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NOISE MAPPING FOR URBAN ROAD TRAFFIC AND ITS EFFECT ON THE LOCAL COMMUNITY

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Abstract: *A major source of noise in an urban agglomeration is the road traffic. In order to analyze the effect of the noise on the population, the local authorities need noise maps, created depending by each major noise source. Data necessary for estimate the noise generated by the road traffic are: vehicle numbers and vehicle speed, by category, and data related to the road segment: traffic flow, road surface construction and gradient. The final result – noise map – is strongly influenced by the accuracy of input data. This paper presents a method for road noise mapping, from the beginning (data acquisition) to the end (printing and evaluation of population exposure), an original approach that gives accurate results.*

Keywords: *noise map, road traffic, data acquisition, GIS, GPS, data processing, CAD programming*

1. INTRODUCTION

Noise is a major source of dissatisfaction in residential areas. There are many noise sources in the urban areas, but only some of them can be taken into consideration for noise mapping and noise reduction action planning. These are: road traffic, railway traffic, airports and industry – see references [3], [15]. In order to know the effect of these noise sources on the population and buildings, we have to know as much as possible about the sources and propagation. The analysis can be done using specialized software. The result is a noise map – a map representing the noise levels as surfaces or contour lines. The input data for the simulation software are a base map and specific properties of the sources (road segments, railway segments, industrial sources and others).

Our team challenge was to realize the noise map for the city of Tg. Mureş, a city with about 150,000 inhabitants. There are more than 30,000 buildings and about 300km of streets, from which about 60km are considered main roads, with significant vehicle traffic. The road traffic is the main noise source in Tg. Mureş, like for almost urban areas [7].

2. PREMISES

The core of the software system used to generate the noise map was Lima 7812. Lima is a powerful noise calculation system. It includes advanced automated data manipulation, geometric handling and allows the user to perform large and accurate noise calculations from existing data sets [16]. In theory, is not necessary to use other software, such as GIS and AutoCAD. In fact, the data and geometry manipulation features are not so powerful and don't gives enough flexibility. The cost for a single license is very high, and it was not affordable to buy or rent more than one license. But a positive point is that Lima has import and export features. When the final result is a noise map, another software system mandatory is GIS software. The cost of a GIS system is also high and, on the other hand, not all the features of such software are useful in noise mapping. In this situation, it was a good choice to use the available CAD software, already in use in our institution, with some dedicated software written especially for this project. Lima was just the kernel of the process, and preprocessing and post processing was done using a proprietary dedicated system. The process diagram is shown in Figure 1.

The preprocessing phase includes the activities for preparing Lima input data: the layers of GIS map (streets, terrain model, buildings, and other obstacles) and noise sources data: traffic volumes, vehicles speed, flow type, road surface and gradient. All that data are stored in an Access database; this is imported in Lima over the base map.

The post processing phase is based on the ERT files created by Lima. These are text files and contain a line for each point of the calculation grid.

All the base map layers were drawn in AutoCAD, and the custom functions for pre- and post processing the data was written in AutoLISP, using extended ActiveX functions available for storing *metadata*.

