International Vehicle Emissions Model - IVE

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Introduction

- In most cities motor vehicle traffic is a major source of air pollution. The production of a reliable estimate of emissions for mobile sources is thus complex and most developing countries do not have the resources to properly develop emissions estimates
- Therefore, it is necessary to quantify mobile emission levels as accurately as possible with appropriate spatial and temporal resolution, for both local and global pollutants, and taking into consideration future trends in urbanization and vehicle technologies



Introduction

- As the economy of many countries improves, their vehicle fleets and the resulting pollutant emissions can be expected to increase.
- Developed nations have spent many millions of dollars to create methods for estimating the pollutant emissions from their on-road vehicle fleets.
- These methods are generally applicable only to the specific country for which they were created and modifications for use in other locations can be very time consuming and expensive.
- Developing countries usually do not have the funding to support the development of emission estimation methods.

IVE methodology

- A novel approach specifically designed for estimating vehicle emissions in international applications, so-called the *International Vehicle Emissions (IVE)* model, has been developed.
- The IVE model provides a much less expensive and time consuming alternative for developing countries to establish their on-road mobile emission inventory and, to assess the cost effectiveness of pollution management strategies.
- A user can use, or modify, activity data in the database. These include the percentage and types of engine technologies, engine size, acceleration-deceleration characteristics, average distance traveled per day and engine start-ups.

IVE Phase I: Traffic activity studies

Lima, Peru (December 2003);
Los Angeles, USA (2001);
Mexico City, Mexico (January 2004);
Santiago, Chile (December 2001, 2002);
Bogota, Colombia (January 2005)

Almaty, Kazakhstan (May 2003);
Nairobi, Kenya (March 2002);
Pune, India (March 2003);
Beijing, Shanghai, China (2004)

Vehicle Technology Distribution

A two-pronged effort –Parking lot surveys coupled with interviews at bus and trucking operations and, videotaping of traffic on streets.

IVE Phase I: driving composition

IVE Phase I: vehicle technology

Fuel type
Engine size
Model year
Manufacturer
Model
Mileage
A/C
Transmission
Catalytic
F/A system
Maintenance

