An opensource tool to build urban noise maps in a GIS

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Introduction

Within the framework of the Environmental Noise Directive (END) 2002/49/CE concerning the assessment and management of environmental noise, cities of more than 100,000 inhabitants are required to construct noise maps to be used in dening noise abatement action plans. For consistency, a preliminary evaluation (mainly by acoustic simulations) of the effectiveness and impacts of these action plans is mandatory.

The use of Geographic Information System (GIS) software is a tool that has become essential for such studies. GIS offers many spatial analysis functions and cartographic capabilities that are useful for understanding the impact of action plans on noise maps at dierent scales (i.e., buildings, administrative units, etc.). The connection between GIS and noise prediction was established more than two decades ago in a Dutch study on the impact of road trac noise on bird reproduction. As early as 1986, simulations were carried out using Silence software on a large area in the Netherlands [3]. Unfortunately, little information is available on the acoustical aspect of the software. The application at hand was clearly focused on the countryside and thus has few implications for urban areas. Today, Silence 3[1] combines GIS with the commercial Predictor software with a focus on highways rather than urban areas.

In this paper, we propose an alternative approach, implementing a noise prediction method within the OrbisGIS[2] software. The noise emission and propagation models are inspired from the French national method \NMPB 2008» [4, 6], but are simplied for two dimensional calculations in urban areas. The method, as well its implementation in the GIS software, are detailed in sections 1 and 2. We then present a case study in section 3 to evaluate several mobility plans in terms of noise impact. The particular interest of this approach is that we implement the model in the two-dimensional GIS software OrbisGIS and pay special attention to algorithm optimization in order to reduce computational times and resource consumption. Our method is able to produce noise maps for very large domains (around several millions of square meters) on a personal computer in just a few hours.

1. Sound prediction methods in a GIS: What and why

We model noise emission according to the French national method \NMPB 2008» [4, 6], based on the decomposition of line sources (i.e., traffic flow) into point sources, with some simplications concerning the type and age of the road pavement, the stopping and starting road sections, vehicle kinematics, and the distribution of light and heavy vehicles over dierent time periods throughout the day. We obtain the traffic flow using a trac model developed by another partner of this research project. This model, based on the VISEM software [3], uses behavior surveys as input data and is tted with in situ traffic flow data. The data are represented as a set of polylines (the road network) described by several attributes extracted from traffic flow simulations in VISEM. The model gives the traffic information (speed, type of vehicle, traffic lane, traffic flow, etc.) required for noise emission computations the eventual construction of noise maps using the prediction method.

We implement the prediction method in the open-source GIS software OrbisGIS. One of the most important advantages of free and open-source software (FOSS) in general is that it facilitates the reuse of existing code and the merging of dierent software packages into new and less costly applications. In OrbisGIS, the user can see explicitly how noise maps are generated, unlike the so-called black box implementations of comparable commercial software packages [7]. OrbisGIS allows researchers to share their results and build a common platform to analyse sustainable urban development. It oers a unique way to understand the impact of human activities using a single tool.

Implementing a method to compute noise maps in OrbisGIS allows us to take advantage of GIS functionalities to merge dierent databases. For example, it is easy to link noise maps and the population distribution using spatial analysis techniques. The populations exposed to dierent noise levels can be located and estimated.

2. Implementation within OrbisGIS

We developed the noise map prediction method as a plug-in of OrbisGIS [9]. The noise plug-in is divided into two main parts. The first part is related to the evaluation of the sound source by considering both light and heavy vehicles as well as electric tram. The second part consists of the propagation model.

The OrbisGIS module noisemap uses the results of the traffic flow simulation to compute the corresponding long-term noise emission levels. These long-term emission levels can be for an entire 24-hour period (LDEN) or from 10:00 p.m. to 6:00 a.m. (LN) . For each road geometry, this module outputs a spectral decomposition of the noise sources from 100 Hz to 5000 Hz.

Another OrbisGIS module is responsible for computing the noise propagation. At execution time, the module ignores the height of the buildings, so that there is no vertical diraction by the tops of buildings. It takes as input data:

- an array of sound sources dened by their geometries (lines or points) and a sound level from each third octave band from 100 Hz to 5000 Hz provided by the first module
- an array of buildings (2 dimensions)
- a list of parameters, like the order of reflection and diffraction, wall absorption and the maximum propagation distance

