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Statistics of road traffic noise levels in shielded urban areas

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ABSTRACT

Usually long-term equivalent levels and maximum levels are used for describing noise immission within the context of community noise and its negative effects. By including time variations of the noise, an improved description of the negative effects may be achieved. Here, the time variations of road traffic noise have been studied concerning A-weighted levels and third-octave band levels. Of special interest are situations with a courtyard shielded from traffic noise. For numerical results, a ray model is used for calculating sound propagation with the traffic modelled as a Poisson process. It is shown both by numerical modelling and measurements that the time variations in noise level are smaller in a shielded courtyard than in a corresponding directly exposed situation. Concerning the description of the noise source, it is concluded that the commonly used model with a single standard deviation for the A-weighted level needs to be improved to enable a more accurate prediction of time variations of third-octave band levels.

1 INTRODUCTION

This paper discusses results from the research programme Soundscape Support to Health [1]. The results of main focus here concern the statistics of road traffic noise levels in shielded urban areas.

The road traffic noise in urban areas has a large negative effect on health and wellbeing today. Possible strategies for improvement involve traffic planning, reduction of source strength by optimising tyre and road surface, noise barriers, tunnels, etc. In the research programme, effects are studied of planning buildings so that the inhabitants have access to a quieter side, for instance with a bedroom facing a shielded courtyard with much lower noise levels than outside the living room facing the street. It is known from previous research that, in many cases, the noise level in a courtyard is built up from multiple reflections and many sources within a large area [2]. This results in an acoustic situation that is different from that on the directly exposed side. With the engineering tools that are available today and during the next few years, is it difficult to make a good noise level prediction for a courtyard situation [3]. Therefore it is of interest to improve the modelling and understanding of such situations (see Ref. [4] for references).

When studying the effects of traffic noise on annoyance, it is important to consider not only the long-term equivalent levels, but also the temporal variations of the noise levels (see e.g. Ref. [5]). The importance of the temporal variations has also been shown in sleep disturbance studies, where the maximum level is an important agent [6].

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It is of interest to study soundscapes and their temporal variations in noise level. Within the research programme, different application examples of residential areas in Sweden have been studied, and two areas were chosen for full-scale demonstration examples. The first example (*Partille*) is a renewal project where the main idea is to fill the gaps between existing apartment buildings oriented parallel to a motorway, in order to create a well shielded side of the buildings. (A description of acoustic measurements and predictions before the start of the construction can be found in Ref. [7].) In the second example (*Bomgatan*), the opening of a U-shaped apartment building will be covered by a new apartment building. (A description of acoustic measurements before the start of the construction can be found in Ref. [8].)

This paper concerns the temporal variations of road traffic noise for a chosen situation with a directly exposed side and a courtyard shielded by a noise barrier. Results have been presented elsewhere for the time patterns and probability density functions of the A-weighted levels [9,10]. A numerical parameter study was performed for different situations with varying traffic flows. Also, results from an in-situ measurement were compared with those from the numerical model. In the present paper we focus on the third-octave band levels, using their standard deviations as a measure of the strength of the temporal variations.

2 METHOD AND RESULTS

2.1 Numerical modelling

A numerical ray model is used for calculating the sound propagation. The model is computationally fast, but the omission of higher-order diffraction leads to limited accuracy. More accurate models would presently be too time consuming, such as finite element or boundary element solutions of the Helmholtz equation, or by using more sophisticated diffraction calculations up to very high orders of reflection. The used ray model is described in Ref. [9], where also a validation by measurements in a scale model is shown. The reader is referred to Ref. [9] also for other details of the work.

The geometry of the situation is shown in Figure 1. Parallel to the straight road is a 3 m high noise barrier, assumed to be thin and hard concerning the diffraction. A long building block is placed 15 m further away, also parallel to the road, thus forming a courtyard together with the barrier. The actual yard is enclosed by a long U-shaped building but here modelled as a straight, infinitely long building, resulting in a model of a courtyard that is enclosed in a two-dimensional sense. In addition, the building is assumed to be infinitely high. The distance from the barrier to the closest vehicle wheels is taken as the source–barrier distance. The different distances to the separate lanes are given in the caption of Figure 1. The sources are placed 1 m from the nearest edge of each lane at ground level. Between the barrier and the building, the receiver is located, at a distance of 7 m from the barrier, and at a height of 1.5 m. The ground surface is flat and grass covered. (Further details of the measurement situation is given in Ref. [9].)

