FEB

ESTIMATING AND VISUALISING FACTORS AFFECTING TRAFFIC NOISE PROPAGATION, BY USE OF ADVANCED GIS TECHNIQUES

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SUMMARY

This paper proposes a methodology through which advanced Geographic Information Systems' (GIS) techniques are applied in the study of environmental traffic-related noise. The spatial nature of the factors affecting traffic noise propagation necessitates the use of GIS, a field of applications offering by default specialised analytical tools and functionalities for managing spatial information.

In this respect contemporary GIS tools have been employed in order to estimate and visualise the impacts of the above factors, on the noise generated by road traffic. GIS capabilities such as spatial analysis and geographical processing, were integrated with proven methods used for calculating road traffic noise, with the aim to enhance the study of factors such as distance from the noise source, screening form intervening obstacles and reflections from buildings facade.

Separate maps representing the impacts of each individual factor, on the basic noise level were produced providing a comprehensive view of traffic noise propagation. All of the analysis was based on splitting the study area into a high-density grid, where each grid-cell corresponded to a reception point. By combining each individual factor's contribution for every separate grid-cell, yielded to the global traffic noise sound field of the entire study area.

KEYWORDS: Traffic noise, GIS, noise propagation, spatial analysis, spatial processing.

INTRODUCTION

Among the environmental problems emerged in the majority of modern cities, noise and air pollution are considered to be the most important ones. According to a Commission Green Paper [1], environmental noise caused by traffic, industry and recreation is identified as one of the main local environmental problems in Europe. Traffic noise is a significant effect of transport in urban areas and a priority issue in the EU.

Various methods simulating traffic noise have been developed (NMBP, NAC, CRTN etc.). These methods focus on the impacts of numerous factors on the final noise levels, such as the distance from the noise source, the nature of the ground surface, the intervening obstructions, the purpose-built barriers, as well as other factors affecting the propagation of sound waves, such as reflection from nearby surfaces, absorption, attenuation, diffraction etc. [2]

The European Commission emphasizes that strategic noise mapping "shall mean a map designed for the global assessment of noise exposure in a given area due to different noise sources or for overall predictions for such an area". [3] Computer models implementing noise methods support map-based representation of the final noise levels. However, there is enough space for improvements, not only with respect to visualisation of traffic noise levels: most of the processes involving spatial data management might benefit the advantages offered by Geographic Information Systems (GIS).

Contemporary GIS, provide the capability of storing, processing and manipulating large datasets of spatial information as well as managing and visualising large image files. In addition, advanced GIS tools and techniques support analysis and design of complex systems, and in many cases simulation of the critical parameters governing such systems. In this framework factors affecting noise propagation generate unique estimation and visualisation challenges through a GIS context and define the objectives of the present study.

METHODS

Advanced GIS techniques applicable to Traffic Noise Study

Contemporary GIS software packages provide a variety of easy-to-use specialised tools applicable to noise related tasks. Although, existing implementations of proven noise methods adopt much of GIS functionality, GIS state-of-the-art capabilities can only be provided by special geographic processing (also known as geoprocessing) tools continuously updated by famous GIS software packages (e.g. ESRI's ArcGIS 9.0). [4] Advanced geoprocessing methods applicable to traffic noise study have been identified in the following subsections.

Georeference

The area under study is commonly provided by a raster aerial photograph or satellite image file. Aligning or georeferencing the raster to the appropriate map coordinate system is the key step for successfully setting its spatial dimension. Through georeference a raster dataset, is defined in terms of its location by use of map coordinates and a coordinate system is assigned to it. As a result, georeferencing raster data allows it to be viewed, queried, and analysed with other geographic data.

Regarding noise study, the spatial reference of any parameter involved in simulating traffic noise propagation is extremely significant, since its coordinates participate in formulas specifying the final noise level at a requested reception point. For example the distance of the reception point from the noise source is automatically provided as soon as the point feature layer containing the receptors and the line feature layer containing the road segments are digitised over the georeferenced study area.

Furthermore, any other external spatial dataset can be combined with the georeferenced study area providing valuable noise data processing and analysis.

Buffering

Buffering is the process through which a buffer is created around a selected point, line, or area feature.

Buffering is a process with numerous applications to noise study: noise propagation is governed by the principles governing the propagation of sound waves such as attenuation due to distance form noise source, reflection to facades, diffraction due to barriers intervening between receptors and sources etc. In most cases the effects of each factor on the waves generated in the noise source could be assigned to buffer lines of equal values as regards the specific factor under consideration. As an example, sound waves attenuate due to their distance from the noise source. Therefore, the desired number of buffers (buffer density) around the point or line source could represent equal noise curves, each one corresponding to the same amount of attenuation.

