GEOMETRY INFLUENCE ON POLLUTING CONCENTRATIONS NEAR URBAN SIGNALIZED INTERSECTIONS

Cordasco Mario
Phd Student University of Calabria – mario.cordasco@unical.it
Crocco Federica
Phd Student – University of Calabria – federica.crocco@unical.it
Mongelli Domenico Walter Edvige
Phd Student –University of Calabria – domenico.mongelli@unical.it

ABSTRACT

Urban signalized intersections represent a critical element for traffic polluting emissions. Often planning the geometry of an urban intersection is tied to the single traffic factors without considering at all the possible environmental conditions near the intersection.

The present study analyzes the affect of geometric parameters at a signalized intersection, like the number and width of lanes, on carbon monoxide (CO) concentrations. Through the analyses carried out, the appropriate geometric characteristics of the intersection are identified in order to minimize (CO) concentrations. The methodology to estimate the polluting concentrations is based on the use in succession of a suitably defined emission model and a deterministic concentration model.

The main result emerging from the analyses conducted is that the effect of geometry on emissions and concentrations is found only for determined vehicular flow values.

Keywords: urban signalized intersections, traffic polluting emissions

1. INTRODUCTION

Research into the sector of estimating polluting emissions produced by transport systems has acquired an important role in the last few years, above all owing to the growing international interest to safeguard the environment and the land. Signalized intersections are affected by consistent traffic flows, so that they stand out as critical points for generally measuring the highest concentrations of pollutants.

The geometrical characteristics of every intersection assume special importance owing to the influence they can have on emissions generated by circulating vehicles. Relating the geometry of the intersections and the concentrations of pollutants, correct planning or adaptation of the configuration of the signalized intersections can be achieved, by taking into account the need for a significant reduction of CO concentrations.

The main components of motor vehicle emissions is made up of water vapour (H_2O), nitrogen (N), Carbon dioxide (CO_2), Carbon monoxide (CO), Lead (Pb), Sulphur dioxide (SO_2), Nitrogen oxides (NO_x), Dusts or particles (PM_{10}), Unburned hydrocarbons (HC) and Ozone (O_3). Obviously the presence in the atmosphere of these pollutants is not exclusively due to vehicular traffic.

Carbon monoxide, among the main polluting emitted, registers the highest values. It is formed during the combustion of organic substances, when they are incomplete because of a lack of oxygen, as in the case of petrol-driven engines. Diesel engines, instead, have a strongly reduced emission of CO. The effects on the environment can be considered negligible, whereas the effects on man are particularly harmful.

The importance of the atmospheric pollution problem and the need to safeguard the quality of the air are well-known to the Legislature that exercises a dual-type of control: a *priori* on unitary emissions of vehicles and a *posteriori* on the maximum acceptable concentration of pollutants in town and out-of-town areas.

The atmospheric pollutant concentrations identified by Italian regulations are defined on the basis of World Health Organization (WHO) indications.

The DM n° 60 of 2 April 2002 established the limit values for polluting agents; the DM 15 April 1994 and the DM 25 November 1994 define the levels of attention, alarm and objectives of air quality, for some pollutants, for large urban areas.

The integration of objective measurements and the prediction data deriving from the application of mathematical models is of fundamental importance; they should be suitably calibrated on the basis of the specific morphological nature of the site and the nature of the traffic.

With the aim of estimating pollutant concentrations generated by vehicular traffic, it is necessary to use successively three types of model:

- traffic models, to obtain information on the quantity and circulating condition of the vehicles;
- emission models, to calculate the emission of the main pollutants;
- dispersion models, to calculate the concentrations of pollutants at some important points of the road network.

The models existing in the literature are differentiated by the degree of aggregation of the data supplied; aggregated-type models carry out an analysis on the mean

composition of the vehicular park in a specific reference period, whereas disaggregated-type models refer to specific typologies of vehicle and period of production.
The models can, also, refer to motion conditions. Instantaneous-type models allow an analysis of the emissions as a function of velocity and of instantaneous acceleration. In particular, they are used to analyse emission distribution on a stretch of road or at a node in the road network, whenever it is desired to identify the pollutants in the area of a stretch of road where accelerations take place, where the velocity remains constant and where decelerations occur. The referred models, instead, at mean conditions refer to mean velocity and acceleration in uninterrupted flow. They are used in the case of macroscopic analyses of the pollution level in a town area or on a regional or national scale. The data deriving from these are, anyway, approximated by defect because of the specific motion conditions that do not provide for stop & go phenomena.
In the literature there are various polluting emissions calculation models. In order that an emission model manages to supply realistic data on the pollution of a determined study area, the data base needs to take into account the possible spatial and temporal contexts of the pollution.
The present study uses the dynamic micro-simulation model of road circulation VISSIM to obtain the necessary information about traffic for the application of the dispersion and emission models. Regarding the emission values, instead, the results of direct measures on the circulating vehicular park were used as input data, whereas for the estimate of the pollutant concentrations reference was made to a canyon-type model particularly adaptable to town traffic conditions.
Finally, the results supplied by the application of the combined emission and dispersion traffic models, allow the evaluation of the geometrical configuration of an urban signalized intersection, in terms of the number of lanes, and the concentrations of carbon monoxide (CO).

2. STATE OF THE ART

The literature on this research field enables several aspects of signalized intersections to be assessed. In order to conduct roadway intersection pollution studies, many researchers have had to work with individual traffic and dispersion models that were not designed to function as an integrated whole. The problems encountered working with separate and independent models include difficulties in linking input/outputs from one module to another and inadequacy in simulating all of the relevant and important conditions. As a result, the accuracy and sensitivity of modelling exercises may be difficult to establish.

In many cases, the use of experimental measurements allows the interaction between the signal control settings, emissions and traffic variables to be explained. Traffic lights are being installed on highways to serve as speed reduction devices (Coelho et al., 2005); the main aim of this type of signal is that while it may be effective in reducing high speed crashes by slowing fast vehicles, it can affect other traffic in such a way that vehicle emissions may increase due to excessive delays, queue formation and speed change cycles. One of the main conclusions of the research is that signal control schemes that result in stopping a larger fraction of speed violators also yield higher emissions. Moreover, standardized driving cycles used in macroscopic models such as

COPERT, MOBILE and EMFAC are less appropriate for the evaluation of traffic interruptions caused by such things as speed control traffic signals.

Other studies are oriented to traffic signal control strategy on a micro-scale around an isolated intersection in which the environmental costs are estimated in terms of CO_2 emission, fuel consumption and standard pollutant emission (Midenet et al., 2004). In the study case the experimental area is limited to approximately 500m-long itineraries centred on an isolated intersection, with vehicles approaching and leaving at free cruising speed: great benefits on stops and delay induce a significant reduction in environmental damage.

Studies using the MEASURE model looking at the effect of signal timing on carbon monoxide (CO) emissions have been conducted (Hallmark et al., 2000). Advanced control strategy benefits on isolated intersections can be assessed on this basis. Moreover, different models for assessing the impact of vehicle stops at traffic signals have been proposed in the literature, based on analytic approaches (Liao and Machemehl, 1998), traffic simulation tools like CORSIM (Hallmark et al., 2000), or on-field driving cycle recording (Rakha and Ding, 2001). In these studies emission and consumption estimates are derived from elemental models based on instantaneous emission data (Biggs and Akcelik, 1986).

Several traffic operations software packages provide emission estimates based on dynamometer testing of vehicles rather than real-life measurements (Unal et al., 2003). On-road data enables the characterization of emissions at any time or location during a trip including the local effect of signal control. These measurements can be classified by mode (e.g. acceleration, deceleration, idle and cruise) leading to modal emission models (Frey et al., 2003). However, it appears that very few on-field experiments have been performed using intersection scale assessment, like for instance the PRODYN strategy in Toulouse (Khoudour and Lesort, 1990).

Li et al. (2004), for example, propose an integrated optimization of signal timing to reduce emissions calculated using the MOBILE model. The emission measurements are mainly based on dynamometer testing but the data are too aggregated for the analysis of intersection emissions.

The real time control strategy efficiency in reducing delay and stops compared to conventional control strategy was demonstrated on site by Boillot et al. (2000). This makes CRONOS one of the most promising control strategies for minimizing environmental damage. The study investigates the range of savings that can be achieved using the proposed strategy. However, the integrated use of traffic simulation tools, emission models and concentration models have not been adequately investigated.

3. METHODOLOGY AND DATA USED

The approach used to estimate the concentrations of CO near a signalized intersection is based on three calculation phases. The first, making use of a traffic micro-simulation tool, coincides with the identification of the main circulation characteristics close to the intersection analysed. Varying the traffic flows in the four roads of the simulated intersection and considering a different number of lanes for each entry, the simulation software chosen (PTV VISSIM 4.0) allowed the identification of the mean velocities, the mean delays, the vehicular traffic density for all the elementary stretches of road into which each entry to the traffic lights was subdivided. It was also necessary to suppose a distribution of the entry velocities as an input datum.

The traffic volumes considered during the simulations carried out vary from a minimum of 400 veh/h for single entry to a maximum of 1600 veh/h, while the lanes analysed vary to a maximum of three lanes for each road. Table 1 shows as an example the results obtained for one lane.

Table 1 Main data of traffic obtained from the simulations carried out for the case of one lane

Stretch	Volume *(veh/h)*	Velocity *(km/h)*	Density *(veh/km)*
0	174	32.6	5.4
35	200	32.5	6.2
70	200	31.6	6.3
105	200	31.6	6.3
140	200	31.5	6.4
175	200	31.6	6.3
210	200	31.5	6.4
245	198	31.1	6.4
280	198	30.7	6.4
315	194	9.1	22.1

Reference was made to a data base of specifications in which all the technical motor characteristics of vehicles in circulation in the province of Cosenza were inserted, gathered from the periodic obligatory revision controls of all the vehicles circulating in Italy. From the database, in particular, the measurements relative to the percentages in volume of CO recorded at the exhaust both in the acceleration phase and at idling were used. Naturally the data are available for every type of cylinder capacity and fuel (tab. 2).

Table 2 Consistence of the vehicular park for cylinder capacity class, fuel and emission

Cylinder capacity class (cm^3)	**Petrol NON Cat** *(%)*	**Diesel NON Cat** *(%)*	**Petrol Cat** *(%)*	**Diesel Cat** *(%)*
<700	0.10	0.01	2.00	0.01
700-899	0.25	0.00	3.00	0.02
900-1099	2.50	0.20	25.00	0.50
1100-1299	4.50	0.10	18.00	0.50
1300-1499	1.50	0.20	11.00	2.50
1500-1699	2.00	1.70	0.42	8.50
1700-1899	0.15	2.50	0.10	4.50
1900-2099	0.15	1.00	0.20	4.00
>2100	0.10	1.00	0.20	1.59
Total	*11.25*	*6.71*	*59.92*	*22.12*

Finally, knowing the number of vehicles that cross the intersection in an hour of observation, as well as the velocities of each vehicle, the number of revolutions of each engine was found. These are important for the subsequent calculation of the emissions.

4. ESTIMATE OF EMISSIONS

Once known the traffic data and the engine characteristics of the circulating vehicular park considered, the calculation of emissions for the different typologies of intersections was analysed.

The emission of a single vehicle crossing the intersection was obtained for the single elementary stretch of road, multiplying the known concentration at exhaust by the total volume of gas emitted, in turn given by the product of the number of revolutions and the relative:

$$E_{acc}(cyl) = [CO]_{acc} \cdot \varepsilon_{park} \cdot \left\{ Cyl \cdot \lambda \cdot \varepsilon_{cyl} \cdot 10^{-6} \left[\frac{v \cdot m_p \cdot m_c}{3{,}6 \cdot \pi \cdot D} \right] \cdot \varepsilon_{fill} \right\} \quad \text{(Eq. 1.a)}$$

$$E_{\min}(cyl) = [CO]_{\min} \cdot \varepsilon_{park} \cdot \left[\lambda \cdot 10^{-6} \cdot \varepsilon_{cyl} \cdot \frac{n_{revs}}{60} \cdot \varepsilon_{fill} \right] \cdot R_{mean} \cdot V \quad \text{(Eq. 1.b)}$$

$E_{acc}(cyl)$: vehicular emission in motion expressed in [g/(s veh.)];
$[CO]_{acc}$: concentration of carbon monoxide in motion expressed in [g/m^3];
v: velocity expressed in [km/h];
Cyl: cylinder capacity in [cm^3];
m_p: final drive ratio;
m_c: gear ratio;
λ: reference coefficient of the number of the engine times;
$E_{\min}(cyl)$: vehicular emission at minimum expressed in [g/h];
$[CO]_{\min}$: concentration of carbon monoxide at minimum expressed in [g/m^3];
n_{revs}: number of revs;
ε_{park}: corrective coefficient of the reference vehicular park at variation of the class of emissions;
ε_{cyl}: corrective coefficient of the cylinder capacity referred to the reference park;
ε_{fill}: filling coefficient;
R_{mean}: mean delay [s/veh];
V: vehicular flow [veh/h].

The calculation, naturally, was carried out both in conditions of vehicle in motion and idling vehicle. Successively, for vehicles in motion it was necessary to find the emission of the elementary stretches by (Eq. 2), obtaining a mean value from (Eq. 3).

$$E_L acc(cyl) = E_{acc}(cyl) \cdot \frac{D}{1000} \qquad \text{(Eq. 2)}$$

$E_L acc(cyl)$: linear emission in motion expressed in [g/(m s)];
D: vehicular density [veh/h].

$$\overline{E}_L acc(cyl) = \frac{\sum_{i=1}^{n} E_L acc(cyl)}{n} \qquad \text{(Eq. 3)}$$

$\overline{E}_L acc(cyl)$: mean linear emission in motion expressed in [g/(m s)];
n: number of elementary stretches;

A different approach was used for the calculation of the mean linear emission of queuing vehicles (Eq. 4).

$$\overline{E}_L \min(cyl) = \frac{E_{\min}}{3600 \cdot L_{Queue}} \qquad \text{(Eq. 4)}$$

$\overline{E}_L \min(cyl)$: mean linear emission at minimum expressed in [g/(m s)];
$E_{\min}(cyl)$: vehicular emission at minimum expressed in [g/h];
L_{Queue}: mean length of queue [m].

For the four entries of the intersection the simulated flows have coinciding values in the two directions, East-West and North-South, with percentages of 50% in the two two-way traffic directions. At variation of the flows supposed the results for a number of lanes varying from 1 to 3 were obtained. As an example figures 1, 2 and 3 show the results of an intersection with a lane for each two-way traffic direction. From figure 1 it can be deduced that in an hour of traffic the emissions calculated result proportional to the supposed flows, data from the sum of the values of the emissions of the vehicles in movement and of the values of the queuing vehicles. The total curve of the emissions has an exponential-type trend, implying increasing values as flows get higher.

From figure 2 it can be seen how, for a single entry, the vehicle emissions, queuing owing to saturation phenomena that happen in single entries, tend to provide a greater contribution when the flows increase. For an hourly flow of 3200 veh/h the contribution made by queuing vehicles is about 1/3 of the contribution of transiting vehicles.

The analyses, moreover, allow an evaluation of the emissions for vehicles entering and leaving the entries under consideration. From the results it can be evinced that the values of the emissions for the entry lanes are higher than those for the exit lanes since the former are affected by the emission component produced by the queuing vehicles.

Figure 3 shows the trend of emissions in the case of one lane for two-way traffic.

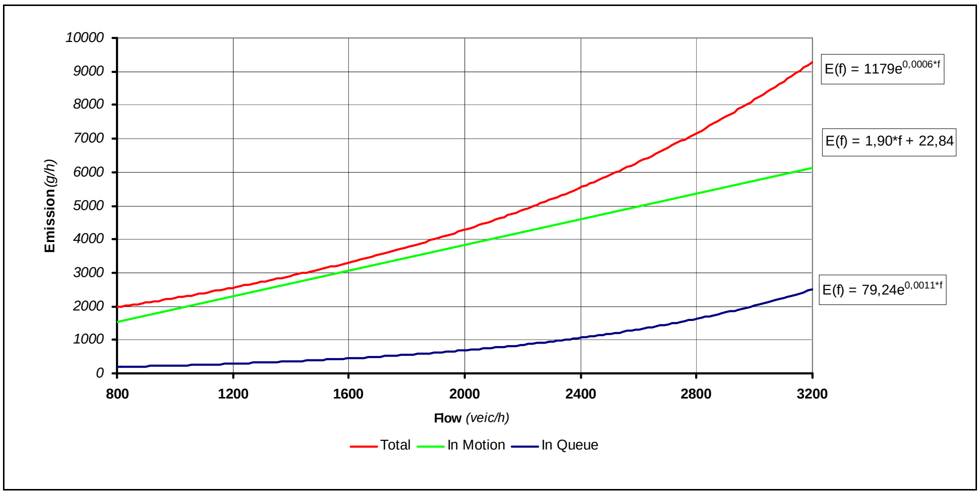

Figure 1 Vehicular emissions at variation of flow in an intersection with 1 lane for two-way traffic

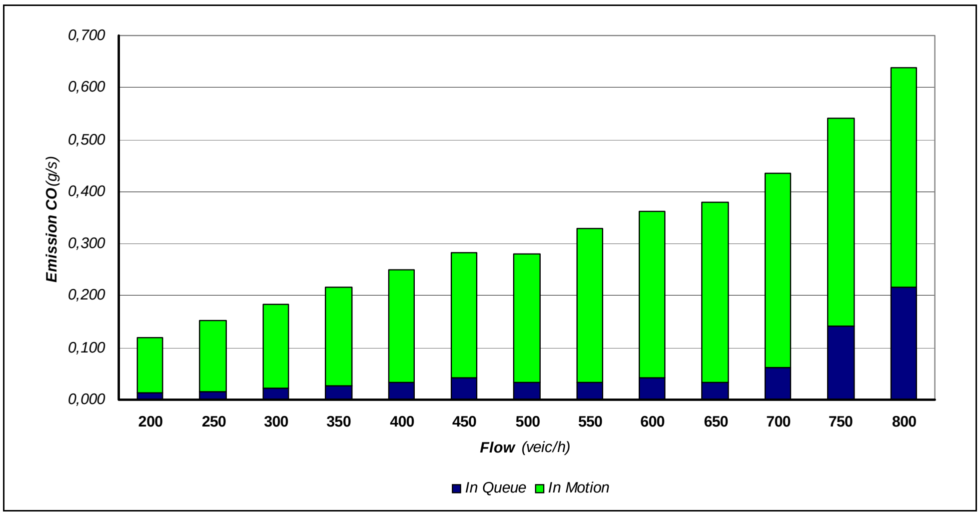

Figure 2 Vehicular emissions at variation of flow for signalized entries with 1 lane for two-way traffic

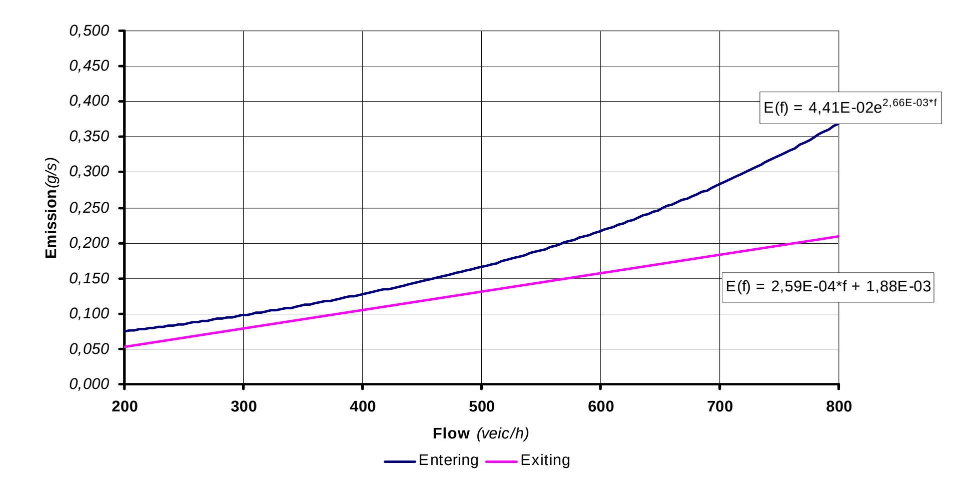

Figure 3 Vehicular emissions at variation of entry and exit flow for signalized entries with 1 lane for two-way traffic

The evaluations carried out for single entries allow global evaluations to be made for the whole intersection. The schemes with which an intersection can be planned are variable on the basis of the number of lanes present at each entry. Considering an intersection with four roads, there are many possible combinations in terms of number of lanes; supposing, as in figure 4, a number of lanes varying from 1 to 3 entering for each pair of opposing roads, there are 6 possible combinations.

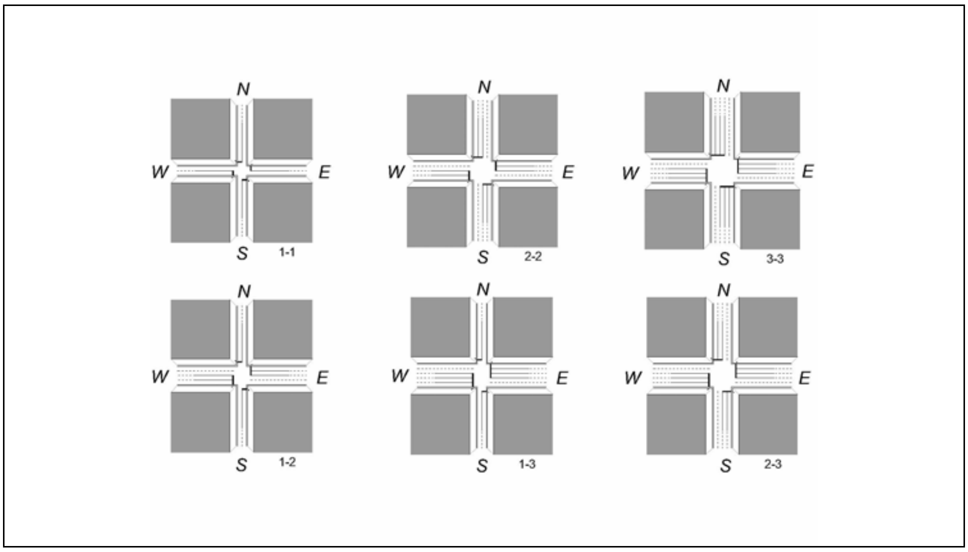

Figure 4 Possible lane combinations

Figure 5 shows the total emissions for different combinations. Each curve refers top a specific vehicular flow value. For heavy flows the effect of the geometry on emissions is much more accentuated because the contribution of the queuing vehicles is greater. On the contrary, for light flows, at an increase of the number of lanes there is no significant variation in the total emissions recorded at the intersection.

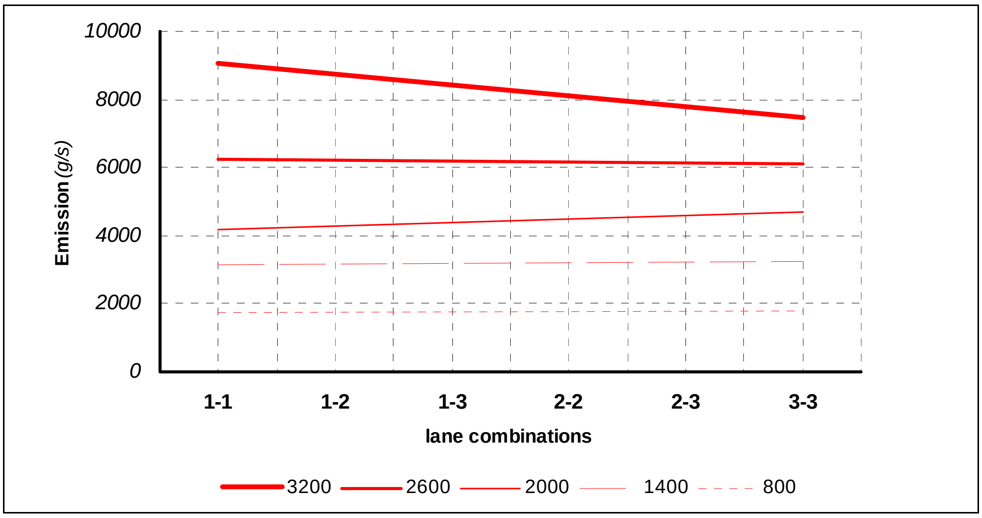

Figure 5 Vehicular emissions for different geometrical configurations

5. CALCULATION OF THE CONCENTRATIONS

The emissions calculated enable the individuation of concentrations of carbon monoxide for each intersection scheme analysed in correspondence to a given receiver. Also in this case, the evaluations were carried out varying the traffic flows and the number of lanes considered. To estimate the concentrations the dispersion model used is the canyon-type, adaptable to urban contexts where there are roads lined with rows of tall buildings.

Various experimental studies have shown that dispersion inside an urban canyon is influenced by its geometrical characteristics and by the air movement characteristics. The fundamental characteristic of an urban canyon is that of favouring, in determined conditions, the setting in of a markedly local air circulation, made up of a helicoidal vortex with parallel axis longitudinal to the axis of the canyon and contained inside the latter. In particular, in the calculation of the concentrations, the following meteorological and geometrical characteristics were considered: wind velocity at roof level of 2 m/sec, 3.6 m width of the single lane, 1.2 shape coefficient α, 2 m height of receiver from road level and at 2 m from the fronts of the buildings.

The results obtained by the application of the chosen model are shown for single entry, the effect of the remaining entries having no influence at the measurement point, as in the basic supposition of the model used. As can be seen in figure 6, the concentrations determined are similar for the cases analysed if the flows considered do not exceed values around 1100 veh/h, whereas they tend to present significant differences for heavy flow values. In fact, in the case of one lane for two-way traffic, the trend is exponential-type, justified by the faster reaching of saturation, and higher concentration values are reached of about 65% compared to the scenario with two or three lanes.

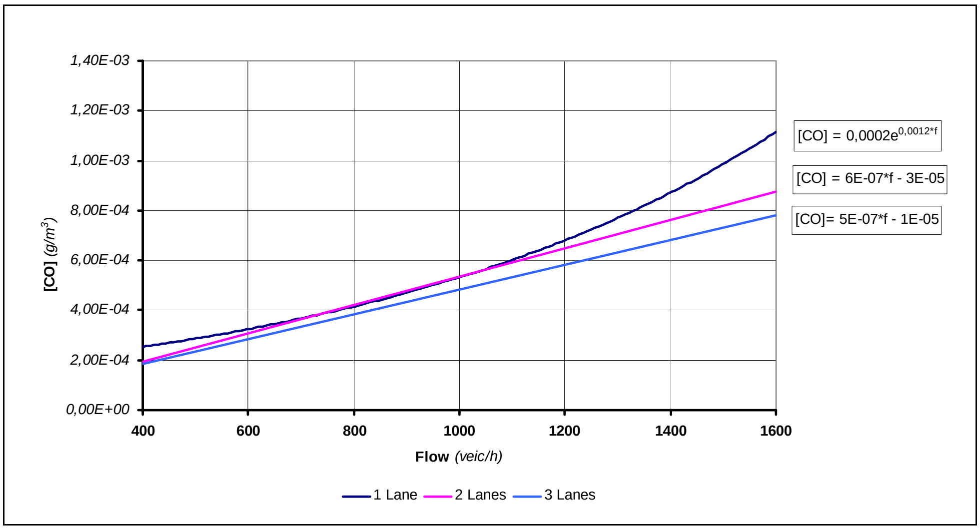

Figure 6 Vehicular concentrations at variation of the flow for signalized intersections with different number of lanes

6. CONCLUSIONS

The study addressed has enabled the determination of how, at variation of flow and of the geometrical characteristic of the intersections, variations of emissions from vehicles in motion or queuing and their respective concentrations, can be obtained.

The emissions of queuing vehicles tend to assume higher values when the flows into single entries, in conditions close to saturation, increase.

In conditions of flows lighter than 1100 veh/h, despite increasing the number of lanes, concrete variations in the concentrations are not observed.

At an increase in flow is associated, instead, a very accentuated effect of geometry on the concentrations, because idling vehicles in a queue determine an important increase in concentrations.

The results of this study can be an important reference for the monitoring of intersections in an urban context and to enable an environmental-type planning choice to be addressed, for signalized nodes in towns.

REFERENCES

BIGGS, D.C., AKCELIK, R. (1986) – “Estimation of car fuel consumption in urban traffic*” – The 13th Conference of the Australian Road Research Board*, vol. 13, pp. 123-132.

BOILLOT, F., MIDENET, S., PIERRELEÉ, J.C. (2000) – “Real-life Cronos evaluation” *– 10th IEE International Conference on Road Traffic Information and Control*, London.

COELHO M. C., FARIAS T. L., ROUPHAIL N. M. (2005) – “Impact of speed control traffic signals on pollutant emissions” – *Transportation Research Part D*, pp. 323-340.

FESTA D. C. , CIRIANNI F. (2000) – "Road traffic and air pollution: some results from statistical analysis and microscale modelling, in Urban Transport VI" – *International Conference "Urban Transport and the Environment for the 21st Century",* Cambridge.

FREY, H.C., UNAL, A., ROUPHAIL, N.M., COLYAR, J.D. (2003) – “On-road measurement of vehicle tailpipe emissions using a portable instrument” – *Journal of the Air & Waste Management Association,* n. 53, pp. 992-1002.

HALLMARK, S.L., FOMUNUNG, I., GUENSLER, R., BACHMAN, W. (2000) – “Assessing impacts of improved signal timing and transportation control measure using an activity-specific modeling approach” *Transportation Research,* Record 1738, pp. 49-55.

KHOUDOUR, L., LESORT, J.-B. (1990) – “PRODYN: trois ans d’experimentation sur la ZELT” – *Recherche Transports Securite*, n. 28, pp. 89-98.

LI, X., LI, G., PANG, S., YANG, X., TIAN, J. (2004) – “Signal timing of intersections using integrated optimization of traffic quality, emissions and fuel consumption: a note” – *Transportation Research Part D,* n. 9, pp. 401-407.

LIAO, T.Y., MACHEMEHL, R.B. (1998) – “Development of an aggregate fuel consumption model for signalized intersections” – *Transportation Research*, Record 1641, pp. 9-18.

MIDENET S., BOILLOT F., PIERRELEÉ J. (2004) – “Signalized intersection with real-time adaptive control: on-field assessment of CO_2 and pollutant emission reduction” *Transportation Research Part D*, pp. 29-47

RAKHA, H., DING, Y. (2001) – “Impact of vehicles Stops on Energy Consumption and Emissions” – *80th Annual Meeting of the Transportation Research Board*, Washington.

UNAL, A., ROUPHAIL, N.M., FREY, H.C. (2003) – “Effect of arterial signalization and level of service on measured vehicle emissions” *Transportation Research,* Record 1842, pp. 47-56.