MOBILE5-Mexico: An Emission Factor Model for On-Road Vehicles in Mexico

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ABSTRACT

A mobile source emission factor model has been developed for on-road vehicles in Mexico. The new model, MOBILE5-Mexico estimates hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NO_x) emission factors for gasoline- and diesel-fueled on-road motor vehicles. It is based upon U.S. EPA's MOBILE5 model and incorporates data from various regions within Mexico to accurately represent the entire Mexican vehicle fleet. MOBILE5-Mexico can be used to estimate emission factors for most of the same scenarios as MOBILE5, including the effects of I/M programs, fuel characteristics, and altitude. Also, a user's guide has also been developed for MOBILE5-Mexico.

The project to develop MOBILE5-Mexico was part of a larger, ongoing effort sponsored by the Western Governors' Association (WGA) with support from Mexico's National Institute of Ecology (INE). The focus of that larger effort is to build capacity within Mexico for emissions inventory development. An advisory group consisting of mobile source experts from the U.S. and Mexico provided valuable guidance in the development of the MOBILE5-Mexico model.

Prior to the development of MOBILE5-Mexico, the only Mexico-specific mobile source emission factor models were developed for a few Mexican cities, such as Mexico City and Ciudad Juárez. MOBILE5-Mexico was developed to provide a single model, which could be used to estimate emissions throughout Mexico. The model is divided into five modules, which are used to model five different regions that have distinct fleet characteristics and regulatory structures. The MOBILE5-Mexico model utilizes existing testing data from Mexico City and Ciudad Juárez, as well as new testing data from Aguascalientes.

INTRODUCTION

The development of the MOBILE5-Mexico model[1] is part of the overall Mexico Emissions Inventory Development Program. This multi-year program is sponsored by WGA and INE. Funding for the Mexico Emissions Inventory Development Program is provided by U.S. EPA through WGA. In addition, generous technical support has been provided by INE and various other governmental organizations within Mexico.

The overall focus of the Mexico Emissions Inventory Development Program is to build emissions inventory development capacity within Mexico. Other tasks conducted under this program include the development of a 10 volume series of emissions inventory manuals, various training materials, and pilot study emissions inventories in Mexicali and Tijuana. These other tasks have been described previously.[2-6]

GENERAL BACKGROUND

MOBILE5-Mexico is not the first Mexico-specific motor vehicle emission factor model. However, previous emission factor models were limited to specific geographic areas. The first Mexico-specific emission factor model was the MOBILE-MCMA model which was developed to estimate emission factors for the Mexico City metropolitan area.[7] This model was initially based upon U.S. EPA's MOBILE4 model.[8] The MOBILE-MCMA model[9] was subsequently updated in 1996 to account for differences between the MOBILE4 and the MOBILE5 models.[10] Both versions of the MOBILE-MCMA model did not directly use emissions testing data to develop basic emission rates (BERs). Instead, Mexico City inspection and maintenance (I/M) test data were combined with a "technology equivalence matrix" that mapped Mexico model year vehicles to equivalent U.S. model year vehicles in order to determine Mexico City-specific emission factors. This approach was used to develop a similar emission factor model for the Monterrey metropolitan area (i.e., MOBILE-MMAp).[11] The next Mexico-specific motor vehicle emission factor model was the MOBILE-Juárez model that was developed for the Ciudad Juárez metropolitan area.[12] The data set used included testing data from approximately 200 Ciudad Juárez light-duty vehicles.

GENERAL CONCEPTS OF MOBILE5-MEXICO

Following the development of the various location-specific emission factor models described above, it became clear that a unified emission factor model was desirable for the entire country of Mexico – thus the name MOBILE5-Mexico. The benefits of a unified emission factor model can be seen by examination of the U.S. situation. The MOBILE5a model is used throughout the entire U.S. (with the exception of the State of California) and provides a common basis of comparison for different emissions inventories. The MOBILE5a model ensures that a thoroughly-tested set of BERs are consistently used in U.S. motor vehicle inventories. These BERs are then adjusted for local variations in vehicle fleets, fuel composition, and implemented regulatory programs through the use of various input parameters.

As part of the Mexico Emissions Inventory Development Program, a Motor Vehicle Advisory Group (MVAG) composed of motor vehicle emission experts was convened to provide guidance leading to the development of the envisioned unified emission factor model. In conjunction with recommendations from the MVAG, it was decided that a model with modules for different types of geographic regions would most effectively serve the needs of Mexico. The MOBILE5-Mexico model was designed so that each module would utilize a different set of BERs based upon the selection of a particular type of geographic regions. The selection of region-specific BERs is analogous to the selection of low- or high-altitude BERs in the U.S. EPA's MOBILE5a model. Beyond choosing the input for the low- or high-altitude parameter flag, the use of low- or high-altitude BERs is entirely transparent to the model user. Similarly, it was decided that the MOBILE5a-Mexico model user interface should remain unchanged, regardless of the region type selected.

