

A FRAMEWORK FOR STRATEGIC NOISE MAPPING IN URBAN AREAS

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Abstract

Noise in urban areas has increased in the past decade, due to a growing urban development. Management and reduction of urban noise has been called for in urban development plans. Environmental noise ordinances have been approved at national and local levels in various countries of the world. They usually establish noise limits for various activities and zones, according to the land uses, and define the basis of noise abatement strategies.

The new European Directive 2002/49/EC on the assessment and management of environmental noise requires the drawing of noise maps of communities with more than 100,000 inhabitants and of areas near the major transport infrastructures for the assessment of noise outdoors.

Noise mapping in large urban areas presents methodological and financial hindrances due to both the technical complexity involved and to the amount of human and technical resources that are necessary. Project management of large scale noise mapping requires special care since several public and private entities have to work together to provide accurate and detailed input data.

The paper investigates a framework for strategic noise mapping. The methodological framework is presented as a seven stage process.

Key words: *urban noise, strategic noise map, noise mapping process*

1. Introduction

European cities have grown by 20% in size and their population has increased by 6% in the past 20 years [1]. The need for more efficient transportation meant an increase in the means of transportation and on the number of vehicles. As a consequence, cities face increasing noise levels. However, a growing acknowledgement of the citizens to their rights to a good (less noisy) environment has called for actions to manage and to reduce noise in cities.

In 1994 it was estimated that during day-time, approximately 22% of the total population of the EU were exposed to noise levels from road traffic exceeding a daily equivalent sound pressure level of 55 dB(A) [2]. Moreover, 49% of the population (77 million) were considered to live in grey areas' of acoustical discomfort. During night-time, more than 30% were considered to be exposed to equivalent sound pressure levels exceeding 55 dB(A) which is considered to be disturbing to sleep [3].

Worldwide, 130 million of people are exposed to noise levels above 65 dB(A), while another 300 million live in uncomfortable noise levels (55 dB(A)-65 dB(A)).

The economic cost of noise to society is estimated as being between 0.2 and 2 percent of the gross domestic product. Taking the lower estimate, this implies an annual financial loss due to environmental noise of more than 12 billion Euro [4].

Therefore, environmental noise caused by traffic, construction, industrial and recreational activities is among the main local environmental problems in Europe and the source of an increasing number of complaints from the public. Generally however, action to reduce environmental noise has had a lower priority than that taken to address other environmental problems such as air and water pollution.

The first EC Directives related to noise management were internal market measures that set harmonised noise limits for motor vehicles, household appliances and other noise-generating products. Ambient noise was considered a matter of subsidiary, best handled at national or local levels. However, as more information became available about the health impacts of noise, the need for a higher level of protection for European citizens came to be recognised.

The 1993 Fifth Action Programme [5] started to remedy this gap in environmental protection and included a number of basic targets for noise exposure to be reached by the year 2000. The Green Paper on Future Noise Policy [6], adopted and published by the Commission in November 1996, was however the first comprehensive step in the development of a noise policy. The aim of the Green Paper was that "no person should be exposed to noise levels, which endanger health and quality of life". It reviewed the overall noise situation in the Community and national action taken to date and developed an outline of a framework for action covering the improvement of information and its comparability and future options for the management of noise from different sources.

Further policy developments include the 2002 Sixth Environmental Action Programme [7], ten-years (2002-2012) policy programme for the environment, which made reference to the World Health Organisation (WHO) standards regarding the

level of noise (in particular from traffic), the Commission's White Paper on Transport [8], the renewed EU Sustainable Development Strategy [9] and Directive 2002/49/EC, adopted by the European Parliament and the Council in June 2002, relating to the assessment and management of environmental noise [10] is commonly referred to as the Environmental Noise Directive or END.

The END defines the basic principles of a harmonized European noise policy, following the publication of the European Commission Green Paper on the Future Noise Policy in 1996.

Community noise ordinances have been promulgated by local and by national authorities in many countries establishing noise zones and noise limits and defining the responsible bodies and obligations to reduce noise.