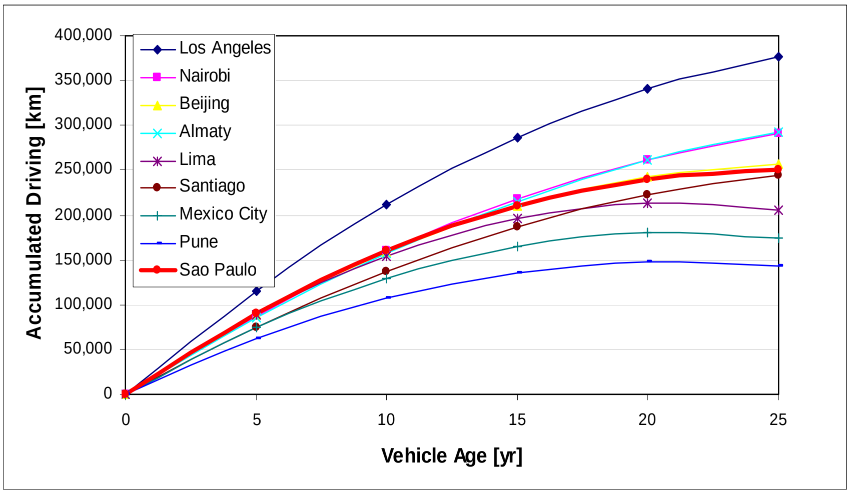
IVE Phase I: driving patterns

IVE Phase I: cold start emissions

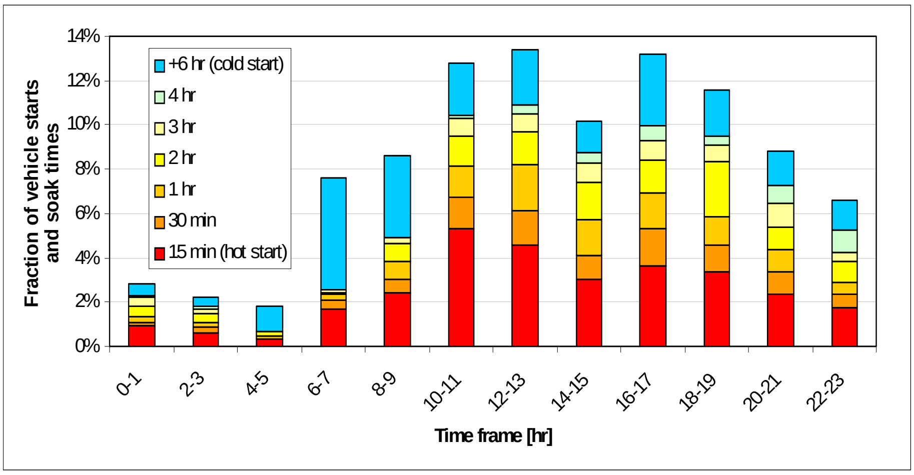
Results: dynamic fleet composition

City, Country	Pass Car	TAXI	2W	3W	BUS	TRUCK	N-M
Almaty Kazakhstan	**83%**	0%	0%	0%	12%	5%	1%
Bogotá Colombia	44%	32%	5%	0%	**15%**	5%	0%
Lima Peru	52%	25%	1%	0%	**17%**	5%	0%
Los Angeles USA	**95%**	0%	0%	0%	1%	4%	0%
Mexico City Mexico	74%	15%	2%	0%	**3%**	5%	0%
Nairobi Kenya	**88%**	1%	2%	0%	4%	5%	1%
Pune India	**12%**	0%	55%	13%	1%	1%	17%
Santiago Chile	79%	8%	1%	0%	**6%**	6%	0%
São Paulo Brazil	75%	5%	10%	0%	**5%**	5%	0%

Results: Accumulated driving



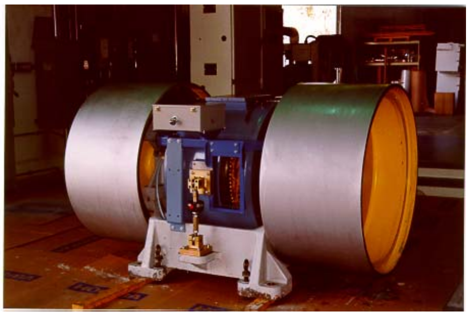
Results: cold starts in Sao Paulo



IVE Phase II: real-world emissions

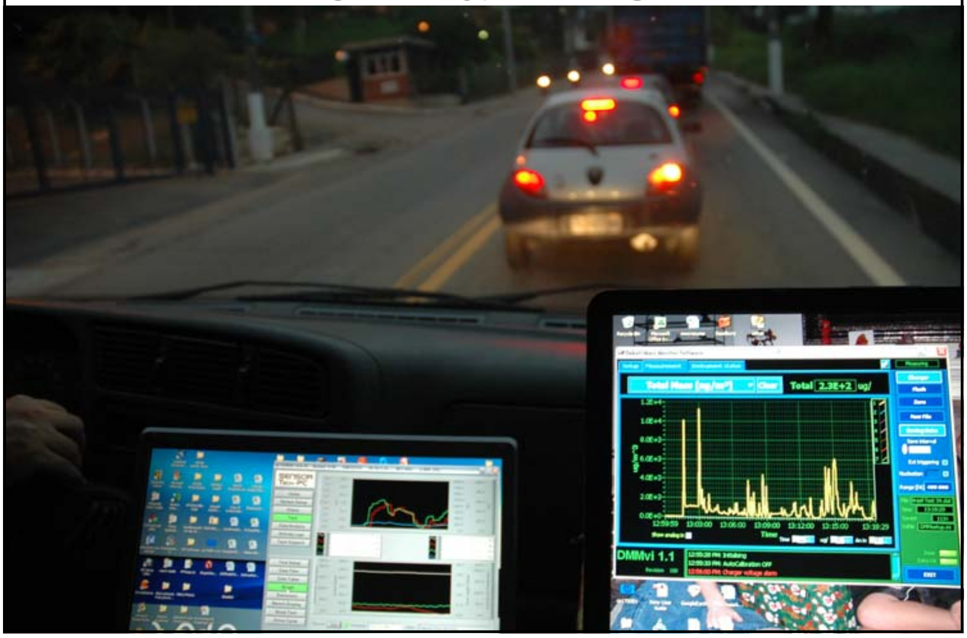
IVE Phase II: Real-world emissions

Chassis dynamometer testing



The most realistic standardized method to measure exhaust emissions from actual vehicles is by the use of an emission laboratory equipped with chassis dynamometer, following specified test procedures.
For testing of light duty vehicles, emission laboratories have been in use in Europe, Japan and the U.S. since the 1960´s, while for heavy duty vehicles the test resources have been very limited due to high costs for a laboratory and in addition lack of stringent emission regulations for heavy vehicles.

