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ENVIRONMENTAL ASPECT ON ROAD NETWORK: A MESOSCOPIC APPROACH TO DEFINE CO₂ AND NO_x 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 is vehicle emissions, and that they are closely related with driving style. It has been found that vehicle emissions contain a wide variety of pollutants, principally carbon monoxide and dioxide, oxides of nitrogen, particulate matter and hydrocarbons or volatile organic compounds, 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. It 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 Le Bourget on French Region of Seine-Saint Denis. It offers 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 (and specific maps) considering a road network. It allows also the comparison of the concentration given by the mathematical modelling fed by real-time data with the European and local Legislation threshold values in terms of CO and NO_x concentration. The results can be integrated on Claire Siti system providing an integrated real-time information for drivers and local Municipalities

1. Network pollutant emission evaluation

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.

This paper presents an application of a mesoscopic methodological framework to address the problem of estimating pollutant emissions for large congested urban networks considering a within-day dynamic context. 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:

$$E_{Tk} = (q_{Tk}L_A + Q_{nv}L_B + Q_{ns}L_C)e_a + (Q_{ns}L_B)e_b + (Q_{ns}L_C)e_c \quad [1]$$

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 (q_{nv}) 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 (q_{ns}) 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 Q_{nv} , Q_{ns} (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. The methodology applied to Le Bourget case study is a developed model made by Gori et al. (2012 and 2013).

In particular on saturated conditions, some vehicles can cross the intersection only after a certain number of cycles (k), they, therefore, emit pollutants according to the number of stop and go phases in the queue (L_B). It is 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.

It is possible to implement the equation 1 considering each pollutant:

- 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 number of cycle lengths that occur before crossing the signalised intersection can be estimate using formula :

$$K = L_B/L * [1/nvs]$$

where

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

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 (1987). In according with the triangular speed-time diagram the e_b can be estimated adopting the following simplified formulation:

$$e_b = e_c * L_B / 2$$

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. Generally it is possible to consider :

$$a+bV+cV^2 \quad (V = \text{Km/h}) \quad [2]$$

Table 1 a) and b) Pollutant parameters values for different vehicles and road type

<i>gasoline light vehicle (50km/h)</i>		Light vehicle	CO (g/Km)	NOx (g/km)
CO(g/km)=5.0786-0.15623 V+0.001375 V ²	0,7046	GASOLINE <2.5 ton	0,745	0,949
NOx (g/km)=0.6089-0.01184V+0.0001100 V ²	0,2919	GPL < 2.5 ton	0,893	0,598
<i>Heavy gasoline vehicle</i>				
<i>diesel light vehicle (50km/h)</i>		Category	CO (g/Km)	NOx (g/km)
CO(g/km)=0.9337-0.0170 V+0.000961 V ²	3,3387	Urban road	70	04.05
NOx (g/km)=0.918-0.014V+0.000101 V ²	0,4705	Extra urban road	55	7,5

Case study on France network: an analytical model to compute emissions at signalised intersections

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 of oxides of nitrogen (NO_x). A major source of air pollution is road traffic. In fact, studies on air emissions conducted by Airparif (2011) show that in 2010, emissions from road traffic correspond to 25% of PM₁₀ and 54% of emissions NO_x on Ile-de-France . This paper is focused on Le Bourget network (in particular 3 signalised intersection) located in North West part of Paris, in the Seine-Saint-Denis department of the Ile de France region. The department of Seine-Saint -Denis was chosen from several studies because there is a large percentage of old vehicles in the fleet. In particular the percentage of vehicles with more than ten years old is 57% of total mix. Results obtained by Carteret et al.(2014) show different values of vehicle mix between the national fleet (75%) and the regional fleet determined in this study (63%), especially in terms of diesel vehicles. The Figure 1 describes the average annual development of mix vehicles on France .The category called "Non" includes the other types of energy and hybrid vehicles and it is also related to unknown category.

