

# Sound sensor network based assessment of traffic, noise, and air pollution.

Luc Dekoninck

Department of Information Technology, Ghent University, Ghent, Belgium.

Dick Botteldooren

Department of Information Technology, Ghent University, Ghent, Belgium.

Luc int Panis

Flemish Institute for Technological Research (VITO), Boeretang 200, 2400 Mol, Belgium  
Transportation Research Institute (IMOB), Hasselt University, Wetenschapspark 5 bus 6, 3590 Diepenbeek, Belgium

## Summary

All traffic related environmental burdens have a common source: traffic on nearby major roads and on the local roads near the dwelling. The actual exposure to traffic is typically relying on external data from the mobility field, in general government related public offices. The traffic data quality at the high-density roads is in most countries very good. Much less effort and by consequence much lower temporal and spatial resolution is available for the lower density roads and the off-peak hours. Traffic data quality is hence low where most people are exposed. Recent developments have also shown that the air pollution exposure and more specifically the particulate matter exposure is varying spatially and temporally with similar resolution as the noise exposure. The lack of data at low-density roads is hampering health evaluations in both disciplines. Exposure at the low-density roads can be improved by performing mobile and fixed noise monitoring. Mobile noise measurements by bicycle provide a new view on the local variability of both noise and air pollution exposure.

For air pollution exposure using instantaneous noise monitoring as a proxy for exposure to traffic enables the disentanglement of the variability due to changing traffic conditions and changing meteorological conditions. Several noise assessments techniques are compiled to increase the spatial and temporal resolution of the traffic attribution. Noise based air pollution exposure models are illustrated, enabling the prediction of the exposure to black carbon and ultrafine particles while being in-traffic and while staying at home.

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## 1. Introduction

The actual exposure to traffic is typically relying on external data from the mobility field, in general government related public offices. The traffic data quality at the high-density roads is in most countries very good. Much less effort and by consequence much lower temporal and spatial resolution is available for the lower density roads and the off-peak hours. Traffic data quality is hence low when and where most people are exposed. During the most sensitive activities for noise exposure (annoyance at home and sleep disturbance), the data quality is low. Less than 20% of the people live near the attributed roads.

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Exposure scientists lack spatial and temporal resolution at the low side of the exposure distribution. This lack of data does not only affect the quality of the noise exposure attribution in the assessments, but also for all other disciplines that rely on local traffic data. The most important field in that perspective is air pollution. Especially the exposure to ultrafine particles (UFP) and Black Carbon (BC) is sensitive to the traffic in the local street ([1][2][3]).

Since the diurnal pattern in the noise measurements are a direct measure for the diurnal pattern of the traffic densities, an interesting synergy emerges. Noise measurements can be a proxy for the local traffic and hence be used for estimation of the local exposure to traffic related air pollutants.

## 2. State of the art noise monitoring

Noise monitoring networks are now capable of measuring many different locations simultaneously at a highly reduced cost. Cheap measurements increase the spatial resolution in number of possible simultaneous measurements and enable long-term monitoring. A sample of different diurnal patterns is illustrated in Figure 1. It shows eight measurements throughout a city and its suburbs. The profiles show  $L_{A01,1hour}$ ,  $L_{A05,1hour}$ ,  $L_{A50,1hour}$ ,  $L_{A95,1hour}$  en  $L_{Aeq,1hour}$ , averaged over a period of two months. The diversity of the diurnal pattern is large with different patterns for different

statistical evaluations. The differences relate to a different combination of local and long distance noise sources. At a measurement point (mp 15) near a railway with building activities on the railroad track is defined by high  $L_{A05,1hour}$  due to the diurnal pattern of the train passages, the  $L_{A50,1hour}$  is defined by the building activities. Long distance sources can be characterized by investigating the  $L_{A95,1hour}$ . Differences between the statistical values and  $L_{Aeq,1hour}$  reveal the dynamics of the noise exposure and can be related to the traffic patterns. A small sample of typical locations throughout a city show huge variability and similar differences in exposure to air pollution can be expected.

