Environmental noise modeling within an open source GIS

L. Biagi, M. A. Brovelli, M. Scuratti,
Polytechnic of Milan, Engineering Faculty, Campus Como, Via Valleggio 11, 22100 Como
ludo@torno.ing.unico.it, maria@ipmtf4.topo.polimi.it, scurra@torno.ing.unico.it

1. Introduction

The work consists in designing and building up a model of noise propagation caused by vehicular traffic in urban environment. Obviously the problem has already been deeply described in literature: the new approach we have studied and developed tries to give a simple model suitable to estimate the noise values and to simulate different scenarios due to a change in the traffic plan in medium or large areas (e.g. urban area of a middle city). Because of the complexity and the large amount of the geographical data involved (noise observations, roads, buildings), a set of functions has been implemented within the GRASS© software. The GIS open-source software GRASS (Geographic Resources Analysis Support System), born at USACERL (United States Army Construction Engineering Research Laboratory) in 1992, is freely distributed via internet under the GNU license; its commands and libraries deal with the manipulation, organization, elaboration of spatial data. At the present, it is maintained by the 'GRASS Development Team', i.e. by two different institutes: the Center for Applied Geographical and Spatial Research of the Baylor University - Texas (www1) and the Institute of Physical Geography-Landscape Ecology of Hannover University (www2).

2. The input data and the algorithm philosophy

In the urban territory vehicular traffic constitutes the main noise source. As it is well known (Cocchi, 1998), the measured noise level linearly depends on the vehicular flux logarithm: moreover, generally speaking, it also depends on the contribution of many values, each of them representing different traffic (for example the vehicle speed) and environmental aspects (the road slope, the presence of buildings and their typology, the atmospheric conditions …). Our aim is to implement an accurate algorithm for the noise prediction in the urban territory in the form of a GIS commands set: the basic idea is that the software should be really useful within an administrative framework, and it should be suitable to compute the noise in a reasonable computation time also for large areas; these requirements involve some simplifications with respect to the rigorous noise modeling and propagation formulas. The actual structure of the proposed algorithm requires the availability of the following input data:

1. the roads map;
2. the buildings map;
3. the vehicular flux and speed on the roads;
4. the noise observations.

Starting from these information/observations the noise prediction in the interest area is computed by two distinct processes:

1. estimation of the noise on the centre line of each road, based on the noise measurements and vehicular traffic information;
2. noise propagation from the roads to the whole territory, taking into account both the diffusion law and the buildings screening effects.

Note a major difference between our starting hypotheses and those usually adopted by the noise modeling software: we try to implement an interpolator for the noise observations that also uses some basic environmental information in the prediction process; the more refined algorithms don't require any noise observation but require more accurate and complete information on the analysis environment.

3. The noise estimate on the roads

According to some other existing models, at the present our algorithm considers only the vehicular flux and speed: the basic idea is the estimation of a mathematical relationship between them and the

noise values. At first every noise observation is assigned to the nearest available road: in the assignment, noise values which assignment is ambiguous (i.e. which could be assigned to more roads) are not considered; moreover roads characterized by a small vehicular traffic (i.e. lesser than 20 vehicles per hour) or by a speed lesser than 10 Km/h (because considered as outlier) are neglected.
The noise attenuation due to geometrical propagation has restricted the research of noise observations to a 5 meter buffer for each road. A speed value is assigned to each road according to the following:

$$speed = \begin{cases} speed_1 & speed_2 = 0, speed_1 \neq 0 \\ \min(speed_1, speed_2) & speed_1, speed_2 \neq 0 \end{cases}$$

where $speed_1$ and $speed_2$ represent the two speeds in the two road directions. Indeed, when a speed value is zero, it is obvious to consider the other one; otherwise, due to technical reasons related to measurement instruments, the lesser value constitutes the best choice. The roads are clustered with respect to the related speed (in the first tests we adopted 3 classes: $10\ km/h \leq s < 25\ km/h$; $25\ km/h \leq s < 45\ km/h$; $45\ km/h \leq s$) and a regression model between the measured noise and the traffic parameters is adopted for each class:

$$L_{eq}(A) = a + 10 * Log_{10}(1 + M + b \cdot M \cdot P)$$

where $L_{eq}(A)$ is the equivalent noise level related to the road class; *M* is the total hourly vehicular flux; *P* is the buses and lorries traffic percentage with respect to the total one. Starting from the noise observations and the traffic parameters, we want to estimate the regression coefficients *a* and *b* for each class. In order to do this, the observation equation is linearized starting from some approximated values assigned to *a* and *b*; the derived equation allows the iterative estimate of the parameters. The estimate can be accomplished by least mean squares method as well as, like in our case, by a robust algorithm: we have chosen the last one in order to eliminate the influence of possible gross errors belonging to the observations set in the parameters estimation. Note that if enough measurements are available we can compute the unknown parameters for each road: in that case the speed information, at the present used only for the clustering, is not taken into account. The computation is done by using numerical libraries belonging to the statistical analysis freeware R software (www3); the results, that is the noise estimates for each road, are stored in files whose format is suitable to the next input in the GRASS GIS.

4. The noise propagation

Some new commands within the GRASS GIS have been implemented, which allow the noise prediction in the areas around the roads; the main problems to be solved were the followings:

1. for each road: the identification of the area in which the noise can be considered as mainly due to the road itself (in the following road pertinence areas);
2. for each prediction site: the noise estimate on the basis of the propagation law within its pertinence area; in the case of a site belonging to more pertinence areas the estimate should take into account the different contributions.

The first command implemented, *v.noise.buffer*, identifies the pertinence area for each road of the network. The pertinence area is obtained by tracing a buffer around the road, whose width is chosen by the user; after that the buffer is overlaid with the buildings map, in order to take into account their screening effect (Fig. 1). In our test we have adopted a buffer width of 35 m: indeed it seemed us reasonable that inside 35 m the noise is due only to the traffic on the nearest road; further more contributions should be taken into account. The result file provided by the command contains the pertinence areas vectorial map in the GRASS format.
The second command, *r.noise*, requires in input the pertinence areas file, the roads network map and the file containing the noise estimates for each road. For each prediction site of each pertinence area the noise is estimated following the propagation law

$$L_{eq,A}(d) = \begin{cases} L_{eq,A}(d=0) & d \le d_0 \\ L_{eq,A}(d=0) - 10 \cdot Log_{10}\left(\dfrac{d}{d_0}\right) & d \ge d_0 \end{cases}$$

where d is the distance between the road centre line and the prediction site, d_0 represents the semi-width of the road (typically set to 5 m) and $L_{eq,A}(d=0)$ is the noise estimate on the road.

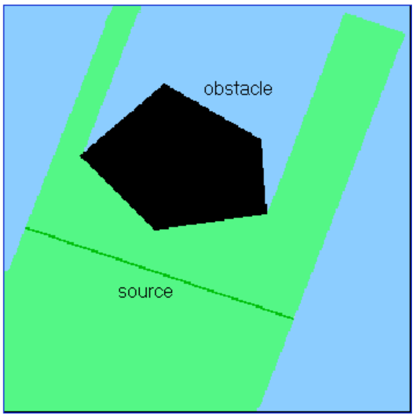

Fig. 1. The pertinence area

At the end, for each site belonging to more pertinence areas the sum of the contributions is computed: a noise digital model is produced in the form of a regular georeferenced matrix of predicted values (GRASS raster format).

5. A case study and the comparison with a reference model

In the framework of the ISOLA project (www4) the prototype of the proposed algorithm has been applied to the noise prediction in the urban territory of the Modena municipality. The main characteristics of the domain and the available data are: domain extension of 400 km^2; road network composed by 650 roads, for a total length of 300 km; 1700 noise observations; the computed noise digital model has a final resolution of 5 m x 5 m, corresponding to 16.000.000 pixels.

The whole computation was done on a PC Intel Celeron® 400 MHz, 64 Mb RAM, Linux RedHat 6.2©: the noise estimates on the roads and the pertinence areas identification required about 1 hour; the noise prediction in the whole territory required about 6 hours. Fig. 2 shows a zoom of the final map: no estimates exist for the sites (i. e. the cells of the digital model) that are not connected to a noise source.

