Improvement of city noise map production processes and sensitivity analysis to noise models inputs.

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Abstract
The relevance of noise maps for large cities following the European Directive 2002/49/EC is questionable, because of poor quality or insufficient accessibility of input data and the large number of input parameters. In the framework of the CENSE project, a sensitivity analysis of noise mapping models to their inputs is proposed in two parts. On one hand, the integration of different sources of data, from academic or open access databases such as OpenStreetMap, was analyzed. On the other hand, a global sensitivity analysis with the Morris method was carried out on 15 of the input parameters of the CNOSSOS-EU models (Directive UE 2015/996). These two studies help to better label and qualify the input data by prioritizing some sources of information and parameters. All these developments were integrated into the open-source tool NoiseModelling ensuring the reproducibility of the results. Acoustic predictions were also compared with available online noise maps for a few French cities.

Keywords: noise mapping, urban noise, Open Street Map, sensitivity analysis,

1 Introduction

The reduction of the noise exposition represents both societal and environmental concerns, in particular for cities that are subjected to a multitude of noise sources and that count de facto numerous exposed people. In this context, noise mapping is acknowledged as a relevant tool to diagnose urban sound environments, to propose action plans to reduce noise annoyance, as well as to communicate with city dwellers. Nowadays, noise maps are essentially produced by means of numerical simulations, with high spatial precision, from a census of road traffic noise sources, followed by a sound propagation modelling. However, the relevance of noise maps for large cities following the European Directive 2002/49/EC is questionable, because of poor quality or insufficient accessibility of input data and the large number of input parameters.

In the framework of the CENSE project [1][2][3], a specific work package focused on improving the production of city noise map. A first aspect of this work concerned the optimization and improvement of the quality of input data, and a second one dealt with the assessment of the sensitivity of the noise maps results to input data. This paper presents the main outcomes of this work package: the first part presents how spatial open database can be used to improve the quality of noise mapping process, and the second part presents the main results obtained from a sensitivity analysis of noise mapping modeling for traffic noise in urban context.

2 Improvement of city noise map production processes

Collecting input data for noise mapping is often a difficult task, and obtaining good quality data is certainly even more difficult. A specific process for noise mapping is presented here based on the coupling between an open source noise mapping software and an open source spatial database that can provide most of the input data for noise mapping.

2.1 Noise computation method and software

Road traffic noise mapping is performed following the CNOSSOS-EU method [4], which is the mandatory method in the 2002/CE European directive (END) framework for the assessment of environmental noise [5]. The first part of the model concerns the modelling of the noise emission of each road section and the second part concerns the propagation of the sound wave between each road section and the receivers. To assess the population exposed to sound levels that exceed a given threshold, the method also gives recommendations for positioning receivers around buildings. A background noise of 35 dB(A) is added to the sound levels calculated at each receiver, to mimic urban background noise and to ensure that realistic noise levels exist for all receivers regardless of the parameters (even if reflections and diffractions are not considered). Even if a receiver is not reached by any sound path, this background noise value will be applied.

The NoiseModelling software is used for noise mapping. It is a free and open-source software dedicated to environmental noise mapping on large-scale outdoor spaces. It can be used as a Java library or be controlled through a web interface [6]. The CNOSSOS-EU model is implemented for the estimation of road traffic emissions, as well as for the calculation of its attenuation along propagation paths. NoiseModelling allows information to be stored at three levels: the noise sources and their sound levels, the geometry of the propagation paths and finally the transfer matrix for each of the source/receiver pairs. This choice was made because the computation time of such a software is essentially concentrated into the pathfinding algorithm. The calculation costs of the CNOSSOS-EU model for both emission and propagation are considerably lower once the geometry is known and the paths are calculated. We can also determine all possible paths between sources and receivers and then adapt the attenuation for each of the paths depending of input parameters.

