A detailed urban road traffic emissions inventory model using aerial photography and GPS surveys


InventAr, Estudos e Projectos Unip, Lda., Portugal.
Departamento de Ciências e Engenharia do Ambiente, Universidade Nova de Lisboa, Portugal.
Comissão de Coordenação e Desenvolvimento Regional de Lisboa e Vale do Tejo, Portugal.

vitorgois@mail.telepac.pt

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Overview

- Scope
- Case-study
- Problem Definition
- Principles
- Methodology
- Results and methodology validation
Scope

- EU law (Directive 96/62/CE) defines zones, where air quality must be assessed in detail, using:
  - Monitoring stations
  - Periodic campaigns (e.g. Passive sampling)
  - Modelling & Air emission inventories

- Air quality problems have been detected in Lisbon area in most recent years
  - Particulate matter (PM10): widespread
  - NO₂: confined to traffic hotspots
  - Ozone in summer

- Particulate levels (PM10) in Lisbon show the highest values in Europe as consequence of:
  - Importance of diesel vehicles
  - Specific meteorological conditions
  - Road re-suspension
  - Topographic conditions
  - Natural events (Saharan dust, forest fires)
Lisbon: Identification of “Zones” of Air Quality Management
Air Quality Problems in recent years
Lisbon area - PM10

PM10 (Daily and/or annual average)
only stations with efficiency >=85%

2005
- <LV
- [LV, LV+MT]
- >LV+MT
2004
- <LV
- [LV, LV+MT]
- >LV+MT
2003
- <LV
- [LV, LV+MT]
- >LV+MT
2002
- <LV
- [LV, LV+MT]
- >LV+MT
2001
- <LV
- [LV, LV+MT]
- >LV+MT

AML Norte
AML Sul
Setúbal

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Air Quality Problems in recent years
Lisbon area - NO$_2$
Urban Transportation as major contributor to Air Quality

• Road Transport is the dominant factor of PM in Lisbon
  
  – Weekly variation, with maximum values at weekdays especially on Fridays when traffic levels tend to be the highest
  
  – Chemical analysis of particles collected in samplers (55 per cent of particulate matter are originated, directly or indirectly)
  
  – Natural events (Saharan dust outbreaks and forest fires)
Air Quality Management Tools under development in Lisbon Region

• Air Quality Management is under responsibility of the Commission for Coordination and Regional Development of Lisbon and Tagus Valley (CCDR-LVT)

• Policies
  – Improvement of the monitoring survey system:
    • Stationary stations
    • Extensive monitoring: period campaigns using Passive sampling (Diffusion tubes and portable PM samplers)
  – Plans and Programs (June, 2005)
    • Identification of measures and policies, mainly traffic related
  – Modelling tools
    • Regional level (TAPM from CSIRO)
    • European level (Chimere, CAMx, REM-3 under CAFE program)
Definition of the Inventory model

• The Air Emission Inventory Model has to consider that:
  – Urban road transport MUST be the major component
  – Air quality problems are very local
  – A high level of spatial detail is necessary
    • Suitable for the scale used in modelling
    • Considering the scale at which policies and measures are defined
  – Affordable costs and low investment
    • Relying in a small team
    • Using available data as much as possible
    • Unfeasible to extend the existing traffic monitoring system

• Main objectives were to gain knowledge:
  – How many vehicles are moving at a given place and time
  – What type of vehicles exist (in movement)
  – How fast are vehicles moving (time of travel)
  – How are they moving (topography)
Methodology: General Structure

Aerial Photography

GPS(i) (km/h)

Path Survey(i) (km/h)

Commuters (k,f) (vehic/day)

Fuel Sales (f) (ton)

Speed(i) (km/h)

Car Counting(i) (number of vehicles)

Car Density(i) (vehicles/km)

Length(i) (km)

TMH(i) (vehicles/h)

TMA(i,f) (vehicles/year)

Gertrude(i) (traffic data)

Temporal Correction Factor(i)

Fuel Consumption (f) (ton)

Vkm(i,k,f) vehic/km

FC Factor (i,k,f) (g/km)

EF(i,k,p) (g/km)

Emissions (i,p) (kg/road link)

Road Network GIS

i - road link
k - vehicle class
f - fuel type
p - pollutant

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Definition of the Urban Structure in the area under study

- Definition of main roads and neighbourhoods should be done prior to data collection considering
  - Major road boundaries;
  - Road structure (density, width, intersections nb, slope)
  - Economic Activity
    - Commerce - frequent stoping/parking 2nd line
    - Institutional
    - Residential
  - Distance to city centre
Identification of moving vehicles

Source: Lisbon Municipality
Density of moving vehicles

- 80,000 vehicles identified
  - 15% total licenses (Insurance data) in the area
Speed:  
Method 1 - Predefined paths