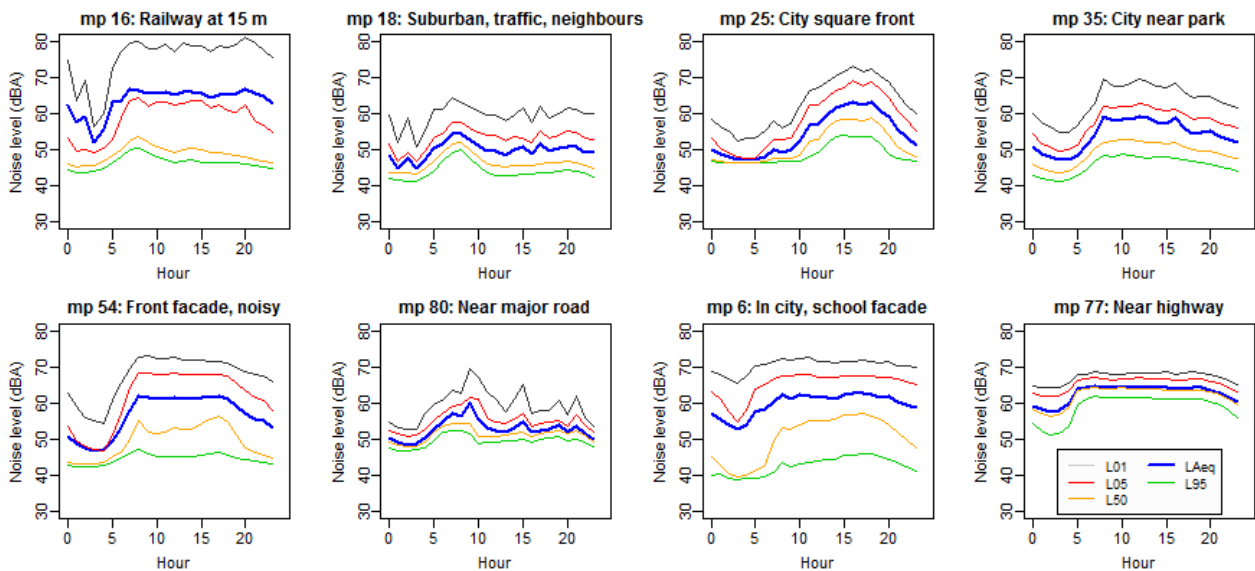


Figure 1. Eight long-term monitoring points throughout a city and its suburbs show a high variation in diurnal patterns and different relation between the statistical levels and  $L_{Aeq,1hour}$  (two-month averages by hour of day).

## 3. Mobile noise monitoring

More fixed measurement position increase spatial resolution but with mobile measurements on a bicycle, the variability along the road segments can be quantified. Between five and ten passages of mobile measurements result in standard deviations below 1.5 dBA for a specific traffic condition [4]. The relevance of noise exposure levels along the road segments was already established in previous work. Noise assessments along the roads enhanced the potential to predict the annoyance of the inhabitants at a dwelling.

High noise levels along the roads segments within 300 m of the dwelling increase the annoyance response of the inhabitants and vice versa [5]. The local traffic was included using trip simulation to improve the local traffic attribution. Simulations require qualitative origin-destination matrices and that information is not always available. With mobile measurements, these simulations could be replaced with actual monitored traffic densities. Combining mobile and fixed measurement stations enable the extrapolation of the mobile measurements to a full diurnal pattern ([6],[7],[8]).

#### 4. In-traffic BC and UFP prediction

An important application of the mobile noise measurements is found in the simultaneous measurement of noise exposure and particulate matter. The noise exposure is used as a proxy for the instantaneous traffic. The particulate matter exposure is highly influenced by meteorology and background concentrations.

Mobile noise measurements added the required instantaneous traffic attribution to disentangle the local variation into a local traffic component and the background exposure. [3]. One of the key features was the inclusion of spectral evaluations of the bicyclists' noise exposure. The noise exposure can be separated in a low frequency engine related component  $L_{OLF}$  and an evaluation of the speed of the traffic flow related to the high frequent rolling noise  $L_{HFmLF}$  (see figure 2). Traffic dynamics of the vehicle flow can be measured and the bicyclists' exposure is sensitive to the traffic dynamics [3].