2.2 Input data of NoiseModelling

NoiseModelling can accept input data (buildings, topography, road traffic, ground characteristics, etc.) in different ways. The most common way is to use data from any available ‘classical’ database (e.g. in France: database from Cerema, IGN, city administration, etc). Another way is to use OpenStreetMap (OSM) data.
A specific process has been developed to use OpenStreetMap (OSM) data for Noisemodelling groovy script manages interactions (Figure 1) between NoiseModelling libraries and a spatial database (PostGIS or H2GIS) for getting most input parameters. Simulation can be performed using a configuration file containing the values on the input parameters, and results are stored in dedicated compressed folders. All the framework is open-source and available on Github (https://github.com/Ifsttar/NoiseModelling/releases) to ensure the research is reproducible and adaptable to other case study.

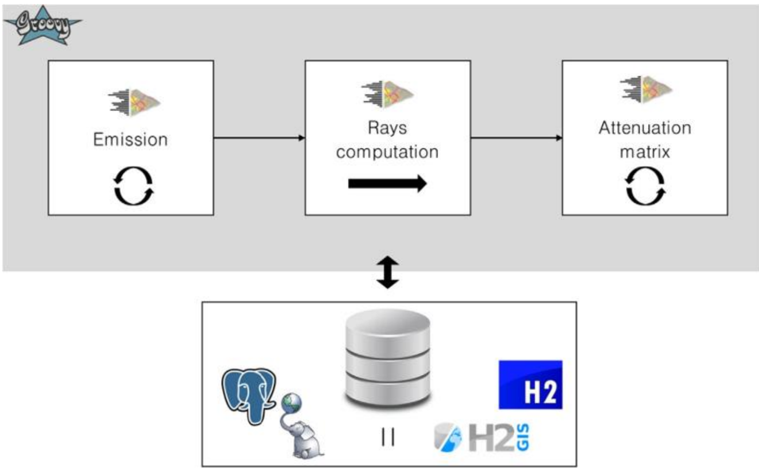
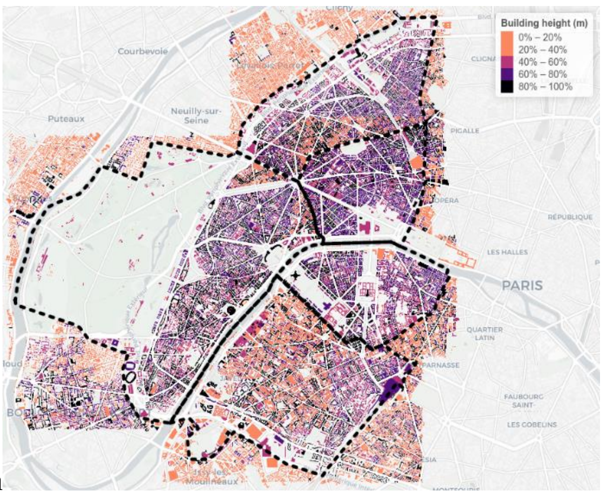


Figure 1 – NoiseModelling / Geoclimate coupling

Most input data of NoiseModelling came from OpenStreetMap (OSM) data, and are requested, processed and formatted by means of the opensource geospatial toolbox GeoClimate (https://github.com/orbisgis/geoclimate/wiki). Data are organized as a series of .geojson files in the form of attribute data from the following GeoClimate layers: 'zones', 'building', 'urban areas', 'roads', 'water', 'vegetation' and 'road traffic'. NoiseModelling requires at least three geographical layers to be able to predict noise levels:

- **buildings** table (Figure 2a) with height information especially ;
- **ground** properties from tables 'water' and 'vegetation' that give information on the vegetation height (low, high) and type (scrub, grass, garden, park, forest, vineyard, hedge, wood, heath, meadow, grassland, tree_row). The ground absorption coefficient G has been set to 0 for water and hard surfaces, 0,7 for garden, heath, meadow, park, scrub, and 1 for forest, hedge, wood, tree_row (Figure 2b) ;
- **roads** table (Figure 2c Figure 2d) with vehicle traffic and pavement type information. The good practice guide WG-AEN [7] gave the association between OSM information and the CNOSSOS-EU model requirements concerning the road type and category (e.g. trunk road, main road, secondary road, etc.) that are used to estimate road traffic information (e.g. the speed and flow of vehicles), and the road pavement.



