emission
factors

fuel
intake

vehicle
usage

maintenance

Emissions

vehicle
type

road
network

Four Simple Equations for Vehicular Emissions Inventory

Sarath Guttikunda

URBAN emissions .info

(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

This report was conceptualized, drafted, and designed by the members of UEinfo.

All the working papers and more are accessible @ www.urbanemissions.info/publications

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Four Simple Equations for Vehicular Emissions Inventory

Emission inventories are used as inputs to air quality models, to study the dispersion of pollutants, in conjunction with local meteorology, topography, and composition of pollutants.

Among many features that a good emissions inventory depends on, one is better understanding of the sources and their strengths. Sources of air pollution are many. In an urban environment, most common are fuel combustion and non-combustion
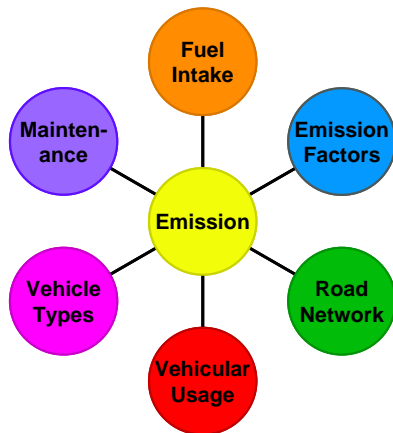
(volatile) sources from industries; vehicular activity – direct vehicular exhaust and indirect fugitive dust from roads; combustion of conventional (coal and kerosene) and non-conventional (wood and cow dung) fuels in the domestic sector; wind blown dust in the dry areas; construction activities; seasonal forest fires and dust storms.

Because of the complexities involved in developing emission inventories and the implications of uncertainties on dispersion model performance and assessments, it is important to evaluate the accuracy and degree of representation of any inventory. However, it is also important that some level of understanding of sources and their strengths is established.

This report will focus on ways to develop transport emissions inventory.

Transport, Emissions, and Information

Owing to growing economy and demand for mobility, vehicle ownership is rising in the developing countries; it is expected to grow manifold in coming years. There will be a few million more cars and motorcycles fighting for the limited space on limited roads.

A number of studies, in developed and developing countries, apportioning the sources of air pollution put the transport sector atop – both from direct exhaust and indirect road dust. Increasing number of vehicles on the road mean emissions increase, air quality will only get worse; fuel use goes up, and instead of moving ahead, people will actually grind to a stop due to congestion, unless a series of actions are in place to not only control the traffic, but also improve the technology to control emissions.

Local, national, and international agencies are working on their respective sustainable transport strategies. For any decision to stand trial, it is important that it is based on some level of information and most of the developing country cities, lack capacity to build an information baseline. A variety of models are available in the market, with varying level of complexities, which allow cities to develop their inventory. Most of these models are data intensive, only delaying the process of building a baseline.

This document outlines four ways of estimating emissions from vehicular activity using commonly available data with the local authorities. Note that this is not being proposed as an alternative to existing models, nor to undermine the integrity of the established models.

Each of the equations has their advantages and disadvantages in estimating the emissions. Depending on the available data, user can choose to utilize the best.

Equation 1 is probably the "**most common**" and the Equation 4 is the "**crudest and gross**" emissions estimator of all. Each of the equations and parameters included are explained below, along with possible uncertainties, and some averages for use.

Equation 1

Emissions (tons/year) = Number of Vehicles *
Vehicle km traveled (km/year) *
Emission factor (gm/km) *
10^{-6} (tons/gm)

Equation 2

Emissions (tons/year) = Fuel Consumption per mode (liters/year) *
Fuel Efficiency (km/liter) *
Emission factor (gm/km) *
10^{-6} (tons/gm)

Equation 3

Emissions (tons/year) = Passenger trips per mode (trips/year) /
Passengers per km *
Emission Factor (gm/km) *
10^{-6} (tons/gm)

Equation 4

Emissions (tons/year) = Concentration ($\mu g/m^3$) *
Vehicular Contribution (%) *
City Cross Sectional Area (m^2) *
Average Wind Speed (m/sec) *
60*60*24*365 (sec/year) *
10^{-12} (tons/μg)

