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Speed frequency distribution in air pollutants' emissions estimate from road traffic

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Abstract

The work discusses the aspects linked to the speed in the application of the CORINAIR methodology to urban areas. In particular, the introduction of a speed frequency distribution (in thirteen classes with range 10 km/h) by vehicle category is discussed. A study on sensitivity finalized to the analysis of the influence of speed on the emissions is presented. Many cases are examined in which, keeping the average speed constant, a different speed distribution is introduced. The estimates obtained through the simulations are compared with those obtained using a single average speed. The result is that a deeper knowledge of driving characteristics and speeds is essential to understand means of the estimates for those pollutants whose emission dependence on speed is strongly non-linear.

Keywords: Road traffic; Air pollutant emissions; Sensitivity analysis; Speed frequency distribution

1. Introduction

The air pollutants' emissions estimate from road traffic in Europe is carried out mainly using the methodology developed by the CORINAIR working group on emission factors for calculating 1990 emissions from road traffic [1]. In particular COPERT, Computer Programme to calculate Emissions from Road Traffic [2], has been widely used.

The CORINAIR methodology for calculating 1990 emissions from road traffic can be used, if opportunely integrated, for the estimate of the emissions in highly congested urban areas or over single road segments [3]. In these applications, particularly for gasoline vehicles, it is better to obtain a more detailed knowledge of the speed frequency distribution. In the following the CORINAIR methodology is generalized to take into account the speed frequency distribution, a sensitivity study is performed and a set of simulation runs are executed using the SETS computer program [5].

2. Methodology

The CORINAIR methodology can be modified to take into account a speed frequency distribution as follows:

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$$E_{ijl} = h_{jl} v_{jl} [1 + \beta_{jl}(Q_{ijl} - 1)] \left[\sum_{k=1.13} d_{jkl} F_{ijkl}^{\text{hot}} \right] \quad (1)$$

where i is the pollutant, j is the vehicle category, l is the fuel type (gasoline, diesel, LPG), k is the speed class (with an amplitude of 10 km/h, from 0–10 up to 120–130), E_{ijl} is the hot and cold emissions (g) of pollutant i of vehicle category j and fuel l, h_{jl} is the number of vehicles of category j and fuel l, v_{jl} is the average annual mileage driven by each vehicle of category j and fuel l, β_{jl} is the fraction of mileage driven with cold engines by each vehicle of category j and fuel l, Q_{ijl} is the ratio of emissions of cold to hot emissions of pollutant i of vehicle category j and fuel l, d_{jkl} is the share of annual mileage driven with speed class k by vehicle category j and fuel l, F_{ijkl}^{out} is the hot emission factor [g/km] of pollutant i of vehicle category j and fuel l with speed class k.

For CO, NOx, and VOC Eq. (1) can be generally put in the following form:

$$E_{ijl} = h_{jl} v_{jl} [1 + \beta_{jl}(Q_{ijl} - 1)] \left[\sum_{k=1,n} d_{jkl} c_1 V_k - c_2 + \sum_{k=n+1.13} d_{jkl}(c_3 + c_4 V_k + c_5 V_k^2) \right] \quad (2)$$

where c_i are constant and V_k is the central value of speed interval. For NO_x, $n = 0$, and Eq. (2) the only relevant contribution is the quadratic one.

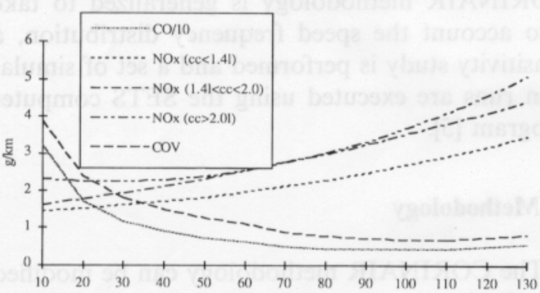

Fig. 1. Gasoline vehicles < 2.5 t ECE 15-04 emissions factors.

