Validating sound propagation predictions with increasing complexity near multi-lane roads

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Summary

Predicting sound propagation from highways over complex terrain can be challenging and validation with measurements is most often lacking. This study considers a 6.3-m high (grown) embankment parallel to a depressed 8-lane ring road having a middle verge. At 2 fixed locations (one near the road's border, the other one on the embankment), continuous sound pressure level measurements were conducted during a full month. In this validation exercise, the full range of prediction methods was covered, going from a highly detailed full-wave numerical technique to common engineering methods. The full-wave technique, here applied in two dimensions, shows a close spectral correspondence with the measurements, including the (limited) effect of scattering by the sparse vegetation near the top of the talud. Also the Harmonoise point-to-point model, allowing a fast numerical evaluation, shows good agreement with the spectral level difference data, indicating that the sound propagation physics are well captured. Other techniques like ISO9613-2, ASJ RTN 2013, CNOSSOS and NORD2000 (the last two methods implemented in a commercial noise mapping software) show poor spectral resemblance with the measurements, making them inappropriate for designing road traffic noise abatement solutions by landscaping.

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1. Introduction

To assess the impact of road traffic noise on its surroundings, a wide range of sound propagation techniques exist.

Full-wave numerical techniques allow accounting for the smallest details like range-dependent soil characteristics, arbitrary terrain undulations, shielding objects of any shape, atmospheric effects, and scattering by vegetation and turbulence. A practical problem is often getting sufficiently detailed input data (at the centimeter scale). However, some care is needed since input data simplifications could give rise to some "artifacts". A known example is the prediction of too strong (destructive) interferences by assuming a fully flat ground surface, or by using a fixed slope in case of an embankment. Although physically correct, this will not appear in practice due to small variations in terrain undulation and ground impedance, or even by the smallest degree of scattering. A question remains to what extent e.g. geometrical data needs to be taken into account for accurate predictions of sound exposure levels near roads.

In addition, due to the strong need for computational resources, calculations are most often performed in two dimensions. One could potentially question to what extent such a simplification could cancel the accuracy gained at other instances during the modeling process.

At the other end of the spectrum, so-called engineering methods appear. They try to approach the complex sound propagation physics by a set of (often) highly simplified (and semi-empirical) formulae that allow an easy - and especially – a rapid evaluation. Clearly, this will come at a price.

Widely used techniques like ISO9613-2 [1] are known to have difficulties in capturing acoustical terrain shielding, and the accuracy of approaches like placing "screens" at slope discontinuities are doubtful. Nevertheless, significant terrain variations are quite common near roads, e.g. in case of depressed roads or roads placed on an embankment. Furthermore, landscaping is gaining more attention in up-to-date noise abatement measures for road traffic. The CNOSSOS [2] propagation module is inspired on ISO9613-2 and ground effects (in combination with terrain and screens) are modeled by somewhat more advanced formulae. The ASJ RTN 2013 [5] model specifically allows for diffraction around embankments.

In between these types of models, there are techniques that balance between physical accurateness, but still allow fast evaluation. The two methods that can be mentioned here are NORD2000 [3] and the Harmonoise point-to-point propagation (HP2P) module [4]. Especially HP2P allows a rather detailed modeling of complex terrain by a succession of linear segments, each having their own ground impedance.

2. Case study description

The case of interest is a part of the Antwerp ring road, bordered by a cycling path on top of a 6.3-m high embankment (relative to the road surface). At this location, the highway consists of 8 lanes with a high share of heavy vehicles. There are 5 lanes closest to the microphone positions, and 3 lanes in the opposite driving direction. The far lanes are partly shielded by a double row of 0.7-m high concrete jerseys. Some very sparse vegetation and top soil is present near this middle verge. The talud consists of rather rough grassland. Near its top, a zone of 20 m of tall (but sparse) vegetation is present (and consequently a forest floor).

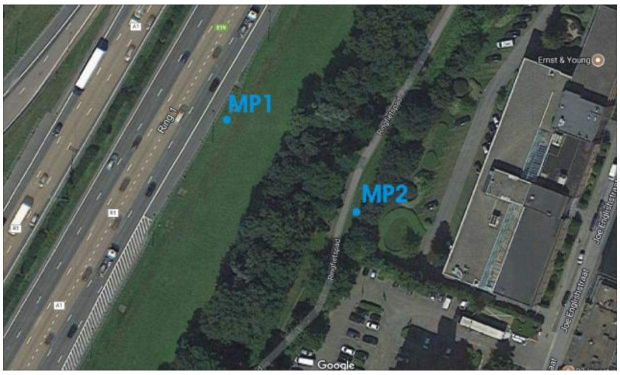

Figure 1. Positioning of microphones at MP1 and MP2 near part of the highway under study. MP2 is positioned on an embankment.

