INFLUENCE OF ROAD GRADIENT ON EMISSION FACTORS

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The present study on the effect of road gradient on emission factors was started on request of the Environmental Agencies of the Autonomous Provinces of Bolzano and Trento (Northern Italy). This is a mountainous region which is crossed by some major transit routes crossing the Alps.

The research has been developed within the framework of the INEMAR emission inventory, which is adopted by many regions in Italy.

At the present state INEMAR implements the reduced version of the COPERT algorithm for traffic emissions. The correction factor for emission factors depending on road gradients is not calculated, although the database already contains most of the necessary parameters.

The aim is to check in what extents correction factors will affect the emission results for what traffic emissions along mountain roads.

An improved formulation implemented in the INEMAR inventory will be shared among the users of this tool, while scientific results and methodology will be made public.
Problem overview

• The problem of evaluating the emission factors as a function of the road gradient cannot be neglected in mountain areas and in high traffic roads, for example major transit routes across the Alps.

• Some calculation tests were performed applying correction factors for road gradient available in literature.

• If the average road gradient is larger than a value of about 2%, the emissions of ascending and descending vehicles do not balance each other, even if the traffic is the same in the two directions. That is, the smaller emissions in downhill direction do not balance the larger emission of the uphill direction.

• We wanted to look for a general continuous formulation to be implemented inside the INEMAR tool; therefore we need a robust, quite simplified, easy implementable and not CPU-hungry algorithm.

• Already existing emission factors data and formulation have been used, namely ARTEMIS and COPERT, trying harmonize and at same time simplify the procedure.
Available data / starting point

1) COPERT (CComputer Programme to calculate Emissions from Road) formulation

2) ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) database

Vehicle classification
   a) Heavy vehicles (HDV):
       • HGV = heavy goods vehicles:
           - RT = rigid trucks
           - TT = truck+trailer
           - AT = articulated trucks
       • BUSES
           - UB = urban buses
           - C = coaches
   b) Light vehicles (LDV):
       • PC = passenger cars
       • LCV = light commercial vehicles

The major issues are on HDV
HDV data classification

ARTEMIS
• 239 heavy vehicles classes
• 3 different loads: 0, 50 e 100%
• Major pollutants (CO, NOx, HC, PM, CO2) + fuel consumption + micropollutants
• 7 gradient classes: -6, -4, -2, 0, 2, 4 e 6%

COPERT 4:
• 114 heavy vehicles classes
• 3 different loads: 0, 50 e 100%
• 4 pollutants (CO, NOx, HC, PM) + fuel consumption (FC)
• 7 gradient curves: -6, -4, -2, 0, 2, 4 e 6%
• 16 different formulas

INEMAR:
• 46 heavy vehicles classes
• 3 different loads: 0, 50 e 100%
• 4 pollutants + fuel consumption
COPERT HDV formulation

- Formulas adopted in COPERT 4, one set of parameters for each gradient class
- For some kinds of pollutants and vehicles classes, the curves corresponding to different gradients intersect
- The problem for the correction factors is not negligible when considering INEMAR classes after the simplification from COPERT
We tried to develop a rational solution to overcome some problems and make it simpler the future implementation in the INEMAR emission inventory 4-steps procedure:

1. comparison between the classes used by COPERT and the ones adopted by INEMAR -> determination of a relationship

2. simplification: use of a single type of formula for all loads, vehicles and pollutants

3. interpolation of all emission curves with the new function on the basis of the ARTEMIS DB for flat roads

4. extension to non-flat roads: emission factors are given as a continuous function of speed and road gradient
1. Correspondence between COPERT 4 and INEMAR classifications

<table>
<thead>
<tr>
<th>INEMAR CLASS</th>
<th>description</th>
<th>COPERT 4 CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>code</td>
<td>description</td>
<td>type</td>
</tr>
<tr>
<td>91</td>
<td>Diesel 16-32t</td>
<td>Conventional Rigid Truck 14-20 t, 20-26 t, 26-28 t, 28-32 t, TT/AT 14-20 t, 20-28 t, 28-34 t</td>
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<td>Diesel 16-32t</td>
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</tr>
</tbody>
</table>

1 class COPERT -> 7 classes INEMAR

2. Choice of the interpolating function on flat roads

In order to homogenize the methodology a single type of interpolating function has been chosen for all vehicles classes, loads and pollutants.

\[ EF(s) = A \cdot \exp(-B \cdot s) + C + D \cdot \exp(E \cdot s) \]
This function reproduces well all COPERT curve types (both for those which decrease monotonically and those which have a minimum)
HDV emission factor – a re-implementation (4)

4. Extension to not-null gradient

\[
EF(s, g) = (A + A_1 g + A_2 g^2) \cdot \exp\left[-(B + B_1 g + B_2 g^2) \cdot s \right] + (C + C_1 g + C_2 g^2) + (D + D_1 g + D_2 g^2) \cdot \exp\left[(E + E_1 g + E_2 g^2) \cdot s \right]
\]

