STUDY OF THE NOISE GENERATED BY A MAJOR ROAD IN A CITY

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***Abstract*—** The paper presents a case study regarding a the noise generated by the road traffic on a main road that traverse a city. Since no input data was available, all data was produced using free available sources for the base map and data collected on site for the traffic volumes and speed. The methods and tools used to process the outputs are also presented. Beside the noise mapping software, are used GPS, GIS and CAD techniques.

***Keywords*—** noise map, road traffic, environmental noise, instrumented vehicle, vehicle speed.

I. INTRODUCTION

THE noise maps are useful tools for estimation of the influence of various noise sources on the environment and on the population. Construction of new buildings will produce noise not only during construction, but also after completion, in the form of increased road traffic noise [1]. Noise is an important factor to consider in urban planning, as new traffic routes and changes to the movement patterns of the vehicles can be identified. Noise maps can be used to predict the sound levels when new buildings and roads are planned, and also to monitor the noise in agglomerated areas, where many dwellings are neighboring with major roads.

In European Union, following the Directive 2002/49/EC, it is mandatory for major roads to prepare noise maps and to develop actions plans for noise mitigation. The general methodology is presented in the "Good practice guide for strategic noise mapping" [2] and there are many commercial software tools available for data processing. A calculation method is based on a summary of many measurements undertaken by the acoustic community and therefore in many cases is more representative than an individual measurement that is more or less a snapshot. A comparison of the noise prediction methods is presented in [3]. The methodology includes various instruments for producing the input data, defined for each noise source. Depending on the instrument used, the results may be more or less accurate. The methodology is described and commented also in papers like [4] and [5]. A review of the existing tools for traffic noise prediction is presented in [6]. Other studies were conducted to predict the ambient levels of road traffic noise and to estimate the population exposed for certain cities [7].

The impact of road traffic on the environment is determined by calculation procedures, which depend on the quality of input data. Data needed to ascertain the level of noise generated by the road traffic are: vehicle count (traffic volume), traffic speed, traffic flow type, and road characteristics. A complete set of these variables is rarely available [8], and certain assumptions and averages should be introduced to the modelling process, with more or less influence the final result. Some usual assumptions include: the number of heavy vehicles in the flow; the average speed of vehicles; topographical data of the area; the road surface type for each road segment. The input data are among the uncertainties included in any model used in noise mapping software and these are the only sources of uncertainty that can be controlled by the user.

II. METHODOLOGY

A. Basic elements for road noise assessment

The effect of noise on the environment is described using an indicator named equivalent sound level, *LAeq*. *LAeq* is a conventional measure that represents the sound level which, if should be constant for the entire reference duration, will give the same acoustic energy like the fluctuating noise of the road. The equivalent sound level is expressed in *dB(A)*, unit that consider the sensitivity of the human ear. The measurable parameter that is at the base of the equivalent sound level estimation is the sound pressure level, calculated using the formula:

$$\mathbf{P_a = 20 \cdot \log_{10} \frac{P_{meas}}{P_{ref}}} \tag{1}$$

where P_a is the sound pressure level (in dB), P_{mas} is the measured sound pressure and P_{ref} is the reference sound pressure.

When the noise is generated by multiple sources (many vehicles travelling on the same road segment), the effect of summation of all sources is calculated using the relation:

$$P_{atot} = 10 \cdot \log_{10} \sum_{i=1}^{n} 10^{\frac{P_{ai}}{10}} \qquad (2)$$

The noise indicators used for the noise maps, as defined by Directive 2002/49/EC [2] are: L_{day} (day-time indicator), $L_{evening}$ (evening-time indicator), L_{night} (night-time indicator), and the compound indicator L_{den} (day-evening-night) noise indicator. The noise indicators L_{den} and L_{night} are used for the calculation of strategic noise maps. L_{den} is calculated based on L_{day}, $L_{evening}$ and L_{night}:

$$L_{den} = 10 \cdot \log_{10} \frac{1}{24} \left(12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}} \right) \qquad (3)$$

The estimation of the noise generated by the road traffic can be made using statistical Traffic Noise Models, which are implemented in noise mapping software. The models used to ascertain the road traffic noise uses an estimation of the speed of passing vehicles. There are more methods that can be used to ascertain the vehicles speed, described in the literature [2], [9].