The MVAG also indicated that the MOBILE-Mexico model should build upon previously developed region-specific emission factor models (i.e., MOBILE-MCMA and MOBILE-Juárez). The existing work was supplemented with a new dataset of emissions testing data from a region of Mexico that had not previously been included in a region-specific model (i.e., Aguascalientes). The module format of the MOBILE-Mexico model also allows future updates of emissions testing data and other information to be easily accomplished.

Because MOBILE5-Mexico is based upon U.S. EPA's MOBILE5a emission factor model, there are not significant operational differences between the two models. The input and output formats used for the MOBILE5-Mexico model are virtually identical to those used in the MOBILE5a model. For the most part, guidance provided in the *MOBILE5a User's Guide*[10] is also applicable to the MOBILE5-

Mexico model as well. A brief description of the main differences between the two models is provided below:

- Specific region types (i.e., Mexico City, border urban, border rural, interior urban, and interior rural) can be selected;
- The effects of the U.S. regulations (i.e., the 1990 Clean Air Act Amendments) should always be disabled in MOBILE5-Mexico;
- Metric units should be used for input vehicle speeds (kilometers per hour [km/hr]) and temperatures (degrees Celsius [ºC]);
- Output emission factors are given in units of grams per kilometer (g/km); and
- Unlike MOBILE5a, some MOBILE5-Mexico data (i.e., registration fractions, mileage accumulation rates, number of vehicles, fraction of Mexico-registered vehicles, local I/M program information, and BER information) are contained in external data files that can be modified by the model users.

Three major characteristics of the MOBILE5-Mexico emission factor model are the capability to select specific region types, the capability to include the effects of U.S. vehicles in the vehicle fleet mix, and the development of Mexico-specific BERs. These three characteristics are described below.

Specific Region Types

A key feature of MOBILE5-Mexico is that one of five region-specific modules can be selected to most appropriately represent a particular region. The reason that these regional modules were established was because each of these regional types exhibit some unique fleet and/or emissions characteristics. The five regional types are briefly described below:

- **1 – Mexico City:** Mexico City and immediate surrounding areas that have similar air pollution regulations and I/M programs. Motor vehicles are more strictly regulated in the Mexico City metropolitan area than in any other part of Mexico. In addition, the I/M programs currently in place in Mexico City are the most stringent in Mexico. The emission characteristics of Mexico City are also impacted by high altitude (approximately 2,250 meters above sea level); all other major metropolitan areas in Mexico are at lower altitudes.

- **2 – Interior Urban:** All metropolitan urban areas within the interior of Mexico except for Mexico City (e.g., Guadalajara, Monterrey, Aguascalientes, etc.). Interior urban areas can be approximately defined as those areas with a population greater than 75,000 people that are located more than 50 kilometers (km) from the U.S.-Mexico border. Interior urban areas will have some air pollution regulations. However, in general, these regulations are not as stringent those in Mexico City. Some of interior urban areas have already implemented I/M programs.

- **3 – Interior Rural:** All non-urban areas within the interior of Mexico. Interior rural areas can be approximately defined as those areas with a population less than 75,000 people that are located more than 50 km from the U.S.-Mexico border. With the exception of any applicable national regulations and standards, motor vehicles are unregulated in these areas. I/M programs are not present in these areas.

- **4 – Border Urban:** All metropolitan urban areas within the U.S.-Mexico border region (e.g., Ciudad Juárez, Mexicali, Tijuana, etc.). Border urban areas can be approximately defined as those areas with a population greater than 75,000 people that are located within 50 km of the U.S.-Mexico border. Because of the proximity to the U.S., air pollution regulations specific to the border area have been implemented. Some of these areas have also implemented I/M programs. The border urban area fleets are greatly affected by the presence of U.S.-registered vehicles, as well as U.S.-manufactured vehicles that have been imported into Mexico.

- **5 – Border Rural:** All non-urban areas within the U.S.-Mexico border region. Border rural areas can be approximately defined as those areas with a population less than 75,000 people that are located within 50 km of the U.S.-Mexico border. Although some air pollution regulations specific to the border area may apply in these areas, I/M programs will not be relevant. Like border urban area fleets, border rural area fleets are also affected by the presence of U.S.-registered vehicles and U.S.-manufactured vehicles, but probably not to as great of an extent.