Strategic noise maps describe spatial distributions of noise levels. They allow an efficient visualization of the noise distributions in urban areas where the land uses are sensitive to noise. Noise mapping is a very efficient noise assessment method in an urban area. For large cities, challenges have to be met in terms of data management, data reduction, calculation methods, optimization procedures, validation techniques and presentation of results so that the maps can be powerful tools to be used for urban noise planning and design.

Noise in cities is contributed by many sources and is part of the urban soundscape. Urban noise must be managed and controlled so that excessive noise levels do not conflict with common human activities and with the people's perception of wellbeing.

Bearing this in mind, this paper explores a methodological framework for strategic noise mapping.

2. Environmental Noise Directive

The aim of the Environmental Noise Directive is to provide for a common approach to the avoidance, prevention and reduction of the harmful effects of exposure to environmental noise. The Directive seeks to harmonize noise indicators and assessment methods for environmental noise. Using these common indicators and assessment methods, it seeks to gather information in the form of 'strategic noise maps'.

Such information will be made available to the public and will form the basis for 'action plans' at the local level. The Directive does not seek to set common EU-wide noise limits. The setting of limits remains the responsibility of Member States.

The aims of the Directive are to be achieved by the progressive implementation of:

- (a) Monitoring the environmental problem; by requiring competent authorities in Member States to draw up "strategic noise maps" for major roads, railways, airports and agglomerations, using harmonised noise indicators L_{den} (day-evening-night equivalent level) and L_{night} (night equivalent level). These maps will be used to assess the number of people annoyed and sleep-disturbed respectively throughout Europe;

- (b) Informing the Public: providing information on environmental noise and its effects;
- (c) Addressing local noise issues by requiring competent authorities to draw up action plans to reduce noise where necessary and maintain environmental noise quality where it is good. The directive does not set any limit value, nor does it prescribe the measures to be used in the action plans, which remain at the discretion of the competent authorities;
- (d) Developing a long-term EU strategy, which includes objectives to reduce the number of people affected by noise in the longer term, and provides a framework for developing existing Community policy on noise reduction from source. In this respect, the Commission has made a declaration concerning the provisions laid down in article 1.2 with regard to the preparation of legislation relating to sources of noise.

The Directive applies to environmental noise to which humans are exposed, particularly in built-up urban areas, public parks, quiet parts of urban areas, quiet areas in the open country and near schools, hospitals and other sensitive buildings and areas. It focuses explicitly on major roads, major railways and major airports. The Directive does not apply to noise caused by the exposed person, noise created by neighbors, noise at workplaces, inside means of transport, or due to military activities in military areas.

To transpose the Directive into the national legislative framework, the following must be established:

- Legal provisions establishing competent authorities responsible for making, approving and collecting noise maps and action plans.
- Provisions for the application of the directive with regard to all elements defined in the directive, including specifically to “agglomerations, major roads, railways and airports”.
- Legal provisions for the drawing up and review of noise maps and action plans, including taking into account in so doing the results of the required public consultation.
- Legal provisions for consultation with the public about proposals for action plans and for public participation in the preparation and review of such plans.
- Provisions for the dissemination to the public of noise maps and action plans.

The actors most likely to be involved in or affected by implementation of the Directive are:

- central government to frame national legislation and, in particular, the government departments responsible for the environment and for transport (and possibly, but to a limited extent, for defense).
- the competent authority or authorities with responsibility for making, approving and collecting noise maps and action plans.

- private sector (particularly transport, but also operators of installations regulated under Directive 96/61/EC on integrated pollution prevention and control, and so forth).
- those responsible for noise-sensitive buildings, such as schools and hospitals.
- NGOs and individuals affected by environmental noise.

3. Transposition of the END in Serbian law

The Directive 2002/49/EC, the “Environmental Noise Directive (END)” [10] has been published in the Official Journal on 18 July 2002 and since this time is in force in Europe. It has to be transposed in national law of the Member States before 18 July 2004.

