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Global sensitivity analysis for urban noise modelling

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ABSTRACT

Regulatory noise maps rely on many input data that can be incomplete, erroneous or inexistent. Thus, operators have to complete/validate/qualify those data by prioritizing some information sources and parameters to the detriment of others. Consequently, the sensitivity of the noise model to such input parameters should be determined to focus on the most influential input parameters. For this purpose, a global sensitivity analysis is carried out on the CNOSSOS regulatory method, implemented in the open-source software NoiseModelling, using the Morris screening method. As part of the ANR CENSE project (2016-2020), a global sensitivity analysis is presented on a case study in the city of Lorient in France. This paper presents an example of a sensitivity analysis of the CNOSSOS model for 9 of its input parameters on 426 receivers (30 buildings) in this area.

Keywords: Open-Source, Noise mapping, Sensitivity analysis

1. INTRODUCTION

Strong relationships between noise levels and both annoyance and health effects are established (1). It is therefore crucial to quantify the noise levels to which populations are exposed. Noise mapping is classically used to quantify these exposure levels. In this objective, traffic and geometric data collected feed noise emission and propagation models to generate sound maps at district or city scales. Then, once crossed with the residential occupations, these sound maps give us access to noise exposure (2).

It is important to use a stable methodology and modelling framework to compare the exposure levels of different cities, or the evolution over time of exposure to a given city. Thus the CNOSSOS model has been proposed to participate in this harmonization of calculation methods (3). However, a large variability of the calculated exposures may remain due to the model configurations and to the accuracy of the different types of input data. In addition, many input data are sometimes difficult to obtain or non-existent, requiring calculation assumptions that may influence the accuracy of the calculated exposure levels. It is therefore necessary to be able to identify the most influential input data and parameters in order to give them priority in the data collection and modelling process. This article presents the framework for a sensitivity analysis performed with the open-source NoiseModelling software v3.0 (4). Regarding screening technique, the Morris method is applied by making a number r of local changes at different points of the possible range of input values.

2. METHODOLOGY

2.1 Morris Method

The Morris method is widely used for global sensitivity analysis, since it is adapted to models with

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quantitative inputs (or parameters) and outputs (5). It is part of the OAT (One At a Time) methods, meaning that the process of exploring the definition domain makes the input parameters vary one at a time. It can be seen as a statistical analysis of empirical estimates of changes in the output of the model with respect to each parameter. In the case of a time-consuming model, or a model with a large number of parameters, the method is a simple way to make a first selection among the parameters according to their influence. A sufficient number of repetitions are still required to ensure confidence in the results obtained.

Its principle is as follows. The method begins by sampling a set of start values within the defined range of possible values for all input parameters, and next by calculating the subsequent model outcome. The second step changes the value for one variable (all other inputs remaining at their start values) and calculates the resulting change in model outcome compared to the first run. Next, the value for another variable is changed (the previous variable is kept at its changed value and all other ones kept at their start values) and the resulting change in model outcome compared to the second run is calculated. This goes on until all input parameters have been changed. This procedure is repeated r times, each time with a different set of start values, which leads to a number of $r(k + 1)$ runs, where k is the number of input parameters. Such number of runs is very efficient compared to more demanding methods for sensitivity analysis (e.g. exhaustive research among each range values, Monte-Carlo, etc.).

For the sensitivity analysis presented in this paper, the total procedure will be repeated 10 times ($r=10$) for a group of 9 parameters ($k=9$), resulting in a number of 100 simulations. To ensure that space exploration does not favour any area, 300 trajectories have been drawn and only the ten trajectories that maximize exploration are retained (6).

2.2 Framework

NoiseModelling (formerly NoiseM@p) is a free and open-source tool, integrated in the OrbisGIS software, designed to produce environmental noise maps on very large urban areas, with few computational resources (4). The CNOSSOS model is implemented for the estimation of road traffic emission, as well as for the calculation of its attenuation along propagation paths (3). 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/receptor pairs and for a given propagation path scheme. This choice was made because the computation time of such a software type is essentially concentrated into the calculation of geometric rays. Thus the calculation costs of the CNOSSOS model for emission and for propagation are considerably lower once the geometry is known and the rays are calculated. To launch a large number of replications of the model, the idea is then to store the geometry of the rays. Then it is possible to recalculate several possible emission levels for the sources, and several possible attenuations for the sources/receivers couples according to the varying parameters.

