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Noise measurements as proxies for traffic parameters in monitoring networks

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Summary

Due to their typically high traffic intensity, urban ring roads are characterized by high noise levels and high concentrations of airborne pollutants. Hence, such locations are often priority measurement locations in monitoring networks. Unfortunately, the high purchase and operational cost of most airborne pollutant sensors severely limits the number of such sensors that can be deployed, leading to a (too) limited spatial resolution. The present research describes how low cost microphones could be used as proxies for traffic parameters. We consider a 7 day measurement campaign for an urban ring road in Antwerp, Belgium, where noise levels and traffic parameters were measured simultaneously. Noise indicators are calculated and are used to construct models to estimate traffic parameters. It was found that a proper choice of noise indicators allows for the accurate estimation of traffic intensities and means vehicle speeds, both for light and heavy vehicles. Furthermore, the usefulness of these estimated traffic indicators in a monitoring strategy is assessed. Carbon monoxide, hydrocarbon and nitrogen oxide emissions are calculated with the pollutant emission model Artemis. By comparing the Artemis outputs when using measured and estimated traffic parameters as input, the suitability of the constructed models is assessed. Estimations of emitted airborne pollutants were shown to be accurate, leading us to conclude that there are indeed significant opportunities to use noise measurements as proxies for traffic parameter measurements for the estimation of airborne pollutant emissions.

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1. Introduction

Due to their typically high traffic intensities, urban ring roads are characterized by high noise levels and high concentrations of airborne pollutants [1-2]. Those two types of environmental stressors have an adverse effect on the health of drivers during their trips, and on dwellings living in the vicinity. Hence those locations are often priority measurement locations in monitoring networks. Unfortunately, the high purchase and operational cost of most airborne pollutant sensors severely limits the number of such sensors that can be deployed. This leads to a too limited spatial resolution for airborne pollutants and the need for alternative methods [3].

The present research describes how low cost microphones could be used as proxies for traffic parameters. Consumer electronics microphones come at a very low-cost, and were shown to be quite accurate for environmental noise monitoring [4]. The underlying idea is that modifications in traffic situations (formation of a congestion, increase of number of trucks, etc.), will modify noise environment in a way that can be captured through relevant indicators [5-6]. Traffic parameters can then be used to estimate pollutant emissions.

We consider a 7 day measurement campaign for an urban ring road in Antwerp, Belgium, where noise levels and traffic parameters were measured simultaneously; see Section 2. Noise indicators are calculated and are used to construct models to estimate traffic parameters. Carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO_x) emissions are then calculated with the pollutant emission model Artemis [7]. Emissions are successively calculated with measured and predicted traffic parameters as input and results are compared; see Section 3. Results are discussed and some directions for further researches are given in Section 4.