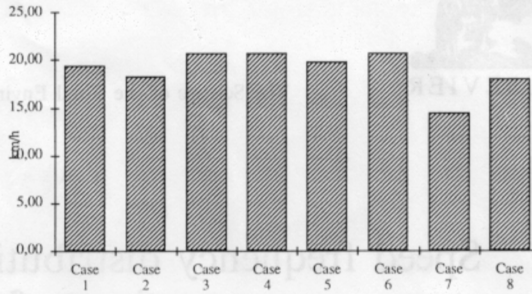

Fig. 2. Average speed in congested traffic for the different simulations.

3. Sensitivity analysis

In a previous work has been studied how uncertainty, or the error related to the evaluation of every single parameter of CORINAIR methodology, affects the evaporative emission estimate [3]. In the following we conduce a sensitivity study of exhaust emissions from Eq. (2) in function of the share of annual mileage driven with speed class k (d_{jkl}).

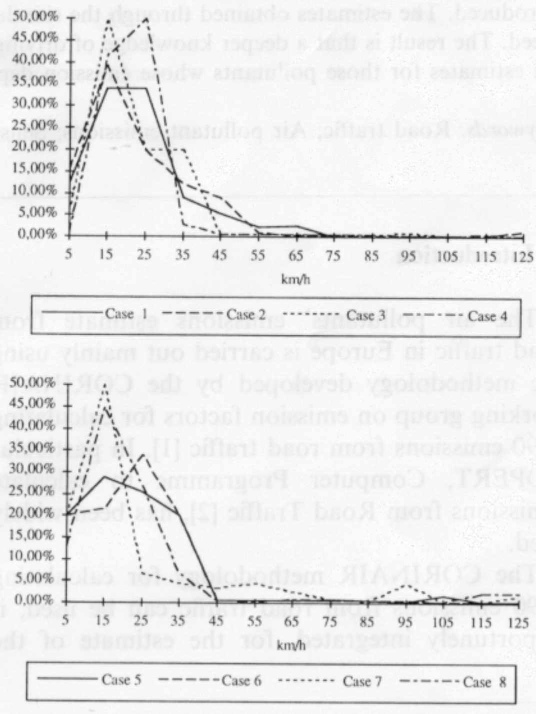

Fig. 3. Mileage distribution by speed (closed loop gasoline cars).

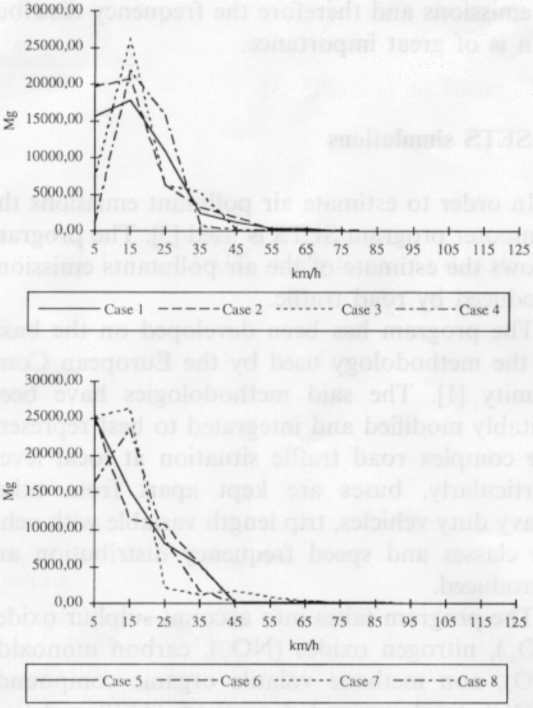

Fig. 4. CO emissions by speed classes.

We can rewrite Eq. (2) as:

$$E = E(d_{jkl}) \tag{3}$$

and consider as constant all the other parameters of the equation.

The speed in Eq. (3) is considered further on as the result of experimental measurements and it is assumed that it is casually distributed following normal distribution. Moreover we assume that the parameters d_{jkl} do not correlate with other parameters that appear in Eq. (2).

