The effect of Traffic Flows on Urban Soundscape Dynamics and how to Analyze it

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Abstract

Subjective evaluation of soundscapes considers without a doubt the change in amplitude and frequency of the acoustic signal over time. The urban environment can make these soundscape dynamics become rather complex and interesting. In this paper we investigate how traffic flows, quite often the main source of noise in urban an suburban environments, influence the dynamics of the soundscape at intervals of the order of a few seconds to minutes. A model for dynamical traffic noise prediction is presented. Novel descriptors based on the power spectrum of noise level fluctuations allow us to show, using static maps, how the dynamics evolve in side streets, on squares etc.

1. Introduction

One of the main challenges for sustainable development of our society, is to guarantee mobility, while minimizing its negative impact on man and environment. Disturbance by noise is an important factor, particularly but not only in urban environment. Today mainstream methods to assess the impact of mobility on the urban sound climate and the quality of life, are mostly based on the calculation of time-averaged levels and derived measures, and model the traffic flow as a steady sound source. Although these models are reasonably successful in predicting the percentage of highly annoyed people [1], some anomalies in the relation between noise exposure and annoyance [2] could be explained by taking into account the time pattern of the noise of vehicles passing by. Recent studies have shown that there are clear differences in longer-term dynamics between different urban settings, caused by the alternation of passby noise and background noise [3, 4].

Traffic flow management is an important tool to change traffic dynamics, and as a consequence traffic noise dynamics. The last few years a considerable amount of effort has been spent on the study of the impact of traffic flow management on overall noise immission levels [5, 6, 7]. The need for traffic noise prediction models able to represent interrupted and complex flow is stressed in [8, 9]. In this paper we present a tool for dynamical traffic noise prediction. This model constitutes of a GIS-based microsimulation of the traffic in an urban neighbourhood or part of a town, coupled with a vehicle noise emission model and a state of the art propagation model. This model allows us to draw maps of the $\mathrm{L_{Aeq}}$, statistical levels and derived measures, and will be compared to measurements in section 3.

However, the introduction of the time component in traffic noise prediction poses an additional problem: what are suitable indicators for these time-variations? From the soundscape point of view, it looks appealing to evaluate the patterns in time variations, on top of indicators that only consider the strength (and number) of individual peaks and background while neglecting the time pattern. A way to do this is to calculate the power spectrum of sound amplitude fluctuations. This was first done for music already in the 1970's [10], and has recently been adopted to environmental soundscape research [11]. We will show how the effect of changing traffic flows on the urban soundscape can be analysed using this descriptor in section 4.

2. Methodology

2.1. Dynamical traffic noise immission model

Nowadays, discrete cellular automata models, shortly called *micromodels* because each vehicle is simulated individually, are becoming very popular in the modelling of road traffic. The traffic noise prediction model described in this paper, uses Paramics [12] to simulate urban traffic. A vehicle noise emission plugin was written, which gathers positional data of all vehicles inside a pre-defined viewport, at each timestep in the simulation. With each vehicle a single sound source is associated, for which emission spectra are calculated based on an external database. These can be a function of different vehicle characteristics such as type, speed and acceleration, or of road variables such as the surface type. Currently the Nord 2000 vehicle noise emission database is used [13], but the design of our plugin makes it easy to extend the emission model, as data becomes available.

Once a set of time-varying vehicle noise emissions are available, the dynamical noise immission at a set of observers can be calculated using a propagation model, specially tuned for time-varying sources. The model that was implemented, consists of 3 steps: path generation, attenuation calculation and immission calculation. A beam tracing model is used to generate paths between the emission points and the receivers. The technique used is *object precise polygonal beam tracing* [14] in 2.5 dimensions. Roughly speaking the simulation environment consists of a terrain model with superpositioned blocks representing the buildings. Multiple reflections and diffractions along a path from emission point to receiver can be taken into account. The attenuation model used is based on the ISO 9613 model, and has been extended with sideway diffraction according to the Nord 2000 model [15].

