Developing a National Emissions Inventory for Mexico: On-Road Mobile Source Emissions Inventory

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ABSTRACT

The first comprehensive national emissions inventory for the country of Mexico is currently under development. The inventory will include point, area, natural, and on- and off-road mobile sources. The inventory will contain emissions for both criteria and visibility pollutants.

Because the availability of data used in traditional on-road mobile source estimation methodologies is limited in Mexico, a unique methodology was developed to estimate motor vehicle emissions. At the current time, this methodology has not been completely implemented. The methodology relies on the development of motor vehicle activity for seven representative urban areas of varying population size. A set of per capita motor vehicle emission rates for each urban area size will then be developed using MOBILE6-Mexico for several different temperature, altitude, and fuel scenarios. These per capita motor vehicle emission rates will be used to develop municipality-level motor vehicle emissions.

INTRODUCTION

The Western Governors' Association (WGA), the United States Environmental Protection Agency (U.S. EPA), the North American Commission for Environmental Cooperation (NACEC), and Mexico's Secretariat of the Environment and Natural Resources/National Institute of Ecology (SEMARNAT/INE) are currently working together to develop a 1999 national municipality-level emissions inventory for the country of Mexico. The Mexico National Emissions Inventory (MNEI), which began in 2001, is being conducted in three phases over three years. Phase I covered program planning and organization, and development of the Inventory Preparation Plan. Phase II, which is the subject of this paper, includes the development of the inventory for the six northern Mexican states of Baja California, Sonora, Chihuahua, Coahuila, Nuevo León, and Tamaulipas. Future work in Phase III will result in an emissions inventory that encompasses the entire country of Mexico.

The MNEI includes emissions estimates for seven pollutants (VOC, CO, NO_x, SO_2, PM_{10}, $PM_{2.5}$, and NH_3) generated by point, area, natural, and on- and off-road mobile sources. A significant component of the MNEI are on-road mobile source emissions which are discussed in this paper. MNEI point, area, natural, and off-road mobile sources are discussed in a companion paper.[1] Development of the natural and off-road mobile source inventories is at a very preliminary stage of development at this time.

Current Motor Vehicle Data in Mexico

As with many countries in the world, motor vehicle emissions are a significant element of the overall emissions inventory in Mexico. According to 1999 Petróleos Mexicanos (PEMEX) internal sales statistics, unleaded gasoline (i.e., Magna) sales were 27,160,793 m^3 (1.71×10^8 bbl), premium gasoline sales were 2,478,263 m^3 (1.56×10^7 bbl), and diesel sales were 12,924,463 m^3 (8.13×10^7 bbl).[2] Leaded gasoline (i.e., Nova) has been discontinued in Mexico and has not been sold since 1997.[3] The 2001 national vehicle fleet of vehicles that are registered and in circulation has been estimated to consist of 12,185,317 passenger cars, 222,259 passenger trucks and 5,376,870 cargo trucks.[4]

An example of the significance of motor vehicles in Mexico emissions inventories can be seen in the 1998 emissions inventory developed for the Metropolitan Zone of the Valley of Mexico (ZMVM). In this inventory, motor vehicles contributed 40 percent of the total hydrocarbon (HC) emissions, 98 percent of the total carbon monoxide (CO) emissions, and 81 percent of the total nitrogen oxides (NO_x) emissions.[5] Similar percentages can also be seen in the Air Quality Plan emissions inventories for the Monterrey, Guadalajara, Ciudad Juárez, Mexicali, and Tijuana metropolitan areas.[6-10]

Compared to the United States, the availability of motor vehicle activity data in Mexico is somewhat limited. In major U.S. metropolitan areas, travel demand models (TDMs) are typically used to estimate vehicle miles traveled (VMT). In Mexico, however, TDMs are not widely used; and the development of TDMs for the entire country is not technically or economically feasible at this time. In the five Air Quality Plan emissions inventories identified above, vehicle kilometers traveled (VKT) were estimated using vehicle registration statistics combined with assumed daily VKT based upon some limited traffic count statistics, informal surveys, and anecdotal information. Examination of vehicle registration data in various areas in Mexico has indicated that there are some deficiencies in the available records. Also, there is inherent uncertainty with the assumed daily VKT estimates.