- \(g\) is the road gradient [%]
- \(s\) is the vehicle speed [km/h]
- \(EF\) is the emission factor [g/km]

- A, B, C, D and E are the coefficients obtained in the interpolation of the curve corresponding to a flat road
- a quadratic correction in \(g\) has been applied to the above coefficients
- for \(g=0\), the formula provides exactly the curve interpolated before for flat roads
- Interpolation of the curve \(EF(s, g)\) has been carried out on the basis of the experimental data of emission factors included in ARTEMIS database.
- 10 coefficients to be estimated for each vehicle class, load and pollutant: \(A_1, A_2, B_1, B_2, C_1, C_2, D_1, D_2, E_1, E_2\)
In many cases the interpolation in 2 variables works well ($R^2$ 0.80 – 0.99 in 95% of the cases)...
**Problems**

- In data interpolation in some (few) cases the function assumes negative values due to dispersion of experimental data.
- The function is not always monotonically increasing with $g$ as expected.
- We obtain some unrealistic result...

**Possible solutions**

- Two constraints are imposed during interpolation:
  \[
  \frac{\partial EF(s,g)}{\partial g} > 0 \\
  EF(s,g) > 0
  \]

- Maybe some subsets of the Artemis DB refer to different conditions and shouldn’t be used for this aim? To be checked...
Emission factors on non-flat roads (LDV)

The formulation for LDV on non-flat roads gives consistent results and has been taken “as is,” the ARTEMIS formulation was used:

- The correction does not depend on the vehicle speed
- The correction does not depend on the load (wouldn't make much sense)
- 10 different classes and 3 different road types are considered

<table>
<thead>
<tr>
<th></th>
<th>Motorways</th>
<th>Rural</th>
<th>Urban</th>
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</thead>
<tbody>
<tr>
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<td>Petrol Euro 0</td>
<td>Petrol Euro 0</td>
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<tr>
<td>2</td>
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<td>Petrol Euro 1</td>
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<tr>
<td>3</td>
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<td>Petrol Euro 2</td>
<td>Petrol Euro 2</td>
</tr>
<tr>
<td>4</td>
<td>Petrol Euro 3</td>
<td>Petrol Euro 3</td>
<td>Petrol Euro 3</td>
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<tr>
<td>5</td>
<td>Petrol Euro 4</td>
<td>Petrol Euro 4</td>
<td>Petrol Euro 4</td>
</tr>
<tr>
<td>6</td>
<td>Diesel Euro 0</td>
<td>Diesel Euro 0</td>
<td>Diesel Euro 0</td>
</tr>
<tr>
<td>7</td>
<td>Diesel Euro 1</td>
<td>Diesel Euro 1</td>
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<tr>
<td>8</td>
<td>Diesel Euro 2</td>
<td>Diesel Euro 2</td>
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<tr>
<td>9</td>
<td>Diesel Euro 3</td>
<td>Diesel Euro 3</td>
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</tr>
<tr>
<td>10</td>
<td>Diesel Euro 4</td>
<td>Diesel Euro 4</td>
<td>Diesel Euro 4</td>
</tr>
</tbody>
</table>

Correction factor as a function of road gradient
Application example

Municipality of Brennero (country border between Italy and Austria), crossed by two major transit routes - A22 highway (~26000 veh/day) - SS12 main street (~5000 veh/day)
Average road gradient: 3.5% in both cases

Secondary streets and diffuse traffic is negligible within the area of the municipality with respect of the main sources

Correction factors calculated take into account different speed of HDV and LDV in the uphill and downhill directions

<table>
<thead>
<tr>
<th>Vehicle speed [km/h]</th>
<th>Highway</th>
<th>Main street</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HDV</td>
<td>LDV</td>
</tr>
<tr>
<td>Uphill</td>
<td>74</td>
<td>105</td>
</tr>
<tr>
<td>Downhill</td>
<td>80</td>
<td>115</td>
</tr>
</tbody>
</table>

For NOx the correction factors calculated as shown above leads to +16% for the highway and +7% for the main street
Conclusions

• An easy to implement algorithm has been developed. It can be used to compute correction factors on already calculated traffic emissions or can be implemented in an emission inventory like INEMAR.

• Already existing emission factors data and formulation have been used.

• Some traffic emissions estimate are expected to grow with respect to flat road of the order of some %.

• Difference is visible for average road gradient > 2% and in mountainous areas crossed by major transit routes, otherwise correction does not make much sense.

• The work is still ongoing and some issues have to be looked at more closely.

• Final results will be available within a couple of months.
Bibliography

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  Mario Keller, Peter de Haan - INFRAS
Thank you for your attention