Figure 1 presents the technical framework behind the global sensitivity analysis using NoiseModelling: A groovy script has been created to interact with Noise Modelling. It also serves as an interface with a database (PostgreSQL[2] or H2[3]). From a configuration file containing the values on the input varying parameters, many simulations are performed and the results are stored in compressed folders.

2.3 Study parameters

When creating a noise map, all the varying input parameters (regarding sound emission and propagation) will be considered as variables in the sensitivity analysis. For example, it will be possible to observe the influence of a 10% variation in the hourly flow rate of light vehicles and to compare it with a 5°C variation in atmosphere temperature. It is also possible to complete the sensitivity analysis by varying the parameters related to Source-Receiver geometry, even if the calculation costs then increases – because the rays will have to be retraced – but without adding complexity to the process and analysis.

[2] www.postgresql.org

[3] www.h2database.com

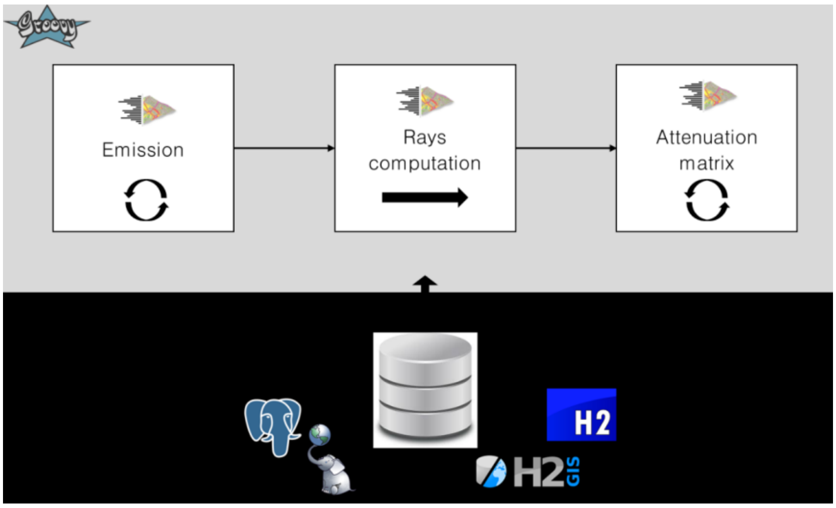


Figure 1 – Sensitivy analysis framework using NoiseModelling

For this first sensitivity study, it is proposed to consider 9 parameters. The road parameters are supposed to vary homogeneously across the network. For example, if the vehicle speed increases by 10%, this is the case for all road segments of the road network. Table 1 shows the parameters, their steps and ranges of variation.

Table 1 – Sensitivity analysis parameters, step and range of variation

Parameter	Code	Variation	Step	Parameter	Code	Variation	Step
Light Vehicle Flow Rate (veh./hour)	Flow_lv	[0.8;1.4]	0.1 (*)	Humidity (%)	Hum	[20;80]	20(+)
Heavy Vehicle Flow Rate (veh./hour)	Flow_hv	[0.8;1.4]	0.1 (*)	Order of Reflection	Refl	[0;1]	1 (+)
Light Vehicle Speed (km/h)	Speed_lv	[0.8;1.4]	0.1 (*)	Horizontal diffraction	Dif_h	[true/false]	-
Heavy Vehicle Speed (km/h)	Speed_hv	[0.8;1.4]	0.1 (*)	Vertical diffraction	Dif_v	[true/false]	-
Temperature (°C)	Temp	[5;30]	5 (+)				

2.4 Score indicators

As an output of the analysis, sensitivity to the model's input parameters is observed on two quantities:

- for each receiver, the sound pressure level for day/evening/night periods (L_{den}) expressed in dB(A);
- the inhabitants ratio exposed to a L_{den} value superior to 65 dB(A).

The Morris method allows us to access to three indicators:

- μ is the arithmetic mean of the effect associated with the *k-th* parameter. In case of an independent linear dependency, μ is the change in the output when the *k-th* parameter changes changes by one step (as defined by its range of variation in Table 1),
- μ* is the mean of the absolute effect associated with the *k-th* parameter. It is similar to μ 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),
- σ 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 depending on the value of this *k-th* parameter and the values of the other parameters. It gives an indication of the presence of nonlinearities or interactions between the *k-th* parameter and other parameters.