2.2. Impact analysis

To analyse the data generated by dynamic noise immission calculations, suitable indicators have to be selected. Although there is a common assumption that fluctuating noise is more annoying, most recent research has focused on long term averaged noise levels; for traffic noise $\mathrm{L_{Aeq}}$ has become the measure most commonly used. In an attempt to assess the annoyance caused by fluctuating noise, several descriptors have been proposed [16], such as $\mathrm{L_5 - L_{95}}$, $\mathrm{L_{10} - L_{90}}$, the Traffic Noise Index and the Noise Pollution Level, all giving an idea about the size of the fluctuations from the average background noise.

All the indices mentioned above have in common that they do not consider the time pattern of the exposure. A few long noise events separated by long periods of relative silence may result in the same statistical levels as a large number of short events separated by short periods of silence. In particular for the evaluation of soundscape quality, it can be important to distinguish between the above-illustrated situations by using a suitable indicator. We propose the slope α of the spectrum of sound level fluctuations over a sufficiently long time period, e.g. 15 minutes, as an indicator that summarizes the dynamics of the sound field, on top of $\mathrm{L_{Aeq}}$ and statistical noise levels (in particular $\mathrm{L_5 - L_{95}}$). In this spectrum, periodic events will show up as peaks.

This spectrum has some interesting characteristics. If the events contributing to the soundscape result from a complex system, then the spectrum will be linear on a log-log scale for the relevant inter-event time scales (0.002 Hz to 0.2 Hz). Self-organization of the underlying system will lead to a $1/f$ behaviour. Steeper slopes indicate high predictability; less steep slopes indicate a chaotic process. It was observed that $1/f$ spectral characteristics are quite common in rural, natural, and urban soundscapes with a mixture of activities [11]. By drawing the link to music, where this temporal structure was observed earlier [10], it is suggested that perception of soundscape dynamics and the spectrum of sound level fluctuations are related and that the slope of the spectrum and its deviation from linearity may be suitable soundscape descriptors [3].

Figure 1: View of the study area Gentbrugge. In grey, the buildings are shown; the black lines give an impression about the road network; 6 observer points are shown with a circle at the measurement side of the road.

3. Validation

A part of Gentbrugge, a suburban area near the city of Ghent, was chosen as a study area to validate the model presented; figure 1 shows a map. The area contains local streets with low and medium amounts of traffic and a district road connecting the city of Ghent, located to the north-west, with other suburban areas in the south. The E17 highway is crossing the area in the south, and is situated on a viaduct about 20 m high, with noise barriers on both sides. The area has mainly a residential function; almost no industry is located in it. Road traffic and daily life of the inhabitants are the main sources of noise.

The evening rush-hour was chosen as the simulation time interval. A network model was set up in collaboration with the Traffic Planning and Highway Engineering research group of the KU Leuven. Overall, the simulated number of vehicles in the network differs by at most about 20% from the actual counts, which is small enough to have no significant effect on equivalent noise levels. Sound measurements were done at the 6 observer points shown in figure 1. Time series of $\mathrm{L_{Aeq,1s}}$ values were measured at a height of 1.2 m and a distance of 1.2 m from the edge of the road, for a period of 15 minutes. Traffic simulations and immission calculations resulted in a similar set of time series.

Figure 2 shows noise immission results at the 6 observer points, both for measurements and simulations.