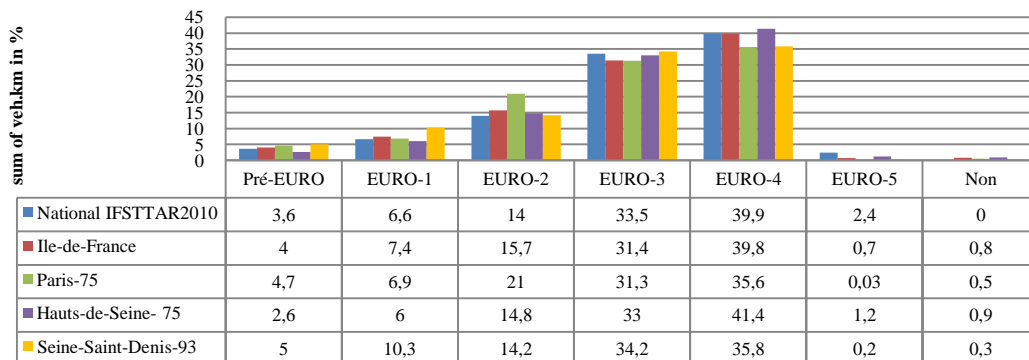


Figure 1 vehicles mix distribution in the Ile de France region

Le Bourget is a French town of 14,381 inhabitants located in the department of Seine-Saint-Denis in the Île-de-France. This paper show the variability of traffic flow and changing environmental aspect related to 3 different 4 arms intersection on the same network titled n°1602, n°1604 and n°1607 located near Le Bourget airport. In order to apply the explained methodology, the following settings have been assumed:

- 24 hours of dynamic traffic simulation (from 00:00 am to 11:00 pm);
- 2 sets of output of the dynamic traffic assignment (average link values for each time interval or dividing each link between congested and uncongested conditions)
- 2 pollutants (CO, NO_x)
- 2 types of emission function.
- 4 different traffic light cycle

The graph below show the 24-hours traffic flow distribution with a peak value of less than 10,000 vehicles/hour during the morning (08:00 am) and less than 14,000 vehicles/h during the afternoon (05:00 pm).

During the period of Salon International de l'Aéronautique and the l'Espace or the Fête de l'Humanité the peak of traffic flow increases by 40 %