Fuel sales data are sometimes used to check the reasonableness of motor vehicle emission estimates. These can also be used to estimate VKT in situations where other VKT estimates are not available, if assumptions regarding fuel efficiencies for various vehicle classifications are made. Currently, PEMEX fuel sales data have been obtained for the 81 bulk terminals in Mexico.[2] However, the PEMEX fuel sales data are not currently available at the appropriate level of disaggregation needed to be directly used in the MNEI (i.e., municipality-level).

Accurate VKT estimates cannot be readily developed for the entire country of Mexico using TDMs, limited traffic count statistics, or fuel sales statistics. Therefore, a unique methodology was developed that utilizes modeled traffic volumes and congestion levels at representative urban areas for different city size categories to generate daily per capita emission rates. This methodology is described below.

METHODOLOGY FOR GENERATING PER CAPITA EMISSION RATES

Due to the data limitations described above and the complexities involved in evaluating traffic levels and emissions throughout Mexico, it might seem reasonable to develop a single average daily per capita emission rate. However, this overly simplistic approach assumes that all urban areas have similar unit congestion levels or that any variations in congestion levels can be disregarded. As cities grow in size, the ability to keep up with the demand for additional transportation infrastructure diminishes and results in the more frequent and more intense occurrence of traffic congestion. Therefore, a methodology was developed to differentiate between traffic congestion and emissions per capita for urban areas of different sizes. Seven urban area size categories were established and the following representative urban areas were selected for each of the size categories:

- Small towns (less than 25,000 population) – Castaños, Coahuila;
- Medium towns (25,000 to 100,000 population) – Río Bravo, Tamaulipas;
- Large towns (100,000 to 250,000 population) – Ensenada, Baja California;
- Small cities (250,000 to 1,000,000 population) – Hermosillo, Sonora;
- Medium cities (1,000,000 to 2,000,000 population) – Ciudad Juárez, Chihuahua;
- Large cities (over 2,000,000 population) – Monterrey, Nuevo León; and
- Mexico City.

A basic assumption used in this methodology is that the daily per capita emission rates estimated for each of the representative urban areas are transferable to other urban areas of similar size. This assumption is reasonable because it has been shown that trip generation rates across different urban area locations and sizes are fairly stable when disaggregated by socio-economic conditions such as household size, income, and employment.[11]

After completion of traffic volume and congestion modeling for each of the representative urban areas, motor vehicle traffic volumes for individual roadway network links will be assigned and combined with corresponding link-specific congested speed emission factors to estimate daily emissions on a link basis using PrepinPlus software. This will result in per capita emission rates for the urban area. Emission factors will be developed using MOBILE6-Mexico (i.e., a Mexico-specific on-road motor vehicle emission factor model based upon U.S. EPA's MOBILE6 model, which is currently under development). For each urban area size category, several sets of emission factors will be developed to account for variations in ambient temperature, altitude, and/or fuel characteristics.

After daily per capita emission rates have been developed for each of the representative urban areas, these rates will be combined with population statistics to calculate annual municipality-level on-road motor vehicle emission estimates.

Trip Generation

As mentioned above, U.S. trip generation rates across urban area locations and sizes are relatively stable when disaggregated by socio-economic conditions such as household size, income, and employment. This suggests that known trip generation rates from the limited travel studies in Mexico can be transferred to other urban areas in the country.

One well-documented travel study has been conducted for Ciudad Juárez, Chihuahua.[12] Two sets of trip generation rates were obtained from the Ciudad Juárez study. The first set of trip generation rates provided daily-person trip productions per household. These trip generation rates were disaggregated as follows:

- Trip purpose (i.e., home-based-work, home-based-other, and non-home-based);
- Household income ranges (i.e., multiples of daily minimum wages); and
- Household size.

