Prediction and evaluation of noise pollution caused by a roads network

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Abstract According to OECD, at least 20\% of the European Union population (around 80 million of people) is exposed in daytime to traffic noise, whose level exceeds the limit of 65 dB(A); traffic represents today the main source of noise in most European countries. Italian laws are very concerned about noise pollution; in particular law no. 447/95 states the obligation - for companies which run public transport services and for those which run road infrastructures - to carry out noise evaluation and reduction plans.

In this context, the local government of the zone of Perugia and the Department of Industrial Engineering of the University of Perugia have started a cooperation aimed at predicting, evaluating and reducing traffic noise in the whole network of the zone (about 2,800 km).

The large extension of the network made necessary the use of a simulation code; a commercial code was used to study the acoustical climate produced by the road infrastructures in a conventional “impact corridor”. The code needs traffic flow data as input and is able to produce 3-D noise maps as well as developing the costs-benefits analysis of the mitigation interventions.

The calibration of the code was made by comparing a significant number of noise measurements with the predicted data. Results were satisfactory in most cases, though corrections regarding traffic flow coefficients had to be introduced into the code. The final accuracy of simulations obtained is about 0.5 dB(A).

1. INTRODUCTION

Noise pollution and the interference turning into noise are relevant parameters in defining the quality of environment. Not long ago, noise was one of the most underestimated and less controlled sources of pollution and only recently it is considered a danger for human health.

In our environment, every day, there are many kinds of noise and their extent can vary. According to OECD, the 17-22\% of the European Union population (about 80 million of people) is exposed in daytime to continuous traffic noise, whose levels exceed the bearable
limits of 65 dB(A). Another 170 million people are exposed to noise levels ranging from 55 to 65 dB(A); this level causes the appearance of first serious damages during the day. Therefore, traffic represents the main source of noise, which causes 9/10 of European citizens to be exposed to noise levels exceeding 65dB(A). A percentage of only 1.7% of the population is exposed to the same noise levels caused by trains, while a percentage of 1.0% is exposed to the same levels created by air traffic [1].

The situation in Italy is not much better. Traffic is one of the main sources of noise both in urban and in suburban areas; among controlled noise sources, traffic shows the highest percentages of noise limits exceeding [2].

In this context the local government of the Perugia area and the Department of Industrial Engineering of the University of Perugia have signed an agreement concerning an Evaluation and Reduction Plan of the noise produced by the whole network in the area. This research, which will last four years, aims at evaluating the area road network (including the local government infrastructures as well as those owned by other institutions but controlled by the local government of the Perugia area) and prioritizing the interventions. They will be distinguished into different levels depending on traffic flows, population density in the “impact corridor” of the road level, the possible presence of very sensible receptors and the results of the noise measurements.

2. LAWS

The awareness of the noise pollution problem has resulted in the creation of laws regulating its acceptable levels. Hereunder a brief overview is given of national and European laws regarding this issue.

Italian general policy law no. 447/95 [3] represents the first attempt to systematically eliminate the noise pollution from houses and from the environment. Pending a law able to regulate the matter, the Decree dated 1st March 1991 had taken into consideration the problem in a systematic way and had fixed, for the first time, the acceptable limits of noise levels all over the Country. Up to that moment, the matter had been regulated by fragmentary and heterogeneous rules issued from different sources of the law, which were not, however, focused on obtaining the necessary protection level for environment and for human health.

Law no. 447/95 states the main principles to protect the environment from noise pollution coming from fixed or mobile sources, but it is a programmatic law since it only defines the dispositions it contains. In fact, the definition of the criteria to be adopted for the acoustic planning and recovering must make reference to ministerial decrees, regional laws and local regulations.

This law also lists the obligations of the Italian central and local governments and introduces the concept of “noise plan”.

Article 10 states that companies and institutions in charge of public transport or infrastructures must make a Noise Evaluation and Reduction Plan, if the noise levels exceed the limits fixed by the law. Moreover, they have to assign a fixed sum, not below 5% of the administration funds allocated for the management and the empowerment of the infrastructures, for interventions aimed at noise evaluation and reduction (law no. 448/98 raised this percentage to 7%).

Rules governing the noise produced by transport infrastructures (the above mentioned general policy law) refer to specific regulations in the form of decrees, aimed at preventing and reducing noise pollution.
The decree dated 29th November 2000 is addressed to the institutions controlling public transport or its infrastructures and states the criteria for preparing a noise reduction plan [4]. These criteria concern the intervention planning and indicate the obligations of the public institutions.

As far as Europe is concerned, the most recent Directive (2002/49/CE) [5] is very interesting because it defines a common approach aimed at avoiding, preventing or reducing, according to the priorities, the problems caused by environmental noise. This policy will be progressively put into effect by specifying and executing acoustic maps and by preparing action plans.

