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Probabilistic modeling framework to predict traffic sound distribution

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Summary

The dramatic impact of sound events on health issues such as awakenings, demonstrated in a plethora of studies in the last decades, invites to reconsider the sound prediction modeling frameworks to enable their estimation. In this paper, a stochastic modeling approach is described, which enables the estimation of sound level distributions and sound event indicators such as the number of noise events, within a classical sound mapping environment. The base modeling used in this study is developed under the open-source GIS software Noisemodeling. The stochastic approach consists in distributing the sources locations through a large set of runs over which statistics are done. The example is illustrated for road traffic noise, and evaluated over measurements performed in Paris. The further improvements for specific indicator calculations are discussed. The GIS environment opens the door to a potential coupling with dwellings spatial distribution for exposure assessments, thus facilitating the evaluation of the links between sound event indicators and health impacts.

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1. Introduction

The wide variety of impacts associated with traffic noise, including annoyance problems, night-time awakenings, etc., and the wide range of noise dynamics due to road traffic (number and intensity of noise events, temporal fluctuations due to traffic flow, wide variety in levels from one street to another), gave rise to a wide variety of indicators to describe the noise environments and evaluate noise mitigation strategies (1, 2).

Noise indicators have been compared in a previous work (3), in the context of environmental noise analyses. The comparison was based on the three following criteria: i) the ability of indicators to describe and physically categorize the urban sound environments, ii) the relevance of indicators for describing the perceptive appreciations of urban sound environments, iii) the ability of indicators to be estimated through classical or more advanced traffic noise estimation models. The conclusion was drift that no indicator fulfill all the expected requirements, although the proposal of a set of descriptors that cover the energetic, the temporal, and the spectral dimension of noise, along with three additional indicators devoted to sound events, enables an accurate physical description of urban sound environments (4).

Beyond this result, the observation was made that, while observatory networks can estimate any sound indicator, their estimation through modeling suffers many limitations, the current spread approaches only giving access to aggregated energetic indicators such as the L_{eq}, because of the static modeling chain that relies on aggregated traffic data inputs.

Dynamic approaches, which rely on a microscopic traffic simulation, enable the estimation of a large set of indicators that reflect traffic noise dynamics (5,6,7,8,9). They however require access to multi-agent traffic modeling which is not common yet in the acoustics community. They moreover imply large computational and data collection costs.

An alternative approach was proposed in (10), based on a probabilistic modeling framework, which gives access to sound level distributions without needing a traffic microsimulation tool to provide input data. The stochastics procedure

consists of creating a set of *n* sound maps corresponding to *n* representations of the possible instantaneous sound environment related to the source of interest, by distributing sources on the network.
We propose here to confront this approach to sound level measurements performed in the 13th district of the city of Paris.

2. Method

2.1. Modelling framework

The modeling proposed in (10) consists of producing multi-source oriented sound maps. We focus here on road traffic. The approach is stochastics: a set of *n* sound maps is created, corresponding to *n* representations of the possible instantaneous sound environment for road traffic sound sources. Each sound map *i* can be seen as the photography at one instant of the possible encountered equivalent 1-second sound environment for the contribution of road traffic sound sources. Statistics are done on a sufficient representative number of maps to characterize the sound environment where the model input parameters are stable (constant density of vehicles on the network links). The objective is thus to account for the 1-s time variability of the sound environment to compute original sound environment indicators. The time evolution of sound environments, that is the coherence between two consecutive iterations *i*, is not a target output of the modeling, compared to dynamic approaches built on vehicle trajectories as in (5,6,7,8,9). The modeling framework in made of four steps, detailed hereafter:

- Step 1: spatial repartition of cars
- Step 2: matrix of attenuation calculation
- Step 3: creation of *n* sound maps
- Step 4: calculation of indicators

Step 1: The spatial repartition of cars is defined. As concerning road traffic, the possible positions for road traffic correspond to the roads documented within Open Street Map in our case. Roads are discretized into point sources as recommended for road traffic noise mapping (11). We choose a 10m-space resolution, which is close to the maximum density encountered on a road network, so that vehicle noise emissions can be individualized. These point sources become potential sound sources for each map iteration, where combined with vehicle densities to activate road traffic sources on the network. Traffic densities are derived from flow rates *Q* and speeds *V*, for different vehicle categories. The key here is access to traffic data inputs, meaning flow rates, speeds per vehicle category and road segments, which are not necessarily available. In this work, the data were made available by the City Council of Paris, France.

