COMBINED ASSESSMENT OF NOISE AND AIR POLLUTION CAUSED BY ROAD TRAFFIC

B De Coensel  Ghent University, Department of Information Technology, Ghent, Belgium
A Can  Ghent University, Department of Information Technology, Ghent, Belgium
M Madireddy  VITO, Transport and Mobility, Mol, Belgium, and Ghent University
I De Vlieger  VITO, Transport and Mobility, Mol, Belgium
D Botteldooren  Ghent University, Department of Information Technology, Ghent, Belgium

Abstract

Road traffic is a major source of noise and air pollution in the urban environment. Hence, traffic management solutions are increasingly called for to address problems of noise and atmospheric pollution. Because changes in traffic flow do not necessarily influence transport mobility, noise and air quality in the same way, there is a clear need for a combined approach. This paper reports on the construction of a model which combines microscopic traffic simulation with emission submodels for noise and air pollutants, and its application to a case study area. The approach presented could be of inspiration for the construction of guidance tools for urban planning practice.

1 INTRODUCTION

Traffic congestion causes travel delays, and thus imposes a substantial cost on society. Urban traffic management solutions, such as introducing variable speed limits, installing express lanes or optimizing traffic signal timing, are commonly used to moderate congestion in urban areas, where expanding the road network is not feasible. Although the potential of traffic management to reduce travel delays is widely accepted, the side-effects on noise and air quality are much less clear. Improving traffic conditions does not necessarily mean that there is less noise or air pollutant emission. Most studies on the influence of traffic management measures on emission consider air pollution and noise emissions at a single intersection at most. On the one hand, field experiments during which emissions are measured are quite complex to carry out. On the other hand, computational models for estimating emissions that return realistic results for the stop-and-go behavior of vehicles in urban environment have not been available until recently.

Small-scale changes in infrastructure can have a large influence on traffic flows; an example is the installment of green waves, i.e. synchronization of traffic lights at several consecutive signalized intersections. In order to study the impact of such measures on traffic flow, researchers are more and more considering the use of microscopic traffic simulation models. Coupled with models for instantaneous vehicle emissions, this approach offers great potential to study the influence of traffic management measures on traffic flow, noise and air pollutant emission simultaneously. In this paper, such a combined model is presented, and results for a case study are discussed.

2 GENERAL METHODOLOGY

2.1 Microscopic traffic simulation

Microscopic traffic simulation models consider the behavior of individual vehicles, as compared to macroscopic models that only consider the traffic flow as a whole. 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 most microsimulation models. They require much more effort to construct, as compared to
Proceedings of the Institute of Acoustics & Belgium Acoustical Society  
Noise in the Built Environment, Ghent, 29-30 April 2010

macroscopic models, because the (urban) environment has to be modelled in great detail (locations of kerbs and stop lines, exact size of intersections etc.). Therefore, they are only useful to study small to medium sized areas (e.g. part of a city). As a benefit, they allow to estimate the impact of detailed infrastructure changes, because the influence of braking and accelerating is taken into account. In this work, Paramics<sup>5</sup>, a commercially available microsimulation tool, is used as the modelling software. The output of the model consists of the instantaneous position, speed and acceleration of each vehicle at each timestep of the simulation (usually 0.5s or less).

2.2 Noise and air pollutant emission

The Harmonoise vehicle noise emission model<sup>4</sup> is used in this work to calculate instantaneous noise emissions. It produces point source sound power levels at a specific height above the ground, on the basis of vehicle type, speed and acceleration. Two sources of noise are considered: rolling noise generated by tire-road interaction, and powertrain and exhaust noise. Emissions are calculated on a 1/3-octave band basis; however, in this work we will only consider the total (A-weighted) source sound power level, noted as $L_W$. When the noise emission of a vehicle trip through the network is considered, we define $L_W^{avg}$ as the average source sound power level of the particular vehicle over the course of its trip (energetically averaged). In a similar way, the total source sound power level $L_W^{tot}$ for the trip of a single vehicle can be defined, which also takes into account the duration of the trip. The Harmonoise model was specifically developed with microscopic traffic simulation models in mind, and has been validated widely on an European scale, using a large number of vehicles, driven on a wide scale of road surface types. The vehicle classes defined in the Harmonoise model represent the average noise emission of the European vehicle fleet.