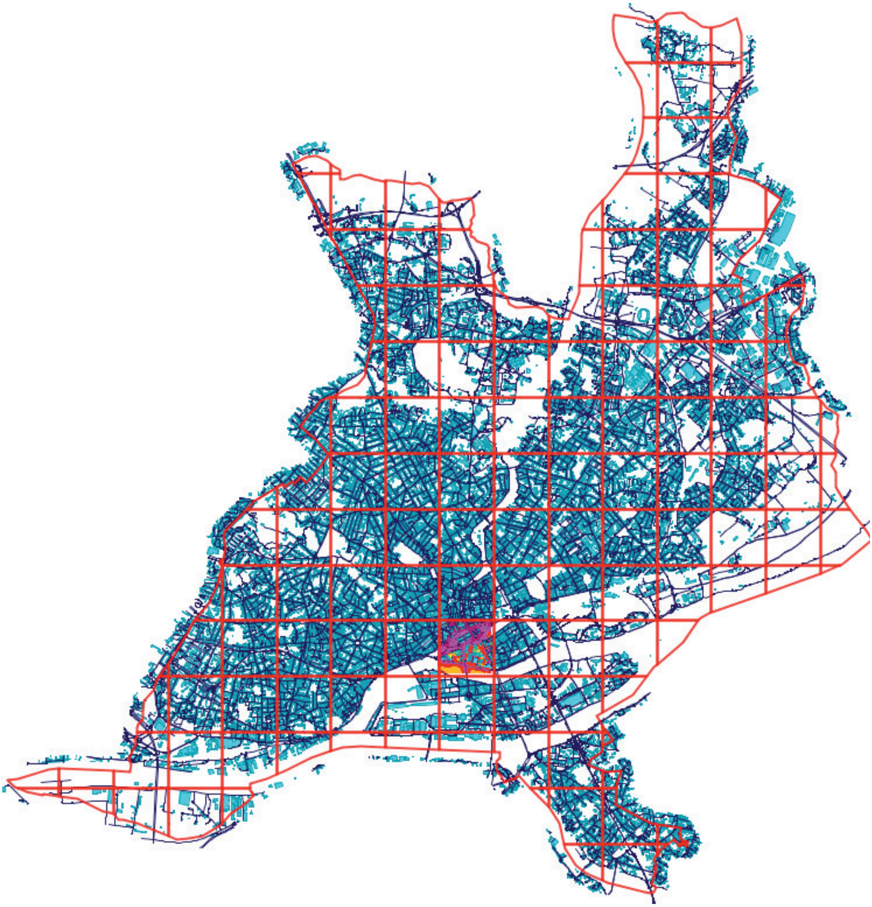

FIGURE 1

Subdomains computed according to the road network. For the colored cell : receiver count = 253,826, direct paths = 40,256,246, reflection paths = 9,429,999, diraction paths = 1,990,872, computation time = 3 hours

The propagation process evaluates the bounding box of the simulation area by using the full envelope of the road network. This bounding box and the maximum propagation parameter are then used to compute optimal subdivided areas of simulation (Figure 1). This leads to greater computational eciency.

For each subarea, we form a constrained Delaunay triangulation of the union of the buildings and roads contained in the subarea (Figure 2). We place receiver points (to simulate microphones) at the vertices of the triangles. This mesh provides an optimal spatial distribution of receiver points, the density of receivers being higher near sound sources as well as buildings with a more complex geometry. An extended subarea box is dened for each subarea by taking the maximum propagation distance into account. This extended envelope does not contain any additional receivers; it is used only to enlarge the propagation domain as a function of the maximum propagation distance. In each extended subarea, outside sound sources and buildings are ignored.

FIGURE 2

Constrained Delaunay triangulation of an area of one square kilometer

At this step, the computation subarea contains all needed information: the propagation domain, the sound sources and the receivers' coordinates. We fix a particular receiver. This receiver looks for sound sources along the roads that fall within a range equal to the maximum propagation distance. Each road is then subdivided into point sources separated by a distance that depends on the distance to the receiver. When all point source locations are available, the propagation paths from the receiver to the sources are computed by considering the direct, reflected and diffracted fields (Figure 3).

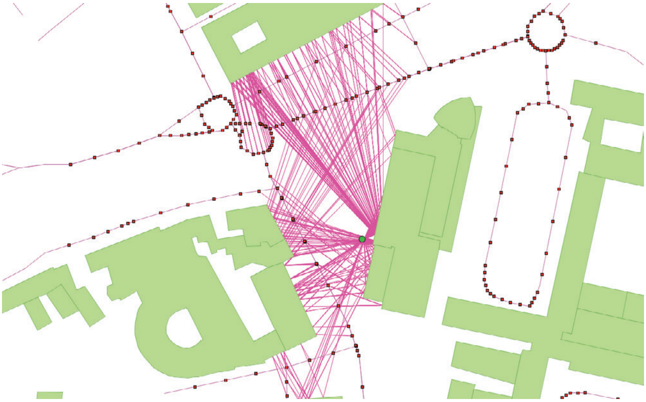

FIGURE 3

Second reflection purple paths that connect the green receiver to the red sources

The noise contribution of each sound source is calculated, then all contributions are energetically summed into the receiver. This same calculation is repeated for each receiver in the subarea. The software then saves the noise level for each receiver in a buer le before moving on to the next subarea. Using this area subdivision approach, a region of more than 500 km² can easily be computed on a standard personal computer. In particular, we exploit multi-core technology by separating data between threads and limiting synchronisation.

