasons for these discrepancies: 1) the owners of some second-hand vehicles sold to the provinces prefer to keep the Istanbul license plate due to a "prestige" factor; 2) whereas in the past businesses and organizations (such as the Istanbul Municipality) that operate fleets would purchase the vehicles and use them for years, the trend now is to lease the vehicles. Leases are usually contracted for a two-year time period and these fleet vehicles are used more heavily than privately owned vehicles (note that the economic crisis can be seen in the drop off of vehicle sales in 2002). 3) most of the companies have their headquarters in Istanbul, where they register their vehicles but operate nationally.

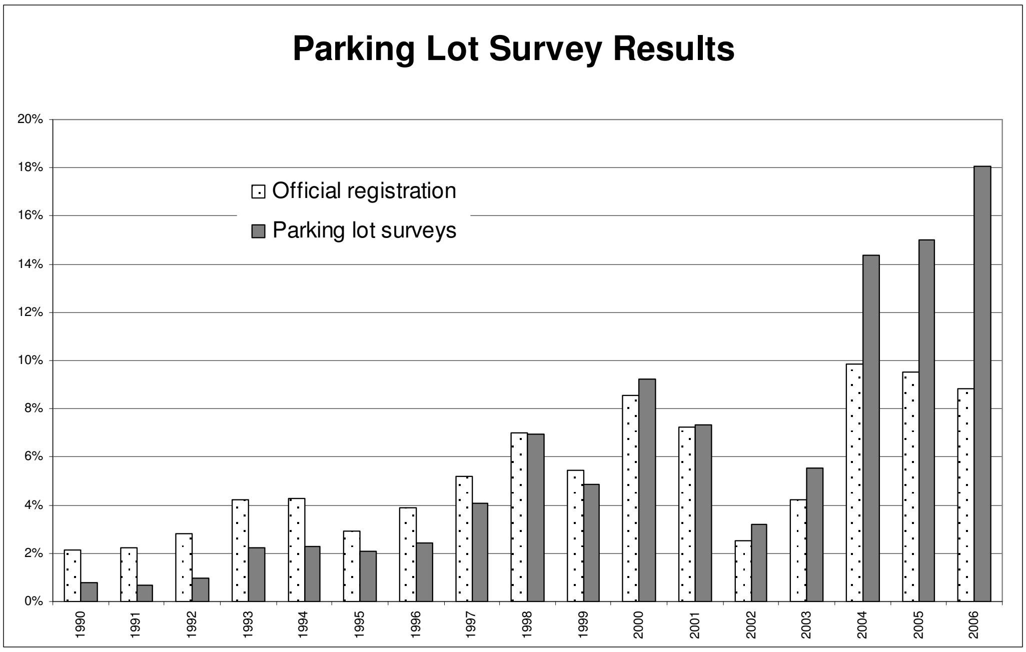

Figure 3 Model Year Distribution in the Istanbul Passenger Vehicle Fleet

Passenger Vehicle Technology Distribution

A total of 2204 passenger cars were surveyed in parking lots. Table 1 indicates some of the general characteristics observed in the surveyed fleet.

Fuel Type	Air Conditioning	Transmission Type	Catalytic Converter
73% Gasoline	87% with	93% Mechanical	11% without
26% Diesel	13% without	7% Automatic	89% with
0.7% LPG and gasoline			

Table 1 General Characteristics of Surveyed Passenger Cars

The IVE Model defines 1,328 technology classifications based on fuel type, engine technology, and control technology, plus 45 user defined technologies. A breakdown of the distribution found in Istanbul based on five of the related categories in the IVE model is shown in **Error! Reference source not found.**, indicating that 88% of the gasoline passenger cars in Istanbul are equipped with a catalytic converter and that 67% are fitted with a multipoint fuel injection system.

