THE ESTIMATION OF AIR POLLUTION FROM ROAD TRAFFIC BY TRANSPORT MODELING

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Abstract: *Air pollution is a consequence of human activities, including the road vehicle use. Thus, transport, especially road traffic, is a major source of air pollution in most of the world. Road traffic associated air pollution comes mainly from burning fossil fuels. In order to improve the air quality at local level and to propose traffic management strategies, it is necessary to investigate the relationship between traffic flow, emissions of pollutants and their dispersion in the atmosphere, as well as their potential impact on operational processes of the network and of the traffic management. This paperwork presents the main methods for estimating air pollution from road traffic, corresponding to different levels of detailing of road traffic modeling (macroscopic, mesoscopic and microscopic levels).*

Keywords: AIR POLLUTION, ROAD TRAFFIC, TRANSPORT MODELING, EMISSIONS FACTORS, MACROSCOPIC MODELING, MESOSCOPIC MODELING, MICROSCOPIC MODELING

1. Introduction

Since the last century, as a consequence of advanced industrialization and remarkable growth of population and its mobility needs, particularly in urban areas, air pollution attributable to anthropogenic activities has accused more acute forms and often irreversible. There was a continuous accumulation of various pollutants in the environment, with increasingly severe consequences on humans, animals and plants, buildings, works of art and landscape in general [9], [12].

The road transport has become a common and necessary component of everyday life.

Despite its value, flexibility and necessary as parts of modern society, the road transport is recognized as having a major contribution to undesirable environmental problems. The transport sector, especially road traffic, constitutes a major source of pollutant emissions.

This paperwork presents the main methods for estimating air pollution from road traffic, corresponding to different levels of detailing of road traffic modeling.

2. Strategies to reduce air pollution from road traffic

Evidence shows that in 2005 the transport sector (excluding international air transport and the sea) contributed about 21% of the total emissions of greenhouse gases in the EU-15 and 56% of the total NOx emissions. Trends of variation of these two pollutants in the period 1990 – 2005 are opposed, registering a growth of about 23% for CO_2 and a reduction of approximately 40% for NO_x [4], [9].

In order to reduce the air pollution from road traffic, it is available a wide range of options and strategies. Basically, they could be grouped into three categories:

- Technological improvements of the cars, which leads to reducing vehicle emissions for each vehicle per unit of travel (eg., improvements of the engines and fuels in order to reduce pollutant emissions or improvements of the treatment systems to reduce the density of the pollutant substances in the emission composition). In the last years there have been recorded significant advances in this field;
- Changes of the operating conditions of the motor vehicles throughout the improvement of the management and control systems, such as vehicles to operate in optimal conditions. For example, the improving of the traffic management system may lead to reducing the number of accelerations and decelerations in the vicinity of busy intersections, both modes of operation having associated high levels of emissions.
- Strategies to reduce the absolute level of personal car using. These are very effective, but the feasibility and success of such measures depend on the availability and attractiveness of alternative means of transport used to meet the mobility needs of individuals. The provision of such alternatives is often quite difficult.

In order to improve the air quality at local level and to propose traffic management strategies, it is necessary to investigate the relationship between traffic flow, emissions of pollutants and their dispersion in the atmosphere, as well as their potential impact on operational processes of the network and of the traffic management.

Consequently, a considerable effort in this research domain has been devoted to developing models that take into account these factors. Macroscopic models have been developed ("the four steps model") at urban and regional levels which integrate issues regarding air quality [5], [9]. The evaluation of emissions with respect to spatial and temporal variations of traffic flow requires the development of traffic models at the microscopic level.

3. Specific models to estimate traffic and air pollution from road traffic

A model can be defined as a schematic and simplified representation of a complex reality with the aim of quantifications, representations achieved through a relationship between relevant variables of the phenomenon [9], [12].

The procedure for modeling air pollution from road traffic consists in different processes, developed separately and then combined, so as to obtain a more accurate representation of reality. In this regard, there are developed simulation models of traffic flows, at both macroscopic and microscopic levels, as well as an estimation model of pollutant emissions corresponding to traffic flows previously modeled *(figure 1).*

In a first phase of the process, it is necessary to collect information about the parameters that influence the trip generation (socio-economic data, demographic data and land use data), trips whose representations in space and time form the traffic flows. The traffic flow is the result of interaction between the transport demand and the transport supply [9], [10].

The transport supply is represented by the transport network that characterizes the studied area, described by roads and its intersections. The formalization of the network is achieved by a planar graph with arcs and nodes, in which the roads are represented by oriented arcs and the junction points by nodes. Arcs can be linked to features such as: direction, length, traffic capacity, number of lanes with their width, impedance. Nodes are associated with characteristics specific to intersections, such as: traffic direction, the type signaling, the traffic light cycle lasting, in the case of intersections with traffic lights.