Vector to Raster technique

Vector to Raster (V2R) transforms a vector layer to a raster one according to an attribute of the vector layer. Each element (pixel, set of pixels) of the raster is assigned the value of the specific attribute.

V2R technique is useful when estimating the initial values of the reception points (e.g. distance from noise source) prior to applying formulas deriving influence of factors affecting noise propagation.

Grid-Cell analysis

A grid subdivides the study area providing the capability of segmenting the application of noise calculation methodology into smaller analysis units. A grid is performed by the creation of a polygonal layer, which in turn is transformed to raster by applying V2R technique.

In the case of traffic noise calculation a discrete unit may represent a reception point at which noise levels are to be assessed. By assigning attributes relevant to factors affecting noise propagation, at any discrete grid-cell of the study area may lead to a variety of analytical mapping visualisations, each one representing an individual noise factor. Combining the various stages of noise propagation, through advanced raster calculation techniques described below, yields the final noise levels. Finally, increasing grid density results to a more detailed consideration of noise theory.

Digital Terrain Model

A Digital Terrain Model, DTM (alternatively Digital Elevation Model) is a data model that attempts to provide a three dimensional representation of a continuous surface. DTMs are often used to represent relief.

Producing a DTM provides further estimation challenges as regards traffic noise propagation, especially in cases where the area relief is characterised by strong variations causing effects in the sound waves propagation.

Raster Calculation

Raster Calculation techniques provide advanced mapping algebra processes such as weighting and combining rasters, applying mathematical operators and functions, or spatial analysis functions.

Raster calculation techniques are proved to be significant at all stages of traffic noise estimation during application of traffic noise theory equations. As most significant application is considered the combination of separate rasters each one representing an individual factor affecting traffic noise propagation, to achieve global noise levels.

RESULTS

Estimating and Visualising Influence of Distance

The impacts of distance on traffic noise propagation are well defined in various noise calculation methods. CRTN [5] calculates the distance correction to be applied on the basic noise level. The geometry providing the critical elements participating in distance effects along

with the formula deriving distance correction are provided in Figure 1b.

In order to exploit GIS functionalities with respect to distance correction the methodological approach proposed comprises the following steps:

Step 1: Importing and georeferencing
the study area raster image

The area under study is usually provided by a raster aerial or satellite image file. Projecting the raster to the appropriate reference system is the key step for successfully setting the spatial dimension of any geographical entity participating in distance effects to traffic noise propagation.

Step 2: Identifying and digitising elements
participating in distance correction

Elements participating in distance correction are considered those constituting the ends of the line representing the requested distance. Since the reception point is considered as the one end, the other end should be there, where the slant line signified from the source line to the reception point, intersects the source line. Therefore, the source line itself collects the ends of all the possible shortest slant distances signified from any reception point. The source line (or lines in case of multiple road segments) is digitised as a line feature providing the spatial entity generating noise in a separate layer.

Step 3: Definition of Reception Points

Depending on the quality of the raster aerial or satellite image as well as on the level of detail required for noise calculation the study area is subdivided into rectangular area units by creating a separate polygonal feature layer. This vector is in turn transformed to a raster grid-cell, where every grid-cell corresponds to a receptor. At the end of the process each cell should contain attenuation values of sound waves due to distance effects.

Step 4: Calculating Receptor's
shortest slant Distance from source line

Buffering on the line source to a distance covering all of the analysis area provide the ability of assigning to every grid-cell, the attribute value of its direct slant distance from the noise source.

Step 5: Calculating Distance Correction
for every Reception Point

Applying the formula deriving the distance correction through subsequent raster calculations on the base raster generated in Step 4, results to the calculation of the final correction due to distance effects.

Further to applying the steps of the formula, conditional statements may also be applied to every grid-cell. In case of applying the British method CRTN "for distances less than 4 meters form the carriageway edge the distance correction should be determined assuming the reception point is located at 4 meters form the nearside carriageway edge" [4].