Passenger Vehicles	Fraction
Gasoline, 4-stroke, Carburetor, No Catalyst	12 %
Gasoline, 4-stroke, Carburetor, 2-way Catalyst	3 %
Gasoline, 4-stroke, Single Point Fuel Injection, 2-way Catalyst	12 %
Gasoline, 4-stroke, Single Point Fuel Injection, 3-way Catalyst	6 %
Gasoline, 4-stroke,Multipoint Fuel Injection, 3-way Catalyst	67 %

Table 2 IVE Emissions Technology: Gasoline Passenger Cars

In addition to the gasoline cars listed in Table 3, 587 out of the 2,204 vehicles surveyed were identified as diesel vehicles.

The parking lot survey was not conducted for trucks and buses in Istanbul. Whereas we have the counts and vehicle kilometers traveled for buses, we do not have a detailed vehicle technology distribution for them.

Vehicle Utilization

Vehicle emissions are a function of both the vehicle fleet composition and vehicle use [27]. Vehicle use includes vehicle driving patterns (including both traffic flow and driver behavior) and vehicle start patterns. Vehicle accelerations and decelerations have an important impact on emissions, and in this study Global Positioning Satellite (GPS) technology was used to measure vehicle speed, acceleration, and altitude of vehicles traveling in Istanbul traffic. These measurements also provide insight into the general traffic flow in the city.

Vehicle start patterns are also important because start-up emissions associated with a cold engine vary dramatically from the emissions of a hot engine. The start-up data collected included vehicle starts, how long the vehicle operated, and how long the vehicle sat idle between starts.

Vehicle Driving Patterns

Vehicle driving patterns were measured using GPS technology, which enables the measurement of vehicle location, speed, and altitude on a second-by-second basis. For passenger cars, three vehicles were outfitted with GPS and driven on the roadways selected for the IVE study in Istanbul Figure 1. The roadways chosen included city highways, arterials and neighborhood streets (Figure 4). A total of 11 days' data (374,400 valid data points) were recorded during the campaign: 111,208 seconds on highways; 155,691 seconds on arterials; and 107,501 seconds on residential streets.

Figure 4 Roadways tested in Lower Income Area

Figure 5 shows the average speed by time of day for each type of road studied. Overall, an average speed of 40 km/hour was observed over highways, whereas an average speed of 23 km/hour and 20 km/hour were observed for arterial and residential streets respectively.

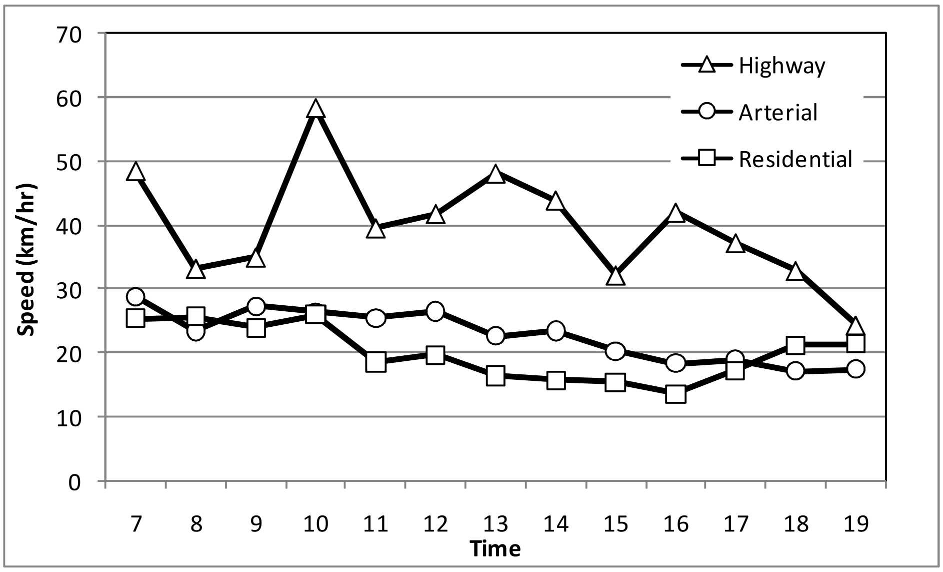

Figure 5 Average Passenger Car Speeds on Istanbul Roads

Figure 6 shows an example speed profile of a passenger car driving in the high income area in the morning, as measured by the GPS unit for about 1000 seconds. Average speeds over the period of time shown in the graphs were 41 km/hr for the highway driving and 24 km/hr for the arterial driving. This graph also illustrates driver behavior, where we see hard braking and rapid accelerations, both of which contribute to excessive emissions.