The demand for transport services has a high degree of quality and differentiation [9], [10].

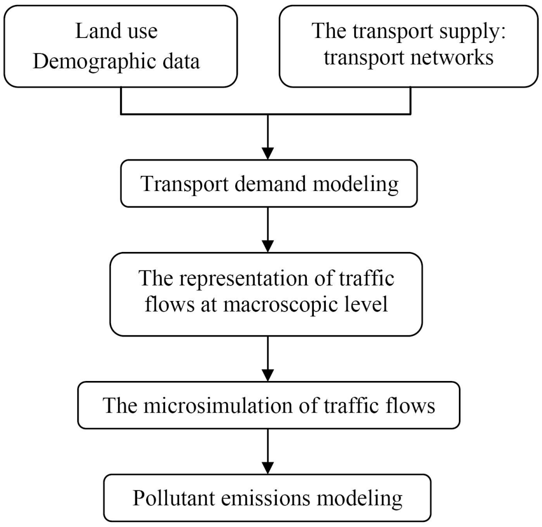

Fig. 1 *Process modeling to estimate the air pollution from road traffic.*

The transport demand for occupies a place in space. The spatiality of demand often leads to lack of coordination, resulting in a strong imbalance between transport supply and transport demand. The transport supply and demand show dynamic characteristics. A significant share of transport demand is concentrated, especially in urban areas, during traffic peak periods. This variable nature of transport demand makes more difficult, but interesting at the same time, the analysis and the prediction. Each trip is the result of a series of multiple choices made by the individual. The demand is influenced by the choice of making a trip for some reason, on a certain route and within a certain time of day, when the user is dependent on the automobile, and, for those who do not have cars, this choice will contain also the stage of option for a transport mode.

The demand models formalize the user choices concerning:

- *the decision of making or not the trip for some reason or purpose;*
- *travel destination;*
- *the transport mode used;*
- *the followed route in a time reference.*

In the case of modeling the transport demand at macroscopic level, it is expressed through origin/destination matrices (O/D) corresponding to analyzed traffic zones. In the microscopic modeling, it addresses a disaggregated treatment of input data, each vehicle being individually simulated.

The aggregation level of variables depends on the purpose for which it is elaborated the model. The modeling at macroscopic level requires data aggregated at zonal level, while in microscopic modeling, more detailed information is needed, and sometimes these data are difficult to obtain.

In the macroscopic representation the traffic is associated with a compressible fluid, so that can be applied the fluid mechanics theories. The traffic is characterized by three variables: flow (volume), speed and density [9], [13]. Supporting this theory is the relationship between traffic flow and traffic density.

The mathematical relationship between the three parameters has the form:

(1) $q = k \cdot v$

with: $q = 1/h$ and $k = 1/s$,

where:

- *q [vehicles/hour] is the vehicle flow;*
- *k [vehicles /km] is the traffic density;*
- *v [km/hour] is the average speed;*
- *h [hours] is succession interval;*
- *s [km] is the distance between successive vehicles.*

Since in the macroscopic approach, the traffic is treated as a continuous flow, there is not possible a detailed representation of travel speed variation, associated with individual or categories of motor vehicles trips, which compose the traffic flows. This issue constitutes a major limitation of the traffic modeling at macroscopic level, because the speed fluctuations shows a considerable importance in modeling air pollution from road traffic.

An alternative to the macroscopic representation of traffic flows is the microscopic representation. Road traffic microsimulation models take into account the individual behavior of vehicles and are used to forecast the likely impact of changes in traffic conditions. In this situation, the traffic flow characteristics are obtained as a result of the aggregation of individual behavior of cars which compose the traffic flow. The particularity of microsimulation models consists in the analysis capability of the congested transport network, due to its ability to simulate the waiting conditions. This ability gives to such type of models a great utility in the analysis of traffic operations in urban areas and city centers, including nodes, roundabouts, marked or unmarked intersections.

To simulate the behavior of each motor vehicle is required, on the one hand, a large amount of input data and, on the other hand, advanced computer systems. Therefore, the microscopic representation of traffic flows, was until recently considered too demanding to be to practically applied in transport studies [6], [9], [11]. In recent years, there has been made considerable progress in terms of capacity and applicability of the macroscopic traffic flow modeling, both in the urban and inter-urban areas. The microsimulation models have attracted attention through its ability to visually represent the expected traffic behavior through 3D animation. The most important software packages which include these abilities are: *Vissim, Tsis-Corsim, Cube Dynasim, Lisa+, Quadstone Paramics, SiAS Paramics, Simtraffic, Aimsun.*

3.1. The macroscopic modeling of air pollution from road traffic

The current approaches in the field of modeling air pollution from road traffic can be classified into three categories: *macroscopic, mesoscopic* and *microscopic.*

In a macroscopic model, the traffic is represented as a compressible fluid, and the movement of each vehicle cannot be monitored. Emissions are usually determined depending on total traffic volume and average speed of traffic flow. Thus, the macroscopic models may not represent, in general, the influence of speed fluctuations.