- **Path definition**
  - Pre-defined objective points
  - 3 random paths at 3 different periods
    - (Morning, noon, evening)

- **Advantages**
  - No special equipment needed
  - Possible to use in all conditions
  - Suitable for areas with low car density

- **Problems**
  - Low detail
  - Restricted knowledge of speed variations
Speed: Method 1

1 - Largo do Rato
2 - EPAL
3 - Cemitério dos Prazeres
4 - Cruzamento de Alcântara
5 - Palácio das Necessidades
6 - Basílica da Estrela
Speed: Method 2 - GPS

- GPS in vehicle
- Rules for test driver
  - Keep with main flow
  - but copy driver behaviour -> objective oriented travel
    - E.g. Service Stations, Museums
- Data acquisition problems in narrow roads with tall buildings
Speed Histograms
Urban and Sub-urban areas

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Main roads</th>
<th>Secondary roads</th>
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</thead>
<tbody>
<tr>
<td>Cascais</td>
<td>39.4</td>
<td>28.2</td>
</tr>
<tr>
<td>Oeiras</td>
<td>49.2</td>
<td>28.3</td>
</tr>
<tr>
<td>Lisboa</td>
<td>25.1</td>
<td>28.1</td>
</tr>
<tr>
<td>Amadora</td>
<td>48.6</td>
<td>24.4</td>
</tr>
<tr>
<td>Odivelas</td>
<td>33.9</td>
<td>27.5</td>
</tr>
<tr>
<td>Loures</td>
<td>52.7</td>
<td>39.8</td>
</tr>
</tbody>
</table>

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Emission Factors

• Base - > EMEP/CORINAIR (EEA, 2002)
  – Based on extensive monitoring and database
  – Variables
    • Vehicle type, age, fuel, technology, engine size
    • Vehicle speed per link
    • Road gradient
    • Vehicle wear
    • Non-exhaust emissions
Characterization of the Fleet (Moving Vehicles)

- Methodology (Torres et al, 2006)
  - Survey/questionnaire in
    - Traffic lights
    - Parking
  - Questions
    - Age (license date)
    - Vehicle type: PC, LDV, HDV, Bus, 2w, mopeds
    - Fuel type: gasoline, diesel, LPG, Natural Gas
    - Engine size (c.c.)
    - Mileage (km)
    - Mobile Air Conditioner
- 17 800 results (5.6% vehicles registered in insurance companies)
Fleet: Results
Emission Factors for a normalized vehicle

\[ y = 0.0000000041991x^6 - 0.00000172276x^5 + 0.0002769847078x^4 - 0.0220572694394x^3 + 0.9163300293065x^2 - 19.6391104069688x + 253.8422015941410 \]

\[ R^2 = 0.9912804495488 \]

\[ y = 0.00000000000189745x^6 - 0.000000000079325611x^5 + 0.00000013102685701x^4 - 0.00001087088226117x^3 + 0.00049295664148669x^2 - 0.01275310043676920x + 0.20095104605219900 \]

\[ R^2 = 0.99866235527923600 \]
Time Variation

- $t_{FAC}$ - Hourly to daily traffic volume
  - 11h-14 h -> Annual Daily Average
  - 10 representative GERTRUDE traffic monitoring stations
    - Working Days + Weekends
  - $TFac = \frac{TMDA}{TMDA_w} \times \frac{TMDA_w}{TMD_{11h-14h}}$
  - $TFac = 0.88 \times 16 = 14.6$
Top-down approach

Consumption = Sales + Import in commuters * FC * Length
Consumption = Sales + (Vehicle Inflow - Vehicle Outflow) * FC * Length
Results: NOx
Evaluation: traffic

- **GERTRUDE**
  
  (Gestion Electronique de Régulation en Temps Réel pour L’Urbanisme, les Déplacements et l’Environnement)
  
  - Lisbon Municipality
  - local groups: 10
  - 110 counters (2000)
  - Restricted to central/busy areas
  - Objective: Traffic Control

\[
y = 0.5068x + 3867.6 \\
R^2 = 0.3386
\]

\[
y = 1.3114x + 9989.5 \\
R^2 = 0.3386
\]
Model Validation
Comparison with air quality surveys

2001 and 2002 average (ug/m3)

\[ y = 0.6851x + 9.5829 \]

\[ R^2 = 0.6851 \]
Final Results: Air Quality Mapping
Conclusions

- Methodology is feasible
- Comparison to air quality surveys shows good possibilities
- Relatively inexpensive
  - Main costs are GPS survey and characterization of the fleet
- Appropriate for diverse media
  - Central urban areas and sub-urban areas
- Several potential uses beyond air emission inventories
Thank you