3. THE NETWORK

The examined roads network is made of about 2,800 Km; among them, approximately 2,000 Km are owned by the local government of the area of Perugia, which connect the various towns and villages of the area to the main network of regional and governmental roads. The other 800 Km are regional and governmental roads, but run by the local government of the area of Perugia.

According to the classification made by the Italian Roads Code, most of the examined roads are secondary extra-urban roads; there are also some local roads. The network is shown in figure 1.

![Figure 1: The examined roads network](image)

4. NOISE SIMULATIONS

The use of simulation procedures and codes is fundamental when analyzing a wide roads network [6], [7], [8].
In the present work simulations are carried out by means of a provisional model called “SoundPLAN”.
The model allows obtaining:
- the acoustic simulation;
- the site map;
- the impact evaluation;
- the optimization of the acoustic barriers by minimizing costs and extension;
- the costs-benefits analysis.

Regarding the acoustic simulation of a road, the program is based on the RLS 90 calculation model, which uses the model of source points with reduction due to the ground effect, screening and reflection.
The necessary data input is given by all the information that can allow producing a ground 3-D model and by information concerning traffic flows.
In the ground 3-D modelling, data can be input by scanning a map (bitmap) or importing digital data from other software; for example: DXF files from AutoCAD (geometry), files from Arc View (geometry + attributes) or ASCII interface that can be personalized in order to import non conventional data.
The results that can be obtained are shown in Figure 2, reporting the 3-D altimetric trend obtained by modelling data in a DXF format.
For road classification two sets of information are necessary: the first one concerning the kind of the road and the second one referring to the traffic flow.
Regarding geometry, data concerning the composition of the road surface are input as well as data concerning the road longitudinal section: number of lanes, width of the lanes and of the traffic dividers, etc.
Data concerning traffic can be input in different ways, but only the following ones are strictly necessary: number of vehicles (cars and trucks) per hour in daytime and at night, and the average speed of cars and trucks.

![Figure 2: ground 3-D model.](image)

4.1. Calibration of the previsional system
Given the large extension of the road network controlled by the local government of the Perugia area (more than 2,800 km), a careful study of the model calibration has been carried
out. This model, indeed, has been used satisfactorily for the acoustic simulation results and can be applied to each kind of road that has to be examined. The model calibration is currently in progress and it is performed by the comparison of a significant number of noise measurements with the predicted data. The calibration proceeding includes the following stages:

a. noise measurement simultaneously with a traffic survey;
b. analysis of the measurement and individuation of the levels recorded by the instruments (LeqD, LeqN);
c. acoustic mapping on the basis of the traffic data recorded during the measurement stage;
d. individuation of the levels (LeqD, LeqN) recorded in the measurement point during the simulation;
e. comparison between the measurement and the simulation data;
f. possible corrections of the coefficient referred to traffic data input in order to compare the two sets of data, in case they were lacking in homogeneity;
g. repetition of the procedure on other roads and comparison among the different corrections, in order to determine, if necessary, a standard procedure to be applied to all kinds of roads.

Table 1 reports an example of comparison between the measurement and the simulation data concerning two road infrastructures managed by the local government of the Perugia area.

<table>
<thead>
<tr>
<th>Road</th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LeqD</td>
<td>LeqN</td>
</tr>
<tr>
<td>SP.169_1</td>
<td>59 dBA</td>
<td>54.5 dBA</td>
</tr>
<tr>
<td>SP.172_1</td>
<td>49 dBA</td>
<td>44 dBA</td>
</tr>
</tbody>
</table>

The results obtained by simulation are satisfactory, but thanks to a correction of the traffic flow (about 20%) and an increase of 10 points in the percentage of the heavy goods vehicles traffic in daytime it is possible to obtain the results shown in Table 2 [9].

<table>
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<th>Measurement</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>LeqN</td>
</tr>
<tr>
<td>SP.169_1</td>
<td>62 dBA</td>
<td>55 dBA</td>
</tr>
<tr>
<td>SP.172_1</td>
<td>53 dBA</td>
<td>44.5 dBA</td>
</tr>
</tbody>
</table>
4.2. Noise maps

Noise maps are graphic representations of the acoustic climate produced by a noise source, in this case, road traffic. The representations of the noise pollution on the road site belonging to the first group were simulated by means of the SoundPLAN provisional software. The first operation necessary for the correct functioning of the simulation program was the 3-D modelling of the ground surrounding the road in subject; this operation was repeated for each road infrastructure. This proceeding requested, as input information, all the level curves and the roadway in a 3-D format, in a DXF format, that could be easily obtained from the data supplied in a DWG format.

Once the Digital Ground Model was done, a geometric characterization of each road was performed by inserting the following data:

- kind of road (suburban, local, etc.);
- lane sections;
- kind of road surface.