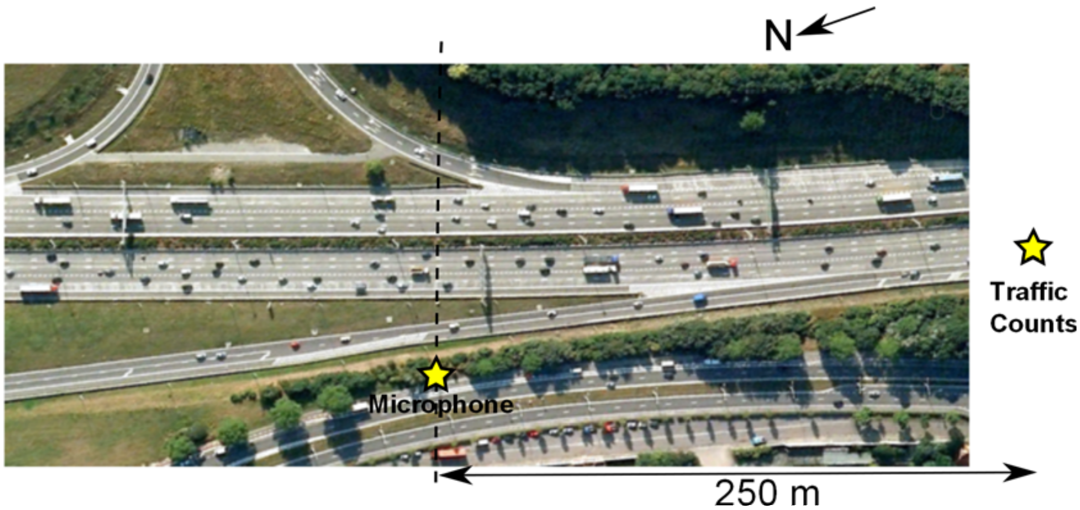

Figure 1. Experimental site

2. Method

2.1. Experimentation

Simultaneous measurements of traffic counts and noise levels were performed during 7 consecutive days between 13/01/2010 and 19/01/2010, on the ring road of Antwerp, Belgium. At the location, a 2-by-5 lane road is present that carries very high traffic intensities, with more than 126000 vehicles/day for the North-South direction, including on average 15% heavy vehicles. The ring road is usually congested during both morning and evening rush hours. The speed limit is 90 km/h, but vehicles often exceed this limit when traffic is free. Traffic recordings consisted of the 1 min evolution of light vehicle traffic intensity Q_{LV}, light vehicle mean speed V_{LV}, heavy vehicle traffic intensity Q_{HV}, and heavy vehicle mean speed V_{HV}. Note that only traffic recordings measured in the North-South direction, which corresponds to the closest direction seen from the microphone, will be used for the study.

Noise measurements were performed at a height of 4 m and 30 m from the closest lane; see Figure 1. The ring road is not the only road in the vicinity of the microphone; nevertheless, as traffic in other roads is limited and as the microphone is placed on a bank, the ring road can be considered as being the main noise source. Sound pressure levels were expressed in 1/3 octave bands (21 bands from 20 Hz to 20 kHz), with an integration period of 1s. High-quality instrumentation was used, consisting of ½" microphone of Brüel&Kjær (type 4189), in combination with pre-amplifiers and professional weather protecting outdoor units. Traffic and noise indicators are calculated from the measurements, aggregated over 10 min periods.

Finally, a meteorological station provided information on air temperature, wind speed and rainfall intensity. Rain was observed during one day only (17/01). An effect of rain on some noise indicators can be expected, as it shifts sound to higher frequencies [8].

2.2. Noise indicators

A large set of indicators was calculated from the 1s evolution of 1/3 octave bands sound levels, to cover the range of temporal and spectral variations. We report here only the indicators that have been found to be the most relevant:

- For A-weighted sound levels, and for each of the 21 1/3 octave bands f in the range {20Hz,…,20kHz}, we calculate the equivalent sound pressure level L_{Aeq} and L_f, and the statistical levels $L_{A,x;y,}$ and $L_{x;y,f}$. $L_{x;y}$ represents the average of sound levels between the percentiles L_x and L_y, L_x being the sound level exceeded x % of the time. We calculate $L_{x/y}$ for each y=x+10, with x varying in steps of 10 from 0 to 90. For example, $L_{0;10,125Hz}$ is the average of the $L_{125Hz,1s}$ values for the 10% noisiest seconds of the period (determined from the $L_{Aeq,1s}$ values).

- For A-weighted sound levels, and for the 1/3 octave bands $f \in$ {125Hz, 2kHz}, we calculate the percentage of time $\delta_{1dB,f}$ when the sound pressure level of the three last seconds exceeds the sound pressure level of the three previous seconds by more than 1 dB.

2.3. Estimation of traffic parameters

Simple regression models are proposed to estimate each of the 4 traffic parameter $p \in \{Q_{LV}, V_{LV}, Q_{HV}, V_{HV}\}$ with two noise indicators $\{I_1, I_2\}$:

$$\log_{10}(p) = a + bI_1 + cI_1^2 + dI_2 + eI_2^2 \qquad (1)$$

We use the $\log_{10}$ function because noise levels evolve linearly with $\log_{10}(Q)$, and so does rolling noise, which predominates for speeds exceeding 30 km/h, with $\log_{10}(V)$ [9-10]. The first three days of measurement (from Sunday to Tuesday) are used to establish relations; the four following days are used to determine the accuracy of the proposed models. The quality of the estimates is judged by calculating the coefficient of determination R^2, and the coefficient of variation of the root mean squared error CV(RMSE) = RMSE/ $\overline{p}$, between the measured and the estimated values of each parameter p. Stepwise methods are used to select the best sets of indicators. Two different models are compared to estimate traffic parameters:

- In Model I, L_{Aeq} is used to estimate the total traffic intensity $Q = Q_{LV} + Q_{HV}$. A ratio of heavy vehicles $r_{HV} = 0.15$ is assumed. Default values of V_{LV} = 90km/h and V_{HV} = 80km/h are used. Note that those values correspond to the average of the values observed during the experiment: hence the performances of Model I might be overestimated in this study.