The second set of trip generation rates provided daily-person trip attractions per employee and accounted for urban activity (i.e., urban population and employment density). These trip generation rates were disaggregated as follows:

- Trip purpose (i.e., home-based-work, home-based-other, non-home-based, and truck-taxi);
- Area type (i.e., central business district, urban, suburban, and rural); and
- Employment type (i.e., basic, retail, and service).

In order to expand disaggregated trip rates into overall trip generation patterns, a zone structure with demographic variables such as population, household size, income, and employment was established for each representative urban area. A zone structure was developed based upon census tracts called Areas Geoestadísticas Básicas (AGEBs). Mexico's Instituto Nacional de Estadística Geografía e Informática (INEGI) has developed demographic and socio-economic information for AGEBs in every urban area in Mexico. Figure 1 shows the AGEB-based zone structure for Hermosillo, Sonora. The zone structures were used to develop geographic information system (GIS) coverages, in order to store zonal attributes for representative urban areas.

In order to determine the number of trip productions by AGEB, it was necessary to input the total number of households in each size and income category for each AGEB, into the trip generation model. However, in terms of income, INEGI only provides information on a per capita basis at the AGEB-level. Therefore, regressions developed from research in Ciudad Juárez were used to convert per capita income data into an average household income value for each zone. The average household size and income values by AGEB were then converted to the total number of households in different size and income categories, using size and income marginal curves developed for Ciudad Juárez from INEGI data.[12] The marginal curves show the percentage distribution of households in different categories based on zonal average values.

The trip generation model also required information on AGEB-level employment by sector in order to establish trip attractions. These employment statistics were also obtained from INEGI for all of the representative urban areas with population greater than 50,000 (i.e., excluding Castaños).[13] As a result, it was assumed for Castaños that 50 percent of its employment is located in the central business area (i.e, approximately 25 percent of the total urban area) with the other 50 percent being uniformly distributed throughout the rest of the urban area.

As previously indicated, the production trip rates were disaggregated by household size and income. Therefore the total productions for a zone were obtained simply by multiplying the production trip rates times the number of households under each category of household size and income. Likewise, total attractions for each zone were obtained by multiplying the attraction trip rates times the number of employees under the corresponding category of area type and economic activity. The end result of this process is a production-attraction table by zone, for each trip purpose. In theory, the trip productions and trip attractions under the same trip purpose need to add up to the same number (i.e., each trip production has an associated trip attraction). However, since the development of trip productions and trip attractions is based on different sources (i.e., a household survey for productions and a workplace survey for attractions), it is common to "balance" or factor one to the other, usually to the more reliable one. In the Ciudad Juárez study, trip attractions were balanced to trip productions.[12] This convention was followed for all of the representative urban areas. Table 1 shows a summary of the raw trip production and trip attraction totals by trip purpose as well as the resulting balance factor. For example, trip productions (P) for home-based-work trips for Castaños were 8,087 person-trips/day. Likewise, trip attractions (A) for home-based-work trips for Castaños were 6,501 person-trips/day. Therefore, in order for trip productions and trip attractions to balance, a factor (F_A) of 1.244 must be applied to the trip attractions. Balanced AGEB-level trip production and trip attraction totals for each of the representative urban areas were then stored in the corresponding GIS layers.

Trip Distribution

The number of trips produced from and attracted to each AGEB zone were entered into a tabular format (see Figure 2). At this point, a rough estimate can be made of the trip-making potential for each zone, but this does not determine the actual trip exchanges with other zones. The trip distribution step resolves trip exchanges between zones and identifies the origin and destination of trips. Figure 2 shows an example of how the productions and attractions for Zone 93 in Ciudad Juárez (totals of row i = 93 and column $j = 93$, respectively) are "distributed" to other zones. As shown in Figure 2, trip exchanges between the zones are presented as a two-dimensional matrix array, where each cell represents the number of trips produced at zone *i* (i.e., row *i*) and attracted to zone *j* (i.e., column *j*). Next, this Production-Attraction matrix (also referred to as the "P-A matrix") is transformed to the Origin-Destination (O-D) matrix, simply by reconfiguring the cell values to produce a symmetrical matrix around the main diagonal.