The spatial average of  $L_{OLF}$  and  $L_{HFmLF}$  are shown in Figure 3 for the city of Ghent, Belgium, illustrating the potential to identify both the traffic density through the engine related noise and the speed of the traffic flow through  $L_{HFmLF}$ .

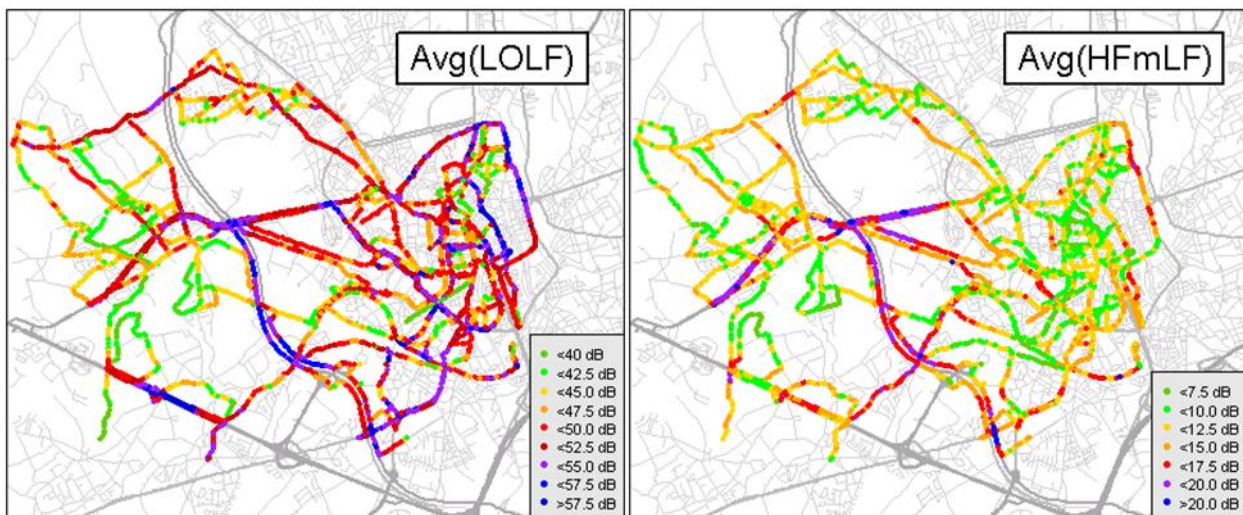


Figure 3. Spatial variation of the mobile noise measurements: engine related noise ( $L_{OLF}$  (left) and rolling noise related noise  $L_{HFmLF}$  (right). Average over a measurement campaign over a full year (about 180 h of data).

At this point it becomes possible to perform mobile measurement campaigns to cover a full network and by doing so add unprecedented spatial resolution to the traffic assessments, including the traffic dynamics. With the instantaneous Black Carbon (BC) prediction model, this results in an

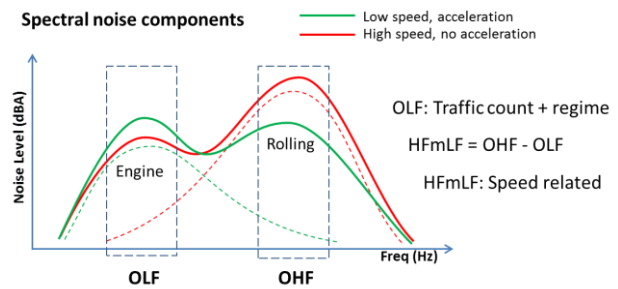


Figure 2. Decomposition of engine and speed related noise exposure in mobile measurements.

The same technique was used in a shorter measurement campaign in Bangalore, India, now including BC and ultra-fine particle (PN). The additive approach was validated in extreme traffic conditions from both air pollutants [9].

The variability of the air pollution exposure due to meteorological effects is high. By consequence, the mobile measurements do not have to reach a standard error below 2 dB to reach a good prediction of a yearly averaged BC exposure along the road network. Only three to four passages are necessary to achieve a yearly averaged BC exposure with an accuracy of  $500 \text{ ng/m}^3$  at any point along the road network [10].

in-traffic exposure map for bicyclists as well. With a yearly meteorology adjusted exposure model, it is possible to predict the yearly average BC exposure over the network [10].