A method considered very accurate is to use devices for automatic traffic flows analysis, like traffic counters-classifiers. The traffic classifiers are convenient for measuring traffic volumes, but the measured speeds are instantaneous speeds for the point were the device is mounted, usually in the middle of each road segment. The speed values will be higher than in other parts of the road. It is easy to calculate the average speed of the traffic flow in the measuring point, but this value cannot be applied with a good accuracy for the entire road segment when the traffic flow is not continuous.

An efficient and cost-effective method for acquiring vehicle speed data for acoustic road traffic modelling is the use of Global Positioning Systems (GPS) technology, as described in [9] and [10]. This means one or more vehicles equipped with GPS receivers will travel following the traffic flow, so that the speed measured by the GPS device is approximately equal with the average speed of the traffic flow. More passings on each road segment will improve the accuracy.

B. Theme and objectives of the study

The theme of the study was to realize the noise map for the noise generated by the road traffic on the road DJ200B on the administrative area of municipality of Voluntari. A previous traffic study revealed on this road a traffic volume of 3,725,555 vehicles, so it was considered major road (over 3 millions vehicles/year) and consequently is necessary to evaluate the effect of the noise on the population of the traversed city.

The only data available when this study was started were the end limits of the road that had to be considered as noise source. No other information was given explicitly, not even a digital map of the area. Under these conditions, the study objectives were defined as follows:

1) *prepare the layers of the base map - streets, buildings, etc;*
2) *estimate the number of inhabitants/dwelling;*
3) *collect traffic data (volume, speed);*
4) *create the noise map for the time intervals day/evening/night (L_{den}) and night (L_{night});*
5) *estimate the number of inhabitants exposed to more than 55 dB(A) L_{den} and 45 dB(A) L_{night};*
6) *propose action plans for noise mitigation;*
7) *create noise maps for the proposed situation, estimate the exposure of inhabitants and generate difference maps.*

In this paper are presented the steps until estimation of the inhabitants exposed to current noise level, without the proposed action plans.

C. Description of the noise mapping process

The process of creating a noise map includes three steps: prepare the inputs, calculate, process the outputs.

The road traffic data are attached to the GIS map layers and represent input data for the calculation software, which is Lima 7812 [11]. The program offer features for preparing the input data and also for processing the calculation outputs; for this study only the calculation module was used.

The noise map outputs can be considered as one or more layers in a Geographic Information System (GIS), with the graphical support and the associated properties according to the GIS rules. The raw outputs are the noise levels for all the points of a grid that covers the entire area of study. The output files are then processed using custom functions that allow the user to evaluate the exposure of each building and to estimate the number of inhabitants exposed to different noise levels.

The software tools used for preparing data are QGIS [12], AutoCAD for preparing the graphic support of the GIS layers and MsOffice for preparing input data according to Lima requirements. Beside these open source and commercial software packages, custom software developed by the project team was also used.

III. Input Data

The input data consist in two categories: map data and traffic data. The map data are included in the layers of the GIS map: digital terrain model, buildings, green areas (forestry, parks, gardens), streets. The traffic data are associated to the road segments and include: traffic volumes, speed, type of traffic flow.

A similar approach is described in [13], where are mentioned also two types of basic data in traffic noise calculations: traffic flow information and the attributes of roads and buildings.

A. Base map

A good resource for GIS layers, free available online, is OpenStreetMap [14]. The map data available from

OpenStreetMap (Figure 1) are accurate, but not complete in the study area. The missing information is available with good details in Google Maps [15], for the study area being available also the 3D views. The views captured from Google Maps were georeferenced using QGIS, then exported into AutoCAD to extract only the necessary contours and to attach custom data, like the height and type of each building and the estimated number of inhabitants.

Figure 1 - The base map imported from OpenStreetMap

The number of inhabitants for the entire neighbourhood was available from the last census reports, but there were no information available about the number of inhabitants for each dwelling. For a closed contour, composed by straight segments, it is easy to calculate the area, in an automatic way, and so it was calculated the living area for the entire neighbourhood. This total area was then divided by the total population number, resulting the area/inhabitant. Then for each building, the living area was divided by the area available for each inhabitant, resulting the number of inhabitants in that building, rounded to integer value.

