INFLUENCE OF CORRELATION BETWEEN DIURNAL TRAFFIC PATTERN AND METEOROLOGICAL CONDITIONS ON LONG-TERM AVERAGE $L_{DEN}$

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ABSTRACT

Traffic intensity strongly depends on the period of the day, as is clear from typical intensity profiles containing maxima in the morning and evening. On the other hand, it is known that favourable and unfavourable sound propagation conditions are often linked to different periods of the day as well. At night and in the early morning, temperature inversion often occurs, resulting in an increased sound pressure level at distant receivers. During the day, there is usually an unstable atmosphere, resulting in upward refraction of sound. Moreover, wind speed is often higher during the day. In this paper, the interaction of the above described dependencies is studied. This work is part of the IMAGINE project. Its aim is to investigate the temporal resolution of traffic intensity data that is needed for the calculation of long-term equivalent sound pressure levels with DEN weighting, proposed as an indicator by the Environmental Noise Directive.

The methodology used consists in combining a typical diurnal pattern for road traffic noise emission calculated from traffic counts with a detailed calculation of propagation. The latter uses the parabolic equation method (PE) and detailed meteo-observations during a 20-day period in May and December (obtained in the HARMONOISE project).
1 INTRODUCTION

This study is part of Work Package 2 of the IMAGINE project, which is on the requirements for traffic models to produce accurate noise maps. Since most traffic models are developed to describe traffic intensity at peak hours (congestion analysis), detailed data on a temporal scale is often missing. The error made by using less frequent traffic data to produce long-term equivalent sound pressure levels is studied in this paper.

Both traffic intensity data and attenuation data have typical diurnal behaviour. Traffic intensity profiles on highways usually contain maxima in the morning and evening, corresponding to rush hours. Favourable and unfavourable sound propagation conditions are often linked to different periods of the day as well. At night and in the early morning, temperature inversion often occurs, resulting in increased sound pressure levels at distant receivers. During the day, there is usually an unstable atmosphere, resulting in upward refraction of sound and decreased sound pressure levels. Moreover, wind speed is often higher during the day. The effect of the correlation between these diurnal behaviours on sound pressure levels is under study.

The Environmental Noise Directive (END) prescribes the use of the noise indicators $L_{\text{den}}$ and $L_{\text{night}}$ to produce noise maps:

$$L_{\text{den}} = 10 \cdot \log_{10} \left[ \frac{12}{24} L_{\text{day}} + \frac{8}{24} L_{\text{night}} \right]$$

where $L_{\text{day}}$, $L_{\text{evening}}$ and $L_{\text{night}}$ are the A-weighted long-term average sound levels determined over respectively day periods (12 hours, by default from 07:00 h till 19:00 h), evening periods (4 hours, by default from 19:00 h till 23:00 h) and night periods (8 hours, by default from 23:00 h till 7:00 h). Sound pressure levels in the evening period are increased (‘punished’) with 5 dB, and at night with 10 dB. In this way, noise annoyance is accounted for to a certain degree: the same noise levels during the evening and at night are experienced as increasingly more annoying than during the day.

2 TRAFFIC INTENSITY DATA

A typical traffic intensity profile was chosen from a database (highways in Flanders) of hourly traffic counts during the working week (averaged over all workdays over one year). The traffic intensity profile (see Figure 1) shows a morning and evening peak, corresponding to rush hours, and a limited amount of vehicles during the night.

3 METEO DATA AND ATTENUATION CALCULATIONS

An axi-symmetric GF-PE (Greens Function Parabolic Equation) model is used, as described in Refs. [1][2]. The vertical grid spacing is one tenth of the wavelength, while the horizontal grid spacing is chosen to be 10 times the wavelength. At the top of the PE grid an absorbing layer is present to simulate an unbounded atmosphere.
Meteo is taken into account by using the effective sound speed approximation. Detailed meteo observations on a tower in Meppen (Germany) were available from the Harmonoise project [3]. The dataset consisted of one-minute measurements of wind direction, profiles of temperature (at 6 heights) and profiles of wind speed (at 8 heights) and relative humidity near the ground (or alternatively, the dew-point temperature and (dry-bulb) air temperature) during two periods of the year (May and December).

