Paper from: *Development and Application of Computer Techniques to Environmental Studies*, CA Brebbia and P Zannetti (Editors).
ISBN 1-85312-909-7

A general model for predicting the environmental impact of urban transportation

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Abstract

In this paper a generalised model is described for the analysis of the pollutant substances released in the atmosphere by urban transportation means. It essentially requires data referring to the running transportation fleet, year by year, that are generally on disposal of the local administrators through official data-bases. Pollutant emissions are here taken into account by means of the algorithms provided by the COPERT methodology, that applies to many European countries.

The method, by means of a suitable statistical analysis of data concerning the running car fleet, allows also the definition of an useful indicator, that is the "yearly average vehicle", that can be assumed as representative of the average pollutant emissions of a given urban context. This indicator can be adopted for suitably ranking the environmental effects produced by different policy options concerning the transportation sector.

1 Introduction

The environmental quality in the urban contexts is rapidly decreasing, due to the human activities that heavily threaten air, water and soil. Among these activities, the transportation sector is responsible of the most relevant emissions of pollutant substances in the atmosphere.

Local administrations are world wide concerned with this problem and they are also generally engaged in the difficult task of mitigating the negative environmental effects induced by the human and freight mobility that, nevertheless, represents an essential factor of the social development.

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2 Relevant characteristics of a decision model

Obviously, the analysis of the amount of pollutant emissions produced by the urban transportation sector does require the availability of effective methods of inquiry, able to provide the comparison among alternative policy options. Moreover, an important feature of such methods should be the friendliness in their approach, for an easy application by local administrators. They, in fact, are generally interested in the ranking of the environmental effects produced by different policy options regarding the transportation sector: modal changes (from private to public vehicles, for example), technological improvements (introduction of a new end of pipe, for example) and energetic choices (adoption of gasoline, diesel or lgp engines) should be easily accounted for by means of this kind of models.

Table 1 summarises issues and features of urban transportation systems that should be taken into account by a generalised model of analysis.

Table 1: Main issues, features and parameters to be taken into account by a decision model of the urban transportation system.

Main issues	Main features	Main parameters	
Characteristics of the urban transportation	People mobility Freight mobility	Running fleet	Cars Bus Trucks Motorcycle
Environmental impact	Atmospheric pollution Noise pollution	Emissions	CO NO_x VOC PM L_{eq}
Decision model	Ranking options System management System design	Policy actions	Modal changes Technological improvements Fuel choices

To date, in Europe the most detailed study concerning the pollutant emissions of transportation means has been performed by the COPERT research group [1]. This study, by means of a split of the vehicles in suitable categories and by means of a further subdivision of these categories in a given number of legislation classes, essentially supplies the emission factors for a relevant number of pollutants.

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Emission factors *EF* provided by the COPERT method, for each pollutant and for each modality of transportation *m* (that is cars, buses, etc.), are characterised by the following analytical structure:

$$EF^{m}_{\lambda jk} = a^{m}_{\lambda jk} + b^{m}_{\lambda jk} v^{c^{m}_{\lambda jk}} + d^{m}_{\lambda jk} v^{2} \quad \text{(g/km)} \tag{1}$$

where index λ refers to the age of the vehicle, *j* to the fuel and *k* to the engine volume (piston displacement); moreover, *a*, *b* and *c* are parameters pertinent to each emitting category. Each emission factor $EF^{m}_{\lambda jk}$ will single out a vehicular emitting class that, for the sake of simplicity, can be only indicated by means of the subscript *i*.
Consequently, the emissions for an assigned pollutant of the *i-th* emitting class can be easily computed as follows:

$$E_i = EF_i \cdot N_i \cdot \bar{p}_i \quad \text{(g/year)} \tag{2}$$

where N_i is the number of vehicles yearly running in the urban context and belonging to the given class and p_i is the length of the mean yearly travel (km).
The configuration of the COPERT method seems to fully meet the requirements of a friendly user model, to be adopted even by non technicians, once data of the running fleet are known. Moreover, it enables a suitable management of data referring to the vehicular fleet.

In fact, the emission factors and the pollutant emissions computed by means of eqns (1) and (2) can be usefully employed for assessing a new synthetic indicator of the pollutants released by the urban transportation system.

Moreover, the frame of the COPERT methods allows the building up of a decision model based on the evaluation of the environmental pressure exerted by different options of the urban transportation system.
Both these issues will be shortly treated in the following sections.