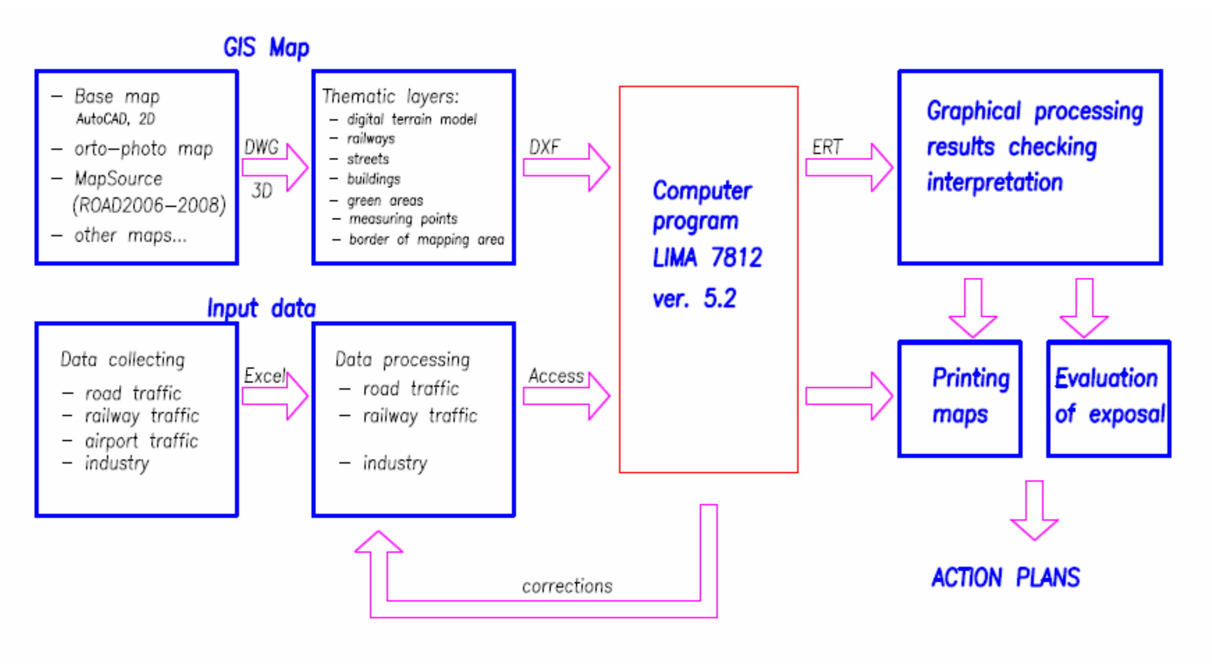


Figure 1- Noise mapping diagram

2. BASE MAP

The base map (GIS map) is composed by some specific layers, each of them containing noise sources or obstacles. The layers necessary for road traffic analysis are: streets (as noise source), buildings, terrain model and green areas (obstacles). There are no noise barriers inside the city. The first source for the base map consists in two maps obtained from the Tg. Mureş authorities – an orto-photo image (aerial view), and an old AutoCAD map drawing (Figure 2). The streets layer in the AutoCAD map was not enough for the needs of Lima. Each street must be broken in segments with the same traffic data. A street segment is a linear noise source [1]. The second map source was the digital map ROAD 2006 (Figure 3); this was the main source for the streets segmentation. The buildings were extracted from the initial AutoCAD drawing, and other buildings were added based on the orto-photo map. The green areas inside the city were drawn based on the orto-photo map. The total surface of the green areas covers about 14% of the city.

A big problem was the terrain model, since the initial drawing didn't includes enough information. Some additional curves were drawn using existing topographic maps as model (paper and digital maps). The altitude interval between the level curves was established to 2 meters [15]. Initially, the level curves were 2D polylines, and altitude information was added as text entities in the drawing. Using a custom function (AutoLISP), the altitude information was extracted from the text entities and added to the 2D polyline as *elevation* – this is a standard property of the AutoCAD objects. This was the digital terrain layer.

The *building* layer is composed by closed polylines (one entity for each building). The height of each building is added as *thickness*, which is also a standard property. Using the standard properties for AutoCAD entities is convenient because are easily transferred to Lima software, through DXF files. Unfortunately, some additional data cannot be transferred through the same DXF file. These are, for the *building* layer, the type of each building (industrial building, medical or educational institution, residential buildings), the number of inhabitants and dwellings in case of the residential buildings.

The metadata can be stored in the drawing using the ActiveX functions [8], and then exported to Lima using Access tables. More exactly, data associated to the AutoCAD entities are exported in text files, which are imported in Excel and saved as XLS files. The XLS files can be imported then in Ms Access, as tables. The link between the Access table and the AutoCAD objects is assured by an ID field, which is the *handle* of the entity, unique in a drawing.

Figure 2 – Aerial view and “street” layer

Figure 3 – ROAD 2006 map (source for streets segmentation)

The *street*s layer (Figure 4) is composed by *open polylines* according to [11]. Since each segment should contain specific data related to vehicle traffic, it was decided to use a single *line* entity for each street segment. The noise mapping software (Lima) accepts both polylines and lines. Each line entity has the traffic data associated as custom properties, or metadata. There are three types of streets: main streets, connection streets and residential streets. The traffic data for residential streets are the same for all the segments, and also for the connection streets. In case of the main streets, traffic data was collected or estimated for each segment, and there are more metadata associated.

Figure 4 – The *streets* layer, detail

It is important to mention that the additional information associated to the geometric entities makes the drawing larger and the regeneration process much slower. It is not easy to maintain the balance between the volume of metadata and the calculation speed.

The entities in the other layers (like terrain model and green areas) don’t contain additional data. In Figure 5 is represented a part of the complete base map, with all the layers included.