In Europe, it has been developed since 1982 a macroscopic model for estimating emissions from road traffic in the Transport Research Laboratory (TRL) in Great Britain. The model defines CO emissions as a direct function of average traffic speed and flow and then express the emissions of other pollutants (eg, HC, NO_x and Pb) depending by the volume of CO emissions.

The empirical relationship between speed, flow and CO emission is:

(2) $E(CO) = 1{,}031 \cdot q \cdot v^{-0{,}795} \cdot 10^{-4}$

where:

- $E(CO)$ $[g/m]$ is the volume of CO emissions;
- q $[vehicles\ /\ hour]$ is the trafic flow;
- v $[km/hour]$ is the average speed.

The environmental Protection Agencies from Germany, Switzerland and Austria (HBEFA) have developed a model for determining the pollutant emission associated to the emissions factors NO_x, CO, HC and SO_2 from individual transport, which is using as input data the emissions volumes specific for each of these factors (figure 2). Each emission factor has an associated regression curve with the form:

(3) $Emiss = a + b \cdot v + c \cdot v^2 + d \cdot v^3 + e \cdot v^4 + f \cdot v^5$ [g/m]

where:

- v is the velocity recorded on each arc from the analyzed network, by categories of vehicles;
- a, b, c, d, e, f are regression coefficients specific to each pollutant, both for cars and for trucks, having as reference the years 1990, 1992 and 2000.

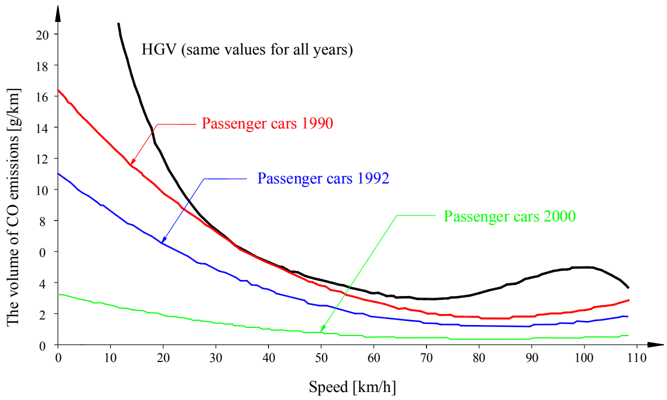

Fig. 2 *The estimation of the emissions volume – CO* [9], [14].

Both described above macroscopic models for calculating emissions from road traffic, provide quick and relatively simple instruments of assessing the impact of road traffic on air pollution, but these have disadvantages regarding the quantification of the impact determined by the changes in vehicles speed.

3.2 The modeling of air pollution from road traffic at mesoscopic-level

Beside the macroscopic approach, the modeling at mesoscopic level has as objective the determination of the influence of speed variations. This is possible by estimating the volume of emissions depending on driving style, characterized by a number of different modes of using the motor vehicle (acceleration, deceleration, cruise and queueing), each of these generating different levels of emissions.

A typical example of mesoscopic approach in this area is the model developed by *Matzoros* and *Van Vliet* [8], realized using the software package *Saturn*. This model can estimate the emissions values for four different usage modes (acceleration, deceleration, cruise and queueing) in the vicinity of an intersection.

In *figure 3* are represented the four operating regimes imposed by the car driver signaled intersections. The duration associated with each operating system can be calculated by applying the waiting string theory. The four operating modes of the motor vehicles are characterized by constant speed during the cruise mode, constant variation of the speed during acceleration and deceleration regimes, and zero speed during idle operation mode.

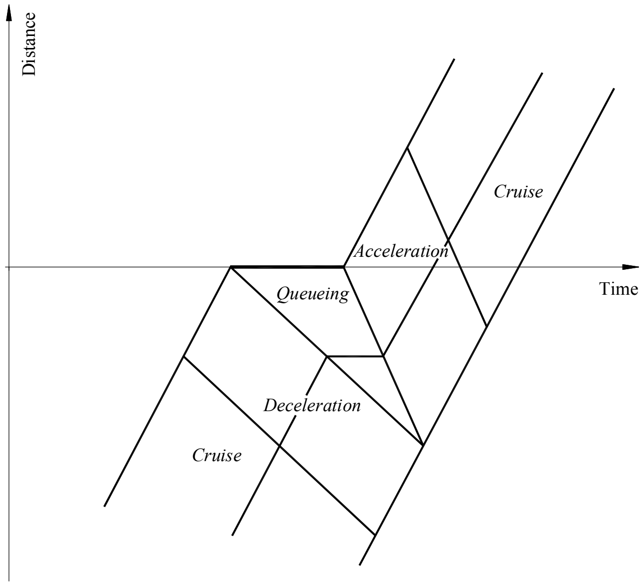

Fig. 3 *The using regimes of the motor vehicle in an intersection* [8], [9].