3 Definition of an average emitting vehicle

Although the COPERT methodology is characterised by a simple structure, the parameters required are seldom in possession of local administrations. These in fact generally hold different data, only concerning the transportation demand (pkm) and the mean occupation rate (pass/vehicle) of vehicles.
As that, equation (2) can be usefully modified [2], by introducing the number of passengers, $pass_i$, belonging to the *i-th* emitting class. That is:

$$E_i = EF_i \cdot N_i \cdot \bar{p}_i \frac{pass_i}{pass_i} = EF_i \cdot \bar{p}_i \cdot pass_i \frac{N_i}{pass_i} = \frac{EF_i \cdot D_i}{to_i} \tag{3}$$

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where D_i (pkm) is the transportation demand and to_i (pass/vehicle) is the mean occupation rate of the average vehicle belonging to the i-*th* emitting class.
Finally, for each pollutant, the global emissions of the considered vehicular fleet, comprised of N_{EC} emitting classes, can be computed as follows:

$$E_{TOT} = \sum_{i=1}^{N_{EC}} E_i = \sum_{i=1}^{N_{EC}} \frac{EF_i \cdot D_i}{to_i} \tag{4}$$

But the application of eqn (4) is still limited by the generally poor level of knowledge of the transportation demand for each emitting class, D_i; on the contrary, the overall transportation demand satisfied by a whole modality of transportation D_m, (that is cars, buses, etc.) it's easier to be achieved. This further consideration calls for the definition of the mean emission factor of each modality of transport, EF^m, in order of enabling the computation of the pollutant emissions in the same form of eqn (4). That is:

$$E\Big|_y^m = \frac{EF^m \cdot D_m}{to_m}\Bigg|_y^m \tag{4'}$$

By referring to a given year y, the mean emission factor of a whole modality of transport can be defined as the "yearly average vehicle" (YAV) [3].
When referring to a specific modality of transport, m, it is reasonable the assumption that the mean travel length and the mean occupation rate are the same for all the vehicles belonging to each modality class. Consequently the total yearly emissions for a transport modality m and for a year y, will be given by:

$$E_{tot}\Big|_y^m = \sum_{i=1}^{N_{EC}} \bar{p}_i \cdot EF_i \cdot N_i\Big|_y^m = \bar{p} \cdot YAV \cdot N_{tot}\Big|_y^m \tag{5}$$

Furthermore, by assuming a constant value for the mean travel length, it's possible to define the parameter YAV:

$$YAV\Big|_y^m = \frac{\sum_{i=1}^{Nc} EF_i N_i\Big|_y^m}{N_{tot}\Big|_y^m} \tag{6}$$

that, more in details, becomes:

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$$YAV\Big|_y^m = \frac{\sum_{\lambda=1}^{N_{FC}}\sum_{j=1}^{N_{AC}}\sum_{k=1}^{N_{VC}} EF_{\lambda jk} N_{\lambda jk}}{\sum_{\lambda=1}^{N_{FC}}\sum_{j=1}^{N_{AC}}\sum_{k=1}^{N_{VC}} N_{\lambda jk}}\Bigg|_y^m \tag{7}$$

In eqn (7) $FE_{\lambda jk}$ and $N_{\lambda jk}$ respectively represent the emission factor and the number of vehicles of the *λ-th* class of fuels, of the *j-th* class of age and of the *k-th* class of engine volume; N_{FC} is the number of classes of fuels, N_{AC} is the number of classes of age and N_{VC} is the number of classes of piston displacement. Parameter YAV defined by eqn (7) also refers to a specific pollutant and to a given year.

Once the year average vehicle has been singled out, the total amount of the emissions for the *m-th* modality of transportation in the year *y* will be computed with the following expression, that is in the same required form of eqn (4):

$$E\Big|_y^m = \frac{YAV\ D}{to}\Bigg|_y^m \tag{8}$$

Moreover, once the yearly average vehicle for all the modalities of transportation, N_m, has been defined, it is possible to build up a global yearly average vehicle, that will take into account all the modalities of transport. That is:

$$\overline{YAV}\Big|_y = \frac{E_{tot}}{D_{tot}}\Big|_y = \frac{\sum_{i=1}^{Nm} E_m}{\sum_{i=1}^{Nm} D_m}\Bigg|_y \tag{9}$$

or:

$$\overline{YAV}\Big|_y = \frac{1}{D_{tot}}\sum_{i=1}^{Nm}\frac{YAV_m\, D_m}{to_m}\Bigg|_y \tag{9'}$$

This global yearly average vehicle can be assumed as an indicator of the mean emissions of the transportation system in a given urban context. It in fact allows the evaluation of the global pollutant releases of a whole vehicular fleet, provided that the aggregate satisfied demand of transportation D_{tot} is known:

$$E\Big|_y = \overline{YAV}\ D_{tot}\Big|_y \tag{10}$$

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4 Building up a decision model for the urban transportation

The analytical expressions introduced in the previous paragraph can be utilised for building up a simple model of the urban transportation systems, able to provide fast and detailed enough information concerning the pollutant substances released by the running vehicular fleet.