Figure 5 – The complete base map, detail

2. DATA ACQUISITION

The data related to the road traffic are the traffic volumes (number of vehicles) and vehicles speed. There are about six hundreds of street segments (only for the main streets) and counting the vehicles for all these segments is not easy. There are two categories of vehicles: light and heavy; the limit is at a weight of 3.5 tones [1]. On the other hand, there are three periods considered for a day: day, evening and night.

2.1 Traffic volumes

The best way is to use traffic classifiers, like radars or inductive devices, but the high number of the necessary devices makes this method not affordable. Using human observers for counting vehicles is a much cheaper solution. There was established a number of points for collecting traffic volumes in the city. Based on the values obtained for these points, the traffic volumes for all the street segments were estimated. Some of the measuring points are shown in Figure 10.

The tool used for estimating the traffic volumes on all the segments of the main streets was an Excel table (Figure 6). It is shown a part of a large boulevard, including three intersections. The yellow cells contain data measured; the other cells are with estimated data.

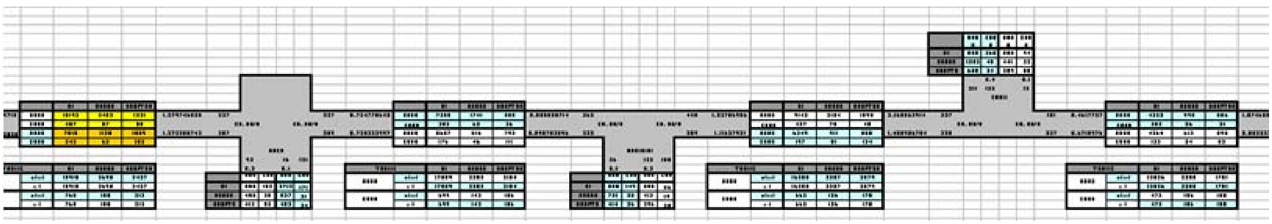


Figure 6 – Excel table used for traffic volumes estimation

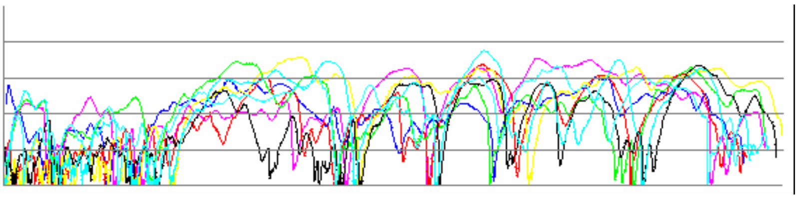
It is not realistic to try to measure the number of vehicles on all the streets in a city. For the secondary streets, the traffic volumes were considered according to the recommendations found in the official literature: [2], [3], [11] and [15].

2.2 Vehicles speed

More difficult than counting the vehicles, it is to measure the speed of the vehicles for each street segment. Using radar devices for this purpose is not a good solution, because the static devices can measure the speed of many vehicles in a single point. Using the legal speed limit for each segment [11] is not accurate. The method used for this case is not listed in the general used literature ([1] to [15]), but is described in [8] and [9]. The method is based on the use of GPS devices for recording position and time information, and then the medium speed is calculated for each segment of each street. These data are collected by driving on each street, at different hours, many times. The GPS devices used should be able to record data each second. The devices used was GPSmap 60CSx (one record per second) and GPS 18x-5Hz (five records per second), both from Garmin - Figure 7. The measuring system includes also a mini-notebook and some accessories, like power inverter, cable data. A detailed description is given in the papers [9] and [11]. The software used for GPS data processing was written also in AutoLISP and runs under AutoCAD; the results are automatically added to the *street* layer of the base map as metadata. Example of the speed evolution for more passings (a different color curve for each passing) on the same route is shown in Figure 8.

Figure 7 – Devices used for speed measurement

The acquisition and recording of data from the GPS 18x-5Hz device (middle of Figure 7) is done using a *stand-alone* software application specially developed for this purpose which runs on the mini-computer (right of Figure 7) – the programming language chosen was Delphi. This data acquisition system is used for many projects types, not only for noise mapping.