OBM & PEMS



On-Board Measurement, OBM

- Regardless the high level of detailed specification for tests carried out in emission laboratories, it will never full replicate in-use operating conditions
- A further alternative is to use a system for measurement of the emissions from vehicles when they are used under normal operating conditions on the road, so called on-board measurement (OBM)
- However, one method can not replace the other; rather they are good complements for a full verification of the actual emissions emitted
- In the future OBM will play an even more important role for measurement of the emissions from especially heavy duty vehicles
- Programs are under development both in Europe and in North America to validate different OBM systems

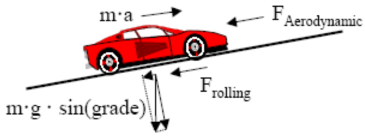
Portable Emission Measurement Systems, PEMS

- Portable emission measuring system (PEMS) are used on a vehicle to measure real-time emissions, collecting continuous exhaust emission rate data along with data on vehicle operating conditions and location
- They are designed for rapid installation in vehicles for in-use exhaust measurements
- There are commercial PEMS-gas units offered by Horiba, Sensors Inc., Clean Air Technologies and Galio Industrial Development Co.; as well as several research units that measure regulated gaseous emissions
- In general, these units have shown to be in good agreement with conventional measurement methods when tested under controlled laboratory conditions
- With the commercialization of PEMS units for gaseous regulated pollutants, there is a strong possibility that there will be a very large increase in real-world vehicle emissions data in the near future

Mass Particulate Matter PEMS

- While optical methods of measuring PM have been used in PEMS units, it has been a research objective to have continuous PM mass measurements
- Proper sampling of vehicle exhaust is a challenge for on-board PM PEMS measurement
- Research needs to continue on the development of PEMS-based PM measurement capability and, as a second priority, other HAPs
- There are some commercial units available by Dekati Ltd., Sensors Inc., TSI, Cambustion and Argonne National Laboratory, as well as research units still under development for particle size distribution, but successful PEMS-PM mass measurement had not been yet reported

Vehicle Specific Power (VSP)



$$VSP = \frac{Power}{Mass} = \frac{\frac{d}{dt}(E_{Kinetic} + E_{Potential}) + F_{Rolling} \cdot v + F_{Aerodynamic} \cdot v + F_{internal\ friction} \cdot v}{m} =$$

$$\approx v \cdot a \cdot (1+\varepsilon_i) + g \cdot grade \cdot v + g \cdot C_R \cdot v + \frac{1}{2}\rho_a C_D \frac{A}{m}(v+v_w)^2 \cdot v + C_{if} \cdot v$$

Based on:
José Luis Jiménez, PhD Thesis
Aerodyne Research and MIT Chemical Engineering

Vehicle Specific Power (VSP)

For typical U.S. light-duty vehicles and light-duty trucks (better estimates of the resistance coefficients should be used when available):

$$VSP = \frac{Power}{Mass} \approx 1.1 \cdot v \cdot a + 9.81 \cdot grade \cdot v + 0.213 \cdot v + 0.000305 \cdot (v+v_w)^2 \cdot v$$

with VSP in kW/Metric Ton, v (speed) and v_w (headwind into the vehicle) in m/s, a (acceleration) in m/s^2, grade defined as vertical rise/horizontal distance

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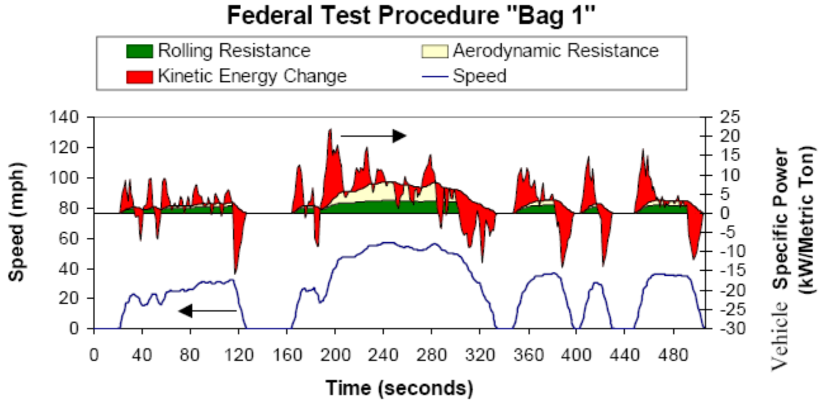
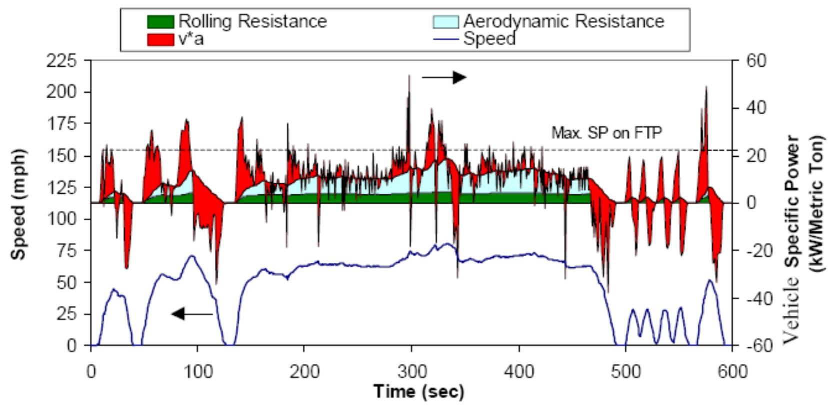
$$VSP = \frac{Power}{Mass} \approx 0.22 \cdot v \cdot a + 4.39 \cdot grade \cdot v + 0.0954 \cdot v + 0.0000272 \cdot (v+v_w)^2 \cdot v$$