Inclusion of U.S.-Registered Vehicles in Vehicle Fleet

In addition to the capability to select one of five geographic regions described above, the MOBILE5-Mexico model also allows the user to model vehicle fleets composed of both Mexico- and U.S.-registered vehicles, for the border urban and border rural regions only. These types of combined fleets are a particular concern in the Mexico-U.S. border region (e.g., Ciudad Juárez, Tijuana, etc.). Border region vehicles often cross over the international border on a daily basis. Prior to the development of MOBILE5-Mexico, the modeling of emission factors for a combined fleet in a border region required two separate model runs (i.e., MOBILE for the U.S.-registered vehicle portion of the fleet and a Mexico region-specific model, such as MOBILE-Juárez, for the Mexico-registered vehicle portion of the fleet) followed by a weighted aggregation of the resultant emission factors.

With the MOBILE5-Mexico model, only one model run is needed to estimate emission factors for the combined fleet. If emission factors for a combined fleet are to be estimated, then the fraction of Mexican-registered vehicles (<u>not</u> the fraction of Mexican-manufactured vehicles) can be input into the MOBILE5-Mexico model. It should be noted that the lower limit of the Mexican-registered vehicle fraction has been set at 50 percent.

Mexico-Specific BERs

The MOBILE5-Mexico model includes the first actual development of Mexico-specific BERs. These Mexico-specific BERs were directly developed for the interior urban module using emissions testing data collected in the city of Aguascalientes in central Mexico. These testing data were collected in 1998 on a portable dynamometer for over 200 Aguascalientes vehicles using appropriate testing protocols. Although the BERs used for the Mexico City and border urban modules are also based on emissions testing data from Mexico City and Ciudad Juárez, the BERs are estimated using an emission control "technology equivalence matrix" which maps MOBILE5a BERs to equivalent Mexican vehicles based upon emissions testing data (e.g., a 1996 model year Mexico vehicle might be equivalent to a 1990 model year U.S. vehicle for exhaust emissions.). However, these BERs (i.e., for Mexico City and Ciudad Juárez) are approximations rather than actual calculated values. More detailed discussion of the "technology equivalence matrix" has been presented elsewhere.[9,12,13] It should be noted that only exhaust BERs were directly calculated for the interior urban module; other BERs were still estimated using the "technology equivalence matrix".

COMPARISON OF MODEL RESULTS

A comparison of model results is provided below to demonstrate differences between regions in Mexico. A comparison between the results from the MOBILE5-Mexico model and the MOBILE5a model is also included. Due to space constraints, it is not possible to fully demonstrate the response of the MOBILE5-Mexico's various outputs to the various ranges of inputs. However, it is expected that the MOBILE5-Mexico model will soon be available on the Internet.

Example Model Runs–Interior Urban Area

To demonstrate the use of MOBILE5-Mexico in one region, three scenarios were modeled for the city of Aguascalientes. Aguascalientes is the capital of the state of Aguascalientes in central Mexico. Aguascalientes is a prosperous city with a relatively new vehicle fleet. The roadways are somewhat congested, with an old city center, peripheral "ring" roads, and few stretches of real "freeway."

The three modeled scenarios covered the calendar years 1996 through 2010. The scenarios are for illustrative purposes, and are not actual inputs used by city policy makers. The first scenario had no I/M program, the second had a Two-Speed Idle (TSI) program, and the third had an I/M program using the IM240 for exhaust measurement. The "No I/M" scenario defined the base conditions to compare the other two scenarios against. All non-I/M parameters were common between the three scenarios. All of the scenarios were modeled to start in calendar year 1996 and the emission factor trends were tracked until 2010. The main input file parameters are listed in Table 1. Results of the model runs for the scenarios are shown graphically in Figures 1, 2, and 3.

Figures 1, 2, and 3 show the emission factor trends for a "Fleet Average" vehicle in Aguascalientes. These trends are similar to what occurs with MOBILE5a. Without an I/M program, average emission factors will decrease because new vehicles entering the fleet are inherently lower emitting than older vehicles that are scrapped. A TSI I/M program tends to lower HC and CO emissions by causing a higher rate of fleet change, but has little effect on NO_x, since it is not measured and repaired for. An IM240-based program has the greatest effect, because the IM240 test is more difficult to pass and all three pollutants are measured and repaired for.

Region-to-Region Comparison

Because MOBILE5-Mexico will be used to model urban area emissions much more than for rural areas, a brief comparison of the three urban region models (i.e., Mexico City, Interior Urban, and Border Urban) is also provided. In this comparison, the interior city is Aguascalientes and the border city is Ciudad Juárez.