a

b

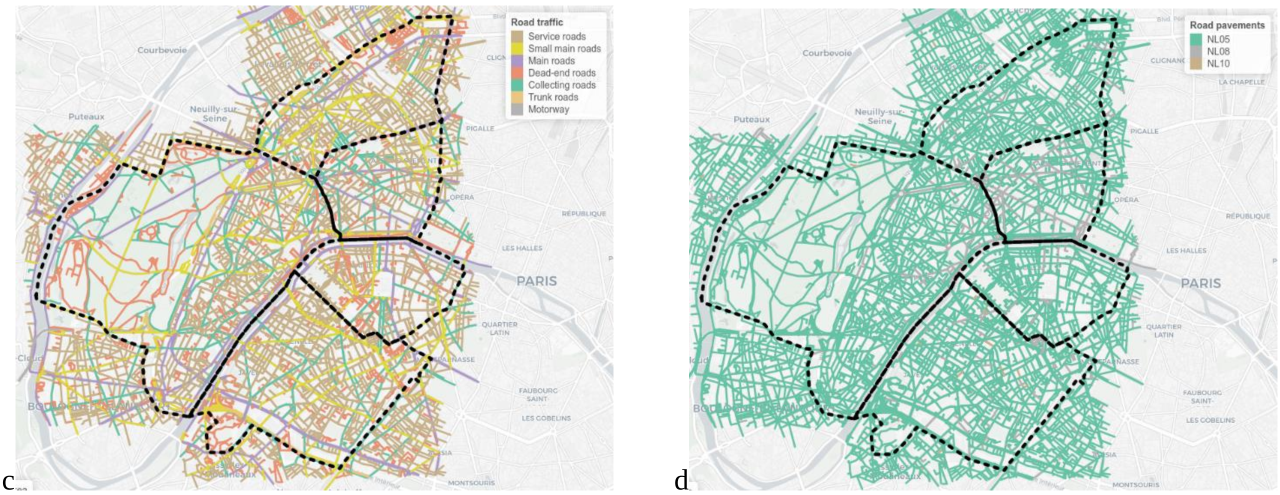


Figure 2 – Main input data for NoiseModelling from OSM (example of a part of Paris city noise map): a) buildings, b) ground absorption, c) road traffic, d) road pavements.

2.3 Validation and discussion

OSM-based noise predictions are compared with reference noise map of 5 districts of the city of Paris (the iso-contours noise map data are available in the form of shapefiles here: https://carto.bruitparif.fr/). Noise calculations with OSM data are performed over random grids of receivers at 4-meter high for each district area (the number of receivers is fixed such as approximately corresponding to 1 receiver every 1000 m2). The errors made on noise levels at receivers are calculated by comparison with the intersecting reference iso-contours noise data. Figure 3 gives the distribution of deviations between L_{den} and L_n maps from OSM-based data and from reference data. It shows that the noise level estimates are mainly overestimated for OS-based map compared to the reference one. Input data of the CNOSSOS-EU model have to be improved by refining the classification of road sections or by using more accurate data than the estimation giving in the guide WG-AEN [6], which empirical laws between traffic and kind of roads might be too rough or not adapted to French road traffic.