	Dist	Durata (sec)	Vit.m/s	Vit.km/h
1	5473	901	6.07	21.87
2	5418	1143	4.74	17.06
3	5619	1340	4.19	15.10
4	5643	1123	5.02	18.09
5	5535	1434	3.86	13.90
6	5465	997	5.48	19.73
7	5624	1514	3.71	13.37
8	5364	934	5.74	20.67

Figure 8 – Vehicle speed on the same route, driving eight times

The positioning data collected with the GPS devices must be converted from the native GPS system (WGS84 datum) in the local coordinates system, which is STEREO 70 for Romania. If the local authorities already had a base map, the transformation can be done using only a 2D translation. If this map is not available, it should be implemented a complex algorithm [13] and in some cases the coordinates should be corrected based on the exact coordinates of a given point, identified on field.

2.3 Other data

Beside road traffic data, there are other data needed for noise mapping. The gradient of each street segment can be determined also using the GPS devices, but it is also possible to use the terrain model, if there are no significant differences between the altitude of the road surface and the terrain around. The type of traffic flow is *continuous pulsating* according to [15], and this is also visible in Figure 8.

In order to estimate the effect of noise on the population is necessary to know the number of inhabitants for each residential building. This information can be obtained from the local authorities. If it is not available (this was our case), it can be estimated starting from the total number of population in the city. First, it should be calculated the total area of dwellings, and the medium area for each inhabitant. Then, for each building, it can be calculated the number of inhabitants, using the total area of the building. This information is added to the polyline entity representing the building, as metadata.

3. CALCULATION

As mentioned before, the input data for the simulation software (Lima) are stored in Access tables, which are connected to the AutoCAD drawings using the entities handle. The base map layers are imported in Lima through DXF files. For the buildings, the height information is sent as color property (the conversion between thickness and color was done previously on the AutoCAD drawing) - Figure 9.

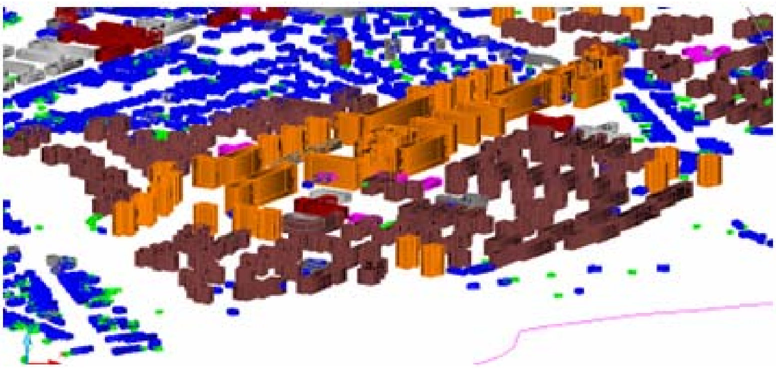


Figure 9 – Buildings prepared for Lima

After importing the geometry some checks should be done in Lima: closing polygons to ensure the correct modeling, especially for buildings; recognizing and preventing multiple existences of objects; linking objects to prevent gaps in the model; smoothing polygons to reduce the number of vectors and speed up calculations [16].

The whole city was split in 97 tiles, each tile containing up to 10,200 grid points, the distance between points being 10 meters. The calculus is very complex and time consuming; for a single run it taken almost 48 hours (only the running time, not including the data preparation and visualization of the result. On the other hand, there was a limitation found when trying to plot the resulted map on a large format (ISO A0) – the user control is quite poor and it was not possible to configure Lima for plotting on that format. Taken these facts into consideration, it was chosen to do the post processing outside the simulation software, using custom software developed by the team members. The development platform was again AutoCAD/AutoLISP.

After the first simulation was done and the first version of the noise map ready, the values obtained was compared with the noise values measured on site (see the feedback line in Figure 1). Some of the measuring and validation points are shown in Figure 10. The measuring points are in most cases the same or nearest the points where traffic volumes was measured.