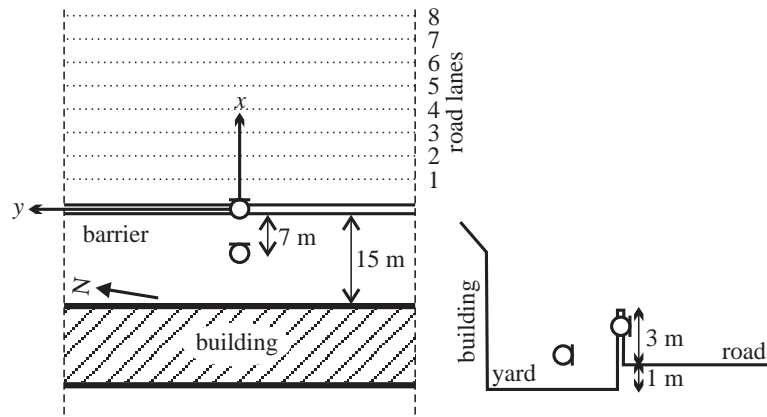


Figure 1. Geometrical model for the measurement site. Left: top view. Right: vertical section. The edges of the road lanes are at $x=4.2, 9.0, 12.8, 16.6, 21.4, 25.2, 29.0$ and 32.8 m.

The used source strengths are derived from the A-weighted equivalent levels given by the Nordic prediction model from 1996 [11]. The vehicles are modelled as point sources with initially randomised positions according to a Poisson process. The Poisson process is a model with a very low level of complexity compared with other microscopic traffic flow models. Less simplified models can involve car-following theories (see e.g. Refs. [12-15]). The use of the Poisson model is motivated for situations when each vehicle can move with weak dependence on the other vehicles, for instance for low flow conditions [12]. It has also been shown that, when there is traffic flow on a large enough number of lanes, the total process can be approximated by a Poisson model [9].

The flow during the noise measurements was 161000 veh/24h, with 10.7 % heavy vehicles. The source spectra for light and heavy vehicles were taken from Ref. [16] as the Swedish data for 70 km/h (from categories *1a* and *3c+3d*, respectively).

A bit south from the measurement site the motorway sloped upwards. By including this in the modelling, slightly higher noise levels were reached within the courtyard, whereas the levels on the directly exposed side were unchanged. (The up-slope started 50 m to the south and continued for 70 m with a constant slope, reaching 2.2 m elevation. Thereafter the motorway was flat.)

The first lane (lane 1) has a lower flow rate (33 % of that on the other lanes) and a lower velocity (50 km/h instead of 70 km/h). This is taken into account in the modelling, except for the change in spectrum due to the lower speed, which is assumed to lead to negligible differences of the A-weighted levels, and also of the third-octave band levels. At the edge of lane 2 and of lane 5 there is a low barrier, with a modelled height of 0.85 m. The effect of the low barriers on the noise in the courtyard is estimated to be negligible. However, on the face of the tall barrier, which has the receiver position 0.6 m below the barrier edge, the diffraction due to the low barriers is taken into account.

After the initial vehicle positions have been randomised, the vehicles are moved along the road, in steps with length $v \Delta t$, where v is the constant speed of the vehicles and Δt is the time discretisation; $\Delta t=0.22$ s is used here.

A random variation of the individual vehicles' source strengths has been applied to the total, A-weighted level. The level is normally distributed, as in the 1996 Nordic model [11], but the standard deviations have been lowered to better estimate the situation today [9].

2.2 Comparison between measurements and predictions

The calculated histograms of the A-weighted level from modelling and measurements are shown in Figure 2, where also the corresponding standard deviations (STD) are displayed. The results for the A-weighted levels have been shown elsewhere [9,10], but are repeated

here for completeness. As expected, the standard deviation is much larger on the front side than in the courtyard, as is shown by both the measurements and the modelling. The difference between the modelling and the measurements does however look significant; the predictions give an overestimate of the standard deviation for the directly exposed side, and an underestimate for the yard. The reasons for the differences are not fully understood at present. In order to reach an improved agreement and understanding, several different sites need to be investigated in a similar way. Thereby a refinement of the modelling could be enabled, as well as a better idea of what level of agreement of the histograms can be expected for this kind of situations.

For the individual third-octave band levels, the standard deviations are shown in Figure 3. The overall difference between measurements and calculations is related to the difference in A-weighted level, which is dominated by the third-octave band results at and around 1 kHz. In Figure 3 a larger deviation can be seen at the lower frequencies, where the standard deviation is underestimated by the calculations. To improve the predictions, third-octave band data are needed for the standard deviation of the source output power.