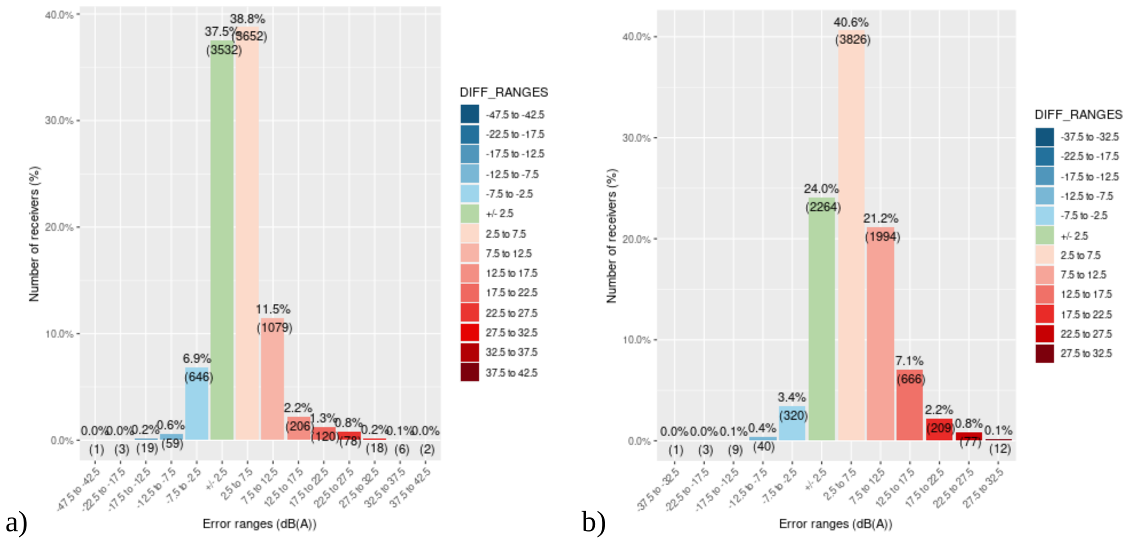


Figure 3 – Deviations distributions between L_{den} (a) or L_n (b) calculated from reference data, and calculated from OSM-based data.

3 Sensitivity analysis of noise mapping modeling

The quality of input information has not the same importance according to each input parameter. We present here the main results of a sensitivity analysis of noise mapping results in order to assess for which parameters it is crucial to have input information of good quality and for which ones rough information are sufficient. More results are given in [8].

3.1 Method

3.1.1 Sensitivity analysis method

The Morris method [9][10] is widely used for global sensitivity analysis, since it is adapted to models with quantitative inputs (i.e. physical or configurational parameters) and outputs [8]. It is part of OAT (One At a Time) methods, meaning that the process of exploring the definition domain makes the inputs vary one at a time. It consists in repeating an OAT plan (trajectory) randomly in the parameters space, where each input parameter interval is discretized into a suitable number of levels. The method starts by sampling a set of initial values within the defined ranges of possible values for all input parameters and by calculating the subsequent model output. The second step changes the values of only one and calculates the resulting change in model output compared to the first result. Then, the value of another parameter is changed and the resulting modification in the model outcome compared to the second run is calculated. This goes on until all input variables are changed.
For the sensitivity analysis presented in this paper, the total procedure is repeated 50 times (r = 50) for a group of 15 inputs (k = 15), resulting in 800 simulations. To ensure that the space of exploration does not favor any area, 500 trajectories are drawn and only the fifty trajectories that maximize exploration are retained (in terms of Euclidean distance), as described in [11].

Three indicators are calculated with the Morris method:

- m is the arithmetic mean of the effect associated with the k-th parameter. In case of an independent linear dependency, m is the change in the output when the k-th parameter changes by one step (as defined by its range of variation in Table 1);
- m* is the mean of the absolute effect associated with the k-th parameter. It is similar to m but it is the average of the absolute differences caused by a change in the k-th parameter. This value is interesting to avoid cancelation effects in the average (as it can be the case for a non-monotonic function);
- r is the standard deviation of the effect associated with the k-th parameter. It tells how much the effect of the k-th parameter changes with the value of this k-th parameter and the values of the other inputs. It gives an indication of the presence of nonlinearities or interactions between the k-th parameter and other inputs.

3.1.2. Noise computation method and software

The sensitivity analysis is performed here following the CNOSSOS-EU method for road traffic noise that is implemented in NoiseModelling. To launch many replications of the model, the idea is to store the geometry of every paths. Then it is possible to recalculate several possible emission levels for the sound sources, and several possible attenuations for the source/receiver couples, according to the varying parameters. We can also calculate all possible paths between sources and receivers and then adapt the attenuation for each of the paths depending of input parameters. For example, if we do not want to consider the reflected paths, we associate an infinite attenuation to them. A path that would change geometry by a change in the study area, such as the height of buildings for example, cannot be considered by our methodology.