Mexico City is an extremely large metropolitan area with a diverse fleet and road network. All road types are found there, and traffic conditions tend to be quite congested. The fleet has a large fraction of intensive-use vehicles. One of the more distinctive parts of the large taxi fleet is its old-style Volkswagen "Beetle" taxis.

Ciudad Juárez is on the border with El Paso, Texas and has some of the heaviest crossing traffic of the entire Mexico-U.S. border. Near border crossings, a larger fraction of the fleet is commercial trucks than in typical cities. A large fraction of the private fleet circulating in Ciudad Juárez and crossing the border is actually registered in El Paso, and so is subject to El Paso emission standards and regulations.

A comparison of the main model inputs for Mexico City and Ciudad Juárez is presented in Table 2. The model inputs for the Aguascalientes Two-Speed Idle scenario presented in Table 1 were also used. The inputs are typical for each region. Mexico City was modeled to have an enhanced I/M program that had transitioned from a well-established two-speed idle program in 1996. The other cities were modeled based on starting a two-speed idle program in 1996. The model results are for the calendar year 2010.

Figure 4 graphically compares model outputs for the three urban areas. It should be noted that the CO emissions presented in Figure 4 were scaled down by a factor of 10 to facilitate clearer presentation of the results. Mexico City is predicted to have the cleanest "Fleet Average" vehicle of the three, probably due to the relatively new fleet and more stringent I/M program assumed to be there. Aguascalientes has a marginally cleaner "Fleet Average" vehicle than Ciudad Juárez, probably because the Aguascalientes fleet is somewhat newer. The difference between Aguascalientes and Ciudad Juárez was expected to be more pronounced. It could be that the effect of Aguascalientes' newer fleet is largely offset by the relatively large fraction of cleaner U.S.-registered vehicles assumed to be driving in Ciudad Juárez.

Mexico-to-U.S. Comparison

The final comparison was for urban areas in Mexico and the United States. Mexico City and Denver, Colorado were selected for this comparison. Both of these areas have relatively sophisticated I/M programs and are at high altitudes.

Mexico City was modeled as described above (see Table 2). MOBILE5b (instead of MOBILE5a) was used to estimate results for Denver. The Denver results were converted from a gram/mile basis to a gram/kilometer basis. The Denver inputs were typical for the area, but are not actual inputs used by city policy makers. Once again, model results were estimated for the calendar year 2010. It was assumed that the Denver area will test all light-duty gasoline vehicles using an enhanced I/M program, and will test all heavy-duty gasoline vehicles with a two-speed idle program. A list of the main model inputs used for the Denver areas is presented in Table 3.

The modeled "Fleet Average Vehicle" emissions for Denver and Mexico City are presented graphically in Figure 5. As in Figure 4, CO emissions in Figure 5 are scaled down by a factor of 10. The estimates for both cities are comparable in magnitude for all pollutants. While the total HC emission factor for Denver is slightly lower than for Mexico City, the NO_x emission factor for Mexico City is lower than for Denver. Predicted CO emission factors for the two cities are essentially the same. These results seem to validate that for two large North American cities with similar vehicle standards (which Denver and Mexico City will have in 2010) and similar pollution control programs (as modeled), the outputs of the two models yield similar results. The observed differences are probably more due to the fact that it was assumed that Denver has a higher proportion (on a vehicle kilometers traveled basis) of heavy-duty diesel vehicles than Mexico City, and these tend to emit less HC and CO, but more NO_x than gasoline vehicles.

AREAS OF IMPROVEMENT

Like most emission factor models, periodic improvements and future modifications to the MOBILE5-Mexico model should considered. As the fleet in a given area changes over time, new data will help maintain, or even improve, model parameters and overall accuracy. There are many aspects of the MOBILE5-Mexico model that should be improved in the future. However, the following are probably the most important:

- Incorporate additional light-duty emissions testing, especially for Mexico City. The existing light-duty vehicle data set is relatively small with a sample size of less than 1,000 tests. In addition, data appropriate for inclusion in the model have not been recently collected in Mexico City. Two new emissions testing data sets have recently been developed. They should be analyzed for appropriateness and incorporated into the model as soon as possible. The first data set consists of data collected by TNRCC in Ciudad Juárez, which is distinct from the Ciudad Juárez data used to initially develop the MOBILE-Juárez model (i.e., the border urban module of MOBILE5-Mexico). The second data set consists of data collected by ARB in Tijuana.