The advantage is that the mesoscopic model can highlight different operating conditions of the flow of traffic along a section of road and near intersections through macroscopic representation of traffic flow. The mesoscopic models do not require additional input data compared with macroscopic models, but only values of standard emissions specific to each operation regime.

The deficiency of this model consists in its inability to describe the influence of speed variation of motor vehicles on air pollution.

3.3 The modeling at the microscopic level of air pollution from road traffic

The microscopic models quantify the emissions at the level of each vehicle in the structure of traffic flow, being taken into account the parameters that characterize the movement of the vehicle, such as: instantaneous speed, acceleration, motorization category. The total emissions associated with traffic flow are obtained by aggregating the specific emissions for each motor vehicle.

Since 1974, such a model was developed by the U.S. Environmental Protection Agency [7], [9]. The volumes emissions of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) were deduced from tests performed on a sample of 170 vehicles in six U.S. cities. This way, it was possible to investigate the variation of motor vehicle emissions in the vicinity of intersections with traffic lights [1], [2], [9].

In recent years, growth in computing power has enabled more and more practical use of traffic microsimulation models. The structure of such a model is presented in *figure 4*.

There are given the necessary input data and processes that take place during microsimulation. There are used data about network configuration, signal systems, volume and structure of traffic flows, as well as characteristic data of the vehicles which form the traffic flows. Following the microsimulation, it is obtained the instantaneous speed and acceleration of each analyzed vehicle. This information is used in the calculation model of emission, resulting the concentration for each emission factor in the analyzed area.

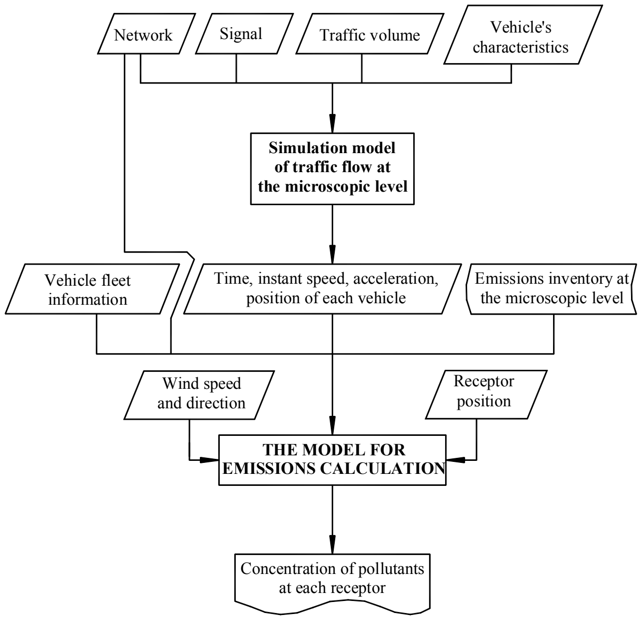

Fig. 4 *The structure of the microscopic model for estimating pollutant emissions from road traffic.*

4. Conclusions

Air pollution is a consequence of human activities, including road vehicle use. Thus, transport, especially road traffic, is a major source of air pollution in most of the world. Road traffic associated air pollution comes mainly from burning fossil fuels.

The general process of modeling air pollution generated by road traffic consists of the following steps: *(i)* collecting data and information underlying the trips generation, *(ii)* estimating the transport demand and the affecting of the traffic flows on the entire analyzed network and *(iii)* the inventory of the emissions from road vehicles which compose the traffic flows.

In the research in the field of transport, traffic flow representation was a key issue in modeling of air pollution from road traffic. Currently, the most used models to represent traffic flow are macroscopic models, which may show the average travel speed along a stretch of road. The data required in macroscopic modeling are moderate and can be easily applied to evaluate a wide range of transport strategies. But these models are not able to reveal the local variations concerning air pollution in the vicinity of intersections or in different traffic conditions. To overcome this shortcoming, mesoscopic models have been developed. Although these are essentially based on a macroscopic representation of traffic flows, they can describe different modes of using vehicles such as acceleration, deceleration, cruising and queueing. As a result, the mesoscopic models may be useful in modeling air pollution in the intersections area of influence. Therefore, special attention in the modeling of air pollution generated by road traffic is dedicated to developing models that are able to detail the traffic flow characteristics, namely the microsimulation models. These models have the ability to characterize the movement of each vehicle in terms of developed instant speed and acceleration. The emissions associated with traffic flow are obtained by aggregating the specific vehicle emissions at the individual level.

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