Hourly averaged meteo data is used. Interpolation with height is performed using the log-linear relationship between height and effective sound speed, as proposed in the Harmonoise project (see also [4]):

$$c_{ef} = a_0 + a_{log} \log \left( \frac{z + z_0}{z_0} \right) + a_{lin} z$$

(2)

Such a model corresponds well with the measured temperature and wind profiles, and allows describing profiles with ground-based temperature inversion ($a_{lin}>0$, $a_{log}<0$). In Figure 2, scatterplots of $a_{lin} - a_{log}$ pairs are shown, split up into day hours, evening hours and night hours, respectively in May and December. The data for all directions of propagation under study are included in these figures.

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Figure 1. Traffic intensity profile used for the analysis in this paper.

Figure 2. Scatterplot of hourly $a_{lin} - a_{log}$ combinations, in May (left) and December (right). The open circles (yellow) indicate day-hours, the crosses (red) evening hours and the squares (black) night hours.
The meteo data consisted of 20 full days in both periods. Relative humidity data and temperature data were used to calculate atmospheric absorption in detail. A constant effective sound speed profile is assumed during propagation between source and receiver.

The ground is modeled by a complex, frequency-dependent impedance with the one-parameter model of Delany and Bazley [5]. A value for the flow resistivity of 200 kPas/m² is appropriate to model grassland. The source height was taken at 0.5 m, while the receiver height was 2 m. Calculations were done up to 100 m, 500 m, 1000 m and 2000 m from the point source, in 8 directions (with an interval of 45 degrees).

For upwind sound propagation, sound pressure levels relative to free field sound propagation were limited at -25 dB [4], in order to prevent unrealistically large attenuations, since turbulent scattering in the acoustic shadow zone is not accounted for (to limit calculations times).

A typical traffic power spectrum is used (passenger car, 100 km/h). Three sound frequencies per 1/3 octave bands are used. The centre frequencies ranged from 50 Hz to 3150 Hz, covering the traffic noise spectrum.

These simulations resulted in hourly averaged attenuation data, taking into account geometrical divergence, atmospheric absorption, ground effect and refraction of sound by a combination of gradients in wind speed and temperature.

4 LINKING TRAFFIC INTENSITY DATA AND ATTENUATION DATA

The most accurate long term average $L_{W,den}$ values are based on calculations that combine the emission at a certain hour with the corresponding attenuation for this same hour (A). In this way, the coupling between the emission of traffic and noise attenuation is accounted for to a large extent. These calculations serve as a reference for less accurate estimates of $L_{W,den}$.

A first approximate calculation assumes that traffic data is known only as an average for the day, evening and night period. The calculation of $L_{W,den}$ is done by combining $L_{W,day}$, $L_{W,evening}$, and $L_{W,night}$ with the attenuations $A_{day}$, $A_{evening}$, and $A_{night}$ respectively (B). For the comparison in this paper, these attenuation values are calculated by energetically averaging the hourly attenuations in the relevant periods. The calculation of $L_{W,day}$, $L_{W,evening}$, and $L_{W,night}$ is based on a summation of the hourly traffic counts in the relevant periods.