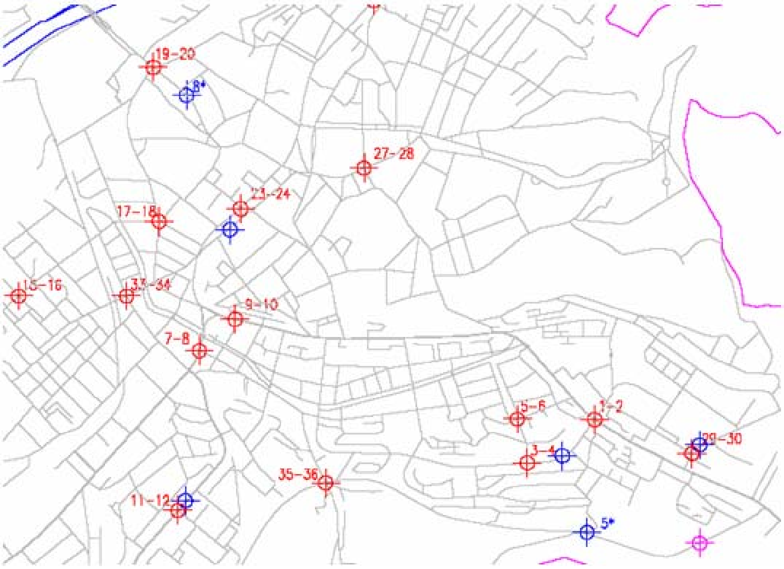


Figure 10 – Measuring points

In case of differences greater than 3 dB (measurement versus simulation result), the input data was corrected and the calculation process was repeated until the differences were fitted in the approved domain.

4. POST PROCESSING AND RESULTS

The output of Lima includes the ERT files, text files that can be processed with external programs. Inside the ERT file, each line corresponds to a point of the calculation grid. The information for each point is: X, Y coordinates in km, Lday and Lngt (equivalent noise level for day and night respectively), Z (altitude), Levg (equivalent noise level for evening), Lden (equivalent noise level for the whole day). The altitude is not useful for plotting the noise map, so the z coordinate of each point can be the noise level. The color legend for points is defined in 5dB intervals [15]. Finally, each point can be representing as a square of 10x10 (10 meters is the size of calculation grid).

The final result is the plotted noise map (Figure 12), presenting the complex noise information in a clear and simple way. In addition, for each noise map (Lden, Lngt) is created a conflict map (Figure 17). Conflict maps show the difference between the predicted noise level and the noise limits (70dB for Lden, 60dB for Lngt).

Using the noise maps and the conflict maps is possible to identify the hot spots and also the quiet areas, and to estimate the number of annoyed people for Lden and Lngt. The quiet areas are defined as areas of at least 4.5 hectares with a maximum noise level of 55 dB. In order to identify these areas, it is first necessary to convert the grid cells of the noise map in noise surfaces. Technically, all the points of the grid cells must be converted in squares and the squares of the same color will compose a surface (the object type is *region*). Then the regions are converted in closed polylines. The area of a region or closed polylines can be obtained using standard AutoCAD requests. Only the contours with an area greater than 4.5 hectares and a corresponding noise level of less than 55 dB are maintained. An example is given in Figure 11. Only those quiet areas placed in residential areas will be taken into consideration. Here another problem was identified: if the traffic volume and speed for residential streets are used according to [14] and [15], the noise level on the streets is over 55 dB and these streets interfere with some possible quiet residential areas.

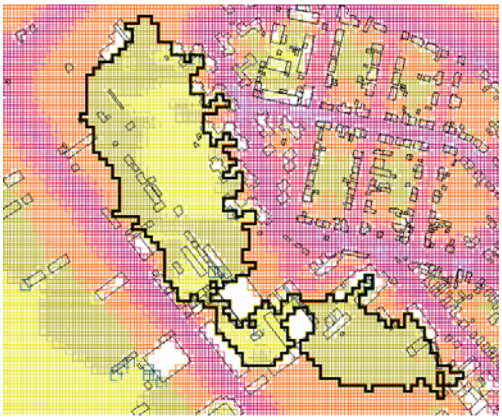


Figure 11 – Example of a “quiet” area identified: 9.6 ha under 55 dB, 576 inhabitants