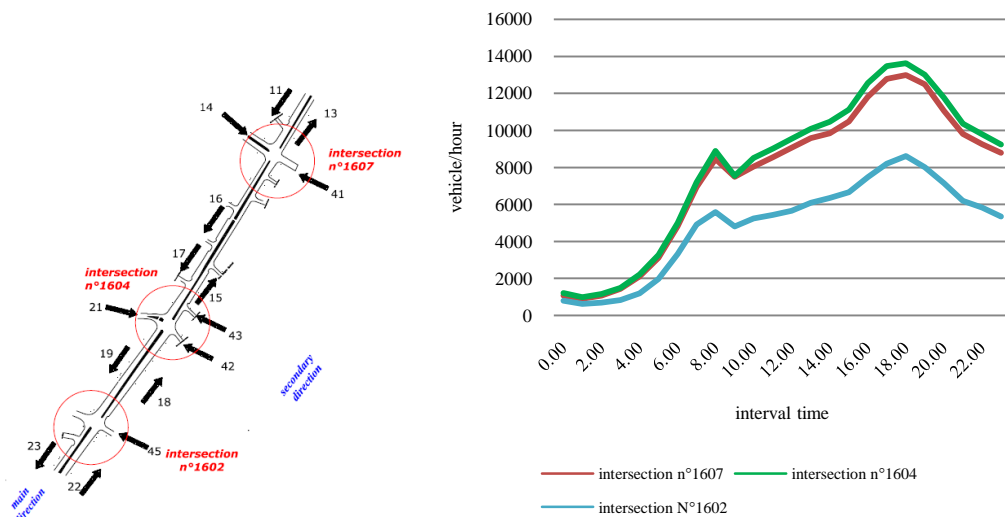


Figure 2: traffic flow distribution on Le Bourget networks

The real time traffic data took place through traffic sensors mounted on the road surface and also using cameras. CO, and NO_x concentration are calculated, considering congested and uncongested condition on main and secondary direction described on figure 2. The graphs below show an example of variation of CO (mg/m³) and NO_x (µg/m³) during interval time 00.00-23:00 on uncongested condition on main direction. It has been also applied in the real case of the Eur network (a district of the city of Rome) and of Brindisi network in Italy, comparing the obtained results with those obtained in previous studies, like describes on Table 2.

Table 2. Comparison between Italian and France network (network performances)

	Interval time analysis	Speed stand deviation [km/h]	Network Total Length [km]	avg speed [km/h]
Brindisi	06:00-23:00	7.50	251.50	52.40
Eur	06:00-10:00	11.50	91.60	29.90
Le Bourget	00:00-23:00	15.6	198.50	54.70

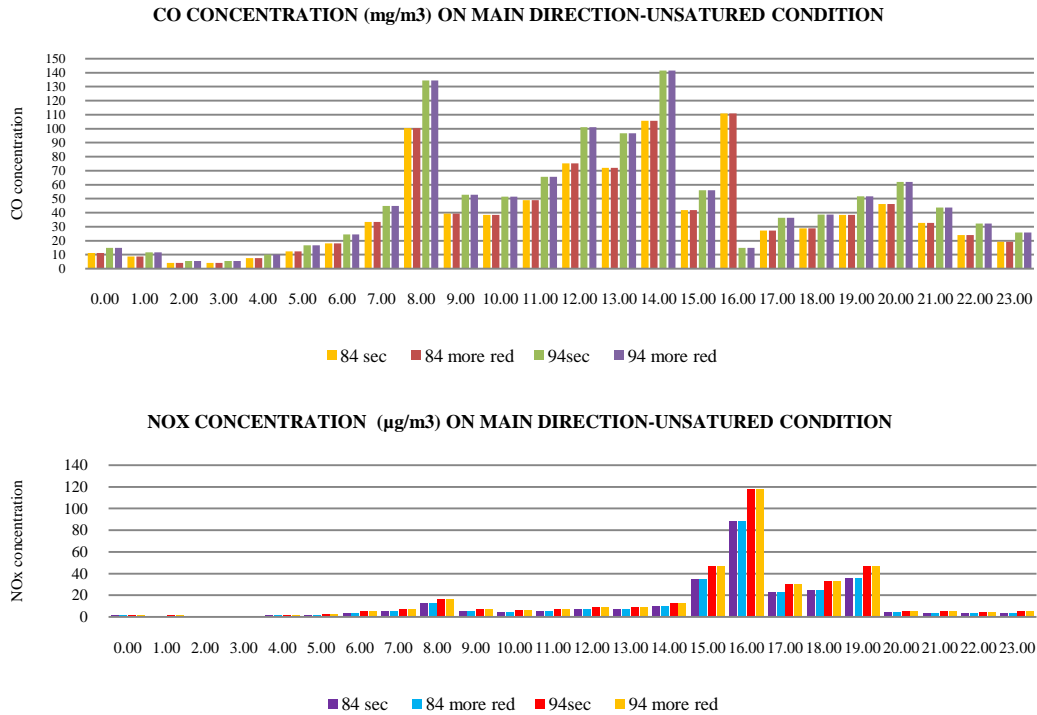


Figure 3: distribution on interval time of CO and NO_x concentration on main direction for unsaturated condition

The peak of traffic flow on 8:00 am and on 5:00 pm is related to the scholar and office activities on daily traffic flow. The results are also compared considering 4 different scenarios of traffic light cycle (84 and 94 sec).