Step 6: Visualising Influence of Distance

As already stated, visualisation at this step only refers to affections of distance on the propagation of sound waves. As a consequence the values related to every discrete cell represented by graduated colour quantify distance correction applied on the base noise level, regardless of the existence of other critical features affecting noise propagation (e.g. barriers). Figure 1a illustrates the results of the methodological approach described in a typical study area.
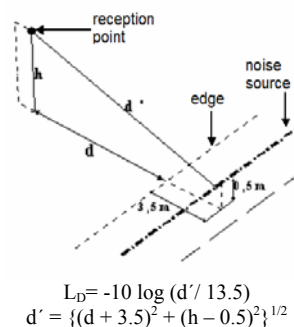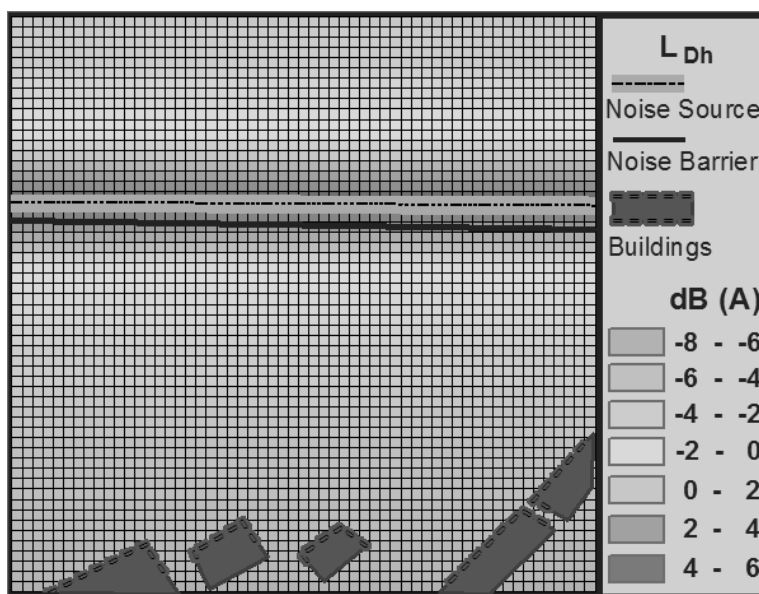

$$L_D = -10 \log (d'/ 13.5)$$
$$d' = \{(d + 3.5)^2 + (h - 0.5)^2\}^{1/2}$$

**FIGURE 1 - a) A sample map illustrating the results of the proposed methodology,
b) Influence of Distance according to CRTN**

$$L_B = A_o + A_1X + A_2X^2 + ...A_nX^n \text{ dB (A)}$$
$$X = \log(a+b-c)$$

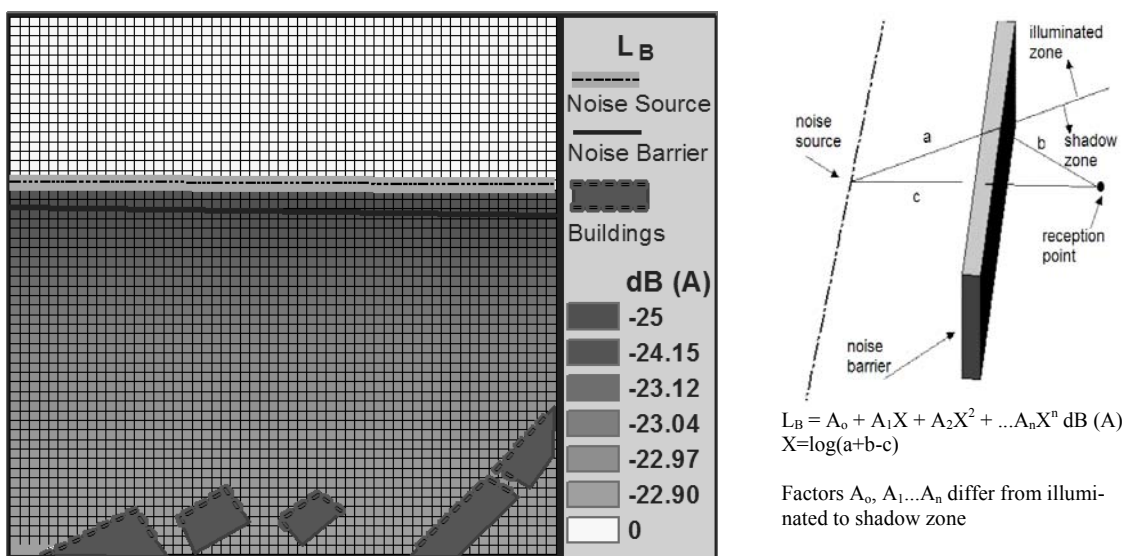Factors A_o, $A_1...A_n$ differ from illuminated to shadow zone

**FIGURE 2 - a) A sample map illustrating the results of the proposed methodology,
b) Influence of Screening due to noise barriers according to CRTN**

Estimating and Visualising Influence of Screening

The impacts of screening effect due to intervening obstructions such as noise barriers depends, according to the British method CRTN, on the relative positions of the effective noise source position, the reception point and the point of the barrier, where diffraction phenomena affecting sound waves happen (Figure 2b).