Starting from the definition of type, class and age of the vehicles and assuming some hypotheses referring to the mean speed and the mean mileage of the vehicles representative of each emitting class, the application of the previous equations enables the evaluation of the total emissions pertinent to a given transportation system. According to the COPERT methodology, total emissions are comprised of three separate components, that is hot emissions, cold start emissions and evaporative (VOC) emissions. In addition the fuel consumption can be also separately computed.

Actually, the computation scheme of figure 1 differs from a mere application of the structure of the COPERT method for the utilisation of the synthetic indicator YAV (yearly average vehicle) as representative parameter of the mean emitting features of the given urban transportation system.

Since YAV has been applied to each modality of transport (car, bus, etc.) instead of to each vehicular class established by the COPERT method, the yearly running fleet must be previously treated and arranged in a suitable way before the computation described in figure 1 takes place.

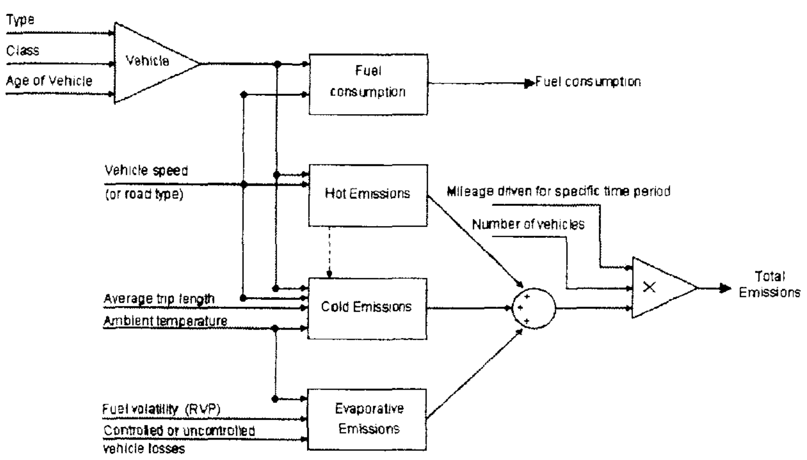

Figure 1: Flow chart of the computation steps leading to the evaluation of the pollutant emissions of urban transportation systems.

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In order of performing this management of data of the yearly running fleet, the decision model has been provided with a specific computation section, that is entered by means of a friendly input routine, as shown in figure 2.

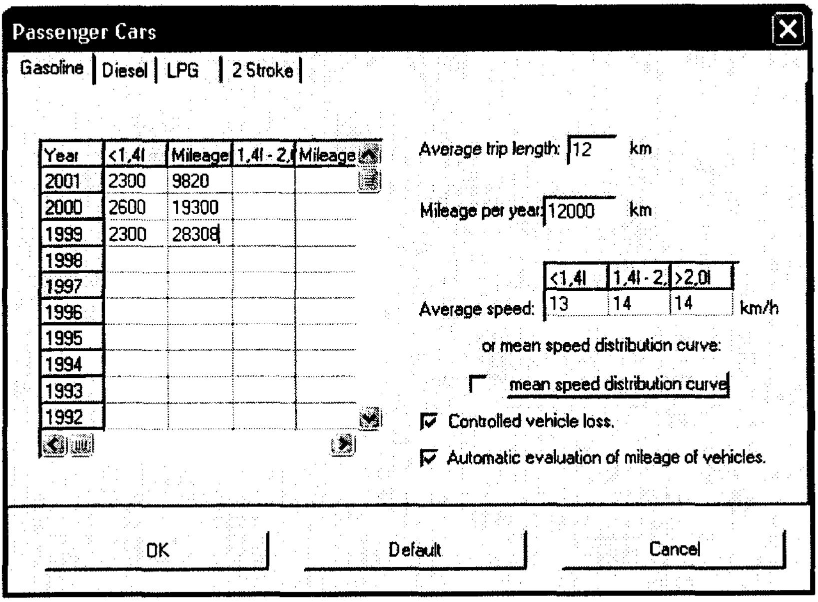

Figure 2: Typical format for entering data referring to the urban yearly running fleet.

These friendly features should enable the utilisation of the method even by non technicians, although at this stage its utilisation is mostly recommended to people aware of the technical contents of the transportation systems.