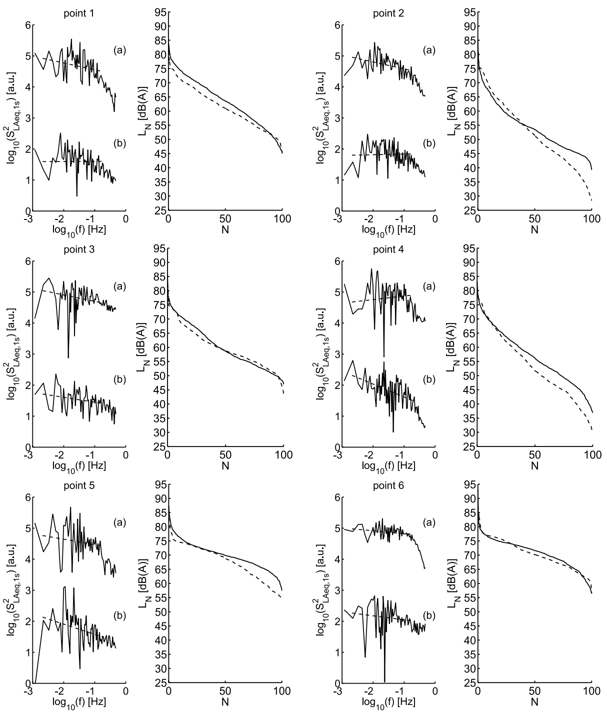

Figure 2: Results at the 6 observer points. At the left the power spectrum of fluctuations in $\mathrm{L}_{\mathrm{Aeq,1s}}$ is shown for measurements (a) and simulations (b), together with a linear fit in the interval [0.002 Hz; 0.2 Hz]. At the right, the cumulative level distribution is shown; the measurements are in solid lines, the simulations in dashed lines.

The deviation between measurement and simulation for L_5 and L_{50} is mostly within 3 dB(A), for L_{95} it is more striking for points 2, 4 and 5. The streets in which point 2 and 4 are situated are low traffic streets. Between the passing by of vehicles, the simulated level drops to values of 30 dB(A) and less; the noise coming from other sources than road traffic may prevent the level not to drop so low in reality. The road at the 5th point carries a high amount of traffic, but because of the presence of a lot of shops in the neighbourhood, also a lot of pedestrians are passing by at the evening rush-hour. In general the power spectra of fluctuations in $\mathrm{L}_{\mathrm{Aeq,1s}}$ are rather flat, typical for an almost random passing of vehicles. The correspondence for α is best for points 3 and 6, for which the statistical and cumulative level distribution correspondence was also the best.

Maps describing the dynamics of the acoustical field at the signalized junction on the main district road between observer points 5 and 6 are shown in figure 3. The appearance of the dots on the maps are a consequence of the discretization of the vehicle positions, characteristic to microsimulation models, and the fact that vehicles are standing still for a much longer period on the minor road on the north-east arm of the junction, due to the traffic signal timing. In any case, only the observer points along the edge of the road are of interest, for obvious reasons.

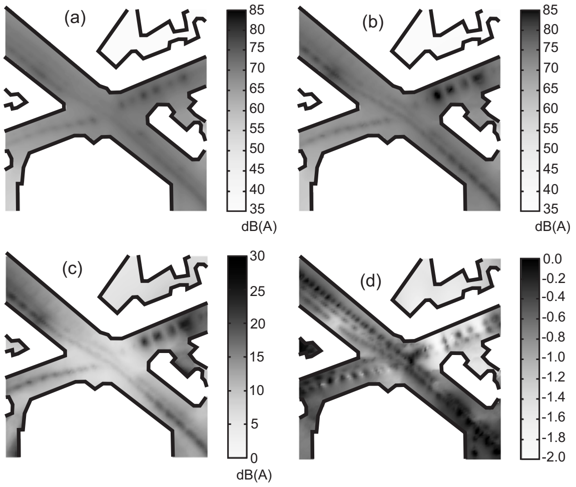

Figure 3: Noise maps at a signalised junction. (a) $\mathrm{L}_{\mathrm{Aeq,15m}}$; (b) L_5; (c) $\mathrm{L}_5 - \mathrm{L}_{95}$; (d) α.

The $\mathrm{L}_{\mathrm{Aeq,15m}}$ and L_5 maps show little variation along the footpath; the $\mathrm{L}_5 - \mathrm{L}_{95}$ map shows much more variation. Near the junction vehicles are passing all the time so both L_5 and L_{95} are high, and a low $\mathrm{L}_5 - \mathrm{L}_{95}$ is observed. In the northern backyard, $\mathrm{L}_5 - \mathrm{L}_{95}$ is also low but this time because L_5 and L_{95} are both low. In contrast, in the backyards to the east and in the south-west corner high $\mathrm{L}_5 - \mathrm{L}_{95}$ is observed. This can be explained by the partial screening: for some vehicle positions, traffic noise can reach these backyards directly. The α map shows a more nuanced picture. Values along the major road are almost zero, implying random traffic dynamics. Values along the stoplines, and in particular on the minor road, have a $1/f^{1.5}$ to $1/f^2$ behaviour, indicating very predictable dynamics caused by stop-and-go traffic. In the backyard in the north, the level fluctuations have a more $1/f$ to $1/f^{1.5}$ behaviour, which differentiates these soundscapes more from the junction itself.