(VSP in kW/Metric Ton, v and v_w in mph, a in mph/sec)

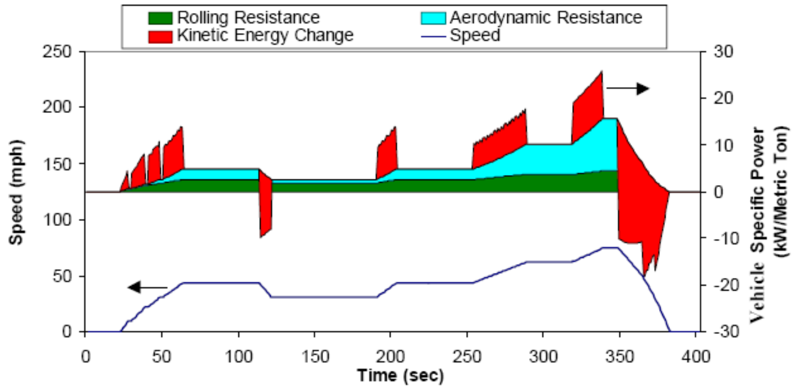
VSP in Emissions Certification Cycles



VSP in US06 Driving Cycle



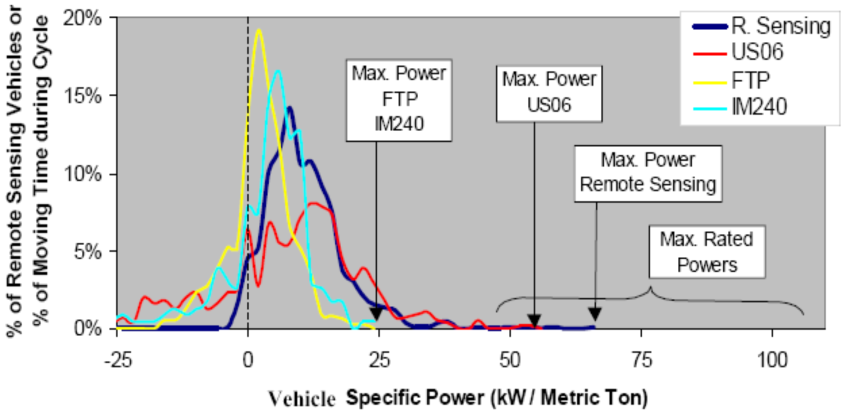
VSP in European ECE2 Cycle



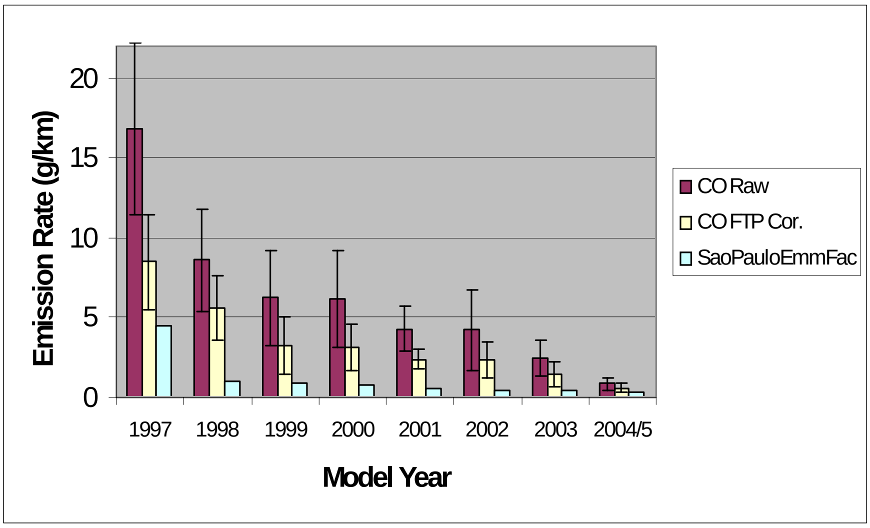
VSP Levels of Various Activities

Activity	VSP (kW/ Metric Ton):
• Max. Rated Powers	44 - 112
• 0 to 60 mph in 15 seconds	33
• 60 mph up a 4% grade	23
• Maximum in FTP/IM240	23
• Rem. Sensing site means	10 -15
• Average in IM240	8
• ASM 5015	6
• ASM 2525	5

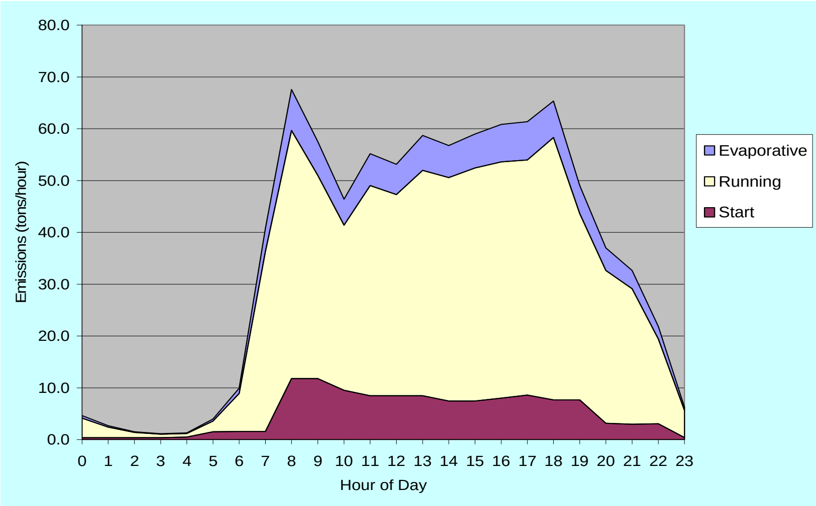
Use of VSP Distributions



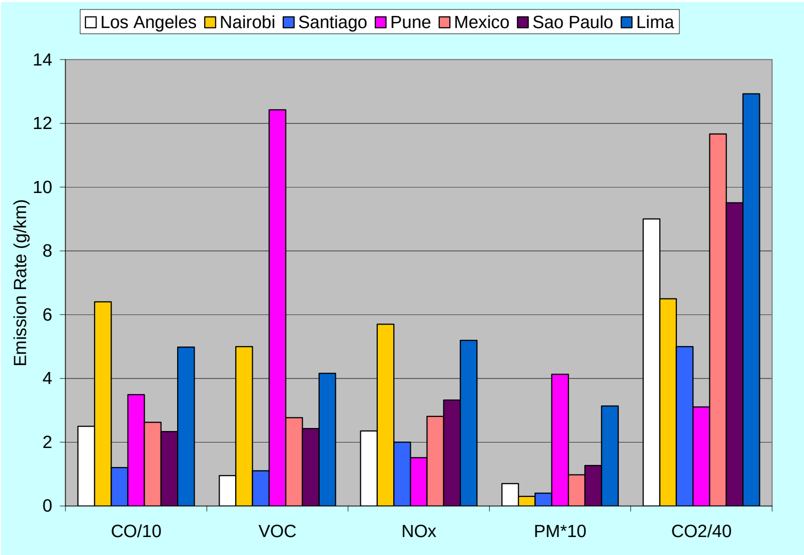
CO Emissions (preliminary)



Results: Temporal distribution (IVE)



Results: inter-city comparison



Conclusions

- Our goal has been to develop vehicle activity data as well as emission data for as many areas in the world as funding will allow. Each new input into the database results in the model having increased utility to a larger number of developing nations.
- At the same time, in each location where we gather information, we make an effort to train local individuals on the operation of the model and the methodology to collect the needed input data.
- Once an area has developed their on-road mobile source inventory, the IVE model can then be used to assess the emission benefits of various pollutant control strategies. Once the benefits are known, the strategies can be ranked by cost-effectiveness to insure the area realizes the greatest health/environmental benefit at the least cost.
- Further information available at: **http://www.issrc.org**