- Incorporate heavy-duty gasoline and diesel vehicle study data (e.g., emission rates, mileage accumulations, tampering rates, etc.) for highways and other areas with a large fraction of heavy-duty traffic. All previous studies have focused exclusively on light-duty vehicles. No model-appropriate on-road data exist for heavy-duty Mexican vehicles. It should be noted that developing appropriate data would require a sophisticated measurement system (i.e., equivalent to a heavy-duty chassis dynamometer laboratory), so this update would probably require more resources than for light-duty updates.
- Incorporate the influence of driving behavior differences between the U.S. and Mexico. The Aguascalientes driving cycle study was a significant development, but further research is needed to properly quantify Mexican driving behavior. The new driving cycles could then be used either to directly measure emission factors for the appropriate area, or to further improve emission factor data for regions that already have recent emission factor data. This could be done by correlating emissions from the Mexican driving cycles to the IM240 or a cycle that is similar to the IM240. (The IM240 was the cycle used to develop the emission factors in the border urban and interior urban areas). These correlations would then be used to adjust the emission factors already used in the border urban and interior urban areas.
- If rural areas are determined to significantly contribute to the overall mobile sources inventory for Mexico, then the MOBILE5-Mexico model should be updated to include specific data from those regions.

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Table 1. Main modeling input variables for three Aguascalientes scenarios.

Parameter	Value	Comment
Common Input Parameters		
Region	High altitude	Higher than 5000 feet
Reformulated gasoline	No	No oxygenates added
Reid Vapor Pressure	6.5 psi	Fuel volatility
Average Speed	31.5 km/hr	All vehicle types
VKT Fractions	LDGV = 0.592, LDGT1 = 0.336, LDGT2 = 0.011, HDGV = 0.013, LDDV = 0.001, LDDT = 0, HDDV = 0.033, MC = 0.015	
TSI Scenario I/M Parameters		
First I/M Year	1996	
Model Years Covered	1968 – 2010	
Cutpoints	HC = 220 ppm CO = 1.2%	Annual test
Vehicle Types Covered	All gasoline-powered vehicles	
Anti-Tampering Program	Yes	Catalyst, evaporative system, gas cap
IM240 Scenario I/M Parameters		
First I/M Year	1996	
Model Years Covered	1968 – 2010	
Cutpoints	HC = 1.2 g/mi (0.75 g/km) CO = 20 g/mi (12.4 g/km) NO_x = 2 g/mi (1.24 g/km)	Annual test
Vehicle Types Covered	All gasoline-powered vehicles	
Anti-Tampering Program	Yes	Catalyst, evaporative system, gas cap

Notes:

g/km = grams per kilometer
g/mi = grams per mile
HDDV = heavy-duty diesel vehicle (>8,500 pounds)
HDGV = heavy-duty gas vehicle (>8,500 pounds)
I/M = inspection and maintenance
km/hr = kilometers per hour
LDDT = light-duty diesel truck (<8,500 pounds)
LDDV = light-duty diesel vehicle
LDGT1 = light-duty gas truck (<6,000 pounds)
LDGT2 = light-duty gas truck (6,000 – 8,500 pounds)
LDGV = light-duty gas vehicle
MC = motorcycle
ppm = parts per million
psi = pounds per square inch

Table 2. Main modeling input variables for three urban regions.

Parameter	Value	Comment
Mexico City, Distrito Federal		
Region	High altitude	Higher than 5500 feet
Reformulated gasoline	No	No oxygenates added
Reid Vapor Pressure	9.0 psi	Fuel volatility
Average Speed	25.9 km/hr	All vehicle types
First I/M Year	1996	IM240 (annual TSI program before 1996)
Model Years Covered	1968 – 2010	
Cutpoints	HC = 0.8 g/mi (0.50 g/km) CO = 20 g/mi (12.4 g/km) NO_x = 2.0 g/mi (1.24 g/km)	Annual test
Vehicle Types Covered	All gasoline-powered vehicles	
Anti-Tampering Program	Yes	Catalyst, evaporative system, gas cap
VKT Fractions	LDGV = 0.772, LDGT1 = 0.182, LDGT2 = 0.026, HDGV = 0.002, LDDV = 0.001, LDDT = 0.002, HDDV = 0.007, MC = 0.009	
Ciudad Juárez, Chihuahua (Border Urban)		
Region	Low altitude	500 feet
Reformulated gasoline	No	No oxygenates added
Reid Vapor Pressure	7.7 psi	Fuel volatility
Average Speed	31.5 km/hr	All vehicle types
First I/M Year	1996	
Model Years Covered	1968 – 2010	
Cutpoints	HC = 220 ppm CO = 1.2%	Annual test
Vehicle Types Covered	All gasoline-powered vehicles	10% gasoline-powered vehicles and 5% diesel-powered vehicles registered in USA.
Anti-Tampering Program	Yes	Catalyst, evaporative system, gas cap
VKT Fractions	LDGV = 0.611, LDGT1 = 0.242, LDGT2 = 0.066, HDGV = 0.056, LDDV = 0, LDDT = 0, HDDV = 0.019, MC = 0.006	

Table 3. Main modeling input variables for Denver, Colorado.