The END transposition at national and local level means enacting the new acts or amending existing acts. Directive 2002/49/EC relating to the assessment and management of environmental noise has been transposed in Serbian legislation by the Law on Environmental Noise Protection, adopted in 2009 (revised in 2010) [11]. The following national sub-laws have been adopted in 2010:

- Regulation on Noise indicators, limit values, assessment methods, noise annoyance, noise effects, impact on health, collecting data for noise assessment (Official Gazette of the Republic of Serbia, No. 75/2010);
- Decree on noise measurement methods, content and range of the report of noise measurement (Official Gazette of the Republic of Serbia, No. 72/2010);
- Decree on necessary conditions for authorizing a company for noise measurements, as well as the necessary documentation for the application to the Ministry (Official Gazette of the Republic of Serbia, No. 72/2010);
- Decree on the methodology for noise area zoning (Official Gazette of the Republic of Serbia, No. 72/2010);
- Decree on content and methods of strategic noise mapping (Official Gazette of the Republic of Serbia, No. 80/2010);
- Decree on methodology for preparing action plans (Official Gazette of the Republic of Serbia, No. 72/2010).

In new Serbian environmental noise acts, the framework of the future legal system for the management of the environmental noise has been settled up with following purpose:

- Establishment, maintenance and improvement of unique system of environmental noise protection;
- Provide a basis for development and completing existing measures in the field of environmental noise in order to avoid harmful effects on human health and environment;
- Establishment of assessment methods for environmental noise and application of harmonized indicators for determination of noise levels :

- Set up and implementation of measures concerning noise emitted by major sources, in particular:
 - road and rail vehicles and infrastructure;
 - aircraft;
 - outdoor and industrial equipment and mobile machinery;
- Application of “principle of prevention” in order to preserve quiet areas in agglomerations;
- Further develop measures in the short, medium and long term.

Aligned with the concept of the sustainable development as a dominant development strategy of the Republic of Serbia, the wider context approach towards the environmental protection becomes more serious, so the problem of the environmental noise is generally aligned with the long-term strategy of the national social, economic and public health interests.

The basic concept of new environmental noise policy include conditions and measures such as follows:

- Space, urban and acoustical planning and construction of facilities;
- Strategic impact assessment of plans and programs, environmental impact assessment of projects and issuing of integrated permit for IPPC installations and activities;
- Regulation of limit values of environmental noise due to different noise sources, the use of the surrounding, different noise sensitiveness of the populations;
- Production, trade and use of noise sources;
- Acoustical zoning: set up quiet area in an agglomeration and quiet area in open country;
- Strategic noise mapping;
- Preparation of action plans;
- Noise measurement and assessment of noise exposure in the environment;
- Public information on noise and its harmful effects.

4. Strategic noise map

A strategic noise map is designed for the assessment of noise exposure in a given area, resulting from strategic noise sources such as roads, railways, airports and industry. A strategic noise map can illustrate how environmental noise levels change across an area.

The purpose of strategic noise mapping is primarily threefold:

- to provide the European Commission (EC) with strategic estimates of noise exposure across Europe to assist in the future development of European noise policy;
- to provide information to the public and decision makers on noise exposure locally, nationally and internationally; and

- to develop action plans for the purpose of managing noise exposure, by reducing noise levels where necessary, or preserving quiet areas where appropriate.

Strategic noise maps are normally produced by computer modeling techniques which calculate the noise level at specific points resulting from the sound emanating from the particular sources. The modeling software utilized source data such as traffic flow, type of road and rail, types of vehicles and the nature of industrial processes. The source data is positioned within a the basic computer model of the area of assessment. The basic model consists four layers: 3D terrain model, obstacles (houses, embankments, bridges, etc, road (rail) axis and absorption (Fig. 1).