Afterwards, an acoustic characterization of the road was carried out; the road was considered as a linear source of noise on the basis of the following data input:

- average vehicles in daytime;
- average vehicles/hour in daytime;
- average vehicles/hour at night;
- percentage of heavy goods vehicles in daytime;
- percentage of heavy goods vehicles at night;
- average daily speed of cars and motorcycles;
- average daily speed of heavy goods vehicles.

Once the complete road characterization was done, as above shown, the simulations producing the maps as reported in Figure 3 were carried out.

![Figure 3: raw output of the simulation code](image)

From this representation it was possible to place this map on the Region Technical Map (CTR) (Figure 4) and on the related ortho-photomap (Figure 5); this way it was possible to verify easily when the limits fixed by the laws in force exceeded.

For the graphic representation authors choose the colour range reported in Figure 6 for the suburban roads whose impact corridor is 150 m wide.

As far as the roads classified as “local” are concerned, whose impact corridor is 30 m wide, and which have lower noise limits, the colour range is as reported in Figure 7.
Figure 4: output placed on the technical map

Figure 5: output placed on the ortho-photomap

Figure 6: day and night colour range used for the suburban roads
5. INDIVIDUATION OF THE CRITICAL AREAS

When the noise maps are placed on the cartographic supports some problems may raise in the impact corridor of the road level. Where there is a sensible “receiver” such as a residential area, a school, a hospital, in a unfavourable situation from the acoustic point of view, a data collection schedule was prepared; this form is filled in after a survey and reports the following data:

- general information on the receiver (identification number, name, involved road, Municipality which the road belongs to, address, involved population, construction date, type of building, number of floors, number of basements, type of frames, acoustic zoning);
- photographic documentation;
- road characteristics (kind of road, speed limit, width, slope, directions of traffic, features of the road surface, data concerning traffic);
- acoustical climate (day/night detailed noise maps with possible exceeding limits);
- acoustical climate after the intervention (kind of adopted solution, day/night detailed noise maps after the intervention);
- indicators concerning the interventions prioritizing;
- group interviews and remarks.

The survey schedule is very useful in calculating the priority index per each critical area/building as well as in drawing up the final classification of the critic situations.

The calculation of the priority index within a given area (A) is made in conformity with the decree dated 29th November 2000 [4]; it is obtained:

1. by dividing the area (A) into a certain number of sub-areas (Ai), so that \( \Sigma Ai = A \);
2. by evaluating the noise limit (\( L^*i \)) imposed by the law concerning the Ai area;
3. by calculating the Ri value (number of exposed people) concerning the Ai area;
4. by calculating the continuous equivalent value of noise pressure (\( L_i \)), during the reference period, approximated to the unit, produced by the road in the Ai area.

The priority index concerning the noise reduction intervention (P) is obtained as follows:

\[
P = \sum Ri (L_i - L^*i) \quad (1)
\]

where if \( (L_i - L^*i) < 0 \), then \( (L_i - L^*i) = 0 \)

In the P calculation, as far as hospitals, nursing and resting homes are concerned, the Ri (total number of beds) value is to be multiplied by 4; in the case of schools, the Ri (total number of
students) is to be multiplied by 3; regarding the other areas Ri is obtained by multiplying the Ai area surface by the most updated statistical-demographical index. When the priority index (P) is the same, the intervention giving the highest value of the differentials sum (Li – L*i) is chosen.

6. CONCLUSIONS
Traffic noise is the most relevant factor in the increase of the noise pollution in the towns. The parameters determining the noise pollution caused by the road traffic are the following ones: the observation point, the geometric features of the road, the hour flow of vehicles, the obstacles on the sound wave path, the presence of reflecting surfaces. The chaotic urban growth typical of the last decades, which did not take into consideration the consequences of the environmental noise, is the main cause of the noise pollution. During the time, some incompatible acoustic situations have become established, as the contemporary presence of schools, hospitals, buildings near fast-flowing traffic roads or near industrial sites. The awareness of the noise dangerous consequences led to a new attitude towards the problems connected with the noise pollution and to a revision of the law on the matter. As a consequence, the local government of the Perugia area and the Department of Industrial Engineering of the University of Perugia have started a “Plan of reduction of the noise produced by the whole network within the Perugia area”. This study aims at showing a method able to analyse the status of noise pollution in a roads network area as well as at giving the local government a technical tool to prepare a noise reduction plan. The large extension of the network made necessary the use of a simulation code; the calibration of the code was made by comparing a significant number of noise measurements with the predicted data. Results were satisfactory in most cases, though corrections regarding traffic flow coefficients had to be introduced into the code. A methodology for the evaluation of a priority index for the most critical areas is also presented, useful to allocate financial resources to the most urgent noise reduction interventions.

REFERENCES