Roadway Networks

In order to facilitate trip distribution, a roadway network was developed for each of the representative urban areas. The networks are simplified versions of the current roadway infrastructure layout and only include freeways, main arterials, and collector roads. Local streets are modeled using artificial links called "connectors" which channel local traffic flows between the zones (represented at zone centroids) and the network system. The networks were developed from the maps of the representative urban areas and organized in a roadway GIS. Figure 3 shows the primary roadway network developed for Hermosillo.

Each link in the network was initially assigned a function class and flow direction. This information was gathered during site visits to the representative urban areas through visual observation and characterization (for the smaller urban areas) and through interviews with local transportation officials. From this collected information, a second set of network link attributes was developed based on average conditions identified in the Ciudad Juárez case study. These attributes were link capacity and average daily speed corresponding to the functional class and area type where individual links were located. These attributes are shown in Table 2. Individual link travel time was then computed using the assigned link speed.

Roadway networks were developed to establish travel times between zones, which are entered into a gravity-model evaluation. Using the network travel times, "skim matrices" for each representative urban area indicating the shortest travel time (in minutes) between all zones/AGEBs were developed.

Evaluation of Gravity Model

The traditional gravity model is a fundamental concept of transportation engineering. It was originally developed based on similarities with the physical world (i.e., Newton's law of universal gravitation). However, it has been improved and modified through entropy-maximizing considerations, in order to more realistically predict actual traffic behavior.

The doubly-constrained version of the traditional gravity model used in this study has the following form:

Equation (1) $$T_{ij} = \beta_i \times P_i \times \alpha_j \times A_j \times f(t_{ij})$$

where

T_{ij} = Tips produced in zone *i* and attracted to zone *j*;
β_i = Total trips produced in zone *i*;
P_i = Balancing factor for row *i* (production constraint);
α_j = Total trips attracted to zone *j*;
A_j = Balancing factor for column *j* (attraction constraint);
$f(t_{ij})$ = Impedance (decreasing) function, based on the travel time between zone *i* and zone *j*.

The traditional gravity model has two constraints that must be met. The first constraint is that the sum of trips in any specific row of the matrix should equal the total number of trips produced in that zone. The second constraint is that the sum of trips in any specific column should correspond to the number of trips attracted to that zone (see Figure 2). These two constraints are presented in Equations 2 and 3:

Equation (2) $$\sum_j T_{ij} = P_i$$

Equation (3) $$\sum_i T_{ij} = A_j$$

The balancing factors (β_i and α_j) can be derived through simple algebraic manipulations of Equations 1-3. These have the following forms are shown in Equations 4 and 5:

Equation (4) $$\beta_i = \frac{1}{\sum_j \alpha_j \times A_j \times f(t_{ij})}$$

Equation (5) $$\alpha_j = \frac{1}{\sum_i \beta_i \times P_i \times f(t_{ij})}$$

As shown above, the balancing factors (β_i and α_j) are interdependent (i.e., the calculation of one set requires the values of the other set). As a result, an iterative process is needed until convergence is achieved. Thus, the practical approach to solving these equations is to specify separate singly-constrained models for productions (Equation 6) and for attractions (Equation 7). Equation 6 is obtained by setting α_j equal to 1 (i.e., the columns are not being balanced); Equation 7 is obtained by setting β_i equal to 1 (i.e., the rows are not being balanced).

Equation (6) $$T_{ij} = P_i \times \frac{A_j \times f(t_{ij})}{\sum_j A_j \times f(t_{ij})}$$

Equation (7) $$T_{ij} = A_j \times \frac{P_i \times f(t_{ij})}{\sum_i P_i \times f(t_{ij})}$$

The solution for the doubly-constrained model can then be iteratively converged upon by applying Equation 6 to balance the productions (rows) and Equation 7 to balance attractions (columns).