It is noteworthy that the propagation module can accept a constrained list of receiver coordinates. It will then output the noise level for those receivers only. This constraint is useful for computing the noise level on building's facades. The computations are carried out by means of several SQL functions available in the Generic Datasource Management System (GDMS) of OrbisGIS [9]. Among other functions, this open-source library facilitates the production of noise maps.

First, the user manipulates roads, buildings and non-geographical data with the native tools of OrbisGIS. The user can then independently call noise modules
from the same graphical user interface in order to :

- convert traffic flow data into noise level data

- compute the emission noise spectrum for a specied type of sound source
- compute the propagation of sound from the sources to the receivers

Second, built-in OrbisGIS functions are used for post-processing in order to :

- interpolate the receivers' levels to construct a fully-customizable noise map
- combine the computation results in numerous ways
- establish a spatial statistical study of the results in association with external data
- publish intermediate or final results as files and/or over networks services

3. Case study

In the framework of the Eval-PDU project, several scenarios have been considered, not only for their impact on noise, but also for several other environmental (e.g., air pollution, energy use) and socio-economic (e.g., property values, behavioral changes, etc.) consequences. These scenarios are expected to express changes in citizens' displacement habits in comparison with the situation in 2008 due to variations in energy price, urban sprawling, and local and national economic changes. For our purposes, we only consider scenarios relating to noise impact :

1. a 25% decrease in road trac
2. a 20% increase in all trac (passenger cars, public transportation, etc.)
3. the doubling of gas prices
4. an increase in public transportation Nantes Metropole represents 24 communes and a surface area of 523 km²

Due to the large size of this study area, we restricted our attention to the city of Nantes (65 km²) only. The traffic data we used are built on top of geographical data using BD Topo, from the French Geographic Institute IGN[4]. The noise map uses the same database. Buildings represented as simple 2D polygons. In total, the database comprises 80,000 objects.

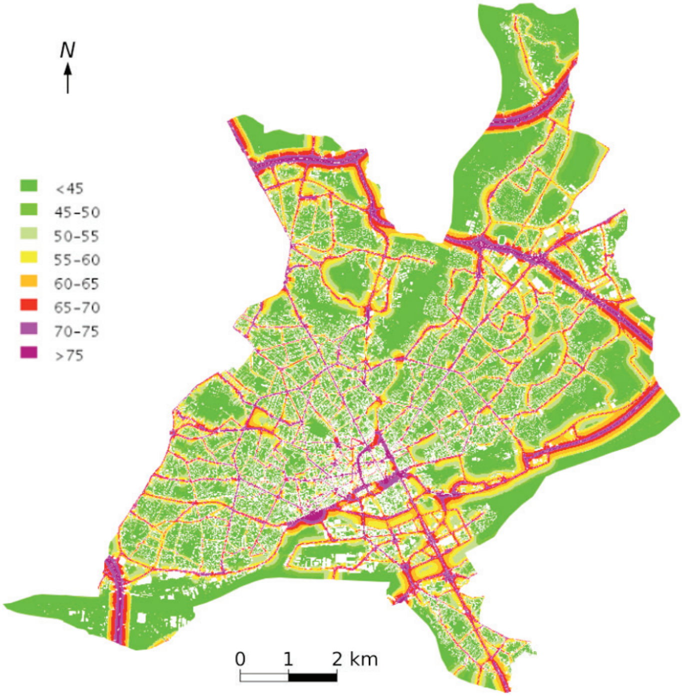

FIGURE 4
LDEN noise map of the commune of Nantes

As an illustration, the noise map of Nantes, shown in Figure 4, requires considering 345 million source-receiver couples for a total of 1.7 million calculations, with a computational time of approximately seven hours. This included the calculation of the direct and first-order reflected and diffracted fields, for a given time period and one octave band on a 2.13 GHz dual-core PC running Linux. We used the noise map to estimate the residents' exposure to noise in an attempt to understand the impacts of the various scenarios. We estimated this exposure by determining the number of residential units for each building and the number of residents per unit [8]. We then computed the maximum noise level at a distance of 1 meter in front of each facades. The number of residents exposed to an LDEN sound level greater than 68 dB can then be incorporated into more useful spatial objects such as commune boundaries or French statistical population units (INSEE).

Our results show that the dierences among the scenarios we considered are marginal in terms of the aected populations. In effect, the number of residents exposed to a sound level greater than the threshold of 68 dB varies little depending on the scenario considered, in the range of 2,974 to 5,204. Nevertheless, we observe that even though the effects may be weak, they are precisely located.

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