Key is to establish a baseline with available data instead of waiting for data availability

Transport Emissions - Equation 1

> **Equation 1**
>
> Emissions (tons/year) = Number of Vehicles *
> Vehicle km traveled (km/year) *
> Emission factor (gm/km) *
> 10^{-6} (tons/gm)

Number of Vehicles	Vehicle kilometers Traveled	Emission Factors
2-Wheelers	Kilometers traveled by each mode	Particulates – 10, 2.5, 1.0
3-Wheelers	of the vehicular type	SO_2, NO_x, CO, CO_2
Passenger – cars, jeeps, SUVs		Hydrocarbons
Buses – small, medium, & large		By Fuel type
Trucks – small, medium, & large		Gasoline, Diesel, LPG, CNG

An example calculation below illustrates the use of the parameters in the equation.

ⓘ Inputs highlighted in Orange

Vehicular Mode	Number of Vehicles	Vehicle km Traveled	EF	Vehicular km Traveled	Emissions
		km/day	gm/km	km/year	tons/year
Cars - Petrol	400,000	40.0	0.10	12,400	496
Cars - Diesel	200,000	40.0	1.00	12,400	2,480
2Ws	1,000,000	30.0	0.10	9,300	930
3Ws	100,000	200.0	0.20	62,000	1,240
Taxi	10,000	200.0	1.00	62,000	620
Bus	10,000	200.0	1.50	62,000	930
Truck	5,000	100.0	2.00	31,000	310
	1,725,000			**251,100**	**7,006**

Assumes **310** days/year for all modes

Beyond the obvious (a.k.a emission factors), largest uncertainty in this equation lies with the "**Number of Vehicles**" for each category. *The categories listed in the table above are for example purposes only* and most common of an urban fleet.

It is assumed that most of the cities have access to the registered number of vehicles, but an ideal emissions inventory would include the in-use fleet, which could be different from what is registered. While estimating the in-use fleet, it is often hard to estimate how many of the registered are in-use in the city limits or outside and vice versa (vehicles registered outside and in-use in the city). First order approximation is to use the registered numbers; as and when further details arise and if there is a provision for full scale survey, adjust the calculations.

Vehicle kilometers traveled (VKT), is a survey data, most commonly evaluated in the units of "kilometers traveled per day". There is no single established method to obtain this data, but to survey. Possible approximations are

1. Public transport buses, operating on fixed or non-fixed routes, operate at an average speed is 30 km/hr for 8 hours a day, which accounts for 240 km per day.
2. Public transport buses operating on long distance routes, travel in and out of the city, which means distance traveled in the city limits is the distance between the depots to the city limits.
3. Passenger vehicles, on average operating at 30-40 km/hr for 1-2 hours on the road. A quick survey among the colleagues, work places, or on road for a day or two will provide an approximate VKT for this category.
4. Another possibility for passenger vehicles is the information from the vehicle registrations, the distance traveled over a year(s) will give an idea of average VKT's per day.
5. Commercial small trucks in the city, again operating at 30-40 km/hr for 8 hours a day, will provide an estimate.
6. Motorcycles (2Ws) are expected to travel at speeds higher than the other modes and for short time periods; unless you are in the cities like Bangkok, Hanoi, or HCMC, where 2 Ws are extensively used for commercial purposes and as small distance taxis.

Please note that these approximate numbers (theories) are for conditions observed in the developing countries, where the congestion levels are on the rise and doesn't allow the vehicles to operate at speeds observed in the developed countries.

"**Emission Factors**", by definition, represent the release of a pollutant due to combustion of fuel, with common units of **gm/veh-km**, under a variety of conditions, e.g., loaded and unloaded; idling; cold starts; and cruising. An emission factor is typically established based on testing a number of vehicles (with varying age and mix) under conditions listed above, to arrive at an average number. Table below presents an average set of emission factors for major vehicular categories for three fuel types (LDV = light duty commercial vehicles)