- In Model II, The best set of noise indicator $\{I_1, I_2\}$ is selected to estimate Q_{LV}, Q_{HV}, V_{LV}, and V_{HV}.

2.4. Pollutant emissions

Airborne pollutant emissions are calculated with the Artemis model. It yields emission factors (in g/km) for CO, HC and NO_x, using traffic intensities and mean speeds both for light and heavy vehicles as input [7,11]. Emission factors are derived from representative driving cycles, thus high emissions at low speeds due to congestion are taken into account [12]. Emissions factors have been adapted to the Belgium car fleet, which contains 80% of diesel vehicles. Percentages of vehicles in each euro class of pollutant emissions are taken into consideration [13].

3. Results

Diurnal patterns of traffic intensities and vehicle mean speeds are depicted in Figure 2. Morning and evening rush hours both affect vehicle mean speeds, which drop to 45 km/h and 60 km/h, respectively. Moreover, the proportion of heavy vehicles varies strongly along the day: it is very high around 5:00 (almost 50%), decreases during morning rush hour as the number of LV increases, then increases again to reach 20% from 10:00 to 15:00 when LV are less numerous; it finally decreases after the evening rush hour.

Model I and Model II are compared for traffic parameters and pollutant emission estimations. Results are depicted in Table I.

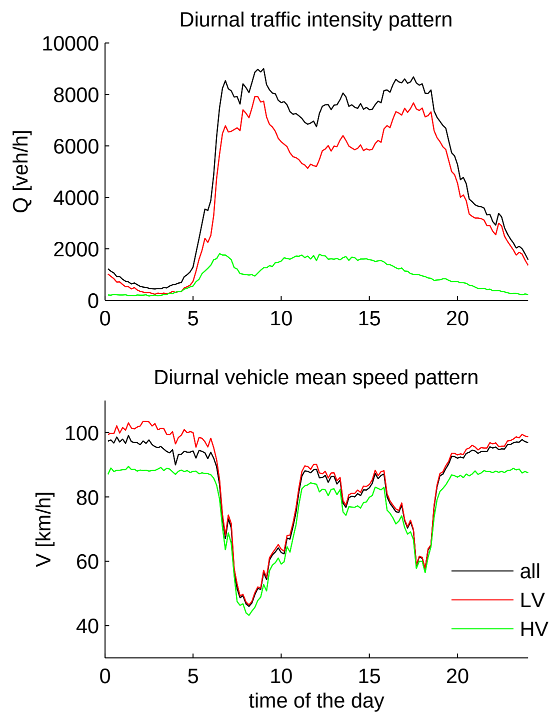

Figure 2. Measured diurnal traffic patterns, averaged over week-day data

Unsurprisingly, Model I, which only relies on L_{Aeq}, does not allow an accurate estimation of traffic intensities on the ring road ($R^2 = 0.41$ for Q estimation). Indeed, it is known that high traffic intensities result in a decrease in vehicle speeds, which produce lower noise levels: the linearity between $\log_{10}(Q)$ and L_{Aeq} is only valid when traffic is free flowing. As a result, pollutant emissions are estimated with a low accuracy. The discrepancy is much higher for the estimation of pollutant emissions than for the estimation of traffic parameters. This is due to: (i) the strong variability of pollutant emissions with speed (for example, CO emissions are three times more important at 20km/h than at 70km/h for light vehicles, as engines work in non-optimal conditions), (ii) the strong differences between emissions for light and heavy vehicles (for example, HC emissions are 6 times more important at 50km/h for heavy vehicles than for light vehicles). Those results discredit the simple approach proposed in Model I for assessing pollutant emissions.

Inversely, Model II offers a refined description of the noise environment, which allows the estimation of flow rates and mean speeds of both light and heavy vehicles with a satisfactory accuracy: Q_{LV}, V_{LV}, Q_{HV} and V_{HV} are estimated with R^2 of 0.90, 0.81, 0.94 and 0.80, respectively. Figure 3, which depicts the time-series of measured and estimated traffic parameters, confirms that the evolution of traffic characteristics is well reproduced by the model. Drops in speed are captured (the one for the third morning rush hour (18/01) is nonetheless underestimated). Moreover, the difference in patterns for the two first days, which correspond to week-end, when no speed decrease and only a few heavy vehicles are observed, is reproduced by the model.