5 Example of application of the generalised model

The previously described model has been applied for determining the pollutant characteristics of the Italian town of Palermo. With reference to the period 1990-1999 [4], four scenarios have been analysed that account for different combinations of private (cars) and public (bus) modalities of people transportation for satisfying the urban mobility demand. Scenarios essentially vary for the different values adopted for the mean velocity and the occupation rate of vehicles (see figure 3).

Since only two modalities of transportation have been here considered, the total demand of transport can be written as follows:

$$D_{tot} = D_{car} + D_{bus} \tag{11}$$

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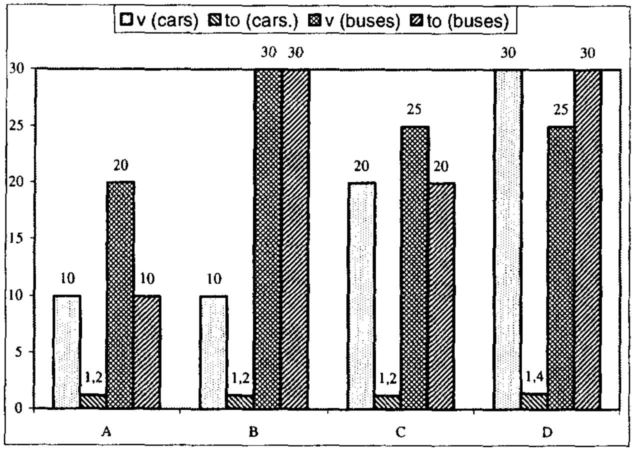

Figure 3: The scenarios adopted for the example application of the model are characterised by the mean velocity *v* (km/h) and by the mean occupation rate *to* (passengers/vehicle) of vehicles.

The application of the model allows the comparison of the environmental impact of the scenarios under analysis in terms of some selected pollutants: CO, PM and NO_x, in this case, respectively reported in figures 4, 5 and 6.

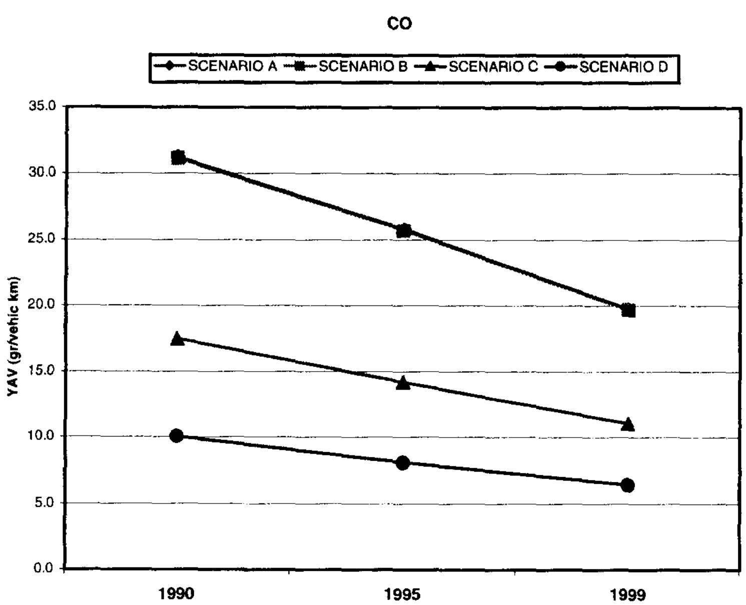

Figure 4: Emissions of CO released by the "yearly average vehicle" of the town of Palermo in the period 1990-1999.

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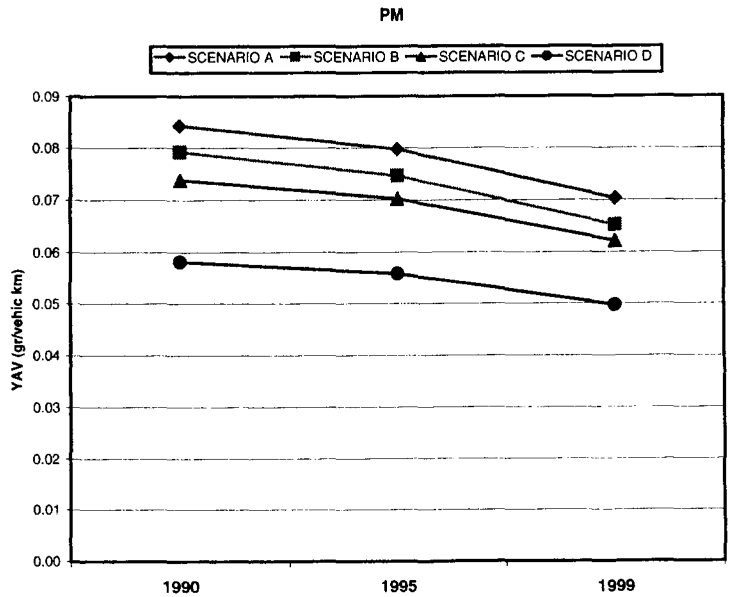

Figure 5: Emissions of PM released by the "yearly average vehicle" of the town of Palermo in the period 1990-1999.

