Micro-Simulation of a Traffic Fleet to Predict the Impact of Traffic Management on Exhaust Emissions.

M. Madireddy[1], B. De Coensel[2], I. De Vlieger[1], D. Botteldooren[2], B. Beusen[1], B. Degraeuwe[1], G. Lenaers[1] , A, Can[2], A. Eijk[3]*

[1]Flemish Institute of Technological Research (VITO), NV, Boeretang, 2400 Mol, Belgium, madhava.madireddy@vito.be
[2] Ghent University, Sint-Pietersnieuwstraat 25, B-9000 Gent, Belgium
[3]TNO, Shoemakerstraat 97, P.O Box 6030, 2600 AJ Delft, Netherlands

Abstract

Despite the stringent air quality standards, urban traffic has been a major source of atmospheric pollution. It is therefore useful to investigate the potential effect of traffic management on emissions. Micro-simulation traffic models shall aid in developing traffic management systems and in urban planning practice. This study presents one such traffic model known as Paramics that can simulate a given traffic scenario based on the composition of the fleet and the characteristics of the roads, and outputs the speeds and the positions of each of the vehicles in the fleet. The output of Paramics was served as an input to Versit+, an emissions prediction model which can predict for each vehicle class, the temporal and spatial concentrations of the exhaust emissions. Before employing Versit+ for this study, the model was validated using the instantaneous emissions collected by VITO's On-Board Emissions and Energy Measurement (VOEM) system. Paramics and Versit+ were jointly used to examine two traffic management schemes in Nieuw Zurenborg, part of the 19th century city belt of Antwerp, Belgium. First, the effect of reduced speed limit in this network on per kilometre emissions is investigated. When the speed-limits for all the roads in this network were reduced, the model predicted that the emissions will be lower for CO_2, NOx and PM. Secondly, the effect of a green-wave (synchronization of traffic signal lights) along the N180, in this network was investigated. The two scenarios, with and without the green-wave were compared for emissions. The results showed that the presence of green-wave reduces the emissions by about 10%.

Introduction

Road transport is one of the major sources of atmospheric emissions and noise. The exhaust emissions are predominantly the byproducts of hydrocarbon fuel combustion which include oxides of nitrogen (NOx), particulate matter (PM), un-burnt hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2). Due to the increasing stringency of emissions standards by the European Environment Agency (EEA) over the past two decades, there has been a significant reduction in the road transport emissions. Despite this reduction, road transport activities still contribute significantly to environmental pollution, especially in areas with heavy traffic. Since increased demand for vehicles is increasing traffic on the roads, smooth traffic flow was key objective for traffic management authorities. But smooth traffic flow does not necessarily mean the emissions are minimized. Hence appropriate traffic management systems which also take into account the air quality effects are the need of the hour; accurate estimates are needed of concentrations and spatial distribution of air pollutants from the vehicles for such locations. This study presents a micro-simulation traffic model known as Paramics, an emissions prediction model known as Versit+, and their coupling. While earlier studies focus on the emissions at single intersection (De Coensel et al., 2007; Pandian et al., 2009), this study focuses on the overall emissions in the whole network.

Paramics: The Micro-simulation Traffic Model

Majority of the traffic management decisions are most often based on average flows on main arterial roads. However, small-scale changes in infrastructure and changes in driving behavior can have a large influence on traffic flows. For this purpose, microscopic simulation models are being increasingly used in the study of urban mobility problems.

Microscopic traffic simulation models aim to represent how vehicles circulate on the network, within an (urban) environment that is modelled in great detail (locations of curbs and stop lines, exact size of intersections etc.). Their outputs are the position, speed and acceleration of each vehicle on the network, at each time step. The model used for this study, Paramics, is based on behavioral rules, such as when to change lanes, when to overtake or how much distance to keep to the vehicle in front, form the core of the model. Its time step is 0.5s. When coupled with emission models for individual vehicles, microscopic traffic simulation models estimates the impact of detailed traffic management measures on emissions, taking into account the influence of braking and accelerating.