	Gasoline			Diesel				CNG			
	2Ws	3Ws	Cars	Cars	LDV	HDT	Bus	3Ws	Cars	LDV	Bus
PM_{10}	0.10	0.20	0.10	1.00	1.25	2.00	1.50	0.10	0.05	0.02	0.02
$PM_{2.5}$	0.05	0.08	0.03	0.60	0.50	1.00	0.80	0.05	0.02	0.01	0.01
SO_2	0.02	0.02	0.07	0.40	0.30	1.00	1.00	0.00	0.00	0.00	0.00
NO_x	0.15	0.10	0.20	1.25	2.00	10.0	10.0	0.35	0.20	3.50	2.50
CO	2.50	8.00	5.00	2.00	2.50	3.50	3.50	3.50	1.00	3.50	3.50
CO_2	40	80	200	250	500	850	850	70	100	450	450
HC	1.50	5.00	1.00	0.40	0.20	1.00	1.00	0.15	0.02	0.10	0.10
Average emission factors for various categories; Authors assumptions based on a variety of sources USE WITH DISCRETION											

Not all the cities in the developing world are equipped with testing facilities, which cost millions of dollars for establishment, operation, and maintenance. ***Where available, a considerable number of tests are being performed to establish these emission factors and where not available, cities are expected to make a close fit based on the mix of the vehicles and technology in use***.

For further research, emission databases include:
1. United States Environmental Protection Agency's AP-42 Handbook
   @ http://www.epa.gov/ttn/chief/ap42/
2. MOVES (Motor Vehicle Emission Simulator)
   @ http://www.epa.gov/otaq/ngm.htm
3. Emission Factor Database by National Atmospheric Emissions Inventory of UK
   @ http://www.naei.org.uk/emissions/index.php
4. Air Pollutant Inventory Program of SEI
   @ http://www.sei.se/gapforum/tools.php
5. Emission Factor Database by Central Pollution Control Board of India
   @ http://cpcb.nic.in/Source_Apportionment_Studies.php
6. Emission Factor Database by DIESEL Program of PCD Thailand & the World Bank
   @ http://www.pcd.go.th/info_serv/en_air_diesel.html
7. Harmonizing Emissions Analysis Tool by ICLEI
   @ http://heat.iclei.org
8. COPERT by European Environmental Agency
   @ http://lat.eng.auth.gr/copert/
9. IPCC Guidelines for GHG Inventory
   @ http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
10. GAINS of IIASA
    @ http://www.iiasa.ac.at/rains/gains.html
11. TREMOVE for European Countries
    @ http://www.tremove.org/index.htm
12. EMEP Corinair Emissions Inventory Guidebook
    @ http://reports.eea.europa.eu/EMEPCORINAIR3/en/page011.html
13. Transport Emissions Analysis for Hanoi by WRI/EMBARQ
    @ http://embarq.wri.org/en/ProjectCitiesDetail.aspx?id=8

Access to local fleet specific emissions factors for inventory development is ideal.

A frequently asked question is the applicability of the borrowed or average emission factors. Emissions factors not only depend on the engine type, which could be common for many countries, but also local fuel quality, maintenance programs, road conditions, driving cycles, and driver's behavior. This only increases the uncertainty of these factors established in a laboratory setting, where reality is assumed and simulated.

Make an average based on where tests are done vs. the technology in use, make appropriate corrections using the examples listed above (add deterioration factors, if necessary), and when the local factors are established, re-check the analysis.

Key is to establish a baseline with available data instead of waiting for data availability

Summary of Euro Standards (http://en.wikipedia.org/wiki/European_emission_standards)

Pass. Cars

Diesel	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1989	2.72			0.97	0.14	gm/km
Euro 2 IDI	1993	1.00			0.70	0.08	gm/km
Euro 2 DI	1993	1.00			0.90	0.10	gm/km
Euro 3	1997	0.64		0.50	0.56	0.05	gm/km
Euro 4	2003	0.50		0.25	0.30	0.025	gm/km
Euro 5	2009	0.50		0.18	0.23	0.005	gm/km
Euro 6	2014	0.50		0.08	0.17	0.005	gm/km

Gasoline	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1989	2.72			0.97		gm/km
Euro 2	1993	2.20			0.50		gm/km
Euro 3	1997	2.30	0.20	0.15			gm/km
Euro 4	2003	1.00	0.10	0.08			gm/km
Euro 5	2009	1.00	0.10	0.06		0.005	gm/km
Euro 6	2014	1.00	0.10	0.06		0.005	gm/km