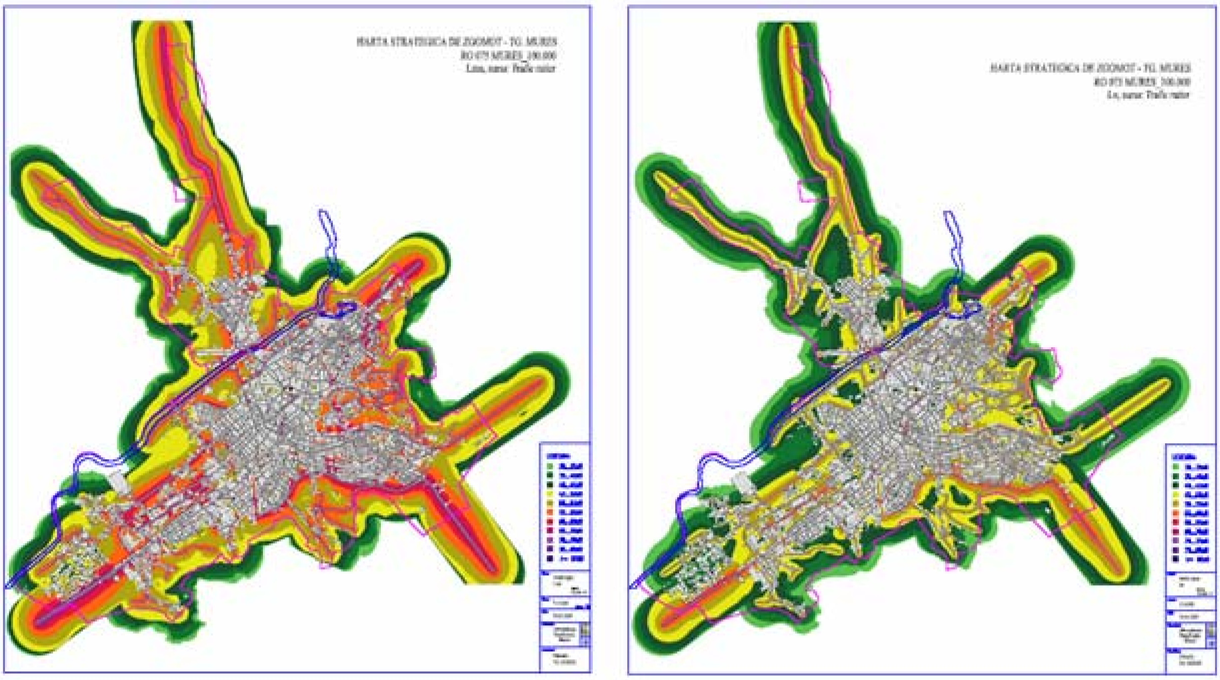


Figure 12 – Noise maps; source: road traffic - Lden (left), Lngt (right)

In this phase all the necessary data for ascertaining the number of people exposed to various noise levels are established. For each building is known the number of inhabitants (stored as *metadata*). From the noise map is possible to identify the exposure of each façade of the building to each noise level (Figure 13). The grid cells are colored according to the equivalent noise level (intervals of 5 dB). The exact noise value is stored as Z coordinate of the cell; adding this value as metadata is not a good idea because the very high number of cells will make the execution of any other command very slow.

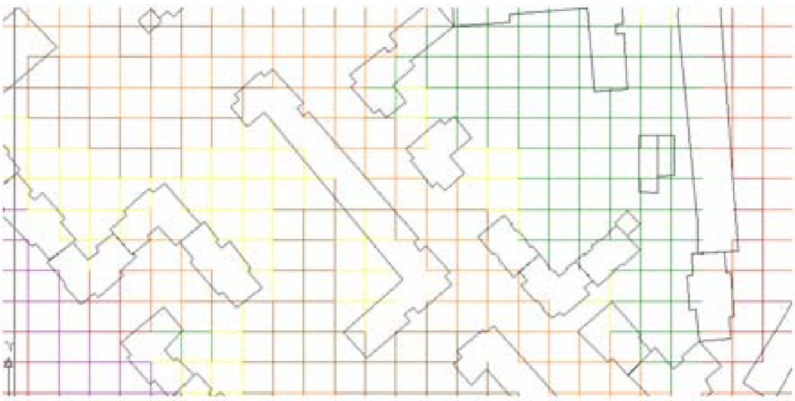


Figure 13 – Exposure of the facades

The first step is to find all the intersections between the building contour lines and the squares representing the grid cells in the noise map. Only the x, y coordinates are used to calculate the intersections, because z is the noise value. For each intersection found the value of the noise associated to the respective grid cell is added to a list – the black list in Figure 14. This list is added to the building object in the drawing as metadata.

```
Command: rent
Select object: (("type" . "casa") ("oameni" . 238) ("lz" 61.1 60.29 60.48 58.3
61.69 59.0 58.07 61.44 54.24 54.91 50.14 58.7 61.63 55.09 57.94 61.87 54.83
61.34 54.0 57.34 54.66 56.86) ("id" . 851) ("h" . 15.0) ("categ" . "locu")
("aria" . 1451.08))
```

Figure 14 – Metadata associated to a residential building

In the second phase, it is calculated the number of inhabitants exposed to each 5dB interval of noise level, then these values are added to the list of exposed people (see Figure 15).

```
Command: !lexp
((30 0) (35 0) (40 0) (45 0) (50 64.9091) (55 86.5455) (60 86.5455) (65 0) (70
0) (75 0) (80 0) (85 0))
```

Figure 15 – People exposed to different noise levels, calculation result

Based on these results, difficult to read and understand for most people, are created the charts shown in Figure 16. The red bars represent the people exposed to a noise level higher than the limit allowed for the respective period (day or night). These red bars are in direct relation with the areas marked in the conflict maps.