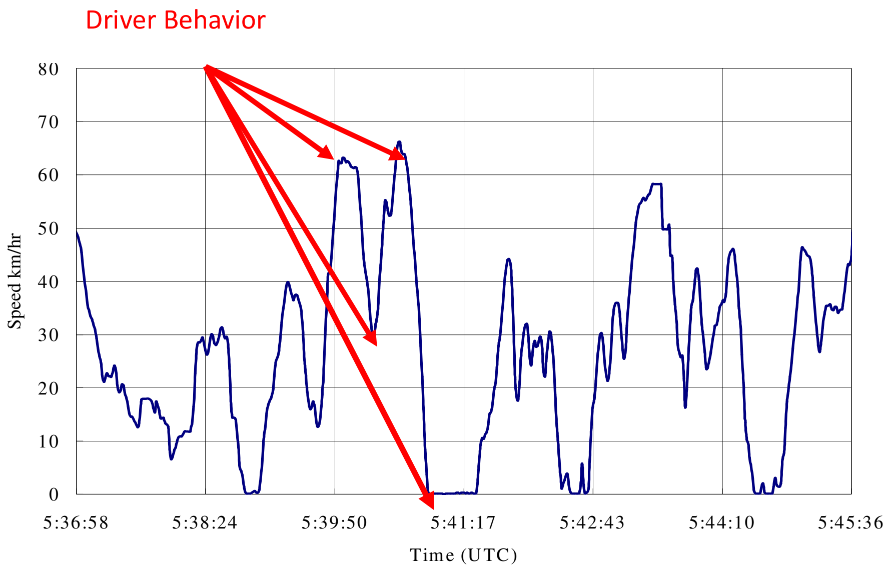

Figure 6 Example of Arterial Speeds in Istanbul

In addition to the three passengers vehicles described above, GPS units were installed on buses, trucks, and taxis. To collect data on road-based mass transit vehicles, a team of three riders equipped with GPS units were asked to board buses and mini-buses (called "Dolmus") throughout the day, on randomly selected routes. This made it possible to collect data pertaining to the traffic flow patterns of minibuses and buses. It should be noted that neither bus nor minibus drivers were very accepting of this process, making it a challenging experience for all three surveyors. Data were collected from 07:00 to 20:00 to provide driving pattern information for differing times of the day.

The riders collected a total of 318,000 valid data points for both buses and mini-buses. For trucks, approximately 280,500 valid data points were collected. For taxis, 410,400 valid data points were collected. Overall 1,382,900 valid GPS data points were collected during driving pattern analysis, which corresponds to 384 hours of data.

The taxi speeds are, as expected, similar to a combination of highway and arterial driving from passenger vehicles. Similar congestion patterns are observed in the taxi driving patterns as the passenger vehicles in terms of steadily increasing congestion and lowering average velocities throughout the day, with the minimum speed occurring between 13:00 and 14:00.

Figure 7 shows a spatial data plot of a metropolitan bus run on which data were recorded. A total of nearly 288,000 data points were collected from buses. Figure 8 indicates average bus vehicle speeds in Istanbul. Throughout the day the average bus speed is typically 12-15 km/hr, with a maximum speed of 25 km/hr around 11 AM.