Steps 1 to 3 are similar to those considered in estimating distance effects: the area under study is georeferenced providing spatial information for every discrete element participating in screening effects including the obstructions affecting noise waves. The rest steps applicable for estimating and visualising effects of screening are as follows:

Step 4: Applying Conditions with
respect to Receptors' location

Conditions regarding receptors' location specify:

- If screening influences basic noise level on a receptor and

- In case of screening effect, if a receptor is located on the illuminated or shadow zone (Figure 2b).

Depending on the attribute value assigned to each receptor with regard to the above conditions, the appropriate formula is applied at the next step of the methodological approach.

Step 5: Calculating Influence of
Screening for every Reception Point

In this step, subsequent raster calculations provide the final impact of screening on the basic noise level for every reception point of the analysis area. The formula is selected on the basis of Step 4 results.

Step 6: Visualising Influence of Screening

Visualisation at this step refers only to affections of screening on noise propagation. Figure 2a illustrates the results of the methodological approach described in a typical study area. As expected there are no influences on the area of unobstructed traffic noise propagation.

Estimating and Visualising Influence of Reflections

Reflections are faced simplistically by noise methods. Figure 3b illustrates how reflection effects are handled by the British method CRTN.

Steps 1 to 3 are similar to those considered in previous sections: georeferencing the area under study and digitising the critical elements participating in reflections effects provide the spatial dimension of the involved geographic entities including building facades reflecting traffic noise waves. Following steps are:

Step 4: Applying Conditions with
respect to Receptors' location

Conditions regarding receptors' location specify:

- If the slant distance signified from the reception point and the building is less than 1 meter and

- If the angle signified by the reception point and the two ends of the facade exceeds 80 degrees.

If the above conditions are satisfied then reflection effects are influencing the basic noise level, either case not (Figure 3b).

Depending on the attribute value assigned to each receptor with regard to the above conditions, reflections is either applied or not during next step.
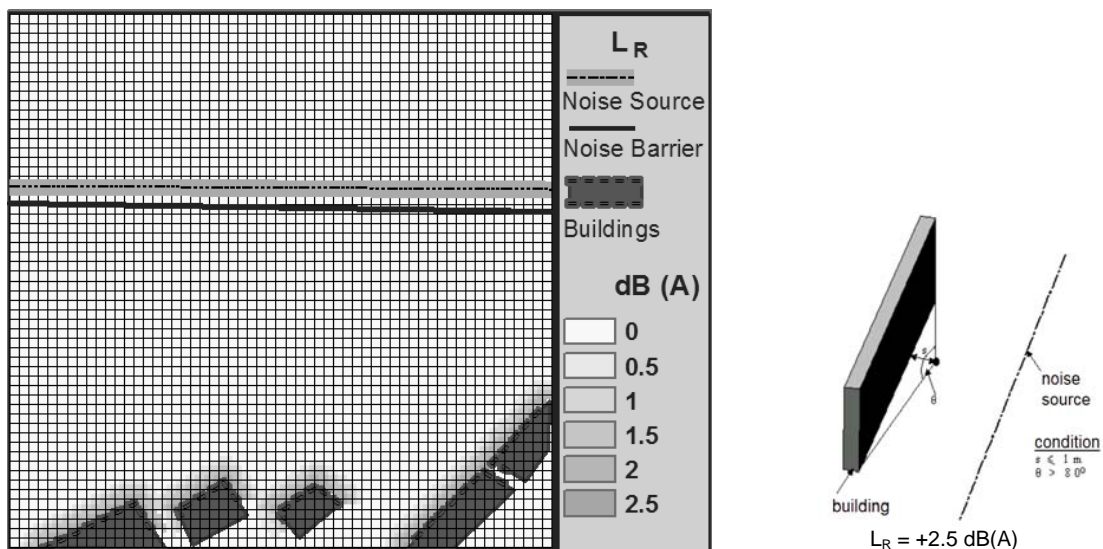
**FIGURE 3 - a) A sample map illustrating the results of the proposed methodology,
b) Influence of Reflections on buildings facade according to CRTN**

Step 5: Calculating Influence of
Reflections for every Reception Point

In this step, a raster calculation provides the impact of reflections to buildings facade on the basic noise level for every reception point of the analysis area. Step 4 specifies whether reflection effects are to be applied or not.

Step 6: Visualising Influence of Reflections

Visualisation at this step refers only to affections of reflections to buildings facade. Figure 3a illustrates the results of the methodological approach described in a typical study area. As expected, influences are applied on the area in front of buildings facade.