Euro Standards for Passenger Cars

LCV < 1.3 tons

Diesel	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1994	2.72			0.97	0.14	gm/km
Euro 2 IDI	1998	1.00			0.70	0.08	gm/km
Euro 2 DI	1998	1.00			0.90	0.10	gm/km
Euro 3	2000	0.64		0.50	0.56	0.05	gm/km
Euro 4	2005	0.50		0.25	0.30	0.025	gm/km
Euro 5	2009	0.50		0.18	0.23	0.025	gm/km
Euro 6	2014	0.50		0.08	0.17	0.025	gm/km

Gasoline	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1994	2.72			0.97		gm/km
Euro 2	1998	2.20			0.50		gm/km
Euro 3	2000	2.30	0.20	0.15			gm/km
Euro 4	2005	1.00	0.10	0.08			gm/km
Euro 5	2009	1.00	0.10	0.06		0.005	gm/km
Euro 6	2014	1.00	0.10	0.06		0.005	gm/km

Euro Standards for Light Commercial Vehicles < 1.3 tons

LCV < 1.7 tons

Diesel	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1994	5.17			1.40	0.19	gm/km
Euro 2 IDI	1998	1.25			1.00	0.12	gm/km
Euro 2 DI	1998	1.25			1.00	0.12	gm/km
Euro 3	2001	0.80		0.65	0.72	0.07	gm/km
Euro 4	2006	0.63		0.33	0.39	0.040	gm/km
Euro 5	2010	0.63		0.25	0.295	0.005	gm/km
Euro 6	2015	0.63		0.105	0.195	0.005	gm/km

Gasoline	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1994	5.17			1.40		gm/km
Euro 2	1998	4.00			0.65		gm/km
Euro 3	2001	4.17	0.25	0.18			gm/km
Euro 4	2006	1.81	0.13	0.10			gm/km
Euro 5	2010	1.81	0.13	0.075		0.005	gm/km
Euro 6	2015	1.81	0.13	0.075		0.005	gm/km

Euro Standards for Light Commercial Vehicles 1.3 to 1.7 tons

www.sim-air.org

Diesel	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1994	6.90			4.90	0.25	gm/km
Euro 2 IDI	1998	1.50			0.96	0.17	gm/km
Euro 2 DI	1998	1.50			0.96	0.20	gm/km
Euro 3	2001	0.95		0.78	0.86	0.10	gm/km
Euro 4	2006	0.95		0.39	0.46	0.06	gm/km
Euro 5	2010	0.74		0.28	0.35	0.005	gm/km
Euro 6	2015	0.74		0.125	0.215	0.005	gm/km

LCV < 3.5 tons

Gasoline	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1994	6.90			1.70		gm/km
Euro 2	1998	5.00			0.80		gm/km
Euro 3	2001	5.22	0.29	0.21			gm/km
Euro 4	2006	2.27	0.16	0.11			gm/km
Euro 5	2010	2.27	0.16	0.082		0.005	gm/km
Euro 6	2015	2.27	0.16	0.082		0.005	gm/km

LCV < 3.5 tons

Euro Standards for Light Commercial Vehicles 1.7 to 3.5 tons

Diesel	Date	CO	HC	NOx	HC+NOx	PM	
Euro 1	1992	4.50	1.10	8.00		0.61	gm/kWh
Euro 2	1996	4.00	1.10	7.00		0.25	gm/kWh
Euro 2	1998	4.00	1.10	7.00		0.15	gm/kWh
Euro 3	2000	2.10	0.66	5.00		0.10	gm/kWh
Euro 4	2005	1.50	0.46	3.50		0.02	gm/kWh
Euro 5	2008	1.50	0.46	2.00		0.02	gm/kWh

Truck & Bus

Euro Standards for Heavy Duty Trucks & Buses (Note Unit Change)

Summary of worldwide emission standards and fuel specifications are available
@ http://www.dieselnet.com/standards/
@ http://www.dieselnet.com/standards/fuels.html

Transport Emissions - Equation 2

Equation 2

$$\text{Emissions (tons/year)} = \text{Fuel Consumption per mode (liters/year)} *$$
$$\text{Fuel Efficiency (km/liter)} *$$
$$\text{Emission factor (gm/km)} *$$
$$10^{-6} \text{ (tons/gm)}$$

An example calculation below illustrates the use of the parameters in the equation.