Figure 7 Typical Bus Run in Istanbul

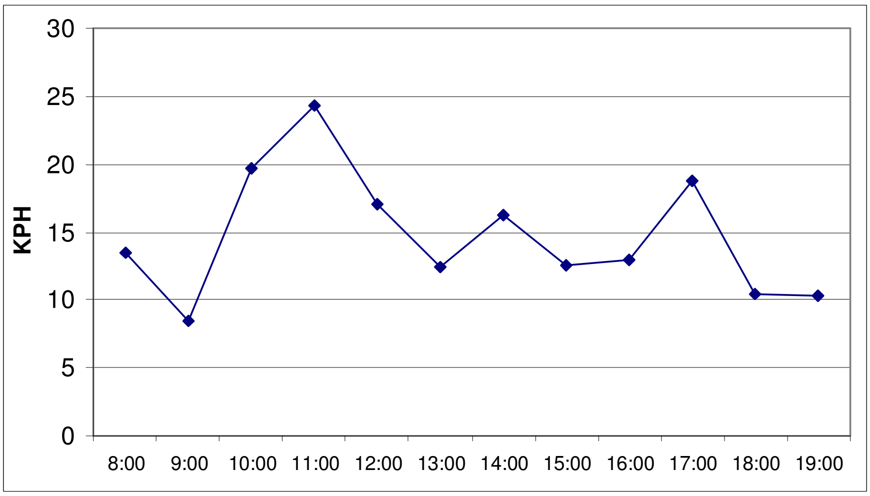

Figure 8 Average Bus Speeds on Istanbul Roads

In general, congestion lowers the average velocity during the daytime hours by 30% to 60% of free flow velocities. Overall, various road types and vehicle types have similar average velocities. It is interesting that the highest and lowest velocities occur on the highway, with the highest speeds during the very early morning hours, and lowest velocities in the middle of the day, when average speeds are even lower than on residential roadways. Delivery trucks maintain a relatively low average velocity throughout the day due to the idle time during deliveries. Buses and mini-buses have almost identical average speeds as passenger vehicles traveling on arterial and residential roadways.

Vehicle Start Patterns

Between 10% and 30% of vehicle emissions typically come from vehicle starts, therefore it is important to understand vehicle start patterns in an urban area to fully evaluate vehicle emissions. To measure start patterns, a small device has been developed that plugs into the vehicle's electrical system through the power port (i.e., cigarette lighter). The device detects voltage fluctuations in the electrical system to determine when a vehicle engine is on and off. The 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 in establishing vehicle start emissions. The units were placed in different passenger vehicles throughout the city and left there for a week.

Data were successfully collected from 56 passenger vehicles (out of 82 units) over approximately 6-7 days for each vehicle. This provides about 330 vehicle days of data. The total number of starts per day for the whole group was equal to 5.8, typical of start patterns observed in other urban areas where starts have been found to vary from 5 to 8 starts per day for passenger vehicles [23, 26].

In Istanbul most starts occur in the 11:00-12:59 time frame. The highest fraction of cold starts (after 6 or more hours soak time) occurs in the early morning time frame (06:00-09:59), as would be expected. Cold starts are also common during the period from 15:00 to 16:59 hours. These long soak times leave the engine cold and result in much greater start emissions.

Gasoline Engine Emissions Measurements

Second by second emissions of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_X), and total hydrocarbons (THC) were measured for 104 gasoline-fueled vehicles over a three week period. The measurements included cold-start, hot-start, and hot-stabilized emissions. A Sensors SEMTECH-G portable emissions monitor [28] with GPS and exhaust flow measurement system was used for the on-road emissions and position, speed, and acceleration measurements providing in-use emissions information for vehicles operating in the study area. SEMTECH instruments have been used widely [3, 5, 29-34] and have been evaluated in laboratory conditions to be in good agreement with laboratory measurement equipment [35]. Calibration and quality assurance procedures were conducted on a routine basis to ensure accurate data collection. The unit was found to be very stable from day to day with the zero and span holding within 1.5 % of the calibration gases. Test vehicles were selected based upon statistics obtained from Turkish General Directorate of Security (Emniyet Genel Mudurlugu) for Istanbul with respect to vehicle type (i.e., automobile, light duty truck, heavy duty truck, etc.) and model year (model years between 1970 and 2006). Out of 104 vehicles tested, 87 of them provided useful data.

