FUNCTIONAL RELATIONSHIPS BETWEEN EMISSION BY CARS AND URBAN POLLUTANT CONCENTRATIONS: A SIMPLIFIED PHENOMENOLOGICAL APPROACH

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ABSTRACT

This work is aimed at providing a contribution toward the singling out of a functional relationship between the traffic flow in urban contexts and the physical dynamic of the pollutant diffusion.

The values of CO concentrations in selected sites of the urban layout are obtained by utilizing as input the number of vehicles predicted by the phenomenological model here introduced. This represents a quite different approach in the simulation of the pollutant dynamics in urban contexts. One of the main features of the proposed traffic model, is the capability of realistically reproducing the characteristic of the traffic flows.

The feasibility of the model to be applied in other urban situations is discussed in the paper along with the possible ways of validating it.

Keywords :transportation, pollutant emission, phenomenological approach

1. INTRODUCTION

Vehicular emissions flowing through urban canyons are mainly responsible of the rising deterioration of the air quality in the towns context. This does represent one of the most important problem that policy makers, technicians and stakeholders have to face with, in the aim of providing people with a comfortable and healthy environment. Researchers, all over the world, are presently engaged in the difficult challenge of better understanding the physical mechanisms governing the emission and the diffusion of pollutants released by cars and other transportation means in urban areas.

Recently, along with the classical approach that tries to establish an analytical relationship between pollutant emissions from mobile sources and the resulting concentrations, another category of analyses is more and more pursued. Starting from the assumption of the intrinsic difficulty of properly modelling such phenomena, this approach is aiming to establish a functional relationship between the cause (pollutant emissions from mobile sources) and effects (pollutant concentrations at the ground level).

In this paper, we introduce a phenomenological model able to calculate the number of running vehicles, once the pollutant ground level concentration of CO is known at some receptor sites. This makes possible the phenomenological assessment of the whole traffic-concentrations system of a given town, that can be further utilized for predicting the pollution episodes produced by different configurations of the running urban fleet.

2. TRAFFIC FLOW AND POLLUTANT CONCENTRATIONS

The current approach to the singling out of the functional relationship between pollutant concentration at urban scale and the main factors affecting air quality (Hag-Yeoul and Guldmann, 2001) is pursued on the basis of the solution of the equations governing the physical phenomena. But, as it is well known, the large amount of such factors, like emissions, meteorology, atmospheric chemistry, pollution cleaning and so on, makes it very difficult the establishing of viable analytical models.

Several works have been produced, for example, in the aim of modelling the relationships existing between pollutant turbulent dynamics and the traffic flow (Daganzo, 1995; Daganzo 1997; Daganzo et al. 1999). As matter of fact, despite the enormous literature produced on this field, the reliability of the proposed models seems to be definitively confined to the site and climatic situation for which they have been built-up.

Starting from this situation, in the present paper a quite different approach is introduced that, overlooking the aim of properly modelling the physical laws, mainly tries to take into account the phenomenological link between cause (the traffic flow) and the effect (the pollutant concentrations at the ground level).

The approach is essentially based on the reasonable hypothesis that an analytical relationship can be established between the number of running vehicle $N(\tau_i)$ and the average measured values of the ground-level concentration of a given pollutant $[C(\tau_i)]$. The time changing property of the model is embodied within the model by considering two subsequant observation times, that is the (i-1)-th and the i-th hour.

The definition of the present model starts with the assessment of a data-deduced traffic model referring to the situation of the running fleet and the measured pollutant concentrations.

The traffic model has been built-up on the basis of data referring to ground level pollutant concentration of the Italian town of Palermo, as measured by AMIA (Azienda Municipalizzata Igiene Ambientale). In particular we considered here data pertinent to the site of Piazza Castelnuovo, since in this site the main microclimatic variables (temperature, solar radiation, wind velocity and so on) are currently monitored. Figure 1 shows the position of the receptor site in the map of Palermo.

The measured data are referred to the two years (1997 and 2002) which seem to be the less affected by systematic error in the monitoring process. The data are averaged out a period of one hour.

Figure 1 Location of the receptor site on the map of Palermo (Google Earth©)

Three main groups of variables are supposed to affect ground concentration of pollutants, that is: parameters timeless influencing concentrations, like the urban layout; the microclimatic (local) conditions characterized by a changing behaviour; the demographic and social parameters, mainly affecting the daily working-day traffic demand, from where quantitative estimations of the time distribution of the number of running vehicles can be assessed.

In the following, some details concerning the data-deduced emission model will be provided: it is noticeable that, apart some statistical manipulations, the method fully relies on the COPERT (Ntziachristos, *et al.*, 2000) computer programme to calculate emissions from road transport, prepared by the European Environment Agency.

3. INTRODUCING A NEW POLLUTANT TRAFFIC EMITTING INDICATOR

The present model totally relies on a new synthetic indicator, the so-called yearly average vehicle, YAV, that represents the mean emitting properties of the running vehicular fleet in a given year at a given urban site (Calvino *et al.*, 2003).

In general, the specific emissions of a type of vehicle, the so-called emission factor, depends on engine capacity, on its age (that in turn encompasses the technological innovations introduced with time), on the fuel propelling the engine, on the mean velocity of the vehicle and on the mean length trip.

Consequently, the pollutant emissions of each emitting class i can be expressed by means of the following algorithm:

$$E_i = FE_i \cdot N_i \cdot \overline{p_i} \quad \text{(gr)} \tag{1}$$

where FE_i (gr/km) is the emission factor, N_i is the number of yearly running vehicles belonging to the class and p_i is the mean length of the yearly travel (km).