3.1.2 Input and output parameters

More than 40 input parameters (either physical or configurational) can be identified when calculating a noise map using CNOSSOS-EU [12]. Only some of them are prone to generate significant uncertainty in the output depending on the period of the map considered (hourly, daily, monthly, etc.), the study area, the receiver's locations, etc. For this sensitivity analysis, we study the case for which an operator wants to know the sensitivity of the CNOSSOS-EU model outputs when making monthly day-evening-night maps of road traffic noise. The proposed sensitivity analysis focuses on 15 input parameters, among which 4 concern the model configuration and 9 are related to physical inputs. The ranges of variation on the physical inputs were defined using information on their monthly range of variation over one year for the studied area and the uncertainty around each input parameter. Table 1 shows the chosen parameters and ranges of variation. Road-related input parameters are considered to vary homogeneously between three categories of roads depending on their flow rate. For example, if the vehicle flow rate increases by 10% for medium axes, this is the case for all road segments of the road network, which have a flow rate included in [300;1000] vehicles per hour. Also, we have chosen a range of variation between 0 and 1 order of reflection even if reflection 0 is not in agreement with the CNOSSOS-EU method. However, the cost of the calculation would have increased significantly for higher orders of reflection. We considered that this cost was too high for results dependent on our case study. Vertical diffraction has been included as a parameter, although it is not required for road noise maps according to CNOSSOS-EU. More generally, all ranges of variation and parameters chosen are specific to this study and should be adapted to any other case study. Above all, our aim is to propose a methodology that can be replicated, including long-distance sound propagation for peri-urban applications for example.

Table 1 - Sensitivity analysis parameters, related topic reference codes, ranges of variation and step types (multiplicative * or additive +)

Parameter	Variation	Step	Parameter	Variation	Step
Total Vehicle Flow Rate on major road (>1000 veh./hour)	[0.7;1.3]	0.2 (*)	Buildings absorption coef	[0.5;1.5]	0.33 (*)
Total Vehicle Flow Rate on medium road (300–1000 veh./ hour)	[0.7;1.3]	0.2 (*)	Temperature (C)	[6;18]	4 (+)
Total Vehicle Flow Rate on small road (<300 veh./hour)	[0.7;1.3]	0.2 (*)	Humidity (%)	[20;80]	20 (+)
Heavy Vehicle Ratio)	[0.5;1.5]	0.33 (*)	Order of Reflection	[0;1]	1 (+)
Medium Vehicle Ratio	[2;8]	2 (+)	Horizontal diffraction	[true/false]	–
2 Wheels Vehicle Ratio	[2.7;3.3]	0.2 (+)	Vertical diffraction	[true/false]	–
Favorable meteo conditions	[0.7;1.3]	0.2 (*)	MaxPropagation distance	[300;750]	150 (+)
Wind direction (°)	[60;60]	30 (+)			

The sensitivity of the model to input parameters is observed through 3 output indicators:

- The sound pressure level for day/evening/night periods (L_{den}) at each receiver (dB(A)) The L_{den} value is computed as defined in [5]. The traffic flow rate are annual average daily flows for the three-corresponding periods (day, evening and night);
- The L_{den} value averaged over all receivers on the whole area of the noise map;
- The population ratio exposed to a L_{den} value that exceeds 65 dB (A) on the same area/map;

The result of the analysis therefore includes 3 sensitivity parameters (m, m* and r), for each of the 15 input parameters, and on 3 observed outputs.

3.1.3 Case study area

The sensitivity analysis presented in this article is part of the CENSE project which includes a noise mapping case study based on both modelling and sensors deployment, in the city of Lorient, France [1][2][3]. It covers an area of about 2 km^2, in which 14,343 receivers (around 1772 buildings of which 1204 are occupied) were selected to serve as a support for this sensitivity analysis. The influent input parameters are a compilation of data collected from Cerema, IGN and the Lorient city council. shows an example of results through the median L_{den} value of the 800 simulations in dB(A) representing 9672 inhabitants. Approximatively 24% of them are exposed to road traffic L_{den} values above 65 dB(A).