On equation (1) the Q_{nv} is defined 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 (q_{nv}) multiplied for the number of cycles C during the considered time slice T (T/C). Results are obtained comparing four different traffic light cycle of 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

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

The evaluation of Q_{nv} , Q_{ns} (Akcelic 1987 and 1999) and L_B (Cantarella and Vitetta, 2010) depends on the conditions, saturated or not saturated, of the link approaching the signalized intersection.

In case of saturated conditions $Q_{nv}=q_{nv}=0$. In case of unsaturated conditions: $Q_{nv}= q_{nv} T/C=q_{tk} *(g/3600)$.

The results are focused on comparison of increase / decrease of CO and NO_x concentration considering also the alert level fixed on 10 mgr/m3 for CO concentration and 140 µgr/m3 for NO_x concentration (red line on graphs below).These alert level is related to human healthiness. Figures 4 and 5 describe the concentration of CO (mgr/km) and NO_x (µgr/km) on saturated and unsaturated traffic flow conditions, changing also traffic light cycle (4 different set of traffic light cycle) on main and secondary direction during 3 different interval time (00:00am-08:00am-05:00pm).

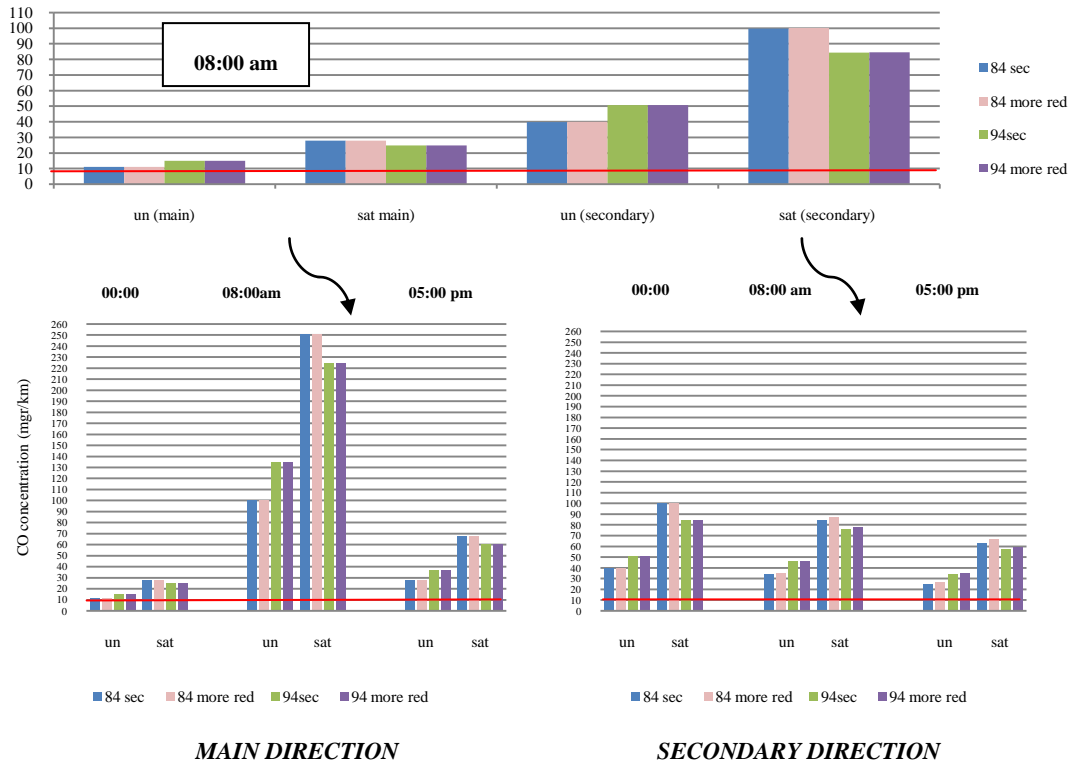


Figure 4: CO real time concentration(mg/m3) at 00:00am-8:00am and 05:00 pm - on the signalised intersections of Le Bourget changing traffic light cycle

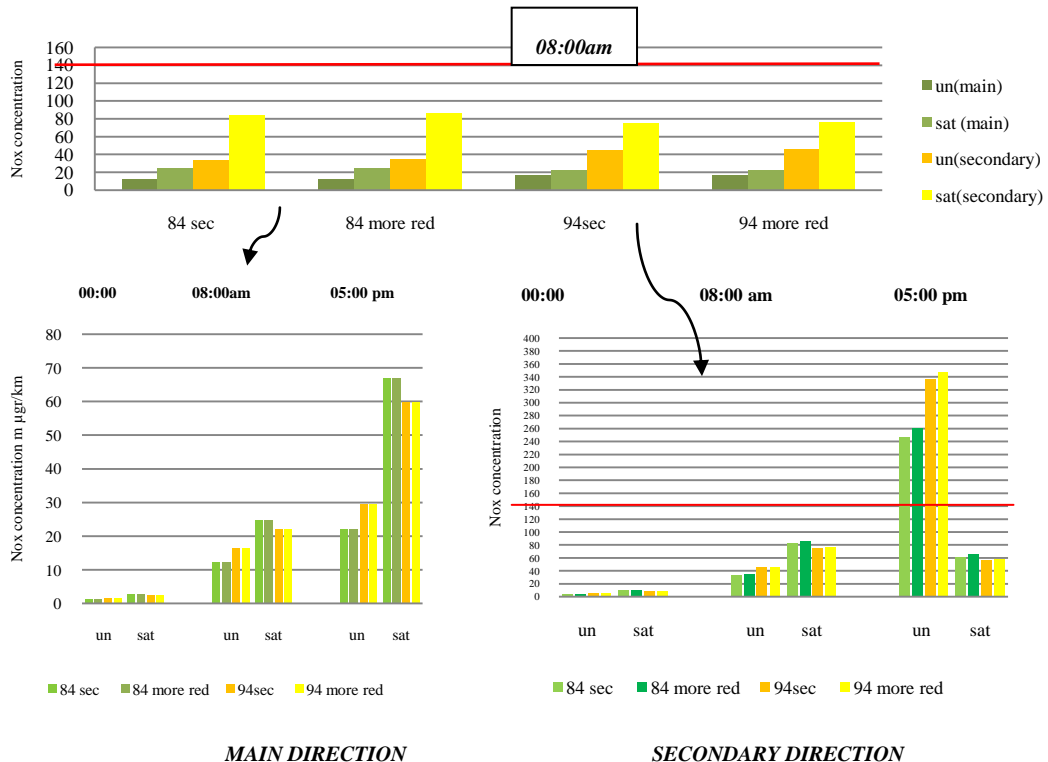


Figure 5: NOx real time concentration(µg/m3) on 00:00am-8:00am and 05:00 pm at signalised intersections of Le Bourget changing traffic light cycle

The CO concentration overcomes everywhere the fixed alert level . In fact the timely values consider an increase of 20-30%. It is related to the mix vehicles (especially related to percentage of EURO 1 and EURO 2) on this area. Considering a comparison of 4 different

traffic light cycle, the concentration of NO_x overcomes the alert level during the afternoon at 05:00 am, mostly on secondary direction. The results demonstrate the reliability of the adopted models and their capability to:

- estimate pollutant emissions with a higher level of analysis respect to the basic macroscopic approach that adopt average link speed data;
- distinguish between vehicles in queue and vehicles entering/exiting the queue (deceleration and acceleration phases);
- provide a map of the intersections showing the different degree of emission level as an operative instrument for the decision support process.

The results made a good step to create real time information for drivers and Municipality: in particular the results obtained through the mathematical approach to successfully implement networks maps considering also the variation in the rates of pollution (in terms of CO and NO_x concentrations) related to traffic flow. Such information can facilitate on the selection of the path to be run or consider environmental or road problems/accidents.

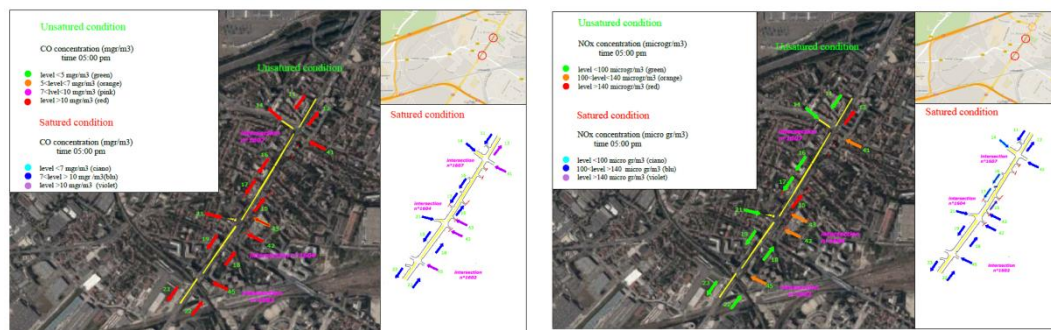


Figure 6: networks map layout considering CO and NOX concentration on saturated and unsaturated conditions, changing traffic light cycle

Conclusion

The paper presents an application of analytical and dynamic mesoscopic approach to obtain reliable values of pollutant emissions in urban network area of Le Bourget in Seine-Saint-Denis on France Region.

The lack of road monitoring units related to environmental parameters allows the application of mesoscopic analysis to estimate CO and NO_x concentrations considering only traffic flow. The results were made in a congested road network considering three signalized intersections where there is a real time monitoring of traffic data by traffic sensors and cameras. In this case the mesoscopic approach allows a preliminary analysis of the environmental side of the road. Other studies on European areas (for example Rome or Brindisi in Italy) confirm the validity of the results, comparing them with other mathematical models and with direct estimates through sensors. The traffic data are obtained by Seine-Saint-Denis Municipalities considering also CLAIRE-SITI system (smart system for Intermodal Transport).

This system integrates and processes data from a wide variety of different transportation systems (road traffic management, parking, transport fleets: bus, tram, ...). The system can monitor the operation of networks through any number of indicators relating for example to punctuality (the delay), regularity (anticipation), reliability (the speed), trafficking (the application flow, concentration), correspondence (transfer times)...etc...

This paper shows the first step of pollutant data acquisition for integrated transport system without sensors. In fact it also represents the various events describing the operating environment (building sites, events, major events, accidents). Built on a space-time model,

the diagnostic function informs jointly disturbances and abnormal operation that affect on various networks.

The mesoscopic approach applied on Le Bourget network shows comparisons of saturated and unsaturated condition for main and secondary direction.

At the same time results were compared ,changing 4 different traffic light cycle with two phases (especially increasing or decreasing red time).In particular the results show the capacity of the model to overcome the limits of the current approaches, to obtain an accurate estimation of the emissions especially for some kind of pollutants such as the carbon monoxide (CO) and the oxides of nitrogen (NO_x). It also shows the capacity of the model to test different off-line and on-line traffic strategies in order to work both on emission and congestion problems.

This analysis allows to implement in real time maps for the user to create awareness related to traffic flow and congestion phenomenon and about localized pollution degree.

These maps also allow local authorities to consider plans to change the traffic-light cycle or implementation of intelligent traffic lights .

These values can be compared with acquisition of a direct type in order to evaluate the effectiveness of the relief and secondarily be used even in areas where it is difficult that the control units can be located.

The acquisition on real time can expand the knowledge of the road network allowing a best resolution of the problem , especially in case of an accident.

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