2.5 Study Area

The sensitivity analysis presented in this article is part of the CENSE project (Characterization of urban sound environments using a comprehensive approach combining open data, measurements and modeling), which includes a noise mapping case study based on both modelling and sensors deployment, in the city of Lorient, France (7)[4]. It covers an area of about 1 km², in which 426 receivers (30 buildings) were randomly selected in order to serve as a support for this sensitivity analysis. The influent input parameters (*e.g.* built-up characteristics, ground topology, road traffic data, ground characteristics, etc.) are a compilation of data collected from CEREMA, IGN and the city of Lorient. Figure 2 shows an example of results through the median sound level of the 100 simulations in dB(A), where 30 buildings are assessed, representing 318 inhabitants and approximatively 17% of them are exposed to L_{den} levels above 65 dB(A).

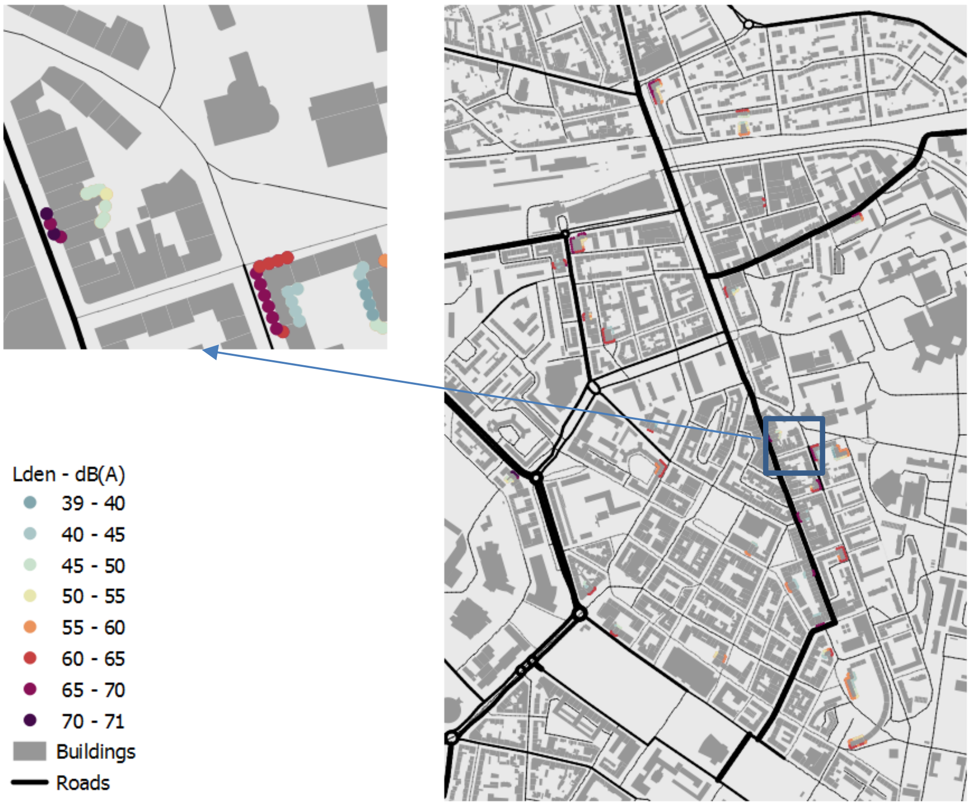


Figure 2 – Noise map of the study area computed with NoiseModelling (median sound level of the 100 simulations). Following this map, the inhabitants ratio exposed to L_{den}>65 dB(A) is about 17 %.

3. RESULTS

3.1 Sensitivity analysis regarding the ratio number of exposed people

Figure 3 shows the sensitivity analysis of the ratio number of inhabitants exposed to L_{den} > 65 dB(A) levels using the CNOSSOS method for its nine varying input parameters (See section 2.3). Results are expressed in percentage of inhabitants exposed to L_{den} > 65 dB(A).