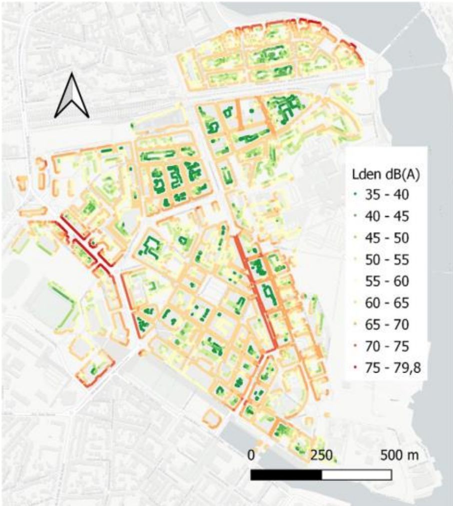


Figure 4 - Study area of the analysis. 14,343 receivers are represented on the map. The color represents the median Lden value at each receiver over the 800 simulations.

3.2 Results

3.2.1 Sensitivity analysis regarding the population ratio exposed to more than 65 dB(A)

Table 2 shows the results of the sensitivity analysis regarding the ratio of inhabitants exposed to L_{den} values of more than 65 dB(A) for the 15 varying input parameters of the model (Table 1).

Parameters likely to impact the ratio of inhabitants exposed to levels above 65 dB(A) are especially those influencing the calculation for receivers at levels close to 65 dB(A). Hence the low importance, for example, of a parameter such as the mean flowrate at small-axis, which impacts receivers subject to levels much lower than 65 dB(A). As a result, the most influential parameters/variables in this study are the horizontal diffraction (Dif_hor), the vehicles flow rate on medium axes (Q_{med}) and the ratio of heavy vehicles (HV) that are two parameters that influence the calculation of noise emissions, and are therefore particularly influential on noise levels around 65 dB(A) often observed at the edge of the roads, with short propagation distances. A variation of 20% in Q_{med} leads on average to a variation of 3.2% in the ratio of inhabitants exposed to levels above 65 dB(A). A variation of 30% in the ratio of heavy vehicles leads on average to a variation of 2.5% in the ratio of inhabitants exposed to levels above 65 dB(A). Finally, the m value reveals that the exposed population increases with these two parameters (m = m*).
The influence of introducing or not the horizontal diffraction in the calculation is also very high, reaching 6.1% of the affected population. This physically means that 6.1% of the receivers have a level that rises above 65 dB(A) if horizontal diffraction is included in the calculation. In addition, the low r/m* value (r/m* = 0.39) tells that this is relatively independent of the other parameter values.

Table 2 - Sensitivity analysis regarding the population ratio exposed to more than 65 dB(A): m, m* and r for each of the parameters

Parameter	m	m*	r
2 Wheels Vehicle Ratio	0.02	0.02	0.08
Vertical diffraction	0.03	0.03	0.09
Maximum Propagation Distance (m)	0.04	0.04	0.22
Total Vehicle Flow Rate on small axes	0.14	0.14	0.92
Medium Vehicle Ratio	0.31	0.31	0.53
Favorable meteorological conditions	0.17	0.44	2.12
Order of Reflection	0.58	0.58	2.30
Humidity (%)	0.05	0.83	2.59
Buildings absorption coefficient	0.38	0.87	0.39
Wind direction	0.13	0.95	1.99
Total Vehicle Flow Rate on major axes	1.10	1.10	1.58
Temperature (°C)	0.14	1.27	2.46
Heavy Vehicle Ratio	2.50	2.50	2.36
Total Vehicle Flow Rate on medium axes	3.22	3.22	0.08
Horizontal diffraction	6.09	6.09	0.09

3.2.2 Sensitivity analysis regarding the mean L_{den} value

The most influential parameter in terms of the mean L_{den} value (Table 3) is by far the horizontal diffraction, which leads to a variation of 3 dB(A) of the mean L_{den} value in this study. This is because some receivers which are not in ‘‘direct” field with the sound sources (‘‘line of sight” thus which cannot be linked via the side of the buildings, as receivers inside courtyard) are not reached by any propagation path if diffraction is ignored. Thus, the sound level at these receivers jumps from the background noise level of 35 dB(A) to a sound level that can be potentially high. This concerns a limited number of receivers but makes the mean of the absolute effect jump to a high value.