ⓘ Inputs highlighted in Orange

Vehicular Mode	Fuel Consumption	Fuel Consumption per Mode	Fuel Efficiency	EF	Vehicular Distance Traveled	Emissions
	%	liters/year	km/lit	gm/km	km/year	tons/year
Cars	15	7,500,000	12.0	1.00	90,000,000	90
Motorcycle	0	0	0.0	0.00	0	0
Taxi	15	7,500,000	10.0	1.00	75,000,000	75
Bus	30	15,000,000	4.0	1.50	60,000,000	90
Truck	40	20,000,000	4.0	2.00	80,000,000	160
Walking	0	0	0.0	0.00	0	0
Bicycle	0	0	0.0	0.00	0	0
	100	50,000,000			305,000,000	415

→ Total fuel consumption

This method is useful when the information is available on "**fuel consumption**" for each of the modes in operation.

It is probably easy to get "**total fuel consumption**" either from the ministry of petroleum or ministry of energy or refineries, if any, or based on the fuel import and export statistics. Some level of approximation is required to break this number into per mode.

If the local authorities have an estimate by mode, it will be useful. If not, possible ways to do so are
1. Estimate the share of fuel pumped at the gas stations among cars, SUVs, 2Ws and 3Ws. A survey among at a representative set of stations and the amount of gas pumped will provide the user, some information to apportion the consumption by mode.
2. Estimates for fuel consumption from the bus and truck companies. Given the limited number of companies operating the buses and trucks, they should be able to provide consolidated numbers.

"**Fuel efficiency**", defined as "kilometers traveled per a liter of fuel", is a survey data and probably the easiest of the data to obtain either directly from the manufacturers or conducting a quick survey among the users from each mode of transport. For "**Emission Factors**", see the previous section.

Transport Emissions - Equation 3

Equation 3

Emissions (tons/year) = Passenger trips per mode (trips/year) /
Passengers per km *
Emission Factor (gm/km) *
10^{-6} (tons/gm)

An example calculation below illustrates the use of the parameters of the equation.

ⓘ Inputs highlighted in Orange

Vehicular Mode	Passenger trips	Passenger trips	Passengers per km	EF	Vehicular Distance Traveled	Emissions
	%	trips/day	pass/km	gm/km	km/day	tons/year
Cars	15	1,500,000	0.150	1.00	10,000,000	3,100
Motorcycle	20	2,000,000	0.105	0.10	19,047,619	590
Taxi	5	500,000	0.150	1.00	3,333,333	1,033
Bus	20	2,000,000	5.500	1.50	363,636	169
Walking	20	2,000,000	1.000	0.00	2,000,000	0
Bicycle	20	2,000,000	1.000	0.00	2,000,000	0
	100	10,000,000			36,744,589	4,893

Assumes **310** days/year for all modes

This method is useful when the surveys are conducted on "**passenger trips**" and "**Passengers per km**", instead of the number of vehicles and fuel consumption. The first two parameters in the equation, indirectly calculate the total vehicle kilometers traveled, followed by use of "**emission factors**". These parameters are again survey based.

Major drawback of this methodology is that it *DOES NOT account for trucks*, since most of this analysis is based on the passenger trips and their travel.

This method is specifically advantageous when calculating the changes in public transport or promoting of non-motorized transport on rest of the trip distribution.