Step 2: The matrix of attenuation per octave band (63-8000 Hz), between each couple receivers and potential sound source, is calculated. We consider that for the stable considered period of time, the acoustic propagation remains unchanged. The method developed in Noisemodelling is very close to the European CNOSSOS Method for the sound attenuation calculations, see details in (11). A resume of the user-defined parameters that have been used for this study is given in Table 1.

Table 1. Values given to the user-defined parameters used in this study for sound propagation.

User defined parameters	User configuration for this study
Reflection order	2
Diffraction Order	1
Maximum propagation distance	500 m
Maximum seeking wall	50 m
Buildings height	10 m
Receivers height	1.5 m
Ground absorption	0
Wall absorption	0.23

Step 3: A set of *n* sound maps is created. Each sound map is calculated by activating randomly a proportion of the potential sound sources. A 1-second equivalent sound power level and spectrum is assigned to each activated sound source, based on knowledge on the source sound spectrum. Each sound map *i* is calculated by summing the contribution, at each receiver, of each sound source activated at *i*. The individual contribution of each sound source is the sum between the sound power level and the sound propagation attenuation calculated at step 2. Note again that the activated sound sources vary at each iteration, but that the attenuation matrix is only calculated once, hence strongly limiting the computation time.
At each computation *i*, the probability to activate a point source is the ratio between the density of the possible sources on the road network (for instance

$K_{max} = 0.2\ veh/m$ if the sources are placed with a space granularity of 5 meters), and the calculated density. For instance with $Q = 900\ veh/h$ and $V = 30\ km/h$, the deduced density is $K = 0.03\ veh/m$, and the probability of activation is 15%.
Once activated, the sound power level and the sound spectrum of a sound source is computed based on the state-of-the-art NMPB2008 French noise emission model, in terms of the vehicle category and vehicle speed (12). The implementation results in a map of instantaneous emissions, which is extended by means of the attenuation matrix into the sound map *i* for road traffic.

Step 4: Sound level indicators are calculated at each receiver based on the sound maps. The original sound indicators can be statistical levels for each modeled sound sources (L_{10}, L_{50} and L_{90}, which stand as the sound level exceeded 10, 50 and 90% of the time, respectively). We focus hereafter on sound levels distributions, but note that sound events indicators could as well be calculated.

2.2. Tools

All the modeling steps are implemented within the open-source GIS software OrbisGis[2]. OrbisGIS allows researchers to share their results and build a common platform to analyze sustainable urban development. OrbisGis is compatible with the use of Open Street Map[3] (OSM) databases (i.e., buildings, roads, etc.) and facilitates the representation of the produced sound maps. In this study, all the geographic information has been imported from the Geofabrik[4] portal except the traffic data which own to the Paris city council.

The sound propagation done during the step 2 presented above utilizes the free and open-source Noisemodelling plugin[5], which has already been developed as an OrbisGis plugin to produce static road traffic noise maps (12). Noisemodelling is designed to produce environmental sound maps on large urban areas, with few computational resources.

2.3. Data collection

The figure 1 presents the study area, which corresponds to the 13rd district of Paris. It is described in details in (13). The area includes a large variety of urban sound environments: large avenues with high traffic density, lively streets with bars and restaurants, schools, small and large parks, quiet streets. The size of the study area is approximately 2.8 km² with a maximum extent of 2 km west to east and a maximum extent of 1.7 km north to south.
Sound data collection was performed at 25 long-term monitoring stations, during 8 months lasting approximately from July 2014 to February 2015. Other Details about the experiment can be found in (14). The measurement devices consisted of an ALIX 3D3 single-board computer, an industrial grade 8 GByte Compact-Flash card, a Knowles microphone with 3D-printed holder and rain screen, and a windscreen with a diameter of 9 cm. The 1s-sound pressure levels $L_{Aeq,1s}$ were collected continuously. In this paper, we focus on the sound levels distributions, for the periods [6h-18h] and only the stations where no defects were observed during the 8 months of measurements were selected (*n=20*).