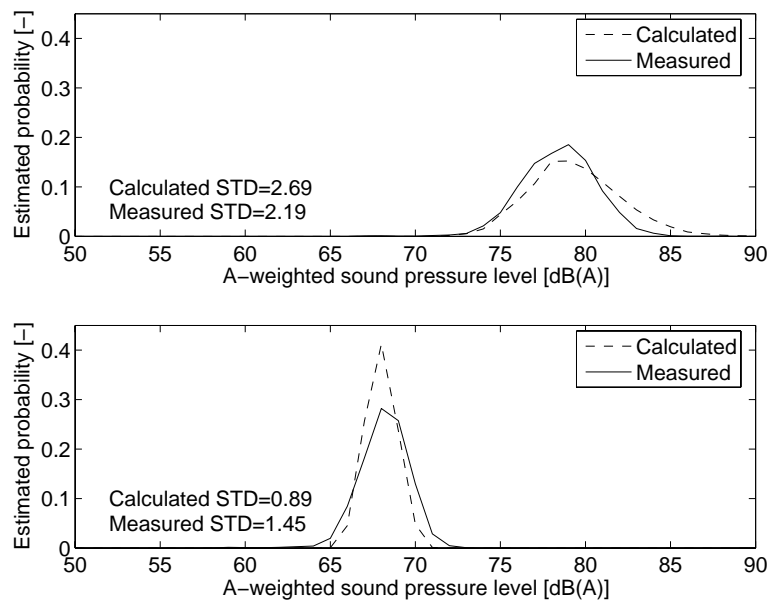


Fig. 2 Calculated and measured histograms of A-weighted noise levels (bin size 1 dB).
Top: Directly exposed side. Bottom: Courtyard.

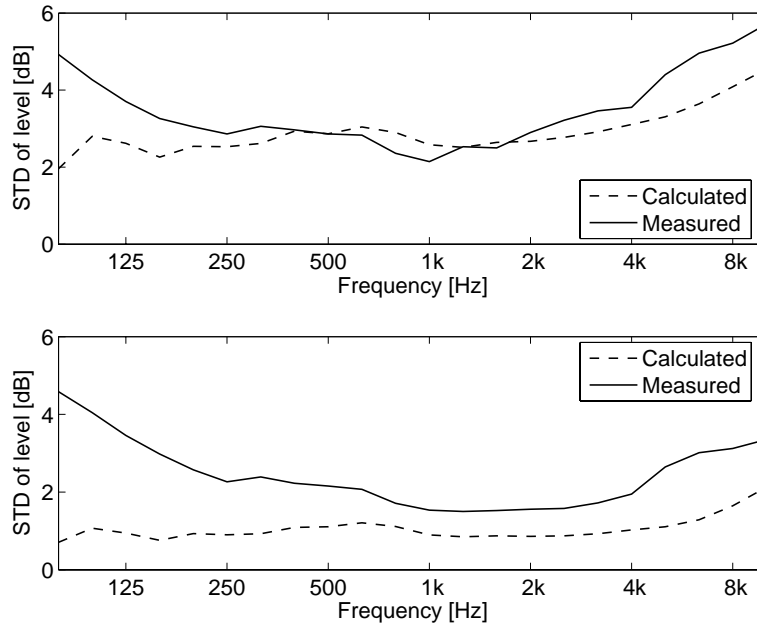


Fig. 3. Calculated and measured standard deviations (STD) of third-octave band levels. Top: Directly exposed side. Bottom: Courtyard.

3 DISCUSSION AND CONCLUSIONS

Time variations of both A-weighted and third-octave band noise levels due to road traffic have been studied for shielded and directly exposed situations. Results from an in-situ measurement have been compared with those from a numerical ray model.

The shielded situation studied here is a courtyard created by a noise barrier in parallel to a building, and with a road outside and parallel to the noise barrier. Due to multiple reflections between the building and the barrier, the noise from a vehicle may decay very slowly with distance, as compared with the case without barrier, i.e. a directly exposed case. This effect has large implications on the traffic noise.

One implication is that the probability density functions (PDFs), or histograms, for the courtyard levels show a smaller spread than the respective PDFs for the directly exposed levels. Predictions of the PDFs can be used for instance for an estimation of the proportion of time during which the noise level does not exceed some chosen value.

For the situation in situ, the agreement between the predicted and the measured PDFs is acceptable in the sense that the predicted shapes of the PDFs can clearly discern between a courtyard situation and a directly exposed one. The differences between the PDFs do however look significant. The reasons for the differences are not fully understood at present.

It should be noted that for predictions of a larger variation of situations than studied here, more advanced traffic flow models would be useful, which can incorporate more detailed conditions, as e.g. in Ref. [17]. However, it has been concluded that for a larger number of lanes, the total flow can be well approximated by a Poisson model [9].

The results for the third-octave bands show a significantly poorer agreement between measurements and predictions than the results for the A-weighted levels. To improve the predictions, and thereby the link to the perceived soundscape, third-octave band data are needed for the statistics of the source output power, which would also improve the prediction of other acoustic soundscape descriptors. It is therefore recommended that probability density functions are estimated for each third octave band when measuring the source strengths of road vehicles.

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