In this study, a micro-simulation network was constructed for the area of Nieuw Zurenborg, part of the 19th century city belt of Antwerp, Belgium. The road map of this network is shown in Figure-1 (left). The network was coded on the basis of Geographic Information Systems (GIS) data which comprises of roads, buildings, and aerial photographs, and traffic light timing data, supplied by the Antwerp police department. Further, traffic counts, supplied by the Flemish Department of Mobility and Public Works, were used to calibrate the traffic flows during morning rush hour. Figure-1 (right) shows a screenshot of the model. These traffic flows were inputted into Paramics by defining ‘zones’, from which traffic flows in and out to another zone.

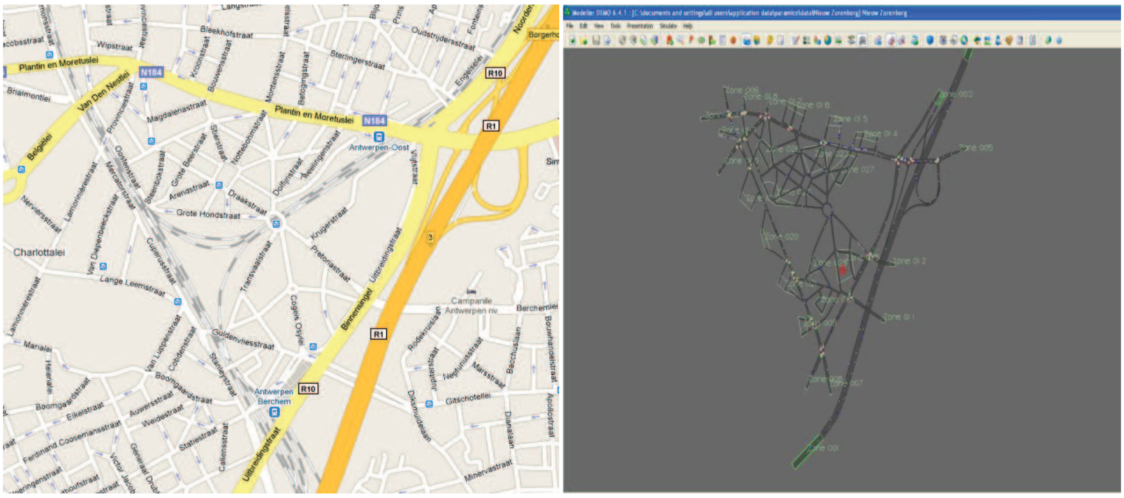

Figure 1: Map of the Nieuw Zurenborg (left) and representation of this area in Paramics (right).

Versit+: The Vehicle Emissions Model

Versit+ (Smit et al, 2007; Ligterink and De Lange, 2009), was developed by Dutch Organization of Applied Scientific Reserarch (TNO), in Delft, the Netherlands. The model consists of a set of statistical models for detailed vehicle categories that have been constructed using multiple linear regression analysis. The model is based on a very large database (12 000 tests on 153 speed profiles) with data for every vehicle class (heavy-duty, light diesel, medium-heavy duty, etc). However, the current version of Versit+ does not allow the user to choose among the Euro classes, fuel types, use of advanced emissions reduction technologies, etc. Hence, the model generates emissions for each vehicle class which represents an average or a typical vehicle. The inputs for the model are vehicle category, vehicle positions and speed for all vehicles in the network. These data can be obtained from measurements or from a microscopic traffic simulation model such as Paramics.

Versit+ defines a dynamic variable, which is a linear combination of velocity and acceleration and for a given driving cycle. Ten different regions were defined in the speed-acceleration map. These regions define the driving behavior of the vehicle such as idling, accelerating, aggressive highway driving, etc. Different emissions functions based on speed and acceleration were developed for each of these regions and the output of these emission functions is afterwards corrected for cold start, ageing and high emitters. Thus, the model is capable of relating emissions to driving behavior.