A circular driving route was selected with a variety of driving situations including low speeds on congested arterials and residential streets, as well as higher speeds and accelerations on highways. Subsequent analysis of the data, using the IVEM methodology [20], provided second by second vehicle power demand (i.e., power required by the vehicle to maintain the required speed and acceleration) [36] in association with the measured emissions. These data were further analyzed to compare emissions with respect to different vehicle technologies and model years. As an example, a comparison of emissions from different vehicle technologies is given in Figure 9 below. Vehicles that have the latest technology (i.e., multi-point fuel injection) tends to emits lower CO, THC and NO_X. However this is not the case for CO_2, where emissions tend to be similar independent of the technology.

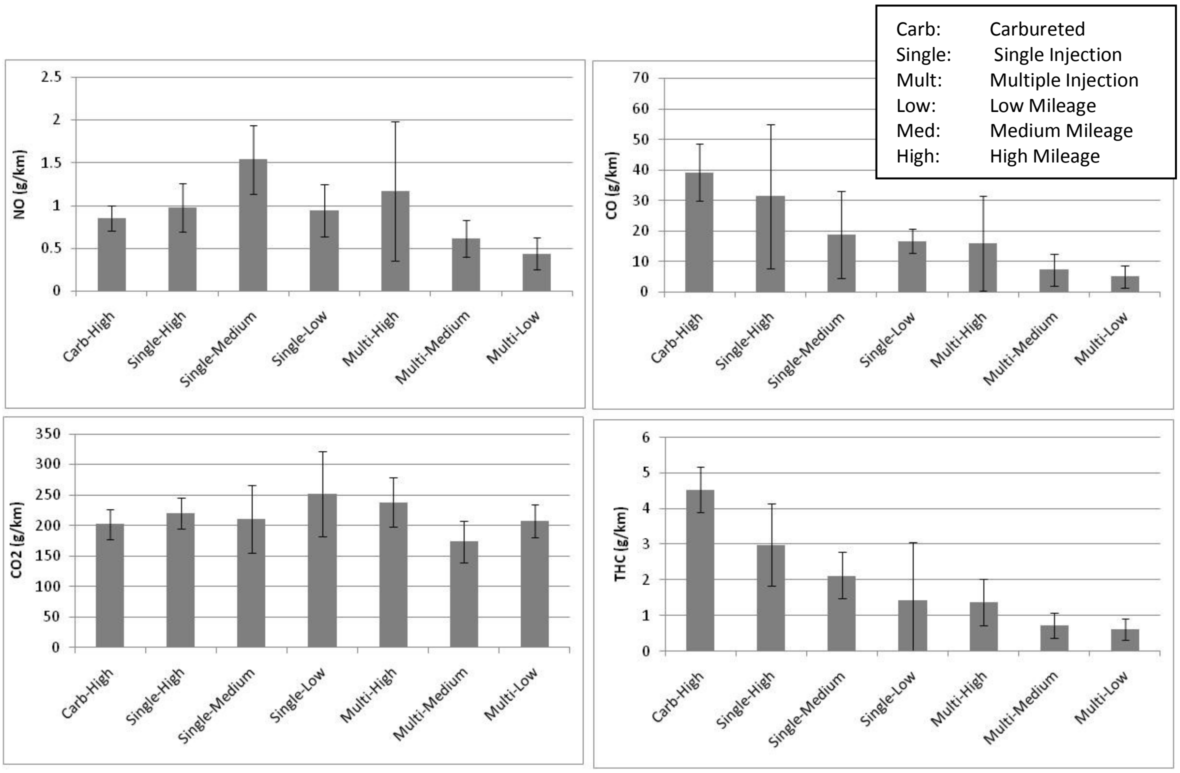

Figure 9 Comparison of Emission Values for the Predominant Vehicle Technologies

Diesel Engine Emissions Measurements

For diesel emission measurement purposes, a Semtech Sensor D gas emissions testing unit [28] was used to measure the emissions of CO, CO_2, total Hydrocarbons (THC), NO_X, and NO_2. The Sensor D testing unit is an integrated emissions testing device designed to be used in on-road testing programs. The Sensor D measures emission concentrations and must be provided with exhaust flow rates and ambient temperatures and pressures in order to determine mass emission rates. The Sensor D is equipped with a temperature/pressure sensor. A Semtech manufactured 4 inch (10 cm) exhaust flow measurement device was used to measure the exhaust flow rate from the bus. This device uses standard dynamic and static pressure measurement to calculate exhaust flow. The Sensor D was also equipped with a GPS device to measure location and speed. All data were collected at one second intervals. The Sensor D test unit was zeroed and spanned prior to each test cycle. The unit was found to be very stable from day to day with the zero and span holding within 1% of the calibration gases.

