Strategic Mapping of Noise and Air Pollution

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Strategic noise maps according to the Directive 2002/49/EC are generally based on computer models of agglomerations or of the environment of main roads, railways and airports. It is of great importance that these models are based on data, that are existing and available and that are updated by cities and communities anyway. With large scale noise maps any modification of data needing manpower can raise the expenditure tremendously. Some techniques are presented that can be used to adapt existing data automatically and software controlled to the needs of environmental calculations. This includes the parallel use of city models for the mapping of noise and air pollution. These techniques include the software supported calculation by computer clusters, the inclusion of the number of inhabitants for each residential building and the assessment of exposure by averaging methods. Examples are presented.

1 Introduction

Noise mapping is a central part of the European Noise Policy. The target of this European approach is to get reliable data about the noise pollution in the cities and to come to optimal harmonized strategies for the abatement. Many noise mapping projects that have been carried out since the ED have shown that such maps can be seen under different angles of view. If the data are acquired and combined to a digital model of the city the model can be the basis of an extremely powerful noise information system used by the city administration and the public. Any question that arises about the noise load of a certain region can be answered immediately without spending further money for expensive experts.

This multiple use of the digital town model is a fairly new approach because some years ago it was not possible to handle such a large amount of data by people who are not specialists in the acoustics field. But today the project file of a city like Munich, Toronto, Vienna, Vancouver, or Lisbon can be handled much like the document file of a word processing system if certain requirements are fulfilled. The main contribution to this is the software used, because it is a tedious, time consuming, and frustrating job to update a noise map. And if the program does not allow the use of all data sources available or if it is not able to load and process the complete model in one run, it won't be used. Furthermore, calculation software which requires splitting the project into hundreds of separate files because of a restriction regