ENVIROMENTAL ASPECT ON ROAD NETWORK: A MESOSCOPIC APPROACH TO DEFINE CO2 AND NOX CONCENTRATION

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Abstract

For some decades the air quality has received, both locally and globally, more and more attention from the scientific community and local authorities. It is well known that one of the major causes of pollution are vehicle emissions, and that they are closely related with driving style. According to studies that define vehicular emissions, it has been found that they contain a wide variety of pollutants, principally carbon monoxide and dioxide (CO and CO_2), oxides of nitrogen (NO_X), particulate matter (PM_{10}) and hydrocarbons (HC) or volatile organic compounds (VOC), which have a major long-term impact on air quality.
This paper describes the correlation between the traffic phenomena of road networks and the percentages of the major pollutants made by vehicle emissions. Results are based on real time data from a road network in France. The paper introduces a new methodological framework application to address the problem of estimating pollutant emissions for large congested urban networks related to real time traffic congestion phenomena. This has been made possible through the studies of impact of signalized intersection, analyzing possible scenarios that lead to decrease of vehicular emissions referring to the French Region of Seine-Saint Denis. Results obtained from a mesoscopic approach offer insights on the use of ITS systems, such as the intelligent traffic lights or Urban Traffic Control (UTC) systems, which are useful to road management policy in terms of pollution decrease. The use of a mathematical model allows the creation of measurement scales of the environmental risk considering signalized and un-signalized intersections on the road network. Also it is possible to compare the concentrations obtained from mathematical modelling obtained by real-time data acquisition with threshold values set by European and local Legislation.

1. Network pollutant emission evaluation

This paper presents an application of a mesoscopic methodological framework to address the problem of estimating pollutant emissions for large congested urban networks in a within-day dynamic context. The different results obtained by the method (survey, local observations and national estimates), although not systematic, question the relevance of the issue and the estimation of pollution calculations that may result.
The following examines various aspects of the calculations that affect the emission calculations.
Since few decades air quality has received attention gradually increasing from part of scientists, the directors and ordinary people. One of the major causes of pollution is vehicle

emissions; they are closely related with the style of driving. In the last decade, studies examined this effect through the use of innovative sensors system often fitted inside the passenger compartments of cars. As in real conditions, the emissions significantly differ from one driver to another: a style of aggressive driving causes a sharp increase in fuel consumption and, therefore, of emissions. The consumption may increase of 12 - 40% and CO emissions increases by about 8 times. Akcelic [2] simplified theory for signalized intersections defines analytical model to a large scale urban network.

For the application of the analytical model, each link of the network is divided in three different parts:

- L_A : the length of link where the vehicles are at free speed,
- L_B: the length of the link where the vehicles are stopped in the queue,
- L_C: the length of the link where the vehicles are in acceleration phase.

The emission estimation for a link k approaching a signalized intersection in the time slice T can be evaluated as follows:

$$E_{Tk}=(q_{Tk}L_a+Q_{nv}L_B+Q_{nv}L_C)e_a+(Q_{ns}LB)e_b+(QnsL_C)e_c \qquad [1]$$

with:

q_{Tk} = average hourly volume [veh/h] on link *k* at time *T*;

Q_{nv} = total hourly volume [veh/h] on link *k* that cross the intersection without any deceleration (i.e. vehicles not penalized by the traffic control): it is computed as the vehicles per cycle not subject to stop and go phases (*qnv*) multiplied for the number of cycles *C* during the considered time slice *T* (*T*/*C*);

e_a = calibrated specific emission function to be adopted in L_A

Q_{ns} = total hourly volume [veh/h] subject to stop and go phases on link k : it is computed as the vehicles per cycle subject to stop and go phases (*qns*) multiplied by the number of cycles during the considered time slice (*T*/*C*);

e_b = calibrated specific emission function to be adopted in L_B;

e_c = calibrated specific emission function to be adopted in L_C

The computation of Qnv, Qns (Akcelic 1987 and 1999) [3] and LB (Cantarella and Vitetta, 2010)[4] depend on the conditions, saturated or not saturated, of the link approaching the signalized intersection. The methodology applied to Bobigny case study is a developed model made by Gori et al. [5,6]. .In the case of saturated conditions, some vehicles can cross intersection only after a certain number of cycles (k), so vehicles emit pollutants according to the number of stop and go phases in the queue (L_B).The number of cycle lengths that occur before crossing the intersection can be estimate using formula :

$$K=Lb/L * [1/nvs] \qquad [2]$$

where

$$nvs= s*g/3600 \text{ (Akcelik, 1999)}$$

where the first ratio is the average number of vehicle in queue while the second one is the capacity of the intersection for each cycle length according to Akcelik. In according with the triangular speed-time diagram the eb can be estimated adopting the following simplified formulation:

$$eb=ec*LB/2 \qquad [3]$$

Air pollution from road transport in urban centres is amongst the main issues in urban areas. Remediation scenarios are based on pollutant emission inventory calculations, which needed the knowledge of air pollutant sources, emissions factors and activity indicators. Road traffic emission factors depend on the pollutant considered, vehicle type (light, heavy, two-wheeled), motorization type (diesel, petrol, hybrid, electric), vehicle model, operating conditions, age and Euro standards corresponding.

Case study on France network

Results obtained by Carteret et al. [7] research show differences in diesel motorization proportions between the national fleet (75%) and the regional fleet determined in this study (63%). The data comparison with the survey “Enquête Globale Transport” (EGT, 2010) is consistent with these results, and show more disparities between the departments of France, especially by Euro standard repartition. For example, the Hauts-de-Seine and the Seine-Saint-Denis departments present 18% average gap for passenger cars Euro 4 and 5. The study conducted by (Carteret et al., 2014) shows a great variability of the data relating to the vehicle fleet is local regional scale. The chart on Figure 1 provides the average annual development of vehicles with a breakdown by category of the Euro categories (combined diesel and gasoline). The category called "Non Interested" takes into account the other types of energy and hybrid vehicles. The category called "Non Information" includes the vehicles for which the category Euro is unknown.

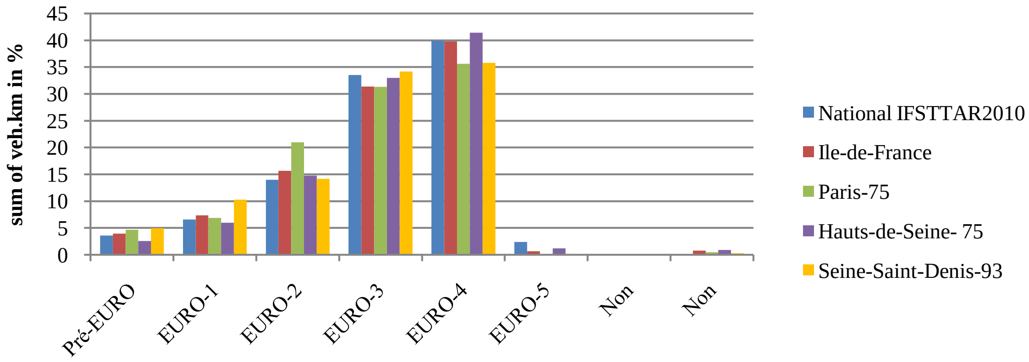

Figure 1 vehicles mix distribution on France

Currently, France is subject to inquiries from part of the European Commission regarding the values of non-compliance and the Limits of Regulatory and concentration of nitrogen dioxide (NO2) in the air, and for exceeding the national limit emissions OXIDES of nitrogen (NOx). A major source of air pollution is road traffic. In fact, studies on air emissions conducted by Airparif (Airparif, 2011) [8] show that in 2010, emissions from road traffic correspond to 25, 30 and 36% of Ile - de -France primary PM10, PM2.5 and PM1, 54% of emissions NOx, 2% of SO2 and 16% of emissions of NMVOC.
The department of Seine - Saint - Denis was chosen from several studies of the sector because of the large percentage of old vehicles in the fleet : in fact, the percentage of cars more than ten years to reach 57%, ten points more than Paris and the closest departments to it (Petite Couronne, Ile-de-France). These departments have a fairly uniform rate: 44% (Hauts-de-Seine) to 48% (Paris, Val - de - Marne Val - d'Oise). At the department of Seine - Saint - Denis, one of three vehicles has more than fifteen years, while the regional average is one in four. Half of the vehicles are third-hand, compared to 39% in the region and third in the Hauts-de-Seine. There has been a slow Fleet renewal compared to other states or regions. Furthermore the area of Paris has been chosen for its high percentage of high power drive. In fact, this rate is twice as high as that in the Paris region (11% vs. 6%). Finally, the Parisian park offers 43% more vehicles than 100 horses against 36% regional average. With 40% of the vehicles over 100 horses, Hauts-de-Seine also differ on this type of vehicle.On the contrary, the park Seine - Saint - Denis has less powerful vehicles (32%) (Courel 2010) [9]. the adopted network is Bobigny’s (the city is located in north west part of Paris, Ile-de-France), characterized by about 90,000 inhabitants, 43 centroids, 884 links, 306 regular nodes (with 20 signalized intersections). The total peak hour traffic demand has been estimated in about 16,000 vehicles using the standard four-step models and the 24-hours

distribution (Fig 2and 3) has been derived considering available traffic flow data of a similar city context.

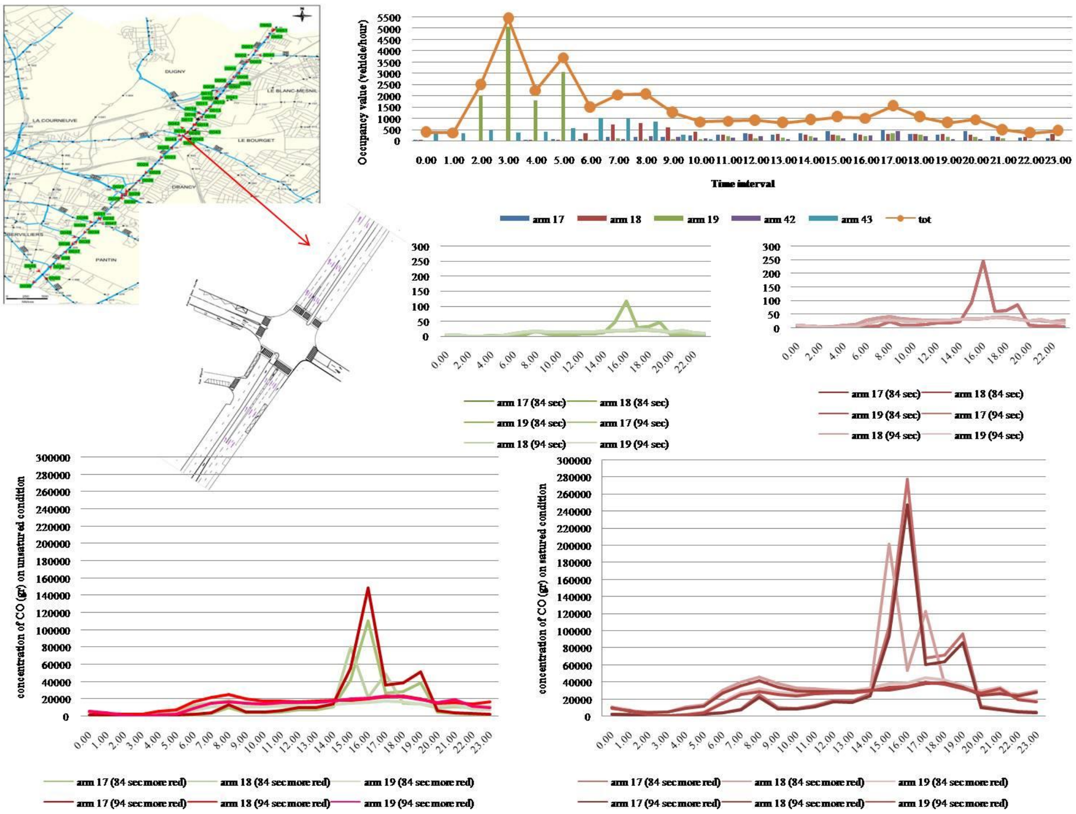

Figure 2: CO and NOx real time results on the signalised intersection in Bobigny

The dynamic traffic assignment (DTA) of the 24-hours (from 00.00-23.00) demand on the Bobigny network is output according to average density, average speed and queue length for each link and for each time interval, along with link attributes like length and free speed.
It has been output to the post-processor model in order to obtain for each time interval and for each link the average flow, the length travelled at free-flow conditions (at free speed) and the average speed of vehicles in the queue.
Emissions of CO, and NOx have been then computed considering the average link flow value for each time interval and the link divided between congested and uncongested condition (free-speed/length of the link travelled at free-flow conditions, the average speed of vehicles in the queue/ queue length). The peak values are compared considering two different scenarios of traffic light cycle (84 and 94 sec like total traffic light cycle). In the case of saturated conditions, some vehicles can cross the intersection only after a certain number of cycles (k), so vehicles emit pollutants according to the number of stop and go phases in the queue (Lb).

In particular it been exported to the post-processor model in order to obtain for each time interval and for each link:

- the average flow;
- the length travelled at free-flow conditions (at free speed);
- the average speed of vehicles in the queue.

The adopted emission functions required to compute the total emission value for each pollutant is:

- a step function with constant values of specific emission factor for different speed ranges;

- a continuous function obtained interpolating single values of specific emission factors corresponding to single speed values.

The graph below shows the variation of traffic flow for each arms (17-18-19-42-43) for the city of Bobigny on segnalised intersection 1604

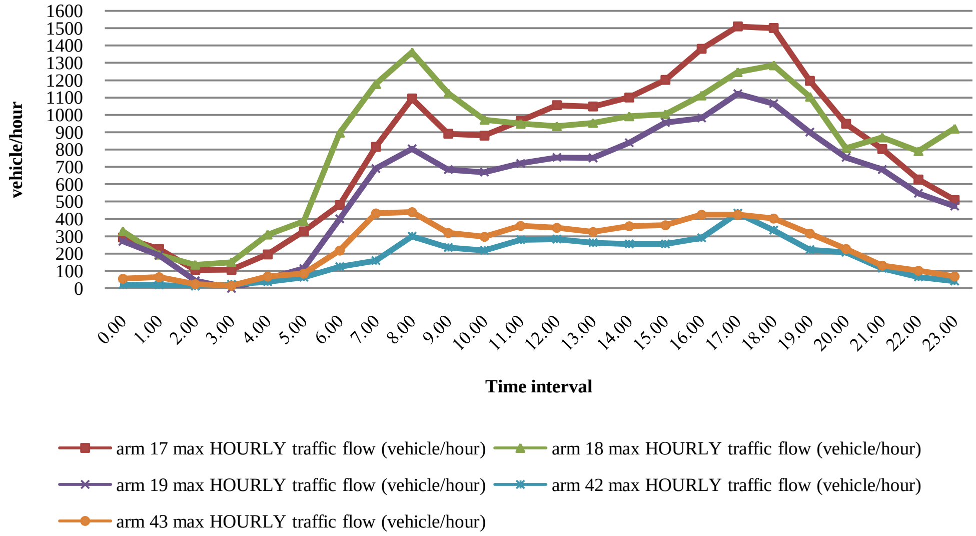

Figure 3: Distribution of traffic flow on arms of N° 1604 intersection of Bobigny (France)

The peak values are related to specific time range like 8am and 5:00 pm, relating to go on and came back to school, office and generally work action.
On equation [1]the Qnv is definite like total hourly volume [veh/h] on link k that cross the intersection without any deceleration (i.e. vehicles not penalized by the traffic control): it is computed as the vehicles per cycle not subject to stop and go phases (*qnv*) multiplied for the number of cycles *C* during the considered time slice *T* (*T*/*C*).
The traffic light setting are 84sec and 94 sec where:

- 84 seconds= 40 green time+39 red time +5 yellow
- 94 seconds= 49 green time+40 red time+ 5 yellow
- 84 seconds=39 green time+40 red time+5 yellow
- 94 seconds=40 green time+49 red time+ 5 yellow

Qns is definited like total hourly volume [veic/h] subject to stop and go phases on link k : it is computed as the vehicles per cycle subject to stop and go phases (qns) multiplied by the number of cycles during the considered time slice (T/C); The computation of Qnv, Qns (Akcelic 1987 and 1999) and L_B (Cantarella and Vitetta, 2010) depend on the conditions, saturated or not saturated, of the link approaching the signalized intersection.
In case of saturated conditions it is possible to define
Qnv=qnv=0

In case of unsaturated conditions:
Qnv= qnv T/C=qtk *(g/3600)

Considering the different traffic light settings is possible to consider the relative increases / decreases in concentration of CO and NOx in terms of gr/h.The other set where it is increased red time is showed on graphs below:

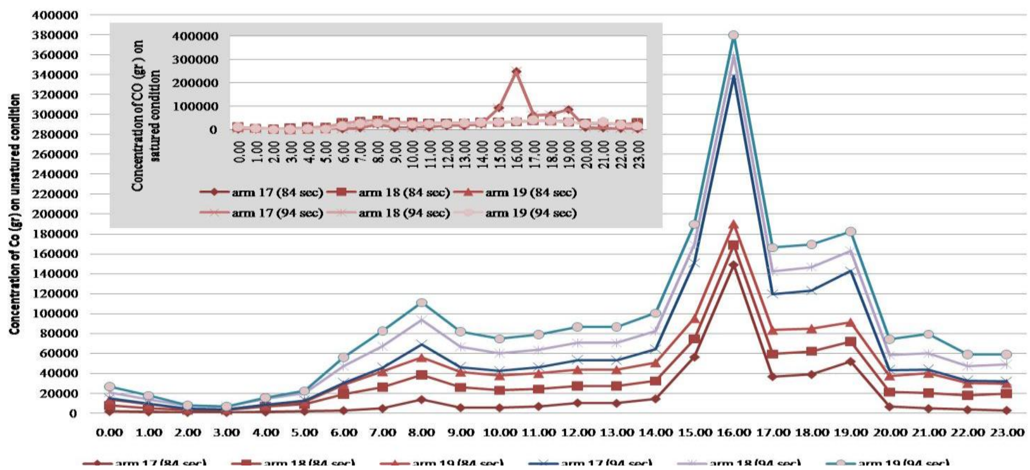

Figure 4: comparison of CO concentration on satured and unsatured condition on arms titled 17-18-19

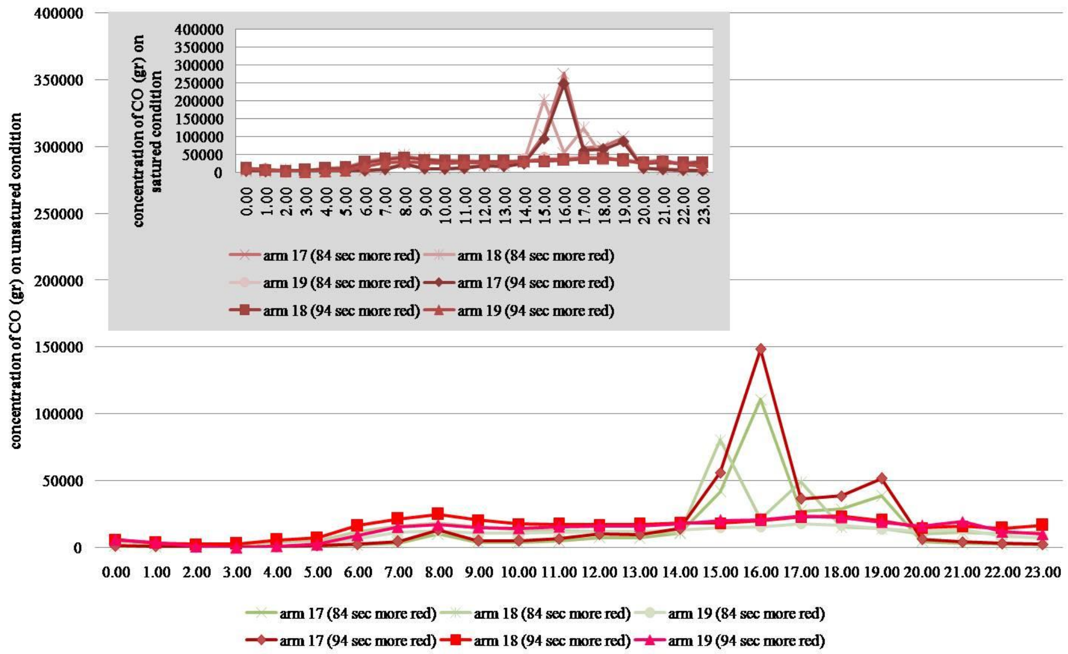

Figure 5: comparison of CO concentration on satured and unsatured condition on arms titled 17-18-19 with increase of red time

In terms of concentration it is clear that a increase of red time on traffic light cycle is related to increase of CO concentration with a peak value during 4:00-5:00 pm time interval , especially on arm 17 with a value of about 280000gr/h par Km of CO , instead the value in the unsaturated results with a decrease 50 % less than the saturated conditions. In terms of NOX concentration Increasing the red time on both the traffic light cycles 84 and 94 seconds ,the value of NOX concentration has a peak on 300 and 600 gr/hour par km on unsatured and satured condition respectively with a with a slight decrease in the value (about 10% of reduction) compared to the traffic-light cycle of 84 and 94 s, where the red time is 39 and 49 seconds . These results demonstrate that a change in the traffic-light cycle in terms of red time involve large variations in the rate of NOx produced between flow of vehicular traffic , that consideration be continued when it comes to CO concentration as shown previously.