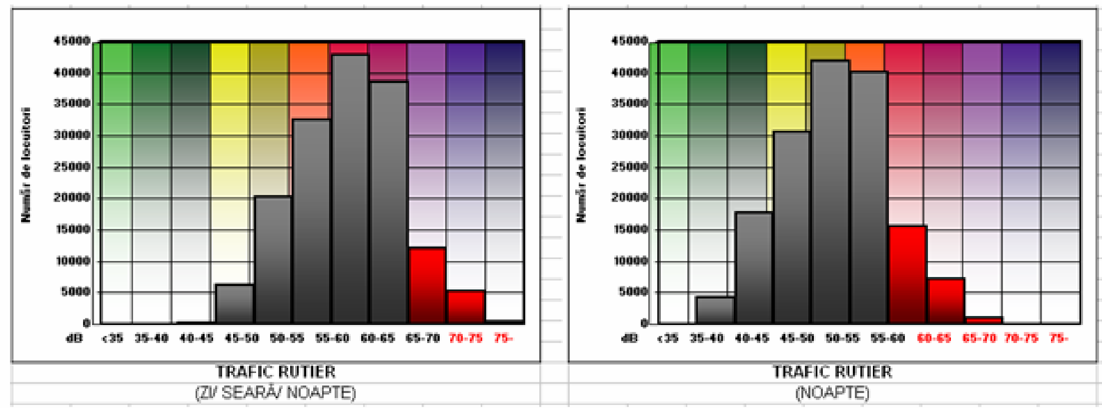


Figure 16 – People exposed to different noise levels, chart

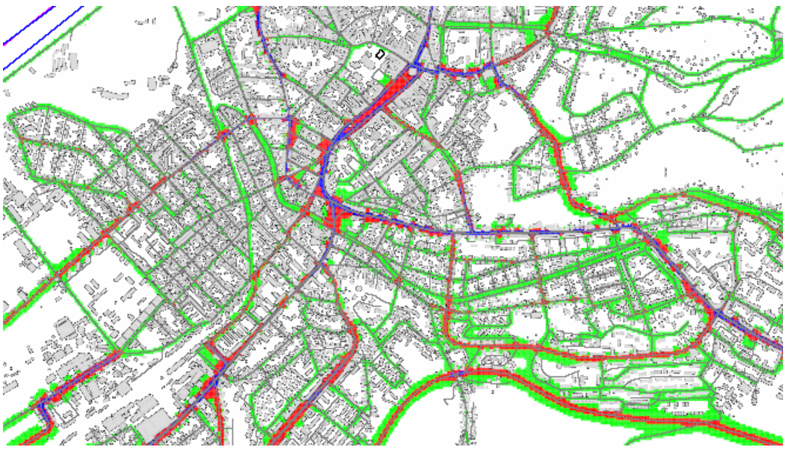


Figure 17 – Part of a conflict map (road traffic noise), detail

The colors used in the conflict maps are: green for a noise level with maximum 5 dB lower than the limit (in Romania the limit for the noise generated by the road traffic is 70 dB for day/evening/night and 60 dB for night); red is for a noise level with maximum 5 dB higher than the limit and blue is for a noise level of more than 5 dB over the admitted limit.

Based on the conflict maps and the number of people exposed to high noise level, the local authorities should propose action plans for reducing the noise level and its effect on the population. Taken into consideration the proposed measures, new noise maps can be created and, again, the number of people exposed to high noise levels can be ascertained. From the initial and the estimated noise maps it can be generated the difference maps, like the one shown in Figure 18. The color scale of difference maps is for intervals of 1dB; in the given example orange means no change (0 dB), green means a gain of 3-4 dB.

The measures which lead us to the difference map in Figure 18 are related only to the road surface construction of the main streets. Other global measures, with significant effects, are difficult to be taken. The noise map in Figure 18 must be compared with the noise map in the Figure 12, left side. The new noise map is more yellow, since the first one was more orange. The differences in color are difficult to be seen at this scale, so a detail is given in Figure 19.