4 http://cense.ifsttar.fr/en

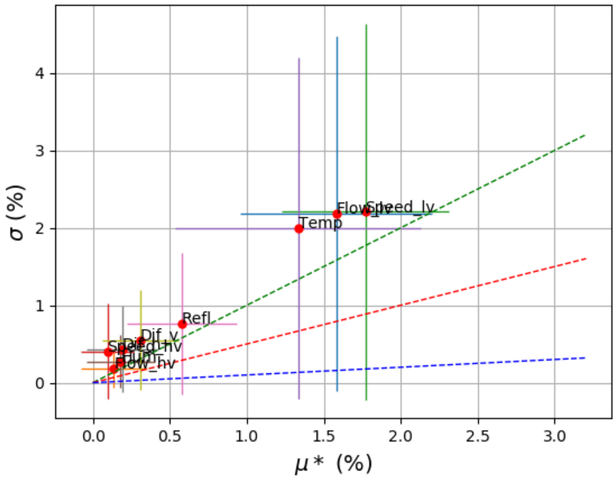


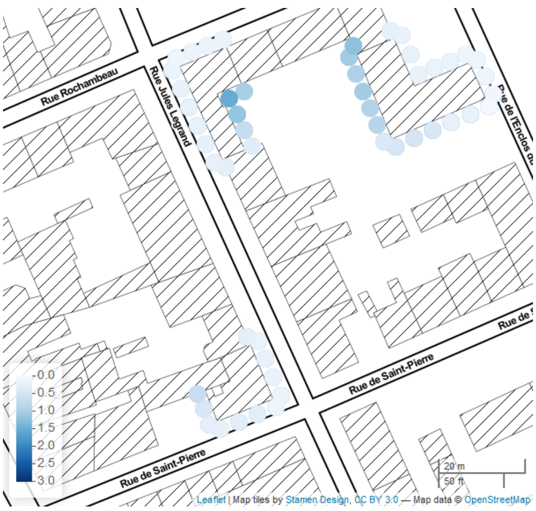
Figure 3 – Results of the sensitivity analysis for the 9 input parameters with NoiseModelling

The most influential parameters in terms of the number of inhabitants exposed to more than 65 dB(A) L_{den} values are the speed and flow of light vehicles parameters and temperature, which can lead to an increment of approximatively 1.5% on the affected population, ranging from 15.5% to 19.5%. These are three parameters that affect noise emission - temperature is an influential parameter of the CNOSSOS emission model - and they are therefore particularly influential on noise levels around 65 dB(A) because they are often observed at the edge of the roads and therefore with short propagation distances. As a result, receivers with L_{den} values close to 65 dB(A) will switch above or below the 65 dB(A) threshold, when these two parameters vary. The range of variation from 0.8 to 1.4 times the nominal value is then sufficient to vary the number of inhabitants exposed to L_{den} values exceeding 65 dB(A).

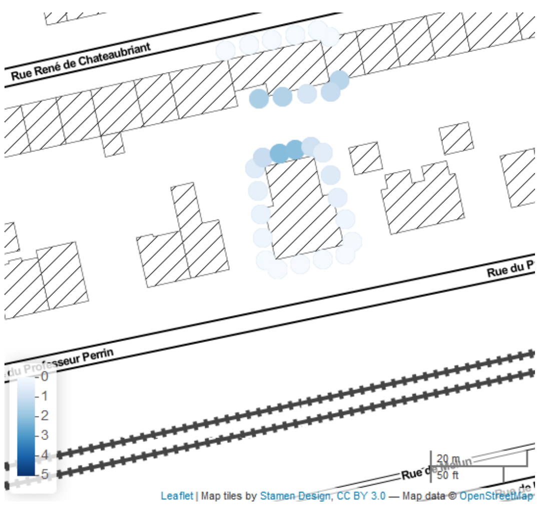
The parameters related to sound propagation have a greater impact on isolated receivers, which may or may not be reached by sound rays, depending for example on the fact the reflection or diffraction are taken or not into account. As a result, these parameters have little effect on noise levels in a range around 65 dB(A), so that the number of exposed persons varies little.

3.2 Sensitivity analysis regarding the sound exposure by receivers

Figure 4 shows the sensitivity analysis of the L_{den} sound level using the CNOSSOS model at 3 of its varying input parameters, namely the speed of light vehicle, the order of reflection, and whether or not horizontal diffractions are taken into account.