Table I also reports the noise indicators selected by the procedure to estimate traffic parameters (only the indicators that offer the best estimates are shown in the paper; they were selected from a large set of indicators through a stepwise procedure):

- Estimation of Q_{LV}: it appears that the number of short term noise variations is strongly inversely correlated to the number of vehicles within the range of flow rates observed during the experimentation, for two reasons: (i) when traffic intensities are low, an increase in the number of vehicles results in a reduction of the gaps between vehicles and thus in smaller noise variations, (ii) when traffic intensities are high and passing bye of vehicles cannot be distinguished anymore, an increase in the number of vehicles gives less weight to the noisy vehicles which could induce strong noise variations. Those facts are captured by the indicator $\delta_{1dB,LAeq}$, which is sensitive to noise variations between three seconds and the three next ones.

- Estimation of V_{LV}: low frequency background noise, which is mainly dominated by engine noise, is important at low speeds and diminishes as speed increases, what is captured by the indicator $L_{80;90,50Hz}$. Inversely, the highest percentiles of the noise distribution, which are affected by the noisiest vehicles, contain more mid-frequencies when speed increases, as they correspond to rolling noise; this is captured by the indicator $L_{10;20,800Hz}$.

- Estimation of Q_{HV}: very low frequencies are mainly emitted by heavy vehicles, thus their global number, expressed by L_{25Hz}, traduces the number of heavy vehicles; this is reinforced by the fact that the increase in number of heavy vehicles coincides with a drop in speed that gives more low frequencies. Moreover, the correlation between Q_{HV} and Q_{LV} is not very high ($R_{pearson}$=0.61), mainly because Q_{HV} is very low during week-ends; see Figure 3. As week-ends correspond to better traffic conditions, and smaller numbers of heavy vehicles, low frequencies are smaller. This explains why $L_{50;60,125Hz}$ helps in estimating Q_{HV}.

- Estimation of V_{HL}: as the correlation between V_{LV} and V_{HV} is very high ($R_{pearson}$ = 0.98), indicators used to estimate V_{LV} can also be used to estimate V_{HV}. Thus the combination of $L_{80;90,50Hz}$ and $L_{20;30,800Hz}$ offers satisfying results.

Note that the presence of rain during 17/01 does not seem to affect the noise indicators selected sufficiently to perturb the estimation of traffic parameters, though it should increase the value of indicators $L_{10;20,800Hz}$ and $L_{20;30,800Hz}$.

Table I. Estimation of traffic parameters and pollutant emissions

		traffic parameters					pollutant emissions		
Model	indicator	Q	Q_{LV}	V_{LV}	Q_{HV}	V_{HV}	CO	HC	NO_x
Model I	R^2	0.41	-	-	-	-	0.34	-0.09	0.39
	CV(RMSE)	0.44	-	-	-	-	0.49	0.66	0.56
Model II	R^2	-	0.90	0.81	0.94	0.80	0.91	0.94	0.95
	CV(RMSE)	-	0.20	0.07	0.22	0.07	0.18	0.19	0.16
	indicators		$\delta_{1dB,LAeq}$ $L_{30/40,125Hz}$	$L_{80/90,50Hz}$ $L_{10/20,800Hz}$	$L_{50/60,125Hz}$ L_{25Hz}	$L_{80/90,50Hz}$ $L_{20/30,800Hz}$			