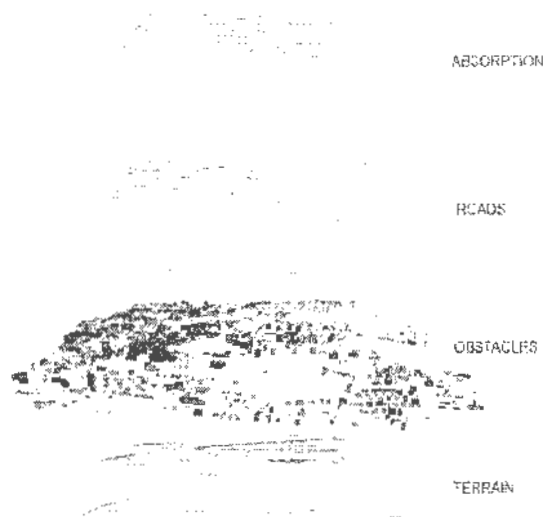


Fig. 1 Layers of basic model [12]

The END has been required Member States to produce strategic noise maps for the main sources of environmental noise, i.e. major roads, major railways, major airports and agglomerations with a population of more than 250,000 persons in 2007 and those with a population of more than 100,000 persons in 2012 and subsequent rounds.

The first round of strategic noise maps production has been finished in the Member States and the second round is going on.

The Serbian Law on Environmental Noise Protection fixes the deadline for implementation of law and taking proposed measures (table 1).

Table 1. Action timetable

Action	Serbian deadline	END deadline
Produce maps for preceding year, for agglomerations 250000+, roads 6000000+, railways 60000+, main airports	30. 06. 2015	30. 06. 2007
Draw up actions plans designed to manage noise issues and effects	30. 06. 2016	18.07.2008.
Produce maps for preceding year, for agglomerations 100000+, roads 3000000+, railways 30000+, airports	31. 12. 2020	30.06.2012.
Draw up actions plans	31. 12. 2021	18.07.2013.

Some Member States experienced difficulties in the allocation of responsibilities for gathering data, in particular when roads or railways crossed administrative boundaries. The need to coordinate between multiple authorities in collecting data generated challenges. In addition, technical problems resulted from differences in data quality, leading to a request for guidance on data quality requirements.

Member States reported gaps in the available data as problematic and cited difficulties in estimating the numbers of people exposed to noise. This was linked to a lack of data regarding inhabitants per dwelling and schools and hospitals exposed to specific values of a noise indicator.

Regarding the methodologies employed for developing the strategic noise maps, all Member States use the noise indicators L_{den} and L_{night} for noise mapping, as required by the END. Some Member States chose to use additional indicators, due to national preferences regarding their suitability in assessing noise and existing experience.

Some Member States developed national guidance on noise mapping. This was effective in ensuring a coherent national approach and in ensuring outreach, since the guidance was then available in the national language.

5. Strategic Noise Mapping Process

A staged approach to the delivery of strategic noise mapping projects which presents a synthesis of the strategies that have been employed in some Member States can be summarized as a seven stage process [13], as shown in Fig. 2. The strategic noise mapping process shown in Fig. 2 is based on the Member States experiences and EC publications [14-16].

Each stage of the process is defined by preceding stages such that requirements and specifications are captured ahead of the datasets. These datasets are then processed and concatenated to develop the model datasets, which are checked and tested prior to the final assessment of noise levels.

It is recommended that the data processing is commenced within a GIS environment, then passed to the specialist noise mapping software environment for final sign-off and the assessment of noise levels. The results of this assessment are then passed back to the GIS environment for post processing, analysis and mapping. Step 5 “Develop Noise Model Datasets” starts within the GIS environment, and is completed within the noise mapping software.

Following the assessment of noise levels the analysis is undertaken using datasets developed to present dwelling and population locations in order to deliver the statistics required by the EC for the reporting requirements of the Directive.