Parameter	Value	Comment
Denver, Colorado (MOBILE5b)		
Region	High altitude	5500 feet
Reformulated gasoline	No	No oxygenates added
Reid Vapor Pressure	13.6 psi	Fuel volatility
Average Speed	19.6 mi/hr	All vehicle types
First I/M Year	1983	
Model Years Covered	1981 – 2010 (IM240) 1967 – 2010 (TSI)	
IM240 Cutpoints	HC = 0.8 g/mi (0.50 g/km) CO = 15 g/mi (9.3 g/km) NO_x = 2.0 g/mi (1.24 g/km)	Biennial test
TSI Cutpoints	HC = 220 ppm CO = 1.2%	Annual test
Vehicle Types Covered	All gasoline-powered vehicles	
Anti-Tampering Program	Yes	Catalyst, air pump, fuel inlet
VKT Fractions	LDGV = 0.395, LDGT1 = 0.383, LDGT2 = 0.127, HDGV = 0.023, LDDV = 0, LDDT = 0.002, HDDV = 0.065, MC = 0.005	

Figure 1. Modeled HC trends in Aguascalientes for three I/M scenarios.

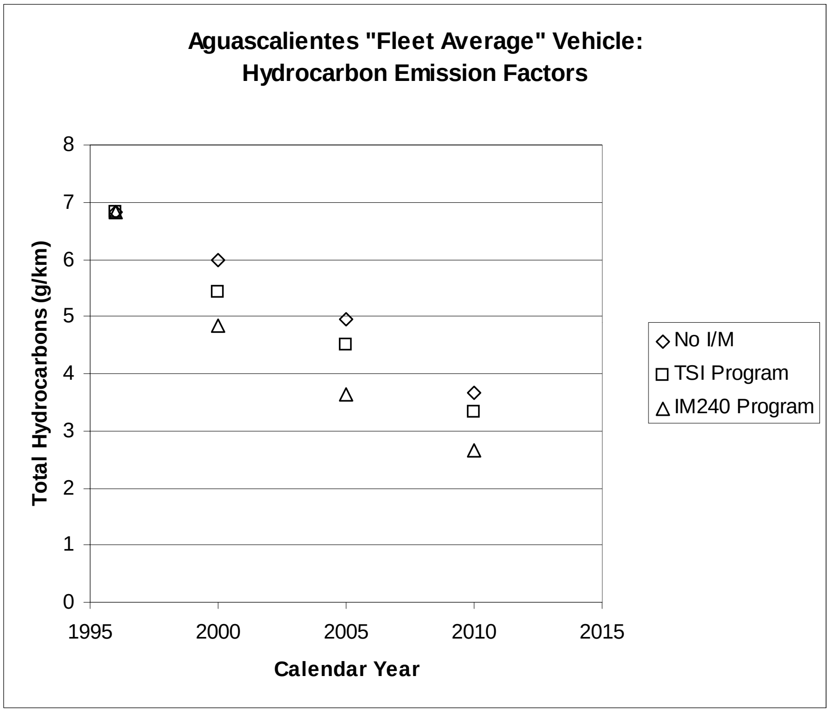


Figure 2. Modeled CO trends in Aguascalientes for three I/M scenarios.