Validation of Versit+

Before Versit+ was used in this study for emissions prediction, a validation study was conducted on the model using the data obtained by VITO's On Road Emissions and Energy Measurement (VOEM) system. A better description of VOEM system was provided elsewhere (De Vlieger, 1997). This data were collected from the tests conducted on four diesel vehicles and a gasoline vehicle. The diesel vehicles tested were Citroen Berlingo, Citroen C4, Nissan Patrol and Opel Vivaro, while Volkswagen Golf is the only gasoline vehicle tested. The drive cycle used to collect this VOEM data was MOL_30, a 30 minute cycle which is a combination of ten minutes of city driving, ten minutes of suburban driving and ten minutes of highway driving. This cycle was chosen because it is more representative of the real-world driving than NEDC (New European Drive Cycle). The speed profiles of each of these vehicle tests were inputted into the Versit+, which gave the spatial continuous emissions predictions for CO_2, NOx and PM. The spatial emissions were then converted into temporal emissions based on instantaneous vehicle speed data. Then for every test, the results from the VOEM measurements were compared with those predicted by Versit+. Figure-3 presents the results predicted by Versit+ for a test conducted on the Citroen Berlingo, a diesel van tested on MOL_30 drive cycle. The correlations of each of the emissions were given in the title of the sub-plot (of figure-3) along with the type of emissions. It should be noted that Versit+ is able to predict the peaks of emissions quite well for both CO_2 and NOx although the true values of instantaneous emissions were over-estimated in most cases. Also, while the correlation of CO_2 is the highest (at about 0.90), the correlation of NOx is reasonable (0.80) and that for the PM was the lowest at 0.53.

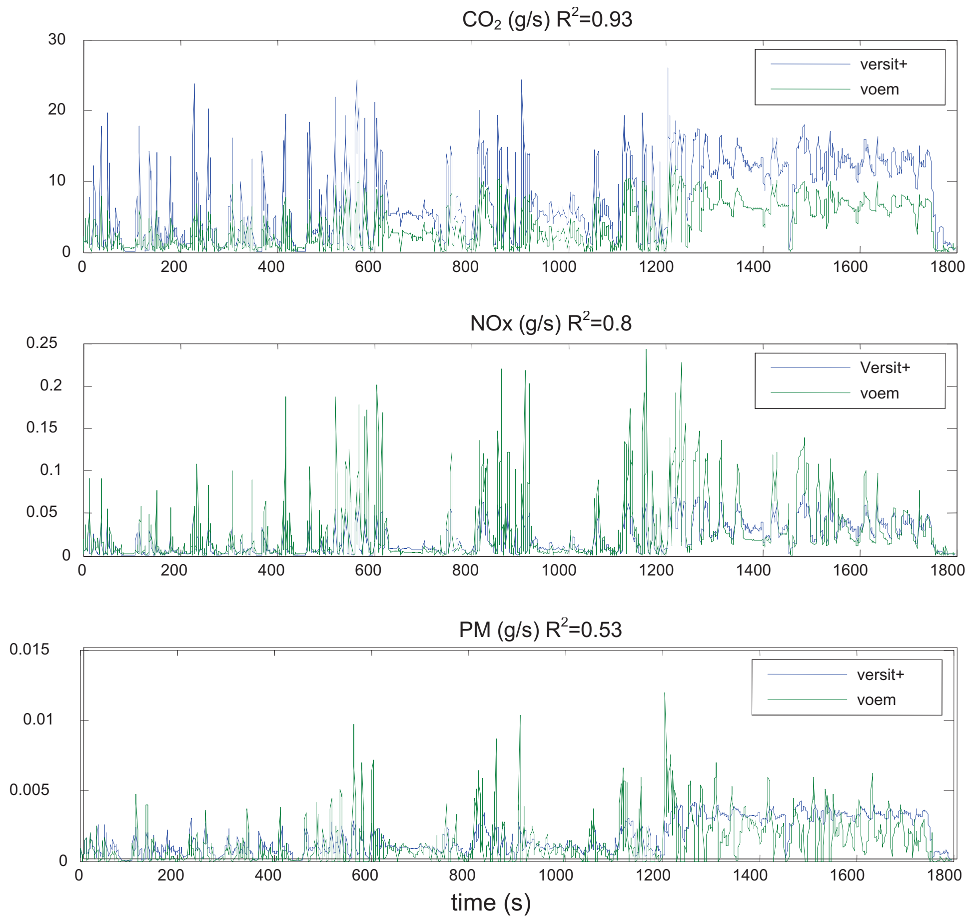

Figure 2: Comparison of the instantaneous data obtained from Versit+ with that of the measured data from VOEM for Citroen Berlingo on Mol_30 driving cycle. The correlations of the predicted and measured emissions are given in the title next to each pollutant.