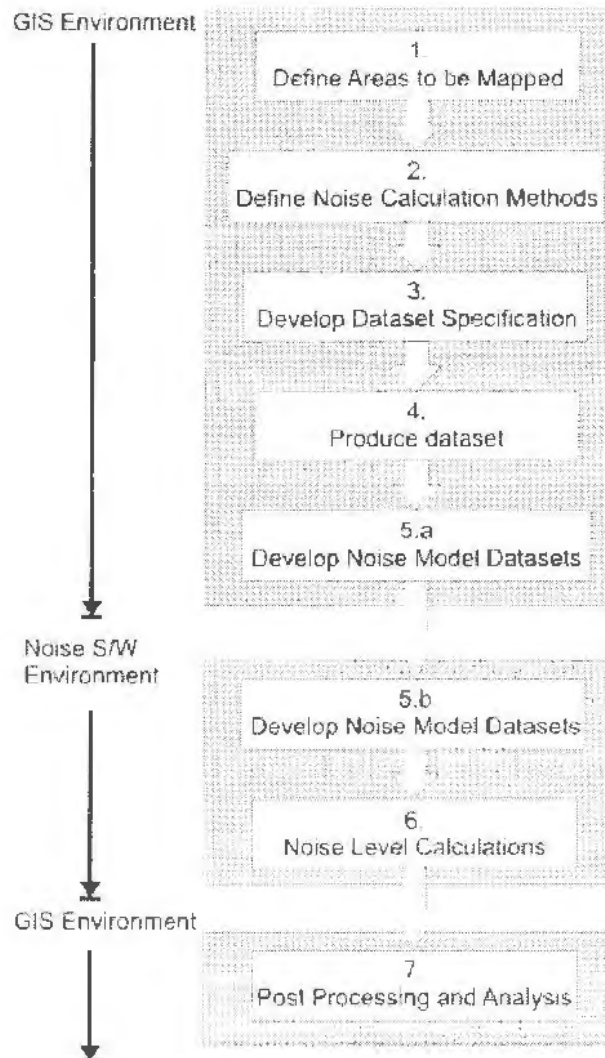


Fig. 2 Overview of noise mapping process

5.1. Stage 1: Define areas to be mapped

The key first stage in any spatial data project is to gain an understanding of the area under review; in this case there are two types of area of interest:

- The area to be mapped (the specific geographical area for which noise calculation results are required):
 - for agglomerations this is generally a clearly defined boundary;
 - for major roads, railways and airports the area is less specific as it is effectively designed by a minimum noise level which is of interest to be reported to the Commission.
- The area to be modelled:
 - in order for the noise levels on the edge of the agglomeration area to be calculated accurately, it is important to consider the noise sources, and propagation screening objects, from an area beyond and outside the actual area to be mapped;

- for major roads, railways and airports the noise source is specifically located, and the area to be modelled is generally the same area as the area to be mapped.

At the end of the stage there will be:

- a specification for the geographical area for which the input datasets are required;
- a specification for the geographical areas for which noise levels will be calculated.

5.2. Stage 2: Define noise calculation methods

Decree on content and methods of strategic noise mapping [17] set out a list of calculation methods which may be used for the production of the strategic noise maps:

- Road traffic noise
 - Emission Model: Guide du Bruit des Transports Terrestres – Prevision des niveaux sonores “, 1980
 - Propagation Model: French national calculation method "NMPB-Routes-96", and French norm "XPS 31-133"
- Rail traffic noise
 - Emission Model: Dutch national calculation method RMR - Section 3
 - Propagation Model: Dutch national calculation method RMR/SMR II
- Aircraft Noise
 - Emission Model: 2003/613/EC Section 3.3
 - Propagation Model: NOISE: ECAC/CEAC Doc. 29
- Industrial noise
 - Propagation model: ISO 9613-2: ‘Acoustics — Abatement of sound propagation outdoors, Part 2: General method of calculation’ (+ ISO 8297 + ISO 3744 + ISO 3746)
 - Emission model:
 - ISO 8297: 1994 ‘Acoustics — Determination of sound power levels of multisource industrial plants for evaluation of sound pressure levels in the environment — Engineering method’
 - EN ISO 3744: 1995 ‘Acoustics — Determination of sound power levels of noise using sound pressure — Engineering method in an essentially free field over a reflecting plane’
 - EN ISO 3746: 1995 ‘Acoustics — Determination of sound power levels of noise sources using an enveloping measurement surface over a reflecting plane’.

After selection of the calculation method, the methodology can be analyzed and a catalogue of input data requirements drawn up, including details such as objects, attributes and limiting values as appropriate.