The end result of the gravity-model estimation-calibration process was the definition of the impedance function (i.e., the $f(t_{ij})$ term). In the previous Ciudad Juárez study, the doubly-constrained gravity models were estimated and calibrated for each of the four trip purposes yielding impedance functions in the form of friction factor (FF) tables.[12] The Ciudad Juárez FF tables were applied to evaluate gravity models for each of the representative urban areas using the corresponding set of skim matrices and P-A tables. The result of this evaluation was the development of trip distribution P-A matrices by trip purpose for each of the representative urban areas.

Development of Vehicle Trip Origin-Destination Matrices

As the final step of the trip distribution process, the all-mode person-trip production-attraction (P-A) matrices were converted into vehicle-trip original-destination (O-D) matrices. In order to make this conversion, mode shares (specifically AUTO mode) were applied to the total number of person-trips by trip purpose to determine AUTO mode person-trips. Then, passenger occupancy rates were used to convert AUTO mode person-trips into AUTO mode vehicle-trips. From the previous Ciudad Juárez study, the following AUTO mode shares and vehicle occupancies were observed:

- Home-based-work trip – 57.7% AUTO share and 1.25 passengers/vehicle;
- Home-based-other trip – 44.4% AUTO share and 1.87 passengers/vehicle;
- Non-home-based trip – 66.1% AUTO share and 1.72 passengers/vehicle; and
- Truck-taxi – 100.0% AUTO share and 1.00 passengers/vehicle.

In addition, in the previous Ciudad Juárez study VKT from the TRANSIT mode represented approximately 2 percent of the total daily VKT.[12] Therefore, transit vehicle activity was incorporated into the VKT distribution in the VKT mix at the emission modeling stages. A similar approach was followed for the other representative urban areas.

In the specific case of Mexico City, a highly developed rapid mass transit system together with a high population density and restrictive automobile-use policies result in a considerably different distribution of travel mode shares compared to other Mexican cities. Only about 20 percent of all daily person-trips are in the AUTO mode, while close to 80 percent are in the TRANSIT mode, of which 66 percent represent the feeder bus share. As a result, a significant proportion of the daily internal combustion VKT is from feeder buses (i.e., about 16 percent of daily VKT).[14] For Mexico City the following AUTO mode shares and vehicle occupancies were used:

- Home-based-work (HBW) trip – 20.0% AUTO share and 1.25 passengers/vehicle;
- Home-based-other (HBO) trip – 20.0% AUTO share and 1.87 passengers/vehicle;
- Non-home-based (NHB) trip – 20.0% AUTO share and 1.72 passengers/vehicle;
- Truck-taxi (TT) trip – 100.0% AUTO share and 1.00 passengers/vehicle; and
- HBW, HBO, and NHB trip – 66.0% feeder bus share and 25.0 passengers/vehicle.

Finally, in addition to the four generic trip purposes characterizing internal local trips within each representative area, an additional trip purpose was added at this stage to account for external trips (i.e., EXT). This trip purpose actually includes all external-external and external-local trips (i.e., trips that have at least one trip-end outside of the representative areas. In order to develop the corresponding O-D matrix, it was assumed that the EXT trip purpose was 5 percent of the total local non-transit vehicle-trip volume, which was the observed relationship in the previous Ciudad Juárez study.[12] Table 3 presents a summary of daily vehicle-trips estimated for the seven representative urban areas.

Traffic Assignment

The final step in the travel demand modeling process and traffic congestion estimation was traffic assignment. In this step, the final O-D matrix for each urban area was assigned to the corresponding network system, using a user-equilibrium (UE) algorithm. Such algorithm assigns volumes to the network links, and through iteration balances congestion levels between similar time alternatives. The process involved re-computation of travel speeds to account for congestion levels as traffic volumes accumulate. The result of this step yielded "loaded" networks for the representative urban areas with traffic volumes and speeds at each of the links of the network. Figure 4 shows the loaded network for Hermosillo with traffic volumes being indicated by lines of varying thickness.