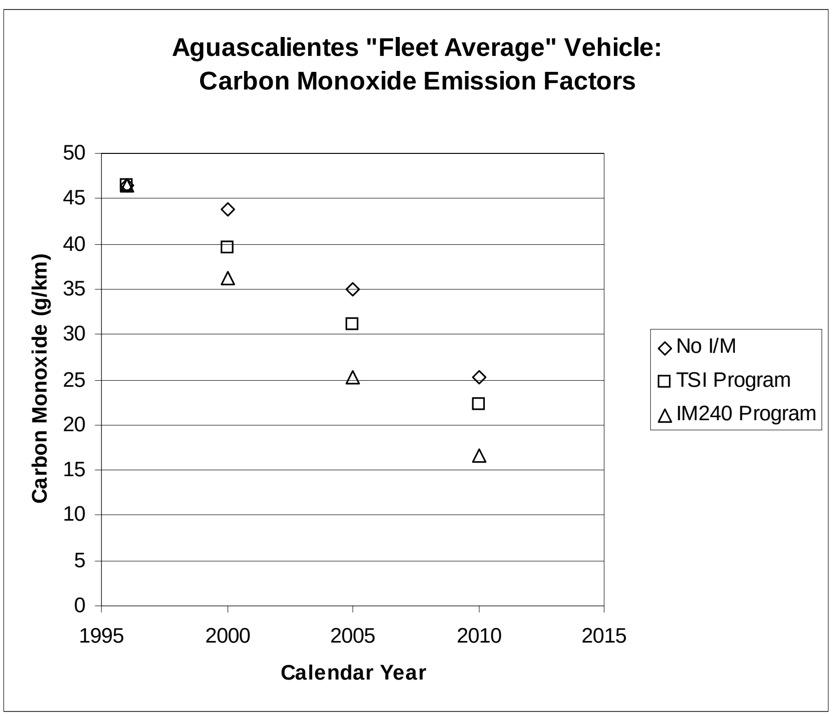


Figure 3. Modeled NO_x trends in Aguascalientes for three I/M scenarios.

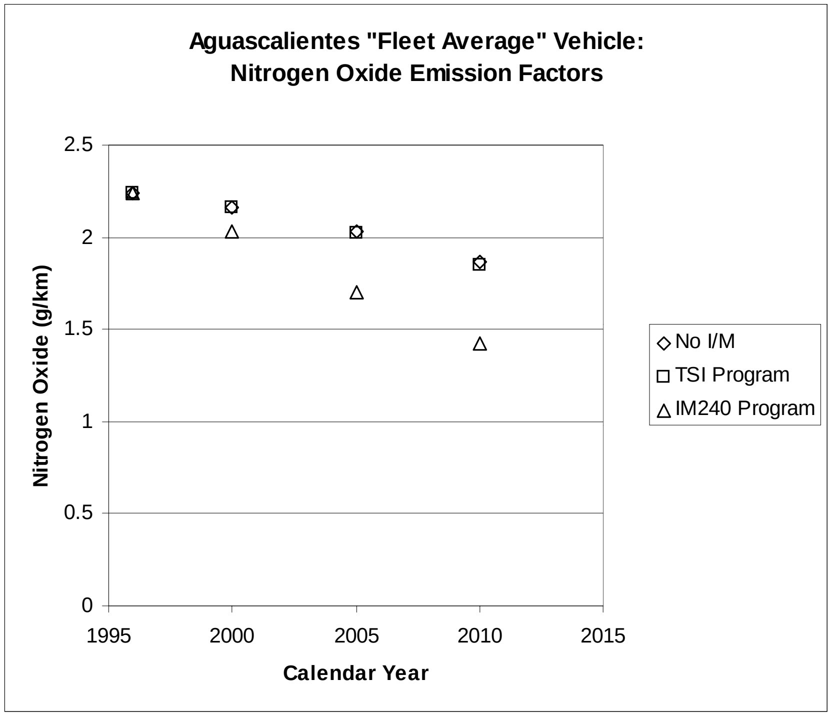


Figure 4. Example outputs for three urban areas in different regions.