The second approximate calculation combines a single (energetically-averaged) attenuation $A_{24}$ for the full day with $L_{W,24}$, based on a summation of the hourly traffic counts over a full 24-hour period (C).

\[
L_{den, hourly} = 10 \log_{10} \left( \frac{12}{24} 10^{L_{W, day} / 10} + \frac{4}{24} 10^{(L_{W, evening} + 5) / 10} + \frac{8}{24} 10^{(L_{W, night} + 10) / 10} \right) 
\]

\[
L_{day} = 10 \log_{10} \left( \frac{1}{12} \sum_{i=1}^{12} 10^{(L_{W, i} - A_{day})} \right), \quad L_{evening} = 10 \log_{10} \left( \frac{1}{4} \sum_{i=20}^{23} 10^{(L_{W, i} - A_{evening})} \right), \quad L_{night} = 10 \log_{10} \left( \frac{1}{8} \sum_{i=23}^{24} 10^{(L_{W, i} - A_{night})} \right) 
\]

\[
L_{den, day} = 10 \log_{10} \left( \frac{12}{24} 10^{L_{W, day} / 10} + \frac{4}{24} 10^{(L_{W, evening} + 5) / 10} + \frac{8}{24} 10^{(L_{W, night} + 10) / 10} \right) 
\]

\[
L_{day} = L_{W, day} - A_{day}, \quad L_{evening} = L_{W, evening} - A_{evening}, \quad L_{night} = L_{W, night} - A_{night}
\]

\[
L_{den, 24} = L_{W, 24} - A_{24}
\]
The influence of temporal resolution of traffic data on $L_{\text{night}}$ is considered separately. Now two approaches are possible, namely accounting for the link between attenuation and emission every night-hour (analogous to (A)), and using a global night emission and a global night attenuation (analogous to (C)).

Note that in our methodology, all acoustical energy produced by the source, and all attenuation of acoustical energy is conserved, and differences between the approaches arise solely from neglecting correlations between source power and attenuation data.

5 RESULTS AND DISCUSSION

In Figure 3, the difference between the 3 approaches is shown (approach (A) is chosen as a reference) for each day during May, for all directions of propagation, at a distance of 2000 m from the source. When looking at $L_{\text{den}}$ values of individual days, the errors by neglecting the coupling between traffic intensity and meteo data can be significant. The maximum deviations amount to 5 dB.

To summarize results, the 1-day $L_{\text{den}}$ values are averaged energetically over the two 20-day periods that are considered. In a next step, the (absolute value of the) differences between the 3 approaches are averaged out linearly over all propagation angles. The results are shown in Figure 4.

During May, approximation (B) is more accurate than approximation (C). The use of a D/E/N period (B) keeps the deviation from using hourly periods (A) small, also at larger distances. Using 24-hour periods (C) results in errors up to 1 dBA.

This trend is not observed during December. There seems to be no preference to use multiple periods per day in that period; the deviations stay limited and have more or less the same magnitude. The different behavior in the two periods under study can be explained by looking at the $a_{\text{lin}}$-$a_{\text{log}}$ plots shown in Figure 2. The spread of $a_{\text{lin}}$-$a_{\text{log}}$ pairs during evening and night time is quite similar in both periods. During daytime in May however, there is a preference for negative $a_{\text{lin}}$-$a_{\text{log}}$ pairs, corresponding to an unstable atmosphere caused by (strong) sun radiation. In December, the spread of the $a_{\text{lin}}$-$a_{\text{log}}$ pairs over the different quadrants during daytime is more uniform.

It can therefore be concluded that there are prominent and typical sound propagation conditions during daytime in May. Therefore, the correlation with traffic intensity is more pronounced. Using traffic intensity data split up in D/E/N periods results in more accurate predictions compared to using (total) traffic intensity in 24-hour periods in that period.

When doing the same calculations (solely) for $L_{\text{night}}$ values, deviations amount up to 0.5 dB at 2000 m (results not shown). The differences in deviations between calculations with hourly periods (i.e. reference) and a full night period is again slightly higher in May than in December. Taking into account the magnitude of the deviations (compared to hourly periods), it seems sufficient to use traffic intensity in D/E/N periods, certainly when looking at larger integration times e.g. one year.

This analysis does not reveal information on the temporal resolution needed for attenuation data, only for traffic intensity data. Traffic intensity data seems to be less demanding than attenuation data.
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REFERENCES