5.3. Stage 3: Develop dataset specification

Stages 1 and 2 have provided a clear description of what data the chosen calculation methods use and for what locations it is required. This information combines with the chosen data management strategy to draw up a series of dataset specifications for each of the layers of spatial and attribute data which are required within the noise mapping process.

One of the approaches to developing a series of dataset specifications is the iterative process shown in Fig. 3.

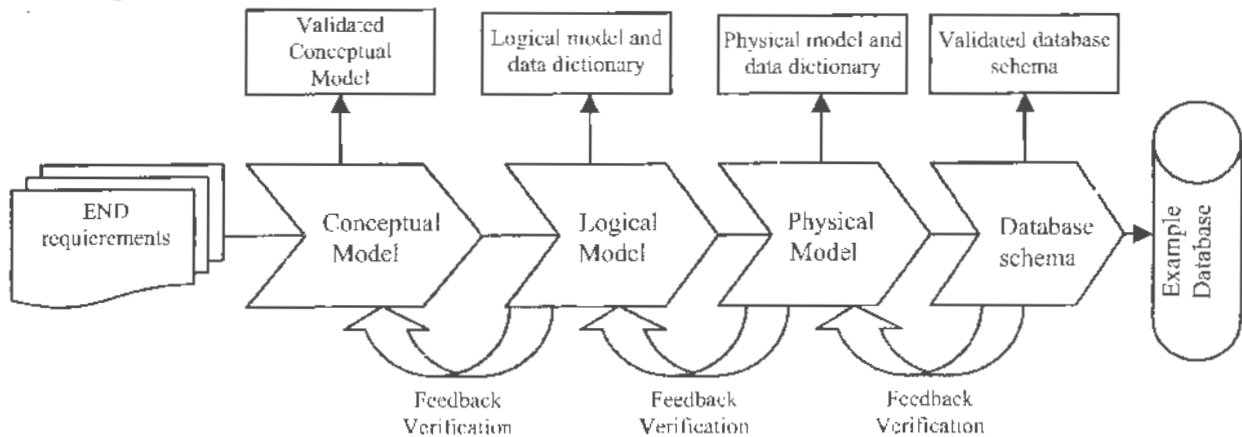


Fig. 3 The schema of developing a series of dataset specifications

In order to make data more manageable it is useful to break the data requirements into the following categories:

- 3D model pathway input data;
- road source input data;
- railway source input data;
- industry source input data;
- aircraft source input data;
- population exposure input data;
- noise model output data.

At this stage it is often most efficient to also select the noise calculation software which will be utilized in Stage 6, that way the specification drawn up can match the requirements of the calculation software, and make the transition from GIS to noise calculation environment as seamless as possible.

The result of this stage is the design of a database schema suitable to support the noise mapping process.

5.4. Stage 4: Develop dataset specification

Within this stage the raw GIS datasets can be collected, collated and catalogued with the aim of carrying out a gap analysis and audit against the specifications drawn up within Stage 3.

The general aim of this stage of the process is:

- to undertake an initial collection of the raw GIS, electronic and paper datasets,
- to collate and catalogue the information available,
- carry out an audit against the specifications draw up within Stage 3; the audit process will provide a gap analysis highlighting any data shortcomings.

The WG-AEN GPG v2 [16] provides a number of toolkits which provide:

- a series of options for sources of genuine data, or guidance on interpolation or use of default datasets,
- quantified accuracy statements where the impact on the acoustic quality of the results is indicated alongside the description of the option in order for the quality of the strategic noise mapping to be estimated.

The result of the stage is the series of input datasets for the total coverage of the area to be modeled.

5.5. Stage 5: Develop noise model datasets

At the end of Stage 4 the input datasets should be completely populated for the total coverage of the area to be modelled. At this point the project will have a series of generic GIS datasets. Modern large scale, wide area noise mapping projects are increasingly using digital datasets, which are predominantly generated and managed within GIS database environments.