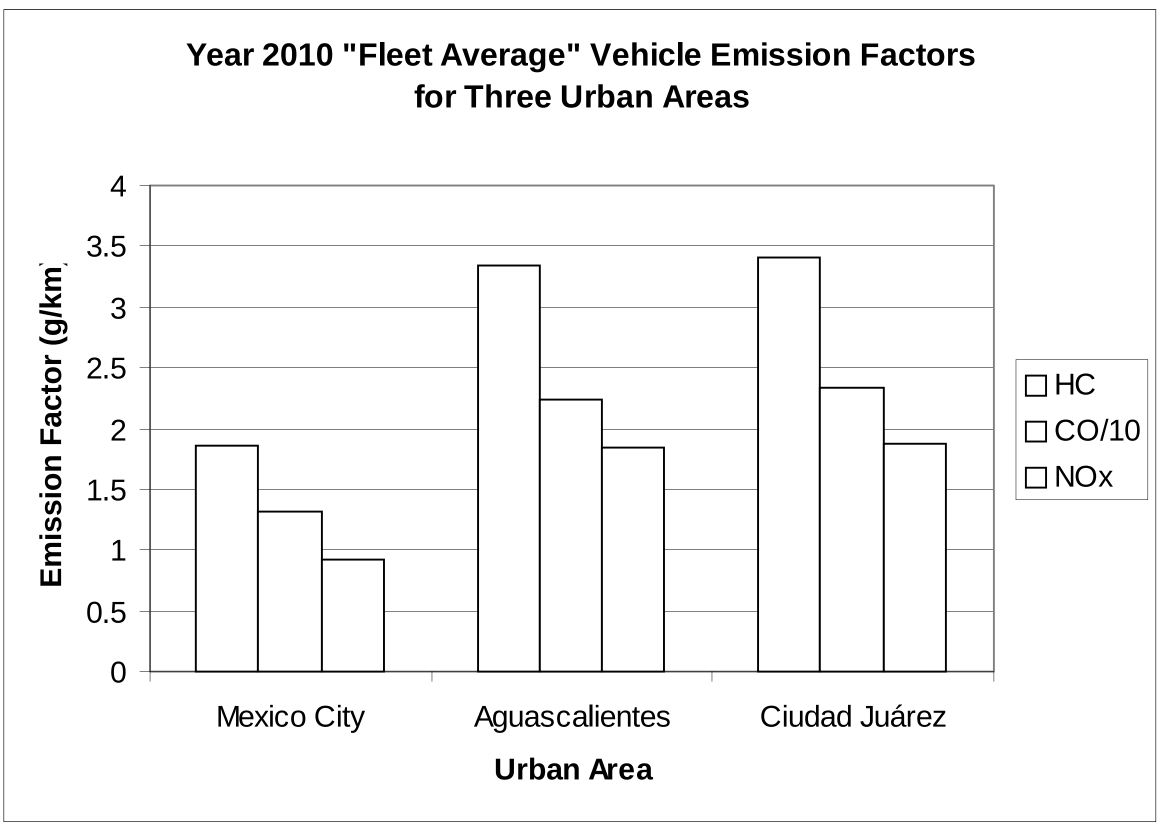
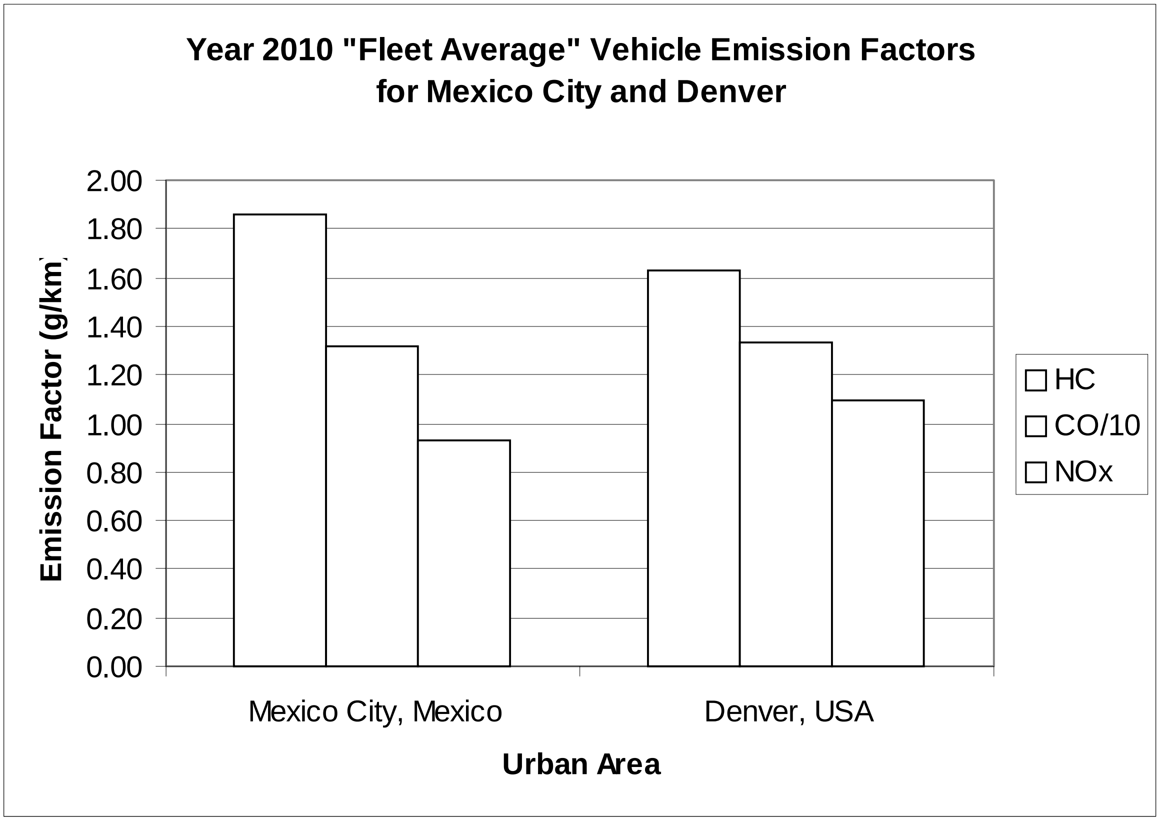


Figure 5. Example outputs for Mexico City and Denver.



KEYWORDS

Mobile Sources
Motor Vehicles
Emission Factor Model
MOBILE5
Mexico