All the map layers have been defined in detail in the CAD files, then imported in QGIS as vector layers. An important property of each CAD entity is the *handle* of the entity. The handle will be used as object identifier to synchronize the geometric objects with the database.

The street layer is composed by open polylines. Like the building entities, the entities that represents the street segments have custom data attached, including the traffic volume and speed for the three intervals: day, evening, night. The length of each segment depends by the road curvature and the changes in the traffic parameters. Close to an intersection the road segments are shorter, in order to capture the quick changes of the vehicle speeds. The road gradient and pavement are similar for all the road segments; the road is considered horizontal and the pavement is smooth asphalt.

B. Traffic volumes

In Figure 2 are marked the road segments (A-E) and the points of traffic counting (1-7). CB represent a part of the Bucharest ring road. On all road segments, the traffic flows on both directions, with a single lane for each direction, except for a part of the segment D where are two lanes in each direction. The methodology chosen for data collection was manual counting.

The calculation model used is the French method for road traffic noise prediction (NMPB – Routes '96) [16]. The vehicle's category used in this method are only two: light vehicles (under 3.5 t) and heavy vehicles (over 3.5 t). Vehicles of both categories were counted for each direction. A special attention was given to the roundabout area, where the vehicles number differ for each entry and each arc of the roundabout, and also there are significant differences in speed [17]. The traffic volume on each of the road segment in the intersection area is determined analytically based on the counts taken in points 1, 2 and 3.

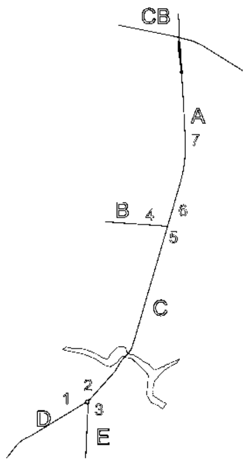

Figure 2 - Road segments and points of traffic counting

The traffic volumes recorded revealed values over the average daily traffic obtained in the previous traffic study, meaning 10,207 veh/day. The new measurements show daily traffic volumes between 8,512 and 14,096 physical vehicles, and that is a variation of the annual volumes between 3,106,880 vehicles on the road segment A and 5,145,040 vehicles on the road segment C. A high daily traffic value was obtained for the road segment E, but this should not be considered as noise source, because is not part of the road DJ200B. A high volume was measured on the road segment B (1,350 veh/hour, approx. 10,800 veh/day), which contributes to the discharge of the road segment A.

C. Speed

The traffic flow inside cities can be generally considered to be pulsating, on horizontal roads. The reason for this assumption is the high number of intersections, where the speed profile includes accelerating and decelerating phases. The noise generated by this type of traffic has a higher level at lower speeds because it involves many accelerations and decelerations.

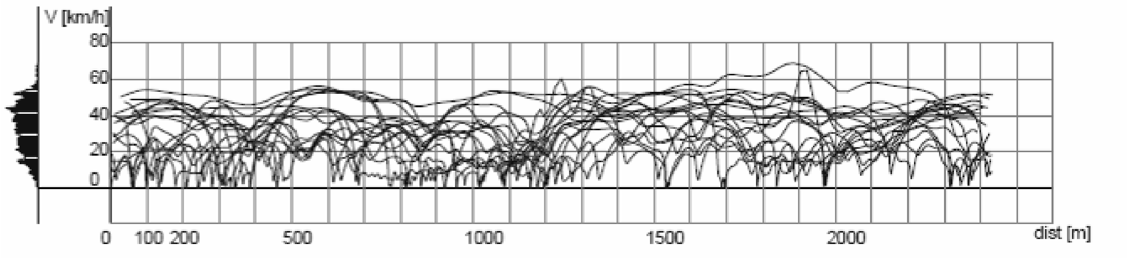

Figure 3 - Speed versus distance diagram for more passings on the road segment C

GIS data are combined with data acquired using GPS devices to determine average speeds of traffic flows. The speed was measured driving an instrumented vehicle on the road of study (using a GPS receiver with an output rate of 1 Hz). Data stored in the receiver memory was imported in the CAD drawing that contain the street layer of the GIS map, and attached to the polylines entities which represent the road segments [18]. There were 17 passings in both directions. Each of the road segments is composed by at least three sub-segments, so that the speed data can be different near the junctions.