For "**Emission Factors**", see the previous section.
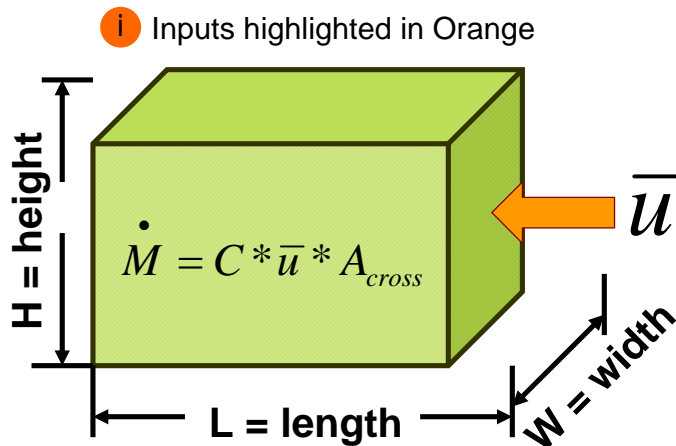
See an application tool
"**Smart Carbon Analysis for Road Transport (smart-CART)**"
@ www.urbanemissions.info/simair

Transport Emissions - Equation 4

Equation 4

Emissions (tons/year) = Concentration (µg/m³) *
Vehicular Contribution (%) *
City Cross Sectional Area (m²) *
Average Wind Speed (m/sec) *
60*60*24*365 (sec/year) *
10⁻¹² (tons/µg)

i Inputs highlighted in Orange

$$\dot{M} = C * \overline{u} * A_{cross}$$

$\overline{u}$

H = height

L = length

W = width

Parameters	Units	
Average Concentration	µg/m³	120
Vehicular Contribution	%	30%
Domain Width	m	**8000**
Domain Length	m	1
Domain Height	m	**100**
Average Wind Speed	m/sec	2.0
Averageing time period	days or season	180
Emissions	tons/average period	896

Parameters	Units	
Average Concentration	µg/m³	120
Vehicular Contribution	%	40%
Domain Width	m	**1**
Domain Length	m	10000
Domain Height	m	**200**
Average Wind Speed	m/sec	1.5
Averageing time period	days or season	180
Emissions	tons/average period	2239

Total emissions in the example = sum of two seasons = 896 + 2,239 = 3,135 tons/year

As illustrated in the equation and the figure above, this method is the "**crudest and gross**" of all four and can only provide with gross estimates for the whole domain. These calculations *heavily depend* on the air quality **monitoring data** (more the samples, better the average), meteorological conditions (**wind speeds and direction**) and results of source apportionment studies highlighting the **contribution of vehicular emissions** to ambient concentrations.

Length and **Width** are city dimensions, and **Height** is ground level height (preferred no more than 100-200m, where majority of the vehicular emissions mix and get advected).

Note that the **cross sectional area** used in the calculations depends on the wind direction. Most often, it is the predominant direction. For example, in the box diagram, cross sectional area is Width * Height

A variety of calculations are possible.
1. Can perform this exercise for annual averages, using an annual average wind speed and constant wind direction for all of 365 days
2. Or perform calculations for each half of the year, with varying directions and wind speeds, as shown in the example calculation above
3. Or perform calculations for each season or each month or each day, depending on the availability of the day.
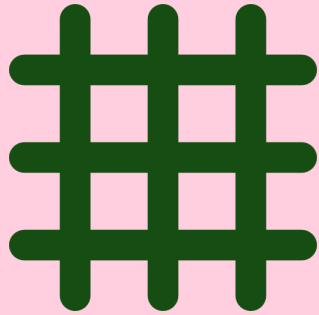
In Conclusion

In the developing countries, a frequent limitation is access to data and resources to collect the necessary data, limiting the institutional capacity to develop information baselines. While we wait for the perfect data to get collected and analyzed, it is necessary to conduct some analysis using the data available.

This exercise is meant to jump start the analytical process by highlighting types of data required and how an inventory could possibly be built.

Qualitative assessment of the four methods						
Method ratings **Equation**	Data availability with local authorities	Need for surveys	Ease of use	Replicability	Methodology examples	Level of uncertainty
1. Using number of vehicles	***	*	***	***	***	*
2. Using total fuel consumption	**	***	**	**	**	**
3. Using total passenger trips	**	***	**	**	***	**
4. Using ambient measurements	*	-	***	*	-	***
* easy/low/few ** medium *** difficult/high/many						

Readers can also access example toolkits (*VAPIS 1.01*) to play with these equations and possible complications @ www.sim-air.org

VAPIS - Vehicular Air Pollution Information System. An application for the city of Bangkok, Thailand (under DIESEL program) is available for download @ http://www.pcd.go.th/info_serv/en_air_diesel.html

www.urbanemissions.info