Another important assumption is that function E is linear or quasilinear (that is, it doesn't differ very much from a linear function for all possible values of d_{jkl}). In this case it is possible to demonstrate that the root-mean-square of E is:

$$s_E = \sum_k (\partial E/\partial d_{jkl})^2 s_{djkl} \tag{4}$$

and going from root-mean-square to relative error:

$$\Delta E_{ijl}/E_{ijl} = \sum_k c_{djkl}(\Delta d_{jkl}/d_{jkl}) \tag{5}$$

where:

$$c_{djkl} = d_{jkl}/E_{ijl}(\partial E_{ijl}/\partial d_{jkl}) \tag{6}$$

Eq. (5) can be used for two complementary aims: to evaluate how an error on different parameters affects emissions estimation and so to evaluate the uncertainty of estimation itself.

c_{djkl} coefficient could be interpreted as the dependence of relative emission variation $\Delta E/E$ on relative variation of parameters $\Delta d_{jkl}/d_{jkl}$.

From Eqs. (6) and (2) we obtain:

$$c_{djkl} = E_{ijkl}/E_{ijl} \tag{7}$$

It results from Eqs. (5) and (7) that the variation on emissions depends on the variation of the share of annual mileage driven with speed class k weighted by the absolute value of the emissions themselves in the single speed class.

Fig. 1 reports, as an example, the emission factors trends for gasoline vehicles <2.5 t ECE

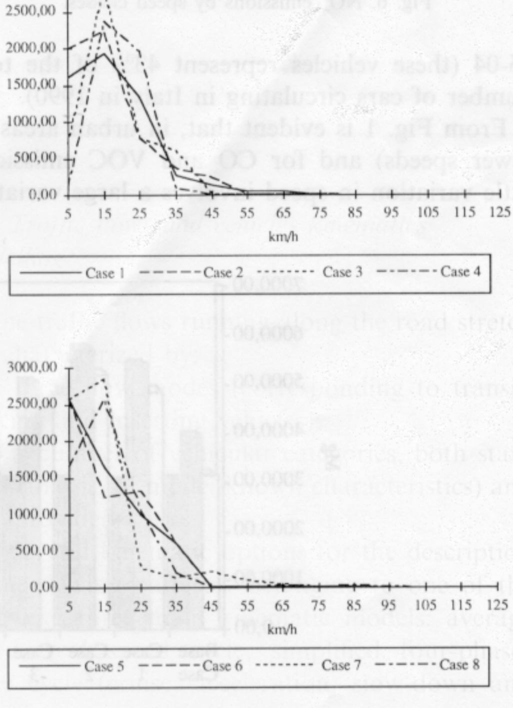

Fig. 5. VOC emissions by speed classes.

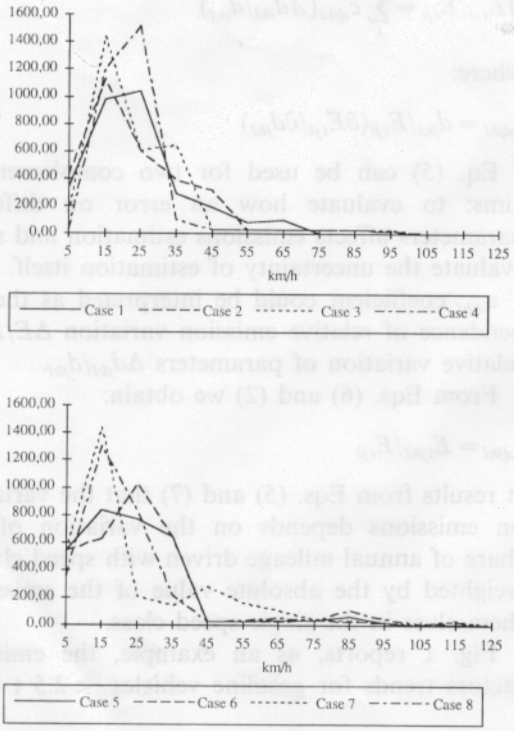

Fig. 6. NO_x emissions by speed classes.

15-04 (these vehicles represent 43% of the total number of cars circulating in Italy in 1990).

From Fig. 1 is evident that, in urban areas (at lower speeds) and for CO and VOC emissions, little variation in speed involves a large variation in emissions and therefore the frequency distribution is of great importance.

4. SETS simulations

In order to estimate air pollutant emissions the computer program SETS is used [5]. The program allows the estimate of the air pollutants emissions produced by road traffic.