Using the data attached to the entities that compose the track, various diagrams can be generated using dedicated functions. Figure 3 shows the speed versus distance diagrams for more passings on the same road segment. At the left of the diagram appear the diagram of speed frequencies distribution, generated automatically by the software function. Using the same data on which is based this representation, with the formula below, it can be calculated the mean speed for the analyzed route:

$$\bar{\mathbf{v}} = \frac{\sum_{\mathbf{i}} \mathbf{f_i} \cdot \mathbf{v_i}}{\mathbf{N}} \tag{4}$$

where $\bar{V}$ is the mean speed, f_i is the frequency of observations in the speed group i, v_i is the middle value of speed in the group i and N is the total number of observations.

The mean speed calculated for this road segment is 33 km/h. The lateral diagram in Figure 3 is used to generate a diagram of cumulative frequencies that allows the graphical determination of the median speed (V50), as well as other speed percentiles. The median speed for the road segment C is 33.44 km/h, which is very close to the value of the mean speed for the same road section.

The values of median speed (V50) for all the road segments used in this study are given in the TABLE I.

The segment IDs which are not clearly identified in Figure 2 are those located near the intersections, like A-6 which is at the end of the road segment A, in the area of the traffic counting point 6. In a similar way are defined the short segments near and inside the roundabout (C-2, D-1, E-3). Some small road segments, like those that compose the roundabout, are not explicitly listed in the table because the median speed has the same value as for the adjacent segments. The speed values for CB and all values for the night interval are adopted.

TABLE I
MEDIAN SPEED DETERMINED FOR ALL ROAD SEGMENTS

Road segment	Light vehicles speed			Heavy vehicles speed		
	Day	Evening	Night	Day	Evening	Night
CB	90	90	90	80	80	80
A-CB	55	55	60	55	55	60
A	51	51	60	51	51	60
A-6	23	23	30	23	23	30
B-4	23	23	30	23	23	30
B	42	42	50	42	42	50
C-5	23	23	30	23	23	30
C	33	33	50	33	33	50
C-2	24	24	30	24	24	30
D-1	24	24	30	24	24	30
D	46	46	50	46	46	50
E-3	24	24	30	24	24	30
E	46	46	50	46	46	50

The traffic volumes and speeds, as well as any other information available about the road (pavement, gradient, etc.), are attached to the polylines that represent the road segments. When the input data are ready, all information is stored inside the CAD drawings, as custom data attached to the geometric objects.

IV. CALCULATION AND RESULTS

A. Use of the noise mapping software

The software use to calculate the noise level was LimA 7812 [11]. The calculation result is a grid where for each node it is calculated the equivalent noise level. The grid is composed by square cells with the side length of 5 meters.

Data are imported in the calculation program as MsAcces tables and attached to the objects (road segments, buildings) using the object ID as reference.

The results delivered from the noise mapping software consist in a grid of noise assessment and can be exported as text files, where each line contains the coordinates of a point and the noise levels (including L_{den} and L_{night}) calculated for that point. The noise mapping software offers features for presenting and printing the noise maps and also for estimation of population exposure. However, a better control of the results is obtained if the raw data are exported and processed with other software. The software tools used for presenting and processing the output data are, as for preparing the input data, QGIS and AutoCAD, with custom designed applications.

B. Noise maps

The processed noise results grid files may be used for production of 5 dB noise contour bands, for graphical mapping of results.