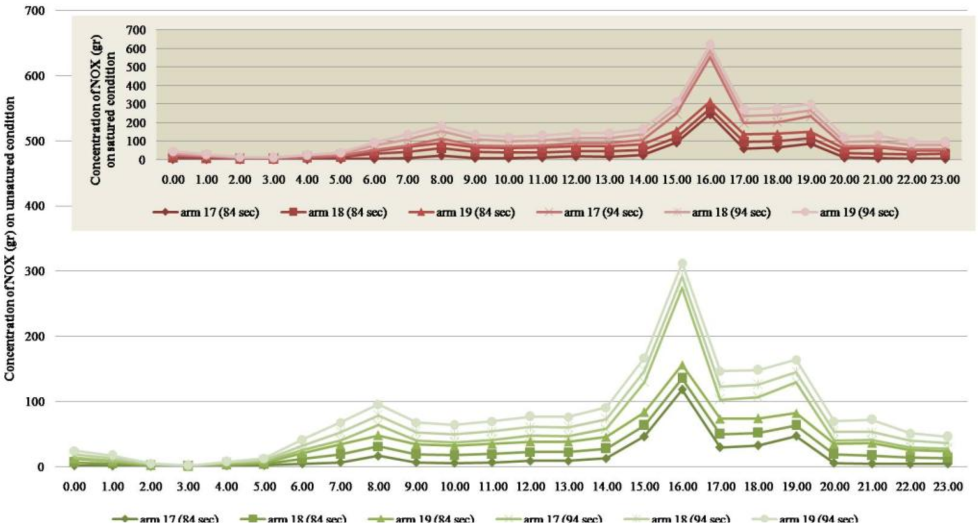

Figure 6: comparison of NO_X concentration on satured and unsatured condition on arms titled 17-18-19

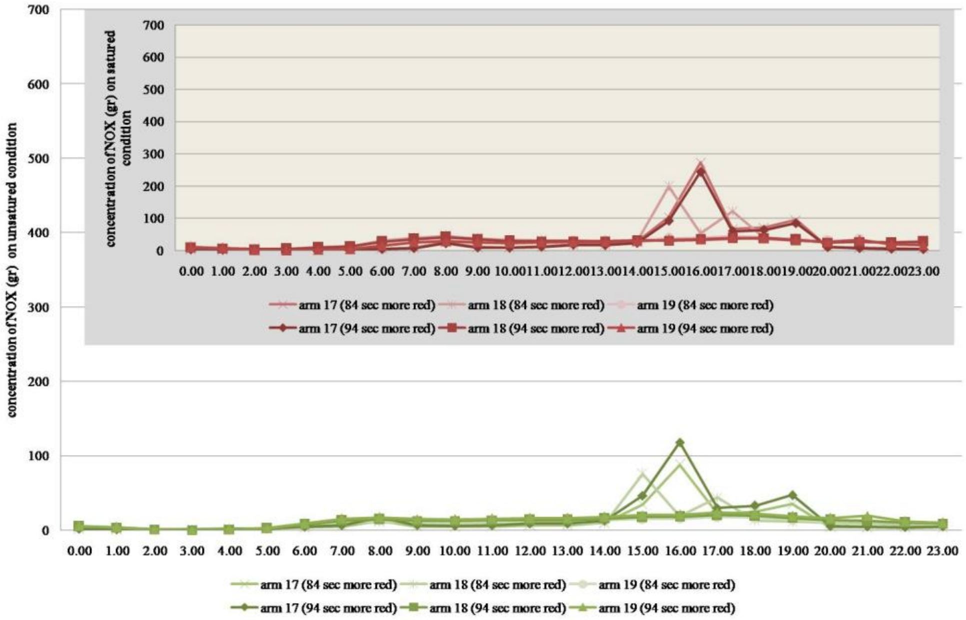

Figure 7: comparison of NO_x concentration on satured and unsatured condition on arms titled 17-18-19 with increase of red time

In fact it may be stated whereas there is an increase in the concentration of NOX in saturated conditions and this values increase more than 70%:it assists to a value of about three times greater in the un saturated and about twice in saturated conditions

Conclusion

The paper presents an application of analytical and dynamic mesoscopic approach to obtain reliable values of pollutant emissions in urban network area of Seine-Saint Denis.
The model applied to the city of Bobigny (France) is relative to signalised intersections. Results show its capacity to pass the limits of the current approaches, to obtain an accurate estimation of the emissions especially for some kind of pollutants (CO and NO_X) and its capacity to test different off-line and on-line traffic strategies in order to work both on emission and congestion. This approach defines the possibility of monitoring the peak values or allowable thresholds related to saturated and unsaturated conditions on the network.

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[10]COPERT software

[11]Google Maps