Particulate matter was measured on a second by second basis using a Dekati DMM testing unit [37]. This unit uses a particle charging process and six stage impactor setup to determine particle mass. The DMM measures particle concentration. The exhaust flow rates collected by the Sensor D unit must be used with the Dekati measurements to determine particulate mass flow rates. The

DMM measures particles in the 0 to 1.5 micron range, which is the size range where virtually all diesel particles reside. The DMM has been found to produce results comparable to the reference particles sampling methods for diesel particles; however, it was found to produce readings about 30% higher in some cases. Dekati experts believe that this is due to the fact that the Dekati measurement process can measure volatile particulate matter that is lost in the case of filter-based particle sampling devices. The DMM was zeroed at the beginning of each testing cycle. The charging and impactor units become covered with particulate matter and must be cleaned after each 2-3 hour test period to keep the unit operating properly.

A series of 42 diesel vehicles were tested in this study. 29 of these vehicles were classified as light-duty vehicles varying from passenger cars to smaller delivery vans. Once emissions testing equipment was installed, the vehicles were operated over a prescribed driving circuit (different than the one used for gasoline tests) that allowed the vehicles to be operated over as wide a range of operating conditions as could be achieved within the time constraints and city limits of Istanbul. The drive time for completing the circuit (which included a moderate hill) varied from 36 to 50 minutes depending upon the traffic situation.

In order to simulate passenger weight, sandbags were placed on the bus. Depending upon the size of the bus, containers were loaded to simulate 30 to 50 bus riders. CO_2, NO_X, and PM emissions from the passenger vehicles and smaller trucks tested in the study are shown in Figure 10. These results, which represent 29 tests, show some reduction in emissions from 1986 to 2006, due to technological improvements in NO_X and PM. The relative magnitudes of the emissions were as expected with the buses producing the most emissions and the passenger vehicles the least. It should be noted, however, that for emissions per passenger kilometer, buses have significantly lower emissions than passenger vehicles.