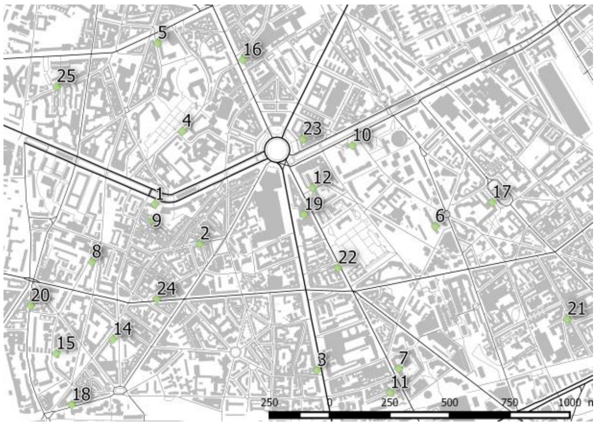

Figure 1. Fixed stations location in the study area

3. Results

3.1. Sound level distribution

The Figure 2 depicts the measured and simulated $L_{Aeq,1s}$ distributions for the [6h-18h] periods:

- Despite the simplifications of the modeling, the shape of the distributions are reasonably well reproduced. The distributions are in particular very well repdroduced for stations 4, 5, 6, 8, 12 and 18. Interestingly, these stations cover both noisy and quiet sound environments, suggesting that the modeling approach is valid in both contexts.

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[2] http://orbisgis.org
[3] https://www.openstreetmap.org
[4] http://download.geofabrik.de
[5] http://noise-planet.org/en/noisemodelling.html

- The modeling approach seems to enable an accurate reproduction of the width of the distributions. The small standard deviations at stations 1, 6 and 11 contrast with the high ones at stations 14, 15, 18 and 24, which are reproduced by the simulation. These high standard deviations mainly correspond to stations located in quiet locations, where vehicle pass byes are occasional. The stochastics approach is sensible to this dynamics.
- More finely, the skewness of the $L_{Aeq,1s}$, which is known for urban environments (right skew for calm environments and link skew for noisy ones), is reproduced as well at some stations. The right skew at stations 10 or 24 is reproduced, as well as the link skew at station 4.

The modeling suffers however some inaccuracies:

- The proportion of very low sound levels (< 40 dB), notably at stations 14 and 15, is over-estimated by the model. This is probably because these sound levels are uncommon during measurements due to the presence of other sound sources than traffic. This may also be due to the presence of a road with dense traffic, which generates a high level of background noise but at a distance superior to 500 m that was the maximum propagation distance parameter defined in this study.