The other tests conducted on Citroen Berlingo and other vehicles gave similar results with good predictions of CO_2 (average R^2 of 0.80). This indicates that the energy usage or fuel consumption was predicted well by the model. However, the predictions of NOx (average R^2 of 0.66) and PM (Average R^2 of 0.24) were not very good. The poor prediction of these emissions can be attributed to the fact that the model does not distinguish the emissions of gasoline vehicle from that of diesel vehicle and NOx and PM are predominantly a byproduct of diesel combustion. Also, the use of diesel particulate filters in some of the cars was not accounted for. In other words, the representation of 'average' car was not the same diesel car used for validation. But even with the poor predictions of NOx and PM for individual vehicles, Versit+ was chosen since the study focuses on total fleet composition in the network and this can be represented well by the database on which the model was based.

Investigation of Traffic Management Schemes

For this study, two different traffic management schemes were investigated: The effect of reduced road speed limit -and the effect of removing the synchronization of traffic lights along one of roads in the network.

Scheme-1: Effect of reduced road speed limit

To understand the effect of traffic speed limit on emissions, two scenarios are created using Paramics network file. The network in NewZurenborg is analyzed with original traffic at regular speed limits and a new scenario is created in the same network with speed limits reduced. The speed limit on the freeway was reduced from 100 kmph to 70 kmph, for the major roads the speed limits were reduced from 70 to 50 kmph, while for the minor roads the speeds were dropped from 50 to 30 kmph. From the results shown in Table-1, there was a significant reduction in all the emissions for both the vehicle classes. The CO_2 emissions dropped about 23% for cars and by about 41 % for HD vehicles.. HD vehicles showed about 32% reduction in both NOx and PM, while cars showed a reduction of 45% in NOx and 27% in PM emissions. This indicates that at reduced speeds in this network, there is a possibility of emissions reduction.

Table 1: Effect of reduced speed limit on network emissions

	Original Scenario		Reduced Speed	
Vehicle Class	Cars	HD	Cars	HD
CO_2 (g/km)	248.3	1241	191.9	736.5
NOx (g/km)	0.79	9.76	0.43	6.55
PM10 (g/km)	0.055	0.42	0.04	0.29

Scheme-2: Effect of green-wave on emissions

To understand the significance of synchronization of traffic lights along a road, the following scenarios were examined on N184 road or Plantijn & Moretuslei. The original scenario is the one with the green-wave, where all the traffic signals are co-ordinated. A second scenario was created by removing the synchronization or 'killing' the green-wave. The corresponding emissions in both the scenarios were compared. All the emissions were measured in g/km for both the vehicle classes (cars and medium-heavy duty vehicles) separately.

The CO_2 emissions increased by 10.3 percent for cars and 9.2 percent for medium-HD vehicles. Also the NOx emissions were increased by 9.9 percent and 9.2 percent, and PM10 emissions by 9.1 percent and 9.8 percent for cars and medium HD vehicles respectively. This indicates that the green-wave plays a significant role in emissions management since if the traffic flow is smoothened, there will be less acceleration and deceleration phases.

Table 2: Effect of green-wave along Plantijn & Moretuslei on emissions

	Original Scenario		Without Green-wave	
Vehicle Class	Cars	HD	Cars	HD
CO_2 (g/km)	328.3	1360	362.1	1486
NOx (g/km)	0.82	11.98	0.90	13.08
PM10 (g/km)	0.055	0.493	0.06	0.54

Conclusion and Discussion

This paper presented an emissions prediction model, Versit+. The model was validated using the real-time measurements and the model predictions were reasonable. Also, a micro-simulation traffic model known as Paramics was used to represent road-traffic in a selected network in Antwerp, Belgium. This network was then fed into Versit+ which generated the spatial and temporal distribution of each of the air pollutants, CO_2, NOx and PM.

The combination of these two models was used to investigate two traffic management schemes. The emissions model predicted that when the network speed-limit is reduced, the per kilometre emissions of CO_2, and thereby the fuel consumption can be reduced by about 25% for a typical fleet. This means that the vehicles are originally driving at a higher speed than is optimum for reduced emissions. In other words, there is originally significant acceleration and deceleration within the network. Reducing the speed-limit in this network could encourage driving at constant speeds and thereby promote eco-friendly driving. Also, if the 'green wave' on Plantijn & Moretuslei was removed, the emissions went up by about 10 percent.

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