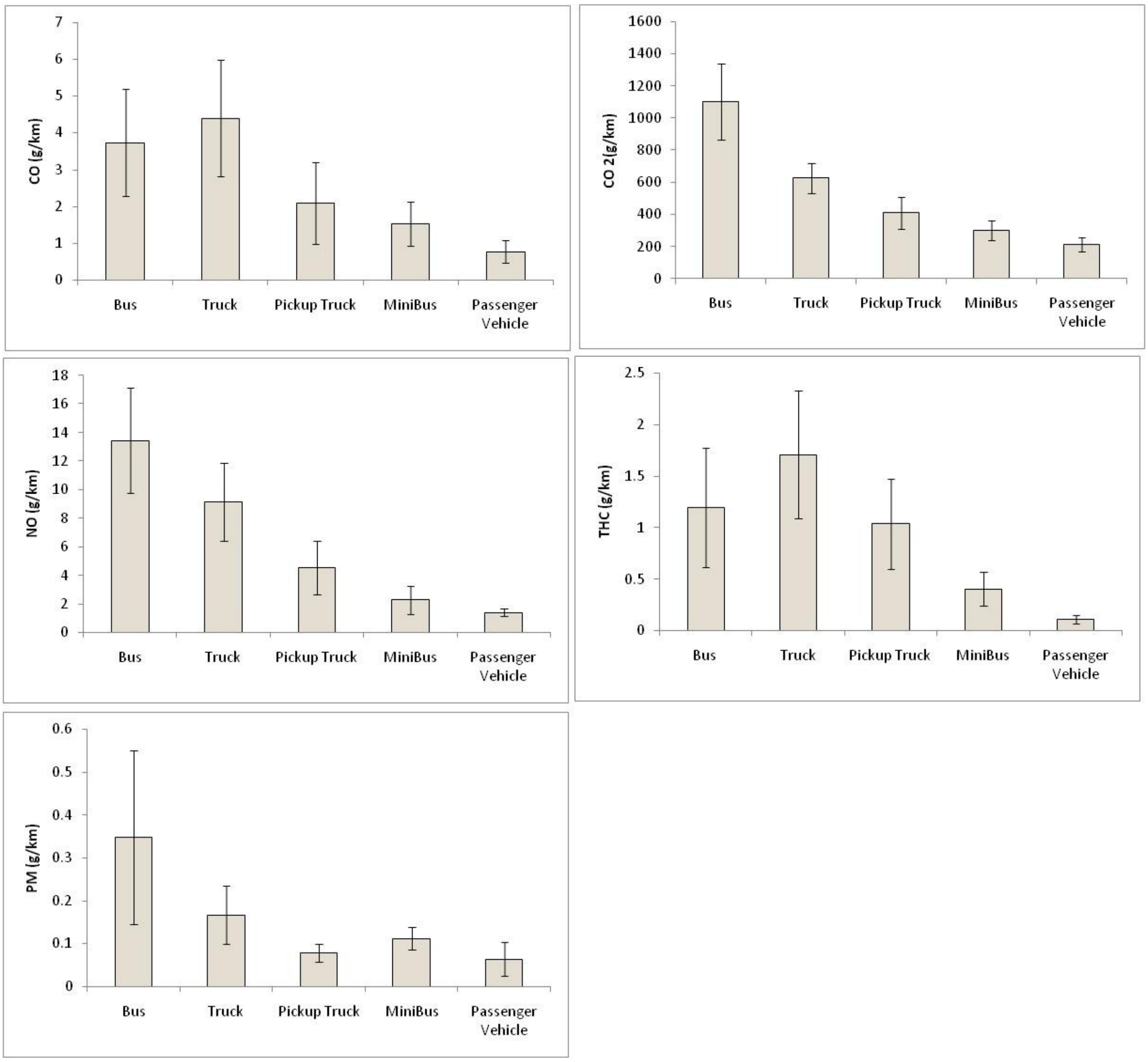

Figure 10 Comparison of Emissions from Different Diesel-Fueled Vehicle Types

Istanbul Emission Inventory

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

The data collected in this study were formatted to allow vehicle emissions estimates using the International Vehicle Emissions Model (IVEM) [20]. The IVE model was developed with US-EPA funding to make emissions estimates under different technology and driving situations as found in various countries, and has been used extensively in several developing countries. Using the IVEM emissions per km were estimated for each vehicle category and fuel type. Then total annual vehicle kilometer traveled for each vehicle category is multiplied to get the total emissions for each category and then those numbers were summed to get the annual total emissions for the metropolitan city of Istanbul. It should be noted that annual vehicle kilometer traveled data were obtained based on surveys that were conducted with owners. For example, a survey was conducted to estimate annual vehicle kilometer traveled for taxi drivers. For heavy duty trucks, it was impossible to gather the data and hence they were left out in estimating the annual emissions from on-road vehicles.