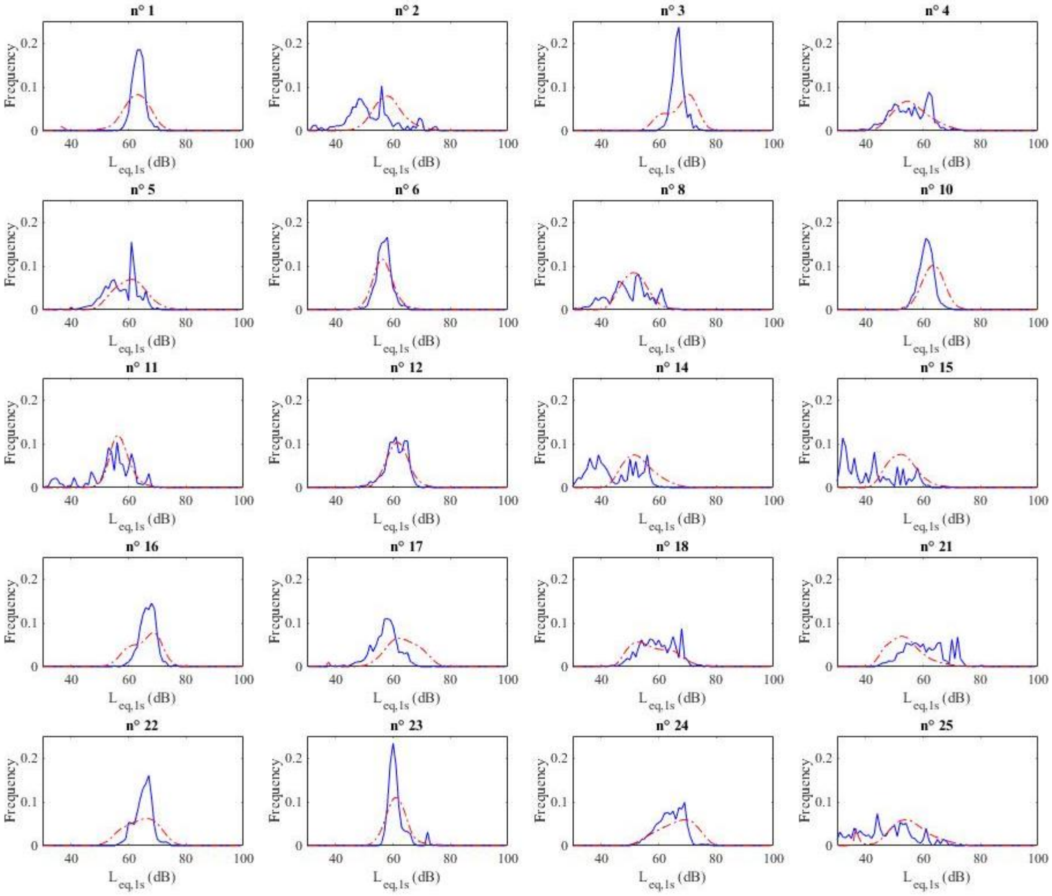

Figure 2. Sound level distributions ($L_{eq,1s}$ in dB), from simulations (line, blue) and measurements (dots, red), for each of the 21 stations.

3.2. Statistical indicators

Figure 3 presents a comparison of 4 statistical sound level indicators according to whether they are measured or simulated. The correlation coefficients between simulations and measurements are high and significant for the three statistical indicators L_{50}, L_{10} and L_{90}. In addition, most of the discrepancies between measurement and simulation are below 5 dB for L_{50}, L_{10} and L_{90}, despite the strong simplification over the input parameters (*e.g.* 10 m height for every building). This reflects a globally correct estimate of the traffic flows and the relevancy of the computation of such indicators using the present methodology. The L_{10}-L_{90} is highly over-estimated by the simulation, for the same reasons than presented in Section 3.1, but the significant correlation coefficient (r=.64, $p<0.05$) shows the interest of the present methodology in order to discriminate locations based on the width of the sound level distribution.

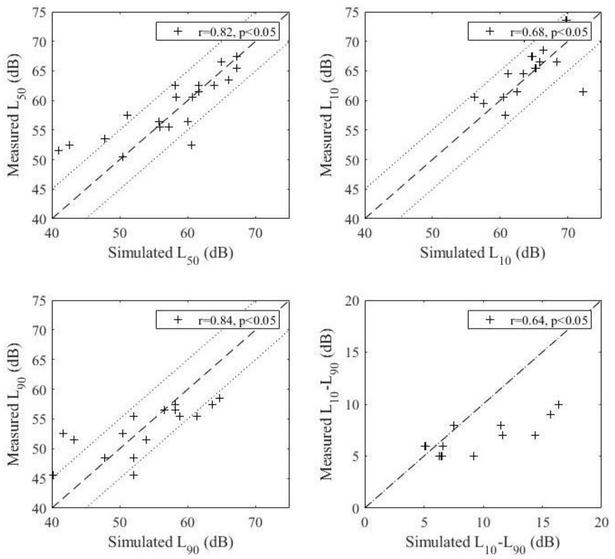

Figure 3 Comparisons between measured (vertival axis) and simulated (horizontal axis) statistical sound level indicators (L_{50}, L_{10}, L_{90}, L_{10}-L_{90}) in dB.

4. Conclusion

In this paper, a probabilistic modeling framework is presented in order to predict road traffic sound levels. For a very low additional cost, the method presented allows the estimation of sound level distributions and statistical indicators in addition to the standard equivalent sound level. The sound level distributions are of particular interest when it comes to the perception of urban environments. Thus, this approach seems to be particularly relevant to use in soundscape studies for example.

Finally, this new modelling framework opens up new perspectives that could reinforce the interest of such a method:

- Sound sources could be distributed on each road link using Poisson distributions instead of linear distributions to better reproduce traffic behavior.
- Vehicle sound power levels could be distributed, to take into account sound events due to unusually noisy vehicle.

Acknowledgement

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