**Combining Raster Images to
Achieve Global Noise Calculation**

Throughout previous sections, a methodological approach consisting of specific actions was proposed for each factor affecting noise propagation. The objectives of this work were to exploit advanced GIS techniques offered by contemporary GIS in order to estimate and visualise traffic noise levels.

The final step is to combine the contributions of every factor with the basic noise level and assess the global noise reaching every receptor of the study area. Combining the grid-cells of all the maps georeferenced under the same map projection leads to the global noise assessment (Figure 4).
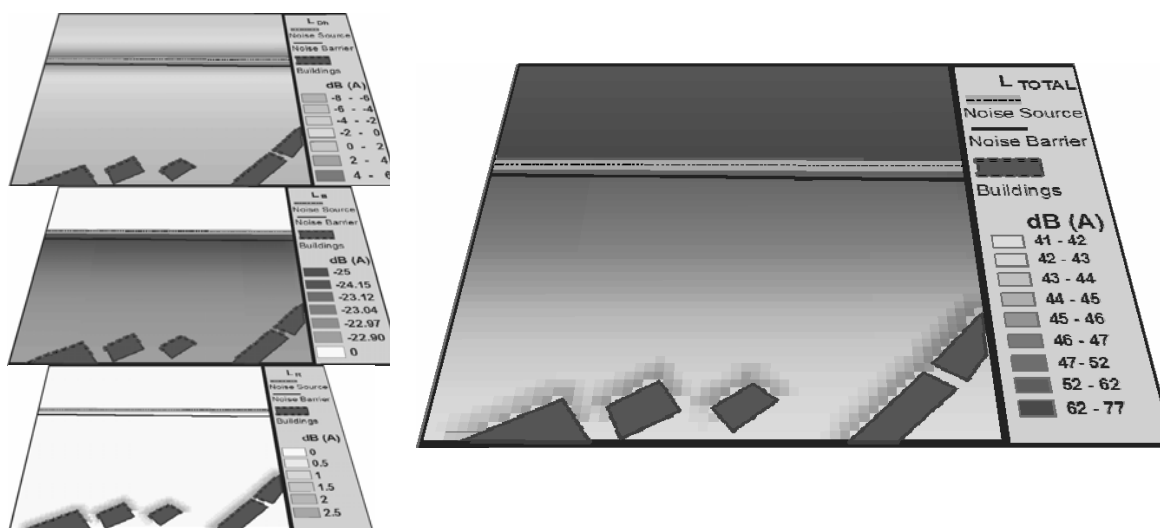

FIGURE 4 - Combining raster images to achieve global noise calculation.

DISCUSSION AND CONCLUSIONS

In this paper we made an attempt to exploit advanced GIS techniques applicable to traffic noise study. The incentive to undertake such a task was the spatial nature governing the factors affecting traffic noise propagation combined with the high-level spatial data management capabilities offered by contemporary GIS software packages.

We identified the critical factors possessing spatial nature and affecting traffic noise propagation to be considered throughout this work, as the distance of the reception point from the noise source, the barriers screening noise propagation and thus reducing noise levels and finally the buildings facade reflecting incident noise waves.

We identified GIS techniques to be adopted in order to estimate and visualise the above factors. Such techniques are nowadays provided through easy-to-use graphical tools embedded in GIS software packages and include among others:

- georeferencing through which the geographical entities involved in traffic noise propagation obtain spatial nature,

- buffering through which vector features simulating noise waves at discrete spaces of equal values, are assigned measurements specific to the factor under consideration

- grid-cell analysis techniques, through which effects are examined for every individual reception point, represented by a discrete space unit of the analysis area

- various raster calculation techniques through which formulas modelling the effects of factors affecting noise propagation are applied

- other techniques placed into the general field of geographical analysis and processing.

Findings of the present work include a proposed methodological approach, consisting of a set of specific actions (steps) to be taken in order to estimate the influence of the factors affecting traffic noise propagation as well as cartographical representations visualising the noise field in the analysis area.

Further work might include a somehow more automated application of the GIS techniques identified in terms of incorporating them inside modern GIS application environments. Such environments, like ArcGIS 9.0, provide a special visual modelling environment through which traffic noise propagation theory could be simulated by customised geoprocessing tools.

Beyond these it is more than obvious that extending the number of factors affecting noise propagation that could be examined by GIS based techniques as well as extending the number of GIS techniques applicable to noise theory, could provide further research challenges.

As a result, we hope that the findings will serve, if not as a series of automated modules, at least as a guidance towards similar efforts.

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