IVE model results indicate that on the order of 5,200 metric tons of PM, 138,000 tons of NO_X, 38,500 tons of VOC, 270,000 tons of CO, and 9,500,000 tons of CO_2 are emitted from on-road motor vehicles annually in Istanbul Metropolitan Region.

6. Conclusions and Future Work

The objective of the vehicle activity and emissions measurement study was to prepare a baseline emissions inventory for on-road vehicles in Istanbul, Turkey. This was the first time such a comprehensive study on vehicle activity as well as real-world emissions data collection were conducted in Istanbul. Key findings and conclusions of this study are:

(1) During peak hours, especially evenings, differences in average traffic speed on different roadways are virtually negligible, suggesting that congestion occurs not only on highways but on arterials and residential streets. This means that no matter where a driver is located in the city, they will be traveling at an average speed of approximately 25 kilometers per hour.

(2) Parking lot surveys revealed that on-road fleet differs significantly from the officially registered fleet in Istanbul: the average age of the registered passenger fleet is 6.5 years old, compared to an average age for the on-road fleet of 5.3 years old. Main reason is the fact that older vehicles, although they are registered as Istanbul vehicles, are being sold and used other cities of Turkey.

(3) Although approximately 90 percent of the vehicles have catalytic converters, emissions measurements revealed that some of them are not functioning properly. This might be due to maintenance problems and/or catalyst poisoning because of low quality fuels. This topic needs further analysis to reach conclusion.

(4) Passenger vehicles are the most dominant vehicle category for all roadway types (approximately 70 percent of the total fleet). Most of the traffic volume occurs on the

highways (with 64 percent). Arterial roads have 29 percent of the traffic whereas residential roads have 7 percent of the traffic.

(5) Gasoline emissions measurements showed that criteria pollutant emissions decrease as technology improves. However, fuel use and CO_2 emissions seem to be independent of the technology. This is due to the fact that the technology improvement (through fuel injection and catalytic converters) focused mainly on criteria pollutants not on fuel use.

(6) Diesel emissions measurements showed, as expected, buses have the highest emission levels followed by trucks, pickup trucks, minibuses, and passenger vehicles. However, when emission levels per passenger are estimated, buses have the lowest level of emissions (passenger vehicles are the highest).

(7) The International Vehicle Emissions Model methodology was implemented successfully to gather the necessary information to estimate annual emission from on-road vehicles in Istanbul. The results showed that on the order of 5,200 metric tons of PM, 138,000 tons of NOx, 38,500 tons of VOC, 270,000 tons of CO, and 9,500,000 tons of CO2 are emitted from on-road motor vehicles annually in Istanbul Metropolitan Region.

7. Recommendations and Future Work

Given that this study was the first of its kind to be conducted in Istanbul, it is not surprising that several topics for additional and/or follow-up study surfaced during this research project. These are:

(1) The breakdown of fleet versus privately owned cars is not well understood. This topic is very important to understanding vehicle kilometers traveled (VKT) for passenger vehicles since the VKT of personal use vehicles differs drastically from fleet vehicle usage which can be driven up to 100,000 km/year as opposed to personal use vehicles which are driven ~12-15,000km/year. It is essential to have a follow-up study to identify the breakdown and VKT for fleet vs. personal use.

(2) The study revealed that there are vehicles with non-functioning catalytic converters on the street. This needs to be studied to identify the real extend of the problem. Also questions needs to be answered on whether the emissions testing regime and standards are adequate to quantify the extent of this problem.

(3) Activity data need to be improved for trucks, for which we could not obtain valid VKT data.

(4) Although this study collected information on vehicle start-ups, the vehicles tested were not randomly selected. Additional studies are required for better understanding of the problem.

(5) Overall, this study needs to be improved by collecting emissions information on more vehicles, under real-world conditions, as well as a more detailed activity data collection.

Acknowledgements

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