An effective noise model require developing following model:

- Digital Ground Model
- Buildings
- Topography
- Barriers
- Noise Source Layer – Aircraft
- Noise Source Layer – Roads
- Noise Source Layer – Rail
- Noise Source Layer – Industry

This stage may be carried out within a GIS environment or within noise modelling software, but needs to be designed in collaboration between GIS and noise modelling specialists in order to produce an optimized noise modelling dataset ready for the calculation process.

The result of the stage is the noise model.

5.6. Stage 6: Noise level calculations

At this stage the final GIS input datasets are transferred into the noise calculation software. The elements of this stage are typically:

- final manipulation of the input datasets to optimize for the calculation kernel;

- selection of the user specified calculation settings within the software tool;
- running of the noise calculations over the entire area to be mapped, using all the data from the model area; and
- production of noise results datasets developed from the calculation process.

The resultant noise level datasets may remain within the noise calculation software environment, or more typically be passed to a third party analysis tool or into a GIS system, for map production, secondary analysis and reporting.

Whilst it is desirable to allow complete freedom of choice over the noise mapping tool to be used by the noise mapping bodies, it is logical that certain desired functionality and a wish for consistency of quality will result in a restriction over the selection of some software tools. The following is a list of criteria that any selected software tool should satisfy in order to be acceptable within the strategic noise mapping process under the Degree on content and methods of strategic noise mapping [17]:

- commercial availability and supported within Serbia;
- documented compliance with XPS 31-133, RMR, ISO9613-2 and ECAC Doc 29 as appropriate, including the relevant adaptations;
- proven record of use in city sized projects and larger;
- means of calculating large areas in a seamless coherent manner which avoids discontinuity of results;
- compatibility with 3D datasets without compromising integrity of height data;
- utilization or acceptance of conventional GIS datasets, therefore import/export, batch process proprietary GIS formats and export results data for use in GIS or publish images;
- scalable, therefore server or GIS based systems to be included; and
 - suitable software should have some or all of these features:
 - ability to use or interface with personal or server based geo-database systems;
 - multi-processor or multi-machine capabilities for parallel processing of calculations;
 - previous experience with handling geo-datasets of over 20km² with more than 250,000 points or objects;
 - ability to enable multi-user working on a project.

5.7. Stage 7: Post processing and analysis

Following the production of noise level results within Stage 6 the calculated levels need to be analyzed in combination with other datasets in order to produce the results

required by the Directive [10] and the Degree on content and methods of strategic noise mapping [17].

The analysis to be carried out then needs to deliver a number of sets of results including:

- no. of people exposed within noise bands;
- L_{den} <55, 55 - 59, 60 - 64, 65 - 69, 70 - 74, ≥ 75
- L_{night} <50, 50 - 54, 55 - 59, 60 - 64, 65 - 69, ≥ 70
- no. of people exposed within noise bands in dwellings with special noise insulation;
- no. of people exposed within noise bands in dwellings with a quiet façade;
- total area exposed within noise bands;
- no. of dwellings exposed within noise bands; and
- documentation on the process undertaken to produce the reported analysis results, including metadata for electronic datasets.

Finally the results of the strategic noise mapping are to be submitted to the Environmental Protection Agency of the Republic of Serbia using the templates from the Degree on content and methods of strategic noise mapping [17]. The results are also to be made available to the public.

6. Conclusions

The paper has provided a general outline of the main areas of influence of the Environmental Noise Directive. The focus has been primarily on the methodological framework concerning the transposition of the Directive in the Republic of Serbia and dealing specifically with strategic noise mapping process.

The Environmental Noise Directive and the Serbian legislative derived from it define the basic rules to carry out strategic noise mapping.

In relation to methodological framework the paper has pointed towards the key difficulties concerning strategic noise mapping. Each mapping project implies a different approach, depending on various case related distinctions e.g. availability and quality of input data, extent of noise annoyance, the form and the volume of output data to be presented.

Based on the experience from various urban noise mapping projects, this paper gives an approach to defining key steps in urban noise mapping and establishing standard step-by-step procedure for strategic noise mapping process in Serbia. The paper has offered a staged approach to the delivery of strategic noise mapping projects in Serbia summarized as a seven stage process in the Fig. 2.

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