In turn, the global emissions of the whole vehicular fleet, composed by N_C different emitting classes, for each pollutant, is simply obtained as follows:

$$E_{TOT} = \sum_{i=1}^{Nc} E_i = \sum_{i=1}^{Nc} \frac{FE_i D_i}{to_i} \tag{2}$$

being D_i the satisfied transportation demand (Calvino *et al.*, 2001), accomplished with vehicles showing a mean occupation rate, to_i, and of a proper emission factor, FE_i. Clearly, the application of equation (2) can be strongly limited in the cases of a poor level of knowledge of the transportation demand for the each emitting class, D_i.

Referring to a specific modality of transport, m, it can be assumed that the mean travel length and the mean occupation rate is the same for all the vehicles belonging to the same modality of transport.

This approach leads to the singling out of a suitable parameter that represents the mean emission factor of a given modality of transport, instead that one of a specific class. This index is the "yearly average vehicle", YAV (Calvino *et al.*, 2002).

By adopting a common value for the mean travel length, the parameter YAV (gr/vehicle km) can be defined as follows:

$$YAV\Big|_y^m = \frac{\sum_{i=1}^{Nc} FE_i \cdot N_i\Big|_y^m}{N_{tot}\Big|_y^m} \tag{3}$$

This variable allies to each pollutant and should be computed at the yearly basis in order of properly taking into account the technical improvements of the running fleet.

4. THE PROPOSED PHENOMENOLOGICAL APPROACH

The building up of this novel traffic model is based on some hypotheses, concerning the observation of concentration data behaviour and its link with microclimatic variables (D'Orso *et al.*, 2007).

- The traffic demand is independent by a specific working day;
- the measured values of concentration in the same interval of time of different working days can assume different values because of a variation in the microclimatic conditions;

The first hypothesis implies that in the same time of different working day the pollutant emissions are constant, in this way providing an upper limit for the ground level concentrations. Of course, this does not mean that the measured values are equal but that they show a maximum or a minimum in the same interval of time.

- From four to five o'clock in the morning, due to the low level of concentration, it is likely to assume that can be reached an equilibrium configuration.

As that, the total mass emitted from the vehicles running from four to five o'clock a.m., $M_E(\tau_5)$, is given by (Nicolosi *et al.*, 2005):

$$M_E(\tau_5) = \frac{A C_{\mathrm{MAX}}(\tau_5)\, T(\tau_5) R}{m \cdot g} \tag{4}$$

where A is the area of the surface of the considered site, C_{MAX} is the hourly average value of concentration at the ground level corresponding to a windless condition, $T(\tau_5)$ is the ground level average temperature in the previously selected interval of time, R is the constant of ideal gases, m is the molecular mass of the pollutant and g is gravitational acceleration of Earth.

- With reference to a given year, it's possible to define the "Yearly Average Vehicle" (YAV) of an assigned modality of transport, that is the amount of pollutants emitted by an average vehicle that is assumed as representative of the whole running fleet of Palermo.
- It appears reasonable to assume that $C_{MAX}(\tau_i)$ is proportional to the global emission appeared in the i-th hour, reduced by an unknown scale factor f(X(i),Y(i),…) depending on the local microclimatic variables X(i),Y(i),…, with i=1,…,24, that is:

$$C_{MAX}(\tau_i) = N(\tau_i)(YAV) f(X(i),Y(i),..), \quad 0 \leq f(X(i),Y(i),..) \leq 1 \tag{5}$$

being $N(\tau_i)$ the number of running vehicles in the i-th hour.

Consequently, it is possible to write:

$$M_E(\tau_i) = N(\tau_i) YAV < p >, \tag{6}$$

where $< p >$ is the average route length.
In this way it is possible to obtain a linear equation for the parameter, that is:

$$N(\tau_5) = \frac{AC_{MAX}(\tau_5)\,T(\tau_5)R}{m \cdot g \cdot (YAV) < p >} \tag{7}$$

And, finally:

$$N(\tau_i) = \frac{C_{MAX}(\tau_i)}{C_{MAX}(\tau_5)} N(\tau_5) \tag{8}$$

A statistical analysis of the calculated $N(\tau_i)$ shows that $N(\tau_i)$ follows a Gaussian distribution. In this way we can obtain an estimation of the average per hour number of vehicles along with the pertinent standard deviation:

$$< N(\tau_x) >= A \pm \Delta A$$

5. DISCUSSIONS AND CONCLUSIONS

Unfortunately, it’s impossible at this stage a direct validation of the present model, mainly due to the incompleteness of the available data. The whole flowchart of the introduced traffic model, along with the validation section, is reported in the Figure 2.

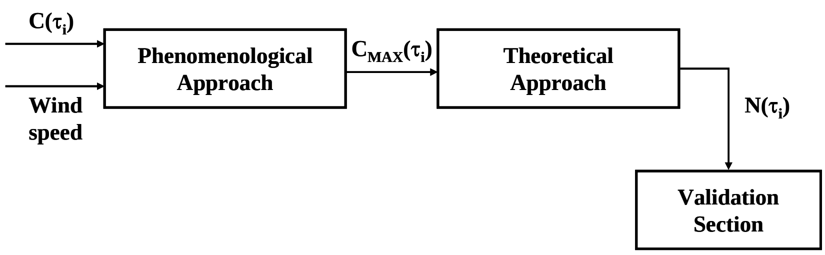

Figure 2 Flowchart of data-deduced traffic model

In conclusion, the main result of this work is the implementation of a traffic model able to functionally linking the measured values of CO concentration to the urban running fleet of vehicles.

The method, here developed, contains the novelty of deducing the average *per hour* number of vehicles on the basis of a few reasonable hypotheses that rely on phenomenological considerations.

A definitive judgement about the reliability of these hypotheses requires further investigations. Specifically, a direct validation by comparison with the actual number of vehicles flowing through the considered site is needed.

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