3. Measurements

Continuous sound pressure level measurements were conducted during almost a full month to characterize the sound propagation between a close point (MP1), directly bordering the highway, and a second one on top of the talud (MP2), as depicted in Fig. 1. MP1 is positioned at about 30 m from the centre of the middle verge, while MP2 is located at roughly 80 m from it.

There is a main interest in the spectral level difference between these two points. The boxplots representing the measurements show to be quite consistent over this period; the interquartile distances (see Fig. 2) stay roughly between 2 dB for all 1/3 octave bands. Rainy periods and wind speeds exceeding 5 m/s (measured at a height of 10 m, data from a nearby meteo post) have been removed. No further selection based on meteorological conditions was made given the rather short distance propagation. Since these are unsupervised measurements, and the cycling path is rather busy (near MP2), many outliers are present.

These measurements nicely show a main advantage of a (natural) berm: the ground effect is preserved to a large extent. This is illustrated by the increase in level difference around the 315-Hz one-third octave band. Behind a noise wall, in contrast, the (soft) ground effect is typically lost. This noise abatement comes on top of the terrain shielding which increases with sound frequency. An overall A-weighted level difference between points MP1 and MP2 is equal to 13.9 dBA during daytime (median over a full month).

4. Validation

Detailed traffic measurements (traffic intensity, vehicle type and speed, separate per lane, on a 1-minute base) were available from a counting station at very close distance from the cross-section under study. In addition, detailed digital elevation data was available for this specific zone.

Calculations have been performed with the finite-difference time-domain technique (2D-FDTD [6], full-wave, previously validated C++ research code, considering a single cross-section normal to the highway), the CNOSSOS model (as implemented in a commercial noise mapping software), ISO9613-2 (engineering method, Matlab implementation, single cross-section normal to the highway), ASJ RTN (engineering method, python implementation), NORD2000 (as implemented in a commercial noise mapping software), and HP2P (using the publically available .dll, applied to a single cross-section normal to the road).

5. Discussion and conclusions

With access to highly detailed input data (traffic information and terrain data), it is possible to model sound propagation at high accuracy with the FDTD method. Spectral correspondence was shown to be very good. The accuracy in overall A-weighted level difference between the measurement points (ΔLp=14.2 dBA predicted, 13.9 dBA measured) is actually close to the measurement uncertainty when using type-1 sound pressure level measurements. These results also justify the 2D approach for the case of a busy highway at rather short distance.

The ISO9613-2 model is far off from the measured data (predicted ΔLp=7.0 dBA vs 13.9 dBA measured). For this specific situation, only a slightly improved prediction is obtained when compared to purely accounting for geometrical spreading and atmospheric absorption (which gave 6.1 dBA). Source and receiver heights are positioned relative to the “averaged” slope as described in the standard [1].

The ASJ RTN model yields only a limited amount of additional transmission loss in the higher frequency range between these two points, relative to ISO9613-2. Note, however, that in case of frequency band analysis, only rigid soils are allowed for [5]. Soft ground is only available when modeling overall A-weighted road traffic sound pressure levels.

Although CNOSSOS provides a good estimate of the total A-weighted sound pressure level difference between the assessment points, the spectral correspondence is however poor as shown in Fig. 2. Low frequency-shielding is clearly overpredicted, while high frequency shielding is underpredicted.

A preliminary conclusion could be that these aforementioned methods are mainly useful to estimate the impact of a spatial distribution of noise sources, but not to design in detail a noise abatement solution by landscaping.

HP2P provides a good spectral estimate at a very reasonable time (in the order of seconds). Note that the computing time for FDTD is in the order of hours. Only these two methods seem appropriate to optimize road traffic noise cases by landscaping. Sound scattering by vegetation could not be modelled with HP2P. In FDTD, randomly distributed scattering elements at the location of the canopies (taking a volume fraction of 0.1%) were used. This probably yields the better spectral resemblance of FDTD compared to HP2P between 800 Hz and 1.6 kHz. Higher sound frequencies have not been considered in FDTD both for reasons of computational cost, and since these do not contribute anymore when considering total A-weighted sound pressure levels.

NORD2000 gives a pronounced ground dip, but at too low sound frequencies. An impedance discontinuity was modeled along the slope, going from 200 (grass) to 10 kPa s/m^2 (forest floor-snow). The shielding by the talud does not seem to be adequately included, given the similar behavior as A_{geo}+A_{atm} in the high frequency range.

Fig. 2. The yellow boxplots represent the measured spectral level difference statistics (based on 5-minute equivalent sound pressure levels) between MP1 and MP2, over the full measurement period, during day time hours. The red "+"-signs are outliers on the measured level difference data. The full colored lines represent various sound propagation modeling approaches.

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