Estimation of VKT

Link-level VKT was estimated by multiplying each link's daily traffic volume times the corresponding link's length in kilometers. Summing the VKT-by-link of all the links in the roadway network resulted in an estimate of total VKT for the representative urban areas. Total VKT estimates, as well as per capita VKT, are shown in Table 4.

It can be seen in Table 4 that as urban areas grow, so does the per capita VKT. However, both Castaños and Mexico City do not follow this trend. For Castaños, it was the only urban area for which employment totals and distribution had to be assumed, which may have resulted in additional uncertainty. Therefore, it is reasonable to combine the two smallest urban area size categories into one category and assume a per capita VKT value of 1.9. For Mexico City, the significant importance of transit use clearly contributes to reduced vehicle activity, which on a per capita basis is lower than Monterrey. However, Mexico City's overall total VKT is the highest of any Mexican urban area.

Estimation of Per Capita Emission Rates

After link-level VKT estimates are obtained for each of the seven representative urban areas, these VKT estimates will be combined with corresponding link-specific congested speed emission factors to estimate daily emissions on a link basis using PrepinPlus software. The PrepinPlus software first converts daily (i.e., 24-hour) traffic volumes into hourly traffic volumes. PrepinPlus then determines link-specific congested speeds for the entire roadway network using volume/capacity and directional split relationships. After hourly link-specific speeds have been determined, then PrepinPlus will match the speeds with the corresponding emission factors from the look-up speed-emissions matrices (to be developed from MOBILE6-Mexico). The look-up speed-emissions matrices will be developed for a generic set of scenarios with varied temperature ranges, altitude, and fuels. The speeds in the look-up matrices will range from 4 to 100 kilometers per hour (kph) with 2 kph bins.

The link-specific emission factor combined with link length and hourly traffic volume will result in total hourly emissions for each link. Daily emissions are estimated by summing up emissions for each hour. These daily emissions are then used to estimate per capita emission rates for the generic temperature/altitude/fuel scenarios for each of the urban area size categories. Annual municipality-level emissions will then be estimated by combining per capita emission rates with population counts for each municipality.

CONCLUSION

The development of the Mexico NEI represents the first comprehensive national emissions inventory for the country of Mexico. Emissions from on-road mobile sources represent a significant portion of this landmark inventory. However, due to data limitations, estimation methodologies and sources of activity data traditionally used in the United States are currently not applicable in Mexico. The methodology described in this paper overcomes these data limitations and provides a very reasonable first approximation of on-road mobile source activity for Mexico. In the future, as other data sources develop, traditional TDMs may be employed.

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Table 1. Raw daily person-trip production (P) and attraction (A) totals for representative urban areas ($F_A = P/A$).

		Castaños	Río Bravo	Ensenada	Hermosillo	Ciudad Juárez	Monterrey	Mexico City
HBW	P	8,087	35,376	97,799	262,182	463,748	1,335,032	7,480,824
	A	6,501	31,673	128,852	311,294	530,313	1,855,649	1,835,297
	F_A	1.244	1.117	0.759	0.842	0.874	0.719	4.076
HBO	P	41,010	181,191	501,099	1,343,821	2,314,037	6,844,204	38,164,009
	A	44,532	236,452	879,372	2,232,804	2,722,470	13,412,955	16,449,908
	F_A	0.921	0.766	0.570	0.602	0.850	0.510	2.320
NHB	P	8,484	36,697	101,511	271,853	494,019	1,385,524	7,800,817
	A	12,205	54,082	192,786	473,823	581,214	2,554,513	4,641,036
	F_A	0.695	0.679	0.527	0.574	0.850	0.542	1.681
TT	P	937	3,915	10,206	28,646	50,964	155,777	807,778
	A	1,174	4,290	17,045	39,287	60,535	184,531	741,081
	F_A	0.798	0.913	0.599	0.729	0.842	0.844	1.090
Total P's		58,518	257,179	710,615	1,906,502	3,322,768	9,720,537	54,253,428
Total balanced A's ($A \times F_A$)		58,518	257,179	710,615	1,906,502	3,322,768	9,720,537	54,253,428

HBO = Home-based-other
HBW = Home-based-work
NHB = Non-home-based
TT = Truck-taxi

Table 2. Average daily speed and link capacity by functional classification and area type for Ciudad Juárez.