Table 3 - Sensitivity analysis regarding the mean Lden value: m, m* and r for each of the parameters

Parameter	m	m*	r
2 Wheels Vehicle Ratio	0.01	0.01	0.00
Maximum Propagation Distance (m)	0.01	0.01	0.02
Medium Vehicle Ratio	0.06	0.06	0.01
Favorable meteorological conditions	0.03	0.09	0.19
Vertical diffraction	0.09	0.09	0.05
Buildings absorption coefficient	0.01	0.11	0.25
Humidity (%)	0.02	0.11	0.26
Total Vehicle Flow Rate on small axes	0.12	0.12	0.02
Wind direction	0.03	0.13	0.28
Total Vehicle Flow Rate on major axes	0.15	0.15	0.04
Temperature (°C)	0.04	0.23	0.30
Heavy Vehicle Ratio	0.42	0.42	0.05
Order of Reflection	0.46	0.46	0.43
Total Vehicle Flow Rate on medium axes	0.56	0.56	0.08
Horizontal diffraction	3.07	3.07	0.52

3.3 Discussion

The choice of input parameters (either physical or configurational) and ranges of variation of their respective values is partly made on study area considerations and sometimes on arbitrary choices which can be subject to discussion. Since sensitivity analysis is partly dependent on choice and ranges of variation of those parameters, conclusions may differ. The choice of background value can be questioned and may potentially influence some of the conclusions of the analysis. One of the limitations of the proposed methodology is also the inability to incorporate changes in geometry (e.g. building height). More generally, all results presented are highly dependent on the selected site, which can be summarized, in our case, as monthly traffic noise maps of L_{den} in a European city downtown. Nevertheless, the open-source approach makes it possible to anyone to apply the present methodology for sensitivity analysis to his/her own city/case study.
Finally, as any model and software, CNOSSOS-EU and NoiseModelling have their own limitations and approximations, thus the present study, as a sensitivity analysis based on those models/tools, partially represents these models/tools.

4 Conclusions

This paper presented some improvements of urban noise mapping process by exploring two aspects: the first one dealt with input data, and the second one with the relative influence of these data on noise mapping results.

We proposed a specific process for noise mapping based on the coupling of an open source noise mapping software with an open source spatial database that can provide most of the input data for noise mapping. The noise mapping is performed with the NoiseModelling libraries and a spatial database (PostGIS or H2GIS) for getting most input parameters. All the framework is open-source and available on github to ensure the research is reproducible and adaptable to other case studies. The advantage of this process is the use of reliable open source software and input data. This makes the noise mapping process easier, without compromising the quality of the results. A comparison between an OSM-based map and a reference map for a part of Paris city validates the feasibility of the approach. It nevertheless shows some deviations for both L_{den} and L_n noise levels, which are probably due to road traffic data used for the OSM-based map estimated from the road type and using the empirical laws of the guide WG-AEN [7], that might not be adequate.

A global sensitivity analysis of the CNOSSOS-EU model concerning fifteen of its varying input parameters has also been presented in this paper. The chosen case study is the production of monthly traffic noise maps of L_{den} in a city downtown. The screening technique is based on Morris' method and simulations were performed with the NoiseModelling v3.0 software.The sensitivity analysis to the input parameters of the CNOSSOS-EU model highly depends on the location of the receivers. The most influential parameter is whether diffraction over horizontal edges is considered or not, regardless of the observed indicator, namely the average sound level over the area or the ratio of the population exposed to more than 65 dB(A). This can be easily explained by the fact that some receivers may not be reached by a propagation path until this parameter is introduced in the calculation. When model configuration parameters are excluded from the analysis, it can be shown that for most receivers, the most influent parameters are linked with the emission part of the CNOSSOS-EU model, and concern the mean flow rates of the category of the closest road to the receiver.
Many of the results presented are highly dependent on the choice of the case study, the parameters chosen and their range of variation, but the experience and the method can easily be replicated thanks to the development of open-source and freely available tools. We therefore encourage practitioners and specialists to use these tools and methods, which are readily available, to deepen their reflections on model uncertainties and propagation errors.

Acknowledgements

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