4. Scenarios

To simulate the effect of a street closure, the north-eastern link of the junction discussed in the previous section was removed. Using the original traffic demands, this resulted in a minimal rerouting of the traffic. This way, it was possible to study the dynamics of the noise in the minor arm of the junction, caused by traffic on the major road. Figure 4(a) shows the resulting $\mathrm{L}_5 - \mathrm{L}_{95}$ and α maps. Subsequently, the traffic demand on the major district road was gradually increased. Figure 4(b) shows the results for a demand 20% higher than the original demand. The traffic becomes more and more dense, small jams are formed but disappear quite rapidly. Figure 4(c) shows results for

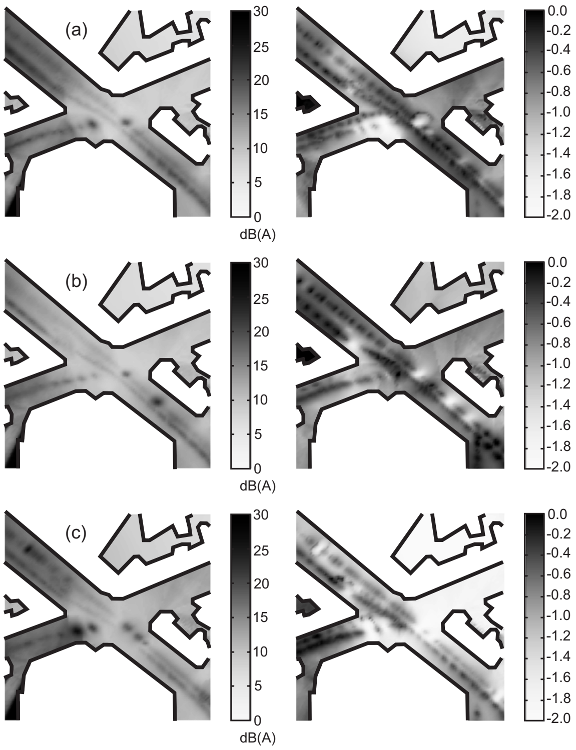

Figure 4: Maps of $\mathrm{L}_5 - \mathrm{L}_{95}$ (left) and α (right) for different scenarios of traffic demand on the main district road, from the north-west to the south-east. (a) original demand; (b) 20% higher demand; (c) 50% higher demand.

a demand 50% higher than the original; in this case some small traffic jams do not disappear any more, resulting in a situation where the individual velocities of the vehicles are strongly correlated to each other, and where the capacity of the major road drops.

A small but visible trend can be found on the $\mathrm{L}_5 - \mathrm{L}_{95}$ maps in the no-traffic arm of the junction. However, when considering the α maps, a clearer evolution is visible. The original demand, which does not display any jams, results in a rather chaotic behaviour with $\alpha \approx -0.5$. The 20% higher demand, near the traffic jam transition point, shows a more $1/f$ behaviour in the closed street; this behaviour is now also found in the northern backyard. When traffic demands are still further increased, the clustering and jamming of the vehicles results in a $1/f^{1.5}$ to $1/f^2$ behaviour of the noise immission spectrum. At the façades along the major road and away from the junction a $1/f$ spectrum is still observed. This corresponds with the earlier findings of $1/f$ behaviour in the power spectrum of traffic flow in microsimulating models near the jamming transition point [17], which is reflected here in the noise immission spectrum.

If anything, these few scenario calculations show that taking into account traffic noise dynamics makes noise maps much more sensitive to minor changes in traffic.

5. Conclusions

A tool for dynamical traffic noise prediction was introduced, which allows to estimate the effect of traffic flow management on noise in a much wider area than previous models. The model was compared with measurements and in general good agreement was found. A method for evaluating the patterns in noise immission time variations, based on the power spectrum of sound amplitude fluctuations, was proposed. A combination of this new indicator with more conventional indicators based on statistical noise levels, allows to monitor the effect of traffic on the urban soundscape more accurately. Based on these indicators, it was shown that minor changes in traffic, possibly caused by flow management, have a much larger effect on the soundscape than expected on the basis of average immission mapping.

6. References

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