(a) – Order of reflections (1/0) - Refl



(b) – horizontal diffraction (true/false) - Dif_h

(c) – Speed of light vehicles - Speed_lv

Figure 4 –L_{den} *variation* (μ*) by receiver of the sensitivity analysis for 3 input parameters

The Figure 4 confirms the high homogeneity in the variations in L_{den} values according to the speed of light vehicles, while the impact of taking into account or not reflections or horizontal diffractions in sound levels calculation is very heterogeneous on the network. In particular, receivers located in building yards are highly affected by parameters such as diffractions. This can be explained by the very high errors made when the number of rays in the simulation reaching certain isolated points, such as building yards, falls drastically when diffractions or reflections are not allowed in the simulation. It is even possible that for some simulations no rays reach the receiver. For these receivers, the variation on these parameters (diffractions, reflections) can therefore induce very large variations on the observed sound levels. It is likely that if indicators of the type "number of persons exposed to less than 40 dB(A)" were considered, these indicators would be very sensitive to these calculation parameters.

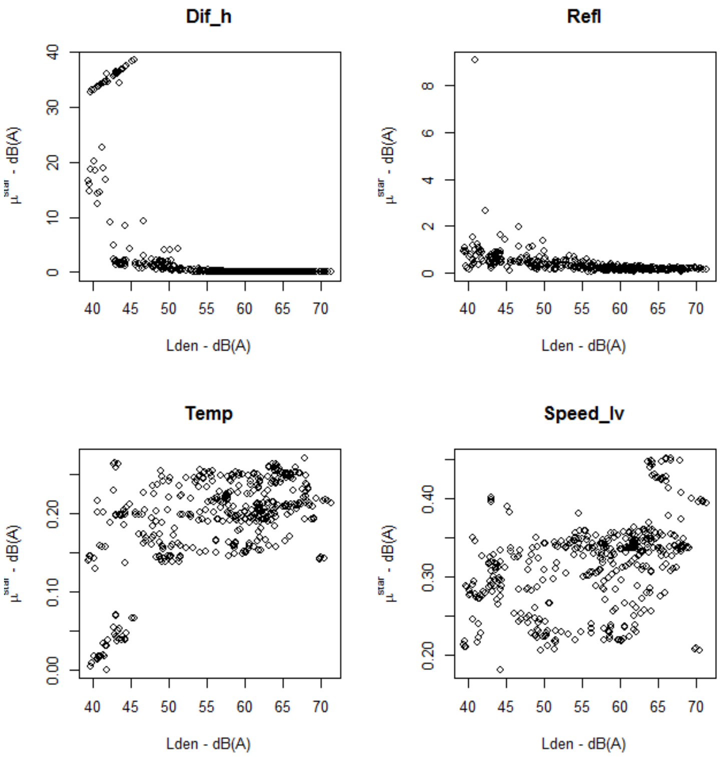


Figure 5 – μ* for each receiver depending on L_{den} sound levels for 4 varying input parameters

Figure 5 shows the existing links between the L_{den} sound level and four parameters:

- The Figure 5 confirms the high sensitivity of low noise levels to whether or not diffractions are taken into account, with receivers that can potentially receive no energy for some simulations (see μ^* >30 dB(A) on the top-left figure);
- When noise levels are low, the impact to whether or not reflections are taken into account can be significant. As for diffractions, receivers that are not in direct field compared to noise sources often have the lowest noise levels and are also those most affected by this parameter;
- The influence of the temperature and the speed of light vehicles on L_{den} values increases with sound levels because the receivers nearest to the streets are the ones with highest sound levels and also those for whom the parameters related to the emission are the most influential ;

4. CONCLUSION

A global sensitivity analysis of the CNOSSOS model at 9 of its varying input parameters is presented in this paper. The screening technique is based on Morris' method and simulations were performed with the NoiseModelling v3.0 tool. The results presented in this article are preliminary results and further research should be carried out in order to propose more general results that can be transposed to other district (or even city) typologies. However, any user can reproduce this methodology for his case study and the groovy script and NoiseModelling are available on the open-source platform Github[5].

Other applications as dynamic noise mapping, uncertainty propagation or meta-model development can benefit from the same structure of the NoiseModelling software.

ACKNOWLEDGEMENTS

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