Speed (mph) Capacity (vpld)		**Area Type**			
		CBD (1)	**Urban (2)**	**Suburban (3)**	**Rural (4)**
Functional Classification	Conn (0)	15 30,000	15 30,000	25 30,000	35 30,000
	Expy (3)	32 13,100	32 13,100	29 11,750	36 10,250
	PartD (4)	12 8,350	12 8,350	24 7,500	31 6,250
	PartU (5)	12 7,500	12 7,500	23 6,800	37 5,600
	MartD (6)	11 7,250	11 7,250	19 6,500	29 4,050
	MartU (7)	12 6,600	12 6,600	20 5,950	31 3,750
	MartUnp (8)	11 6,200	11 6,200	17 5,550	28 3,350
	Ramp (12)	20 18,000	20 18,000	18 18,000	34 18,000

CBD = Central business district
Conn = Connector
Expy = Expressway
MartD = Minor arterial – divided
MartU = Minor arterial – undivided
MartUnp = Minor arterial – unpaved
mph = miles per hour
PartD = Principal arterial – divided
PartU = Principal arterial – undivided
vpld = vehicles per lane per day

Table 3. Daily vehicle trips for representative urban areas.

	Castaños	Río Bravo	Ensenada	Hermosillo	Ciudad Juárez	Monterrey	Mexico City
HBW	3,732	16,327	45,136	121,002	214,029	616,144	1,394,426
HBO	9,742	43,040	119,031	319,211	549,677	1,625,773	5,089,242
NHB	3,261	14,105	39,017	104,490	189,881	532,541	1,113,013
TT	937	3,915	10,206	28,646	50,964	155,777	807,778
EXT	884	3,869	10,670	28,667	50,228	146,512	349,675
Total	18,555	81,256	224,060	602,017	1,054,778	3,076,746	8,754,134

EXT = External
HBO = Home-based-other
HBW = Home-based-work
NHB = Non-home-based
TT = Truck-taxi

Table 4. Daily total and per capita VKT for representative urban areas.

Name	Population	Total VKT	Per capita VKT
Castaños	19,586	38,162	1.9
Río Bravo	81,821	129,278	1.6
Ensenada	213,304	926,922	4.3
Hermosillo	598,703	3,140,586	5.2
Ciudad Juárez	1,065,000	6,579,080	6.2
Monterrey metro area	3,255,739	30,693,199	9.4
Mexico City metro area	16,660,173	104,859,418	6.3

Figure 1. AGEB-based zone structure for Hermosillo, Sonora.

Figure 2. Trip generation table and trip distribution matrix.

Trip generation table

ZONE	Productions	Attractions
1	3,643	4,670
2	1,237	1,854
3	5,049	2,983
⋮	⋮	⋮
93	**9,351**	**5,360**
⋮	⋮	⋮
425	942	661

Trip distribution matrix

j=93

P \ A	1	2	3	.	.	.	93	.	.	.	425	
1	215	306	421	.	.	.	128	.	.	.	13	
2	259	198	235	.	.	.	560	.	.	.	22	
3	362	268	210	.	.	.	376	.	.	.	69	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
i=93 **93**	163	754	196	.	.	.	412	.	.	.	63	$\Sigma T_{93j}=$ **9,351**
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
425	16	39	53	.	.	.	12	.	.	.	321	
						$\Sigma T_{i93}=$	**5,360**					

Figure 3. Primary roadway network for Hermosillo, Sonora.

Figure 4. Loaded network for Hermosillo, Sonora.

KEY WORDS
Mexico
Emissions inventory
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Motor vehicles
Transportation modeling