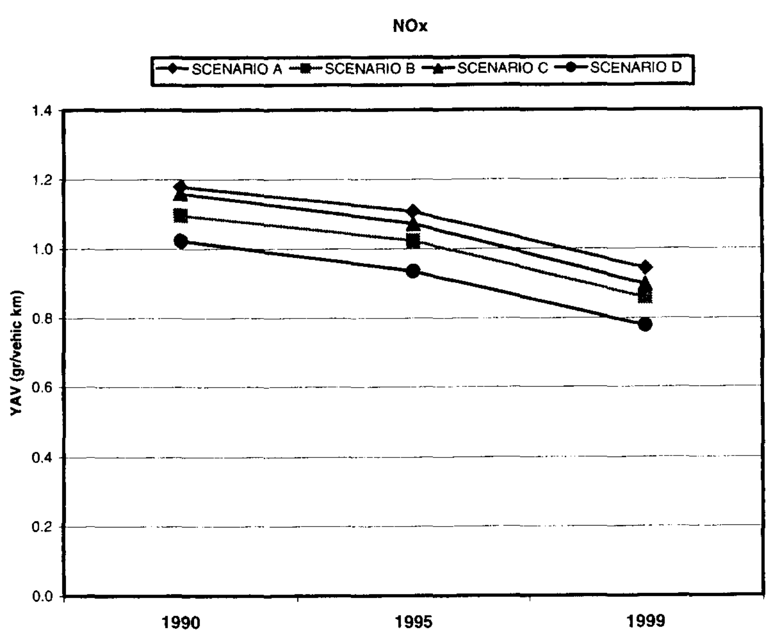

Figure 6: Emissions of NO_x released by the "yearly average vehicle" of the town of Palermo in the period 1990-1999.

These graphical representations can be usefully utilised for analysing the main characteristics of the given urban transportation system.

Although all the considered pollutants decrease in the period 1990-99, due to the technological improvements introduced with time in the running fleet, some differences can be single out in the behaviour of the four scenarios. Carbon monoxide (strongly depending on the emissions of cars) shows almost the same emitting properties for the scenarios A and B, while the scenario D offers the best environmental trend. Particulate matter emissions exhibit a decreasing behaviour from scenarios A to D: these releases, in fact, depend almost totally on the diesel buses that have been here supposed to accomplish the public transportation demand. Regarding the NO_x emissions, the emitting trend of the scenarios is rather different: the scenario C appears more environmental impacting than the scenario B, due to the strong dependence of the released NO_x on the occupation rate of the public means and, in turn, on the number of buses running in the given urban context.

Of course, information like these are of paramount importance for public administrations when environmentally ranking various transportation mixes.

6 Conclusions

A simple model has been introduced, devoted to the analysis of the environmental impact exerted by transportation systems in urban context. By adopting a new synthetic indicator of the average pollutant emissions of a given running fleet (that is the "yearly average vehicle", YAV), the method can be also utilised for ranking different transportation configurations, with a particular attention to the modal changes, to the technological improvements and to the fuel options.

References

[1] Ntziachristos, L. & Samaras, Z. (ETC/AEM eds). *COPERT III. Computer programme to calculate emissions from road transport. Methodology and emission factors (Version 2.1).* European Environment Agency, Technical report No 49: Copenhagen, 2000.

[2] Nucara, A., Rizzo, G., Rodonò, G & Scaccianoce, G. Introducing new indicators for assessing pollutant emission scenarios of urban traffic sector. *Proc. of the 18th International Conference with Exhibition "Science and Motor Vehicles 2001 - Automotive Engineering for Improved Safety"*, eds. Yugoslav Society of Automotive Engineers, Belgrade 2001, ISBN 86-80941-26-3, pp. 127-130, 2001.

[3] Nucara, A., Pietrafesa, M., Pignato, A. & Rizzo, G. Running car fleet and urban pollutant emissions. *Proc. Of the International Conference Air Quality in Europe - Challenges for the 2000s*, eds. V. Cocheo, E. de Saeger, D. Kotzias, Short Paper Book, pag. 142, 1999.

[4] ACI, Automobil Club d'Italia. *Personal comminication,* 1999.