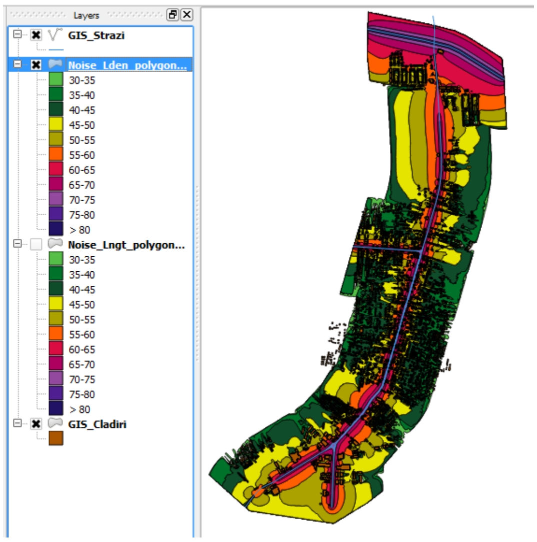

Figure 4 - Noise map - L_{den}

QGIS allows the user to import data from text files organized in rows and columns, and the user has to specify which columns represent the coordinates of the point corresponding to each line, and the other columns will represent properties of that point. Such properties are the noise level indicators. An available plug-in for QGIS can calculate the contours defined by certain values of the point properties and creates contour or polygon layers based on those properties.

The 5 dB bands required in noise maps start at least with 55 dB for L_{den} and 45 dB for L_{night}. In Figure 4 is presented the noise map obtained for the study area, for the L_{den} indicator. The lowest noise level band displayed in the figure is 30 - 35 dB.

C. Validation of the calculation results

At the same time with vehicles counting, measurements of the sound level were made using a sound level meter (Bruel&Kjaer, Type 2250), in the points 1, 6 and 7 (as per Figure 2). The duration of each measurement was 30 minutes. The differences between the measured and calculated sound levels should not me higher than 3 dB. The measured and calculated values are listed in TABLE II. The resulted differences are less than 3 dB (max. 2.5 dB in the table).

TABLE II
VALIDATION OF THE CALCULATED SOUND LEVELS

Measuring point	Sound level [dB(A)]		
	Measured (L_{Aeq})	Calculated (L_{den})	Difference
1	73.7	71.2	2.5
6	73.3	70.9	2.4
7	72.4	69.9	2.5

D. Population exposure

As results of the noise mapping process, it is required to report the total number of dwellings (in hundreds) exposed to L_{den} and L_{night} higher than 55, 65 and 75 dB for major roads. It is also required the estimated number of people (in hundreds) living in dwellings that are exposed to noise, in 5 dB bands, for the various scenarios mapped. The results are presented in TABLE III.

TABLE III
PEOPLE EXPOSED TO NOISE LEVELS

	Noise interval [dB(A)]									
	<35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	>75
People exposed (hundreds), L_{den}	13	22	27	36	45	28	15	5	1	-
People exposed (hundreds), L_{night}	55	28	20	13	10	5	3	1	-	-

V. FINAL COMMENTS

On the base of noise maps are generated the conflict maps, which highlights the areas with noise levels over the limits established by the national authorities (Environmental Protection Agency). These limits are, for road traffic noise, 70 dB(A) for L_{den} and 60 dB(A) for L_{night}. The conflict maps and the lists of population exposure help the organisation that administer the road to take measures for noise mitigation.

Since the main goal of the study was to assess the influence of the noise generated by the major road on the environment, the road traffic on the adjacent streets was ignored, except the road segment B, which is considered to have a high influence on the traffic volumes measured on the main artery.

It can be consider that for this study was used data of high quality, as the most important input data was collected on site. No information was available when the project started, so that third party GIS data and on site observations were used. The traffic volumes were counted manually, in critical points of the road, and the speed was measured using an instrumented vehicle, equipped with a GPS receiver. The grid cell size used in calculation was 5 meters.

Measuring the accuracy of the results obtained by noise mapping is a difficult task, as each data type used has its own level of accuracy. Globally, on the final maps, the values of the calculated noise level for certain points should be with no more than 3 dB different by the measured noise level in the same points. The noise map of the major road DJ200B was validated with differences between measured and modeled values of 2.5 respectively 2.4 dB, so it was not necessary to adjust the input data and then to model again the noise map.

The lower accuracy used in input data is for the traffic volumes. This is because the counting was done during a single day. The existence of a long term vehicle counting database would allow the determination of seasonal, monthly and daily correction factors, allowing more accurate measurements when using short-term counting (eg. one hour). Lack of historical data is a premise of increasing uncertainty. The uncertainty of a result is reduced only if all input data are of acceptable accuracy. In case of a high uncertainty of all input data, the total uncertainty will exceed any of the individual values.

The accuracy of results is important in creating conflict maps, where the noise levels are compared with limit values, in order to develop action plans for noise mitigation, that involve public spending.

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