The program has been developed on the basis of the methodology used by the European Community [1]. The said methodologies have been suitably modified and integrated to best represent the complex road traffic situation at local level. Particularly, buses are kept apart from other heavy duty vehicles, trip length variable with vehicle classes and speed frequency distribution are introduced.

The program takes into account sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), non methane volatile organic compounds (VOC), total suspended particles (TSP) and lead (Pb) and provides for the subdivision in speed classes with an amplitude of 10 km/h, starting from class 0–10 up to class 120–130.

In the following the computer program SETS is used, taking into account only the automobiles and comparing the CO, VOC and NO_x emissions obtained using eight different speed frequency distributions (case $1 \div 8$) with those obtained us-

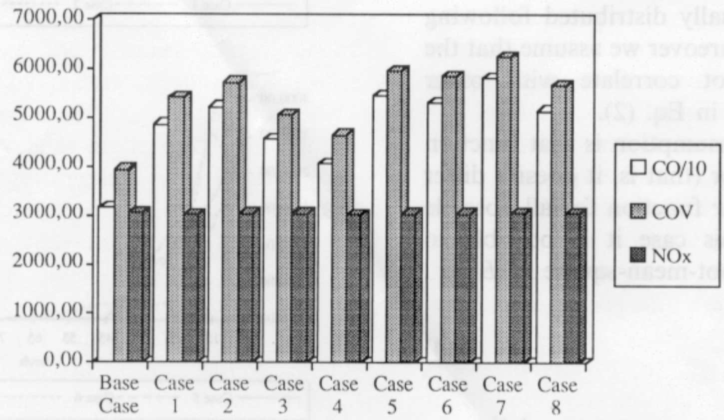

Fig. 7. Total emissions by case.

Table 1
Total emissions and average speed in congested traffic by case

Case	CO (mg)	VOC (mg)	NO_x (mg)	Speed(km/h)
Base	31696.55	3935.44	3042.96	22.84
1	48699.44	5414.01	3023.33	19.42
2	52316.22	5725.61	3032.72	18.32
3	45630.57	5072.02	3028.77	20.69
4	40496.04	4656.21	3024.90	20.75
5	54518.15	5950.93	3036.27	19.82
6	53204.04	5848.49	3028.12	20.64
7	58164.49	6257.79	3048.88	14.49
8	51585.30	5667.05	3050.80	18.00

ing a single average speed (base case). In the base case vehicle number, average annual mileages and speed average are relative to an application of SETS to Florence urban area. The eight alternative simulations are built setting as first constraint that the average speed is equal to 22.84 km/h (as in the base case). The next constraint is that the speed in the first four classes, relative to highly congested traffic, does not depend on vehicles category. The last constraint is on the maximum speed that has been set differently for the different vehicle classes.

The eight speed frequency distributions simulate different traffic conditions with the same global average speed but different average speed for highly congested traffic. The average speed in a situation of highly congested traffic, obtained as averages on the first four speed classes, are reported in Fig. 2. As an example, Fig. 3 reports the mileage frequency distribution as a function of speed for closed loop gasoline cars with cc > 2000. The results of simulations are reported in Figs. 4–7.

5. Conclusions

Results outlined in Fig. 7 show that the total emissions of CO for the base case are lower that in each alternative case. The maximum value (Table 1) is in case 7 (58 164 Mg) where we have the lower average speed in a situation of highly congested traffic (14.5 km/h). Furthermore, the total emissions for case 3 (45 631 Mg) are 17% lower than for case 6 (53 204 t) but the average speed is very similar (20.64 km/h for case 6 and 20.69 km/h for case 3). Relevant in this case is the different mileage frequency distribution as a function of speed (Fig. 4).

The same observation, but with lower differences between different cases, can be applied to VOC (Figs. 5 and 7).

NO_x emissions, on the contrary, are not depending on mileage frequency distribution as a function of speed (Figs. 6 and 7).

In conclusion a deeper knowledge of driving characteristics and speeds is essential to means of the estimates for those pollutants (CO and VOC) whose dependence of the emissions from speed is strongly not-linear.

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