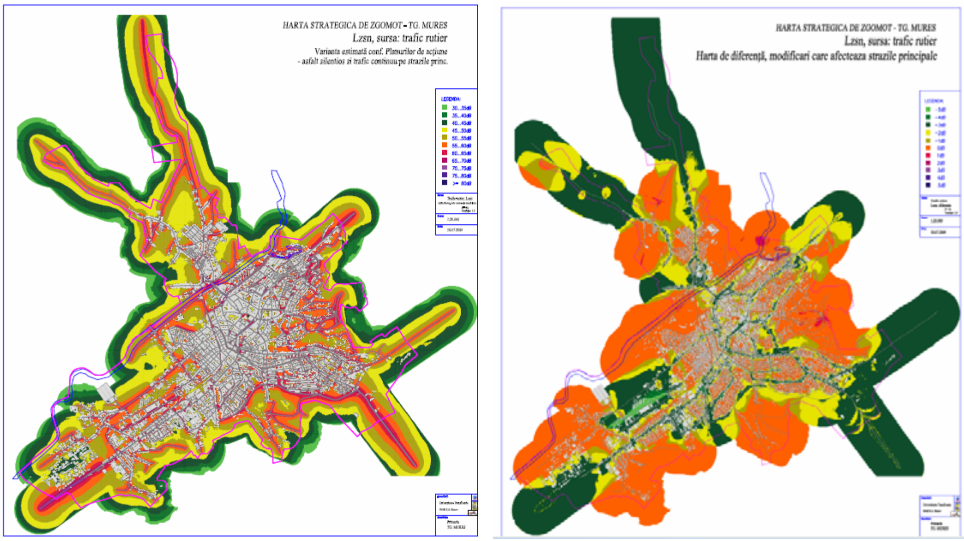


Figure 18 – Example of an updated noise map (after action plans) and a difference map

Figure 19 – Details of the initial noise map – the real situation (on left)
and of the updated noise map - after action plans (on right)

In Figure 19 it can be seen that the intense blue color (the highest level of noise) was disappear and, in general near the main streets, each color is turned into the next lower level. There are no changes across the buildings which are not close to the main roads, because the secondary roads were not affected by the proposed measures.

The difference maps and the noise maps post- action plans are just what could be, not what will be. Only the representatives of the local authorities can decide to apply the proposed measures entirely, or just on some parts of the city.

5. CONCLUSION

Road noise mapping has usually three phases: preparing the input data (base map and traffic data acquisition), calculation and analysis of the effects (people exposed). Then can be defined action plans for reducing the noise in such manner that the number of the people exposed to high level of noise to be reduced significantly. In a classic way, the first phase is managed using GIS software, the second and the last phases are done with the noise calculation software. We have realized the noise map in a different way: the first was done using AutoCAD and some custom application developed in AutoLISP; the second phase using Lima (noise mapping software) and the last phase was done using again AutoCAD and custom AutoLISP applications.

Our approach has two main advantages: it is more flexible and less costly than the classic way. The methods used for collecting traffic data assure a good accuracy, better than other methods described in literature - [11]; [15].

There are some problems and limitations identified working with the documents [2], [3] and [15]: only two categories of vehicles are considered, light and heavy, and is not possible do propose measures for encouraging the use of less noisy vehicles; a noise source is the road-tire interaction, but only the road surface can be controlled, not also the tires; the terrain model is treated ambiguously, the recommended distance between the level curves is contradictory [15]. The traffic volumes recommended for residential roads are probably too high and this leads to fewer and/or smaller quiet residential areas identified. It is stated [15] that using GIS software it is easy to convert the maps designed in a projection system like STEREO 70, in a datum like ETRS89 (in order to transmit the noise maps to the European Commission) or WGS84 (to display the noise map in Google Earth (!)). This affirmation is completely wrong. However, for the year 2012 new directives are expected for elaborating the noise maps.

It is better to work with the road segments individually, as single lines, not combined in open polylines, at least for the main streets, where the traffic data are different for each segment.

It is very difficult to propose realistic measures for reducing the noise in an urban agglomeration. Many of the possible measures are related to road traffic management and should be integrated in a more complex action plan, not only intended for noise reduction. So the action plans is better to be based not only on the existing noise maps, but also on road traffic studies.

The whole process of noise mapping is complex and the team members should be specialists not only in acoustics, but also in road traffic and data processing.

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