The VERSIT+ vehicle exhaust emission model<sup>5,6</sup> is used in this work to calculate instantaneous CO<sub>2</sub>, NO<sub>x</sub> and PM<sub>10</sub> emissions. This model, developed and supported by TNO, is based on more than 12500 measurements on vehicles of a wide range of categories and makes. It takes into account detailed effects such as cold started engines or the wearing of tires and brakes. A derived model (VERSIT+<sub>micro</sub>) was recently developed by TNO, specifically targeted at a coupling with microscopic traffic simulation models. For this, emission parameters of different vehicles (with varying fuel type) were aggregated into a prototypical vehicle emission model representing the average emission of the Dutch vehicle fleet. Only two main classes of vehicles are considered: light duty (including passenger cars) and heavy duty vehicles. As with the Harmonoise emission model, instantaneous emissions are calculated on the basis of vehicle type (light or heavy), speed and acceleration, extracted from the microscopic traffic simulation model.

It has to be noted that only emissions are considered in this paper; the propagation of sound and the dispersion of air pollutants are not modelled.

3 CASE STUDY

3.1 Construction of the microsimulation network

To illustrate the above methodology, the case study area “Zurenborg” was selected. The area is located in the southeastern part of the 19th century city belt of Antwerp, Belgium. Figure 1, left, shows a map of the region. The area is bounded by a freeway and a major road in the east, a major arterial road in the north and a railway track along the southwest. The major arterial road (the “Plantin en Moretuslei”) connects the city of Antwerp (situated at the west side of the area) with suburban areas in the east. This road has 2 lanes in each direction, and implements traffic signal synchronization. More in particular, during morning rush hour, all signals along this road operate at the same cycle time (60s to 90s, depending on the presence of pedestrians or buses), and the temporal offset of the cycle of each intersection is set up such that vehicles travelling from east to west encounter only green lights, when driving at the desired speed of 50 km/h. A similar signal setting is applied in the reverse direction during the evening rush hour.

Vol. 32. Part 3. 2010
A microsimulation network (Figure 1, right) was constructed on the basis of GIS data (roads, buildings, and aerial photographs) and traffic light timing data (from the Antwerp police department). Network wide traffic demands were calibrated for the morning rush-hour, based on traffic counts made available by the Flemish Dept. of Mobility and Public Works. Two types of vehicles (light and heavy duty) are considered, which are linked to the respective emission classes of the Harmonoise and VERSIT+ emission models. A railway track passes through the area, but this is not modelled. In order to show how this model can be used to investigate the influence of traffic management measures, three different scenarios are considered. The first scenario represents the current situation, with a green wave along the arterial road. The second scenario is identical to the first one, except for the traffic lights along the arterial road, which are not synchronized. This allows us to see the influence of the installment of the green wave on emissions. In order to desynchronize the signals, a small but random number of seconds was added to or subtracted from the cycle times. This way, a wide range of waiting times at each intersection is encountered over the course of the simulation run. In the third scenario, speed limits have been reduced as compared to the first scenario, from 50 km/h to 30 km/h along the arterial road. The signalized intersection offsets have been adjusted to this new desired speed, so there is still a green wave in this scenario.

3.2 Individual trip emissions

In this section, we will consider the total emission of vehicles during their trip through the network (simply called the trip emission). Because the northern arterial road is of main focus, only the emissions of the vehicles driving along this road, from east to west into the city, are considered for the analysis in this section. Table 1 gives an overview of the average trip emissions. Comparable trends are found for both light and heavy duty vehicles. It should be mentioned that the optimal
conditions could be different when the cross-flow direction is also taken into account, although this
direction carries much less traffic (200 to 300 vehicles/hour).

Considering noise, it can be seen that the average vehicle sound power would decrease by 0.6 (for
heavy duty vehicles) to 0.9 dB(A) (for light duty vehicles) when the green wave is removed. However,
because trips would take longer to complete, the average total emission would still
increase with 0.1 to 0.3 dB(A). The effect of the green wave on total noise emissions thus seems to
be negligible. On the other hand, reducing speeds has a clear beneficial influence on noise, with
reductions in total emission from 1.2 to 1.9 dB(A).

Considering air pollutant emissions, it can be seen that removing the green wave would increase
emissions by 10 to 13%, for all types of pollutants. When speeds are lowered to 30 km/h, the
picture is not that clear anymore: CO₂ and NOₓ emissions would drop, but PM₁₀ emissions would
rise by 11% to 19%. The slower speeds in scenario 3 cause the vehicles to consume less fuel and,
as a consequence, to emit less pollutants per second on average, but vehicles also take more time
to complete their trip. For CO₂ and NOₓ emissions, the longer trip duration is overcompensated by
the reduction in emissions per second, while this is not the case for PM₁₀.