## 6. Noise and BC at a dwelling façade

With the accumulated evidence to predict air pollution exposure using noise as a proxy, an experiment was set up to measure simultaneous the noise exposure and the BC exposure at the dwelling façade. A narrow city in-bound road with dense public transport (busses) was chosen as a first test. The BC exposure and the noise exposure is evaluated at a 15 minute interval to acquire sensitivity to the duration and the traffic dynamics during the rush hour. Evaluations at a temporal resolution of one hour would not fit that criterion. To increase the temporal variability in the

measurements, the measurements included several official holidays and a low traffic period (two weeks of Easter holiday with adjusted bus schedule). The background Black Carbon concentration was also highly variable during the measurement period. The diurnal profiles of the Black Carbon exposure and the noise levels are visualized in Figure 4. Note the higher variability of the noise evaluations during the morning rush hours, detecting the differences in the rush hour during holidays and weekends.

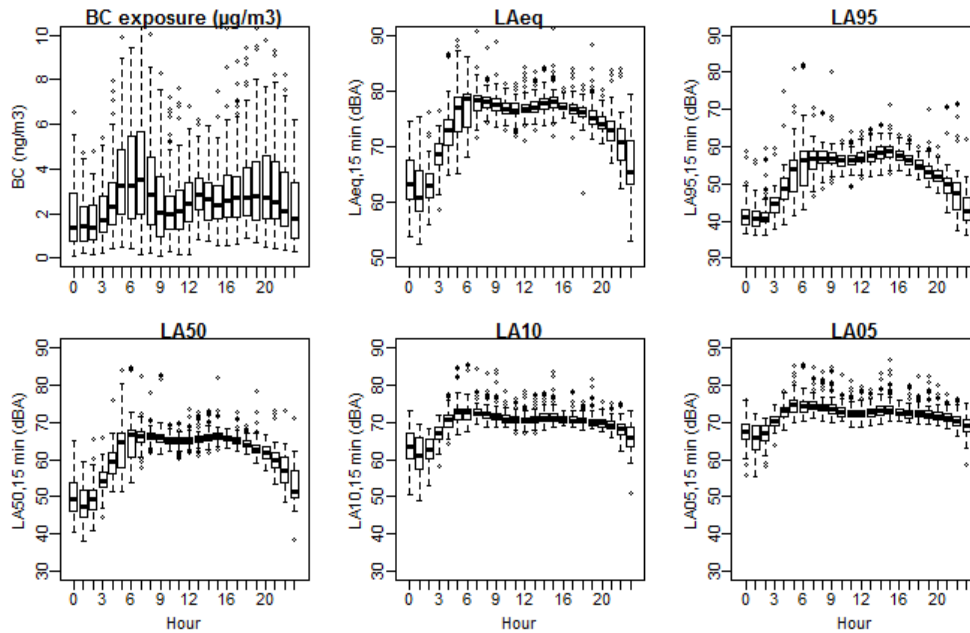


Figure 4. Diurnal variation of Black Carbon,  $L_{Aeq,15min}$ ,  $L_{A95,15min}$ ,  $L_{A50,15min}$ ,  $L_{A10,15min}$  en  $L_{A05,15min}$  for a period of six weeks, including weekends and the Eastern holiday period.

The additive approach, successful for the bicyclist's exposure, is tested on this data set as well. The gam model technique, based on  $L_{Aeq,15min}$ , reveals the correlations between traffic and BC exposure. The gam model is built in two variants, the  $gamBC_{raw}$  is using the measured BC exposure, a  $gamBC_{loc}$  is using a background adjusted BC exposure according to [3]:

$$BC_{loc,fac} = BC_{raw,fac} - BC_{excess,bkg}(t)$$

The background exposure is the strongest component in the  $gamBC_{raw}$  model, but adjusting for the background results in the  $gamBC_{loc}$  model remove the sensitivity of the model for the background exposure. The  $L_{Aeq,15min}$  value at the facade becomes in the  $gamBC_{loc}$  model the

strongest component. The splines of the two gam models illustrate this in Figure 5. The  $gamBC_{raw}$  model (top row) shows the strong dependency to the nearest available background BC measurement station. The bottom row shows the  $gamBC_{loc}$  model with the strong reduction of the background sensitivity and an increased sensitivity for  $L_{Aeq,15min}$  and the instantaneous wind speed.