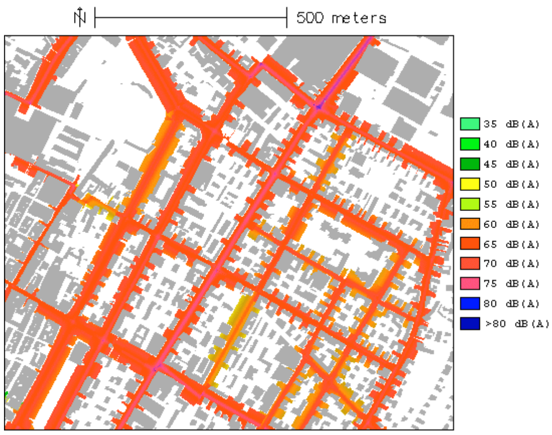

Fig. 2: noise prediction in Modena municipality

Noise estimates were available for some sites of the Modena territory, grouped in two main locations (Fig. 3); the estimates were computed by Artemis® software (HEAD Acoustics GmbH) that is a noise prediction and simulation complex software: in the estimation both the traffic and the environmental characteristics are taken into account; moreover several physical effects are modeled, according to the *C.ET.UR.* (*Centre d'Etudes Urbain, Ministeire du Trasport Français*) specifics. So we have done a comparison between Artemis estimates and our results (Tab. 1): it is clear that, despite the simplifications adopted, our results are in good agreement with the reference ones.

Conclusions

A simplified method has been implemented for the noise digital model prediction based both on traffic information and on noise observations. The model simplicity, and so its high numerical processing speed, makes it useful in the computation for large areas, such as the whole urban territory of a city; despite the simplifications involved by our model, in the first tests it has provided results which are in good agreement with those obtained by using more sophisticated, and more complex, models. In a second step we will insert the modeling of several effects at the present neglected: at first a simplified model for the noise reflection due to the buildings will be considered. Nevertheless our first aim is now to fully implement the prototype, and particularly to develop a more user friendly and robust interface, in order to allow its use in the ISOLA project and to distribute it to the scientific community.

Site	Artemis (dBA)	r.noise (dBA)	Site	Artemis (dBA)	r.noise (dBA)
1-1	69.0	69.4	2-5	60.0	65.0
1-2	75.0	72.0	2-6	67.3	70.0
1-3	71.0	70.7	2-7	67.7	70.0
2-1	67.1	67.6	2-8	68.0	70.0
2-2	67.0	67.7	2-9	66.0	70.0
2-3	69.5	68.0	2-10	69.8	71.0
2-4	69.9	67.3	-	-	-

Tab. 1. Comparison between Artemis and the our algorithm:
location 1: 3 prediction sites; location 2: 10 prediction sites

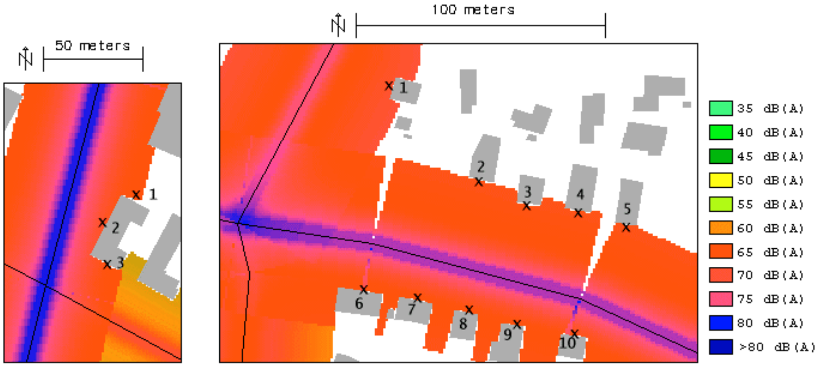

Fig. 3. The comparison locations

References

A. COCCHI, 1998, Calculation of Road Traffic Noise, Department of Transport, Welsh Office, Maggioli Eds.

A.PERETTI, P.SIMONETTI, 2000, Inquinamento da rumore, Traffico e Ambiente, Atti del Convegno Nazionale, Trento, 21-25.02.2000

WWW1: *http://www.baylor.edu/~grass*

WWW2: *http://www.geog.uni-hannover.de/grass/welcome.html*

WWW3: *http://r-project.org*

WWW4: *http://www.comune.modena.it/isola/*