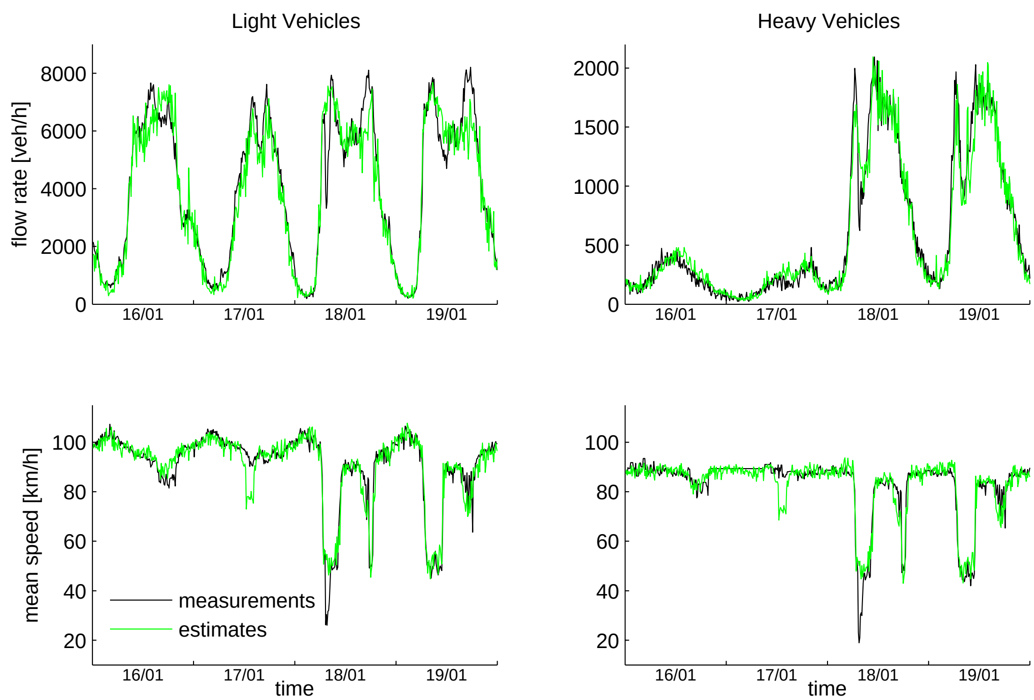

Figure 3. Time series of traffic parameters measured and estimated with Model II.

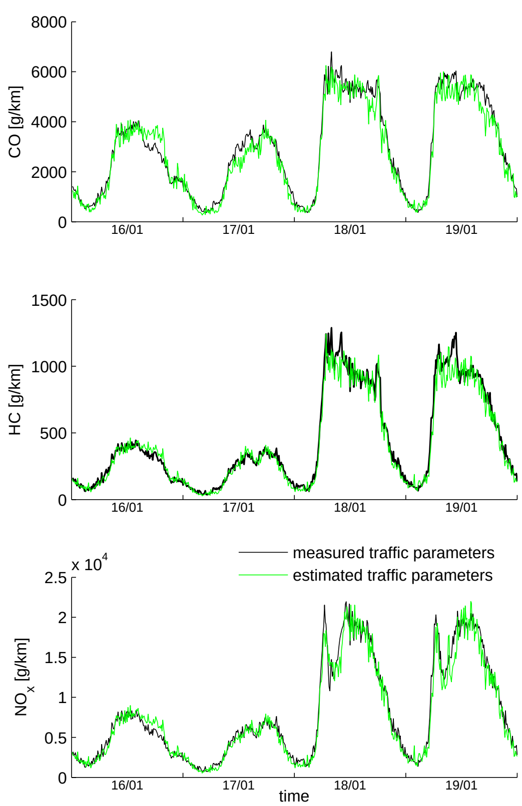

Figure 4. Time series of pollutant emissions calculated with measured and estimated traffic parameters.

Consequently, as the bias in the estimation of traffic parameters is small, time series of pollutant emissions estimated with the measured and the estimated traffic parameters are very similar. CO, HC and NO_x are estimated with an R^2 of 0.91, 0.94 and 0.95, respectively. Moreover, Figure 4 shows that the evolution of pollutant emissions is reproduced with a very convincing accuracy. It can therefore be concluded that noise measurements can be used as proxies, leading to sufficiently accurate traffic parameter estimations to be used for airborne pollution emission modeling.

4. Conclusion

The present research describes how noise measurements could be used as proxies for traffic parameters, in turn allowing high resolution estimation of pollutant emissions. Simultaneous measurements of traffic counts and noise levels were performed, during 7 consecutive days on the ring road of Antwerp, Belgium.

We showed that well-chosen noise indicators permit the estimation of traffic flow rates and mean speeds of both light and heavy vehicles with a very satisfying accuracy. The resulting estimation of pollutant emissions, tested with the emission model Artemis fed with estimated and

measured traffic parameters, is consequently very accurate.
The models involved in this study are simple, thus improvements could easily be proposed; but they might be unnecessary for our monitoring purpose, as concentrations in airborne pollutants are also highly affected by dispersion processes. The integration of those processes is indeed the next step of our research.
Moreover, in this study, only one direction of traffic flow was considered. Hence an interesting conclusion is that the noise indicators selected help in estimating traffic parameters in the closest road direction seen from the microphone, whatever the traffic direction in the other direction is. Thus, the best method to account for traffic characteristics in both directions would be to place a couple of microphones, one on both sides of the ring road.
Finally, further research is required to confirm the reproducibility of the results proposed in this paper. On-going measurements will offer material to test those hypotheses.

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