The additive approach, valid for the bicyclists' exposure, will be useful as well at the facades of the dwellings. Using spectral evaluations to improve the gam models at a dwelling facade in future work.

Disentangling the local traffic and the background contribution in a model capable of predicting BC facade exposure levels at multiple dwellings with

different diurnal patterns and different street canyon properties will require extensive a

combined noise and air pollution measurement campaign.

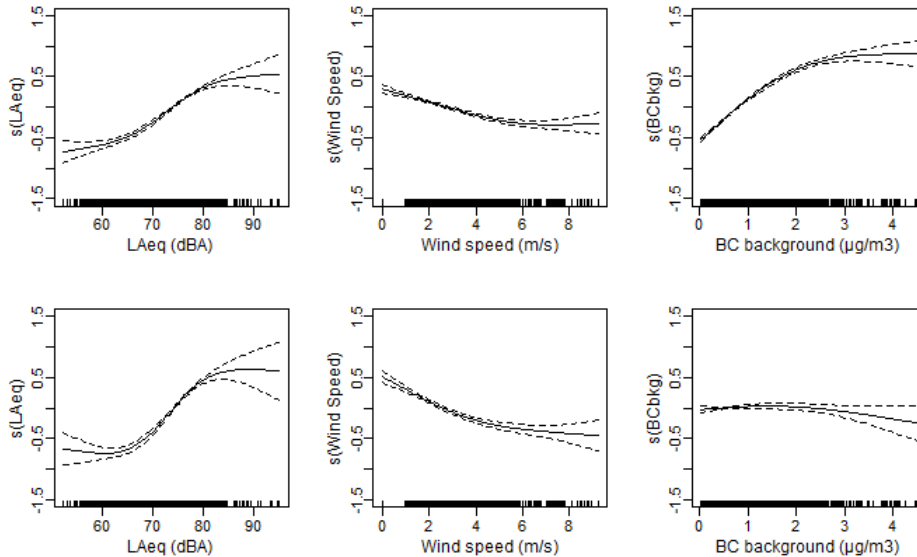


Figure 5. Splines of Diurnal variation of Black Carbon,  $L_{Aeq,15min}$ ,  $L_{A95,15min}$ ,  $L_{A50,15min}$ ,  $L_{A10,15min}$  en  $L_{A05,15min}$  for a period of six weeks, including weekends and the Eastern holiday period

## 7. Multidisciplinary applications

The mobile noise measurements and existing noise mapping combined with long-term noise monitoring at fixed locations can provide a proxy to traffic exposure with impressive resolution in space and time and a spatial extent of agglomerations and their vicinity. The joint efforts of noise assessments and modelling techniques at the Acoustics Group at INTEC (UGent), will be able to provide a highly detailed noise assessment and monitoring. Many components are published recently ([6] [7] [11] [12] [8] [13]).

The noise based traffic evaluation relates to multiple disciplines. Within the noise discipline, for both annoyance and sleep disturbance, we require more spatial and temporal detail of the exposure, adding detail information on events and local dynamics. In traffic related air pollution, instantaneous traffic assessments through noise assessments enable the disentanglement the variability in the air pollution measurements into traffic and meteorological influences [3][9][10]. This is necessary to resolve the bias in the air pollution measurements due to the huge influence

of meteorological conditions in the mostly to short mobile air pollution measurement campaigns. Simultaneous measurements result in add extreme value to the air pollution field.

Increased resolution in the exposure assessments will result in improved assessments of the epidemiological data with the potential to resolve mutual confounding between noise and air pollution [15].

## 8. Conclusions

Noise measurements are capable of quantifying the local traffic and local traffic dynamics instantaneously in a high spatial resolution by using mobile measurements and in a high temporal resolution in fixed measurements. Combining the data and models, results in spatio-temporal maps. Measuring multiple agents in a sensor network results in synergies, surpassing the acquisition and data flow advantages. Large benefits emerge for all involved disciplines and strong improvements in health effect evaluations can be expected.

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