Figure 2 shows the histograms of the trip emissions for light duty vehicles travelling along the main
arterial road. Overall, the most compact distributions are found for scenario 3, which indicates that
the flow is most homogenous with the lower speed limit of 30 km/h.

<table>
<thead>
<tr>
<th>Speed limit</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green wave?</td>
<td>50 km/h</td>
<td>50 km/h</td>
<td>30 km/h</td>
</tr>
<tr>
<td>Avg. trip duration</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>217s</td>
<td>274s (+26%)</td>
<td>311s (+43%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light duty vehicles</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lₚₐᵥ̅</td>
<td>93.9 dBA</td>
<td>93.0 dBA (-0.9)</td>
<td>90.4 dBA (-3.5)</td>
</tr>
<tr>
<td>Lₚₜₜ</td>
<td>117.2 dBA</td>
<td>117.3 dBA (+0.1)</td>
<td>115.3 dBA (-1.9)</td>
</tr>
<tr>
<td>CO₂</td>
<td>1329 g</td>
<td>1502 g (+13%)</td>
<td>1081 g (-19%)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>3.355 g</td>
<td>3.748 g (+12%)</td>
<td>2.188 g (-35%)</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>0.2236 g</td>
<td>0.2495 g (+12%)</td>
<td>0.2479 g (+11%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heavy duty vehicles</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lₚₐᵥ̅</td>
<td>106.8 dBA</td>
<td>106.2 dBA (-0.6)</td>
<td>104.4 dBA (-2.4)</td>
</tr>
<tr>
<td>Lₚₜₜ</td>
<td>130.6 dBA</td>
<td>130.9 dBA (+0.3)</td>
<td>129.4 dBA (-1.2)</td>
</tr>
<tr>
<td>CO₂</td>
<td>5804 g</td>
<td>6402 g (+10%)</td>
<td>4450 g (-23%)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>50.94 g</td>
<td>56.15 g (+10%)</td>
<td>39.52 g (-22%)</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>2.0326 g</td>
<td>2.2846 g (+12%)</td>
<td>2.4142 g (+19%)</td>
</tr>
</tbody>
</table>

3.3 Spatial distribution of emissions

In this section, we will consider the spatial distribution of noise and air pollutant emission. A
rectangular subregion with a size of 1400m by 350m, surrounding the northern arterial road, was
selected. Note that all vehicles are considered in this section, not only those that drive along the
arterial road from east to west. Figure 3 shows the spatial emission distributions for the first
scenario, and the differences between the other scenarios and the first scenario. For the noise
maps, hourly equivalent source power levels are aggregated to a grid of emission points, with a
spatial resolution of 5m. For the air pollutant emission maps, total emissions are aggregated into
bins with a surface of 25 m².

Removal of the green wave, or reduction of the limit speed, causes changes in noise emission that
are more or less evenly distributed along the arterial road. In contrast, changes in air pollutant
emission are more concentrated, because of the greater influence of acceleration on air pollutant emission. Removal of the green wave would result in much higher emissions (up to 50% locally) near the downstream arms of the intersections, where vehicles accelerate. In contrast, a speed reduction would have the highest impact in the stretches of road in between intersections.

**Figure 2** – Histograms of trip emissions for the three scenarios.

**Figure 3** – Spatial distributions of emissions along the arterial road (bins of 25m$^2$).
4 CONCLUSIONS

In this paper, a computational approach for assessing the environmental impact of traffic management measures was described, which combines microscopic traffic simulation with emission models for noise and air pollutants. Simulation results for a case study area were presented, including scenarios with a green wave and a speed reduction. It was found that changes in traffic flow do not always influence travel times, noise and air pollutant emission (CO$_2$, NO$_x$ and PM$_{10}$) in the same way. The results indicate the importance of a combined approach, when considering the environmental impact of urban traffic management decisions.

ACKNOWLEDGMENTS

This project was partly funded by the Flemish Policy Research Centre for Mobility & Public Works (Steunpunt Mobiliteit en Openbare Werken, spoor Verkeersveiligheid). Bert De Coensel is a postdoctoral fellow, and Arnaud Can is a visiting postdoctoral fellow of the Research Foundation–Flanders (FWO–Vlaanderen), the support of this organisation is also gratefully acknowledged.

REFERENCES

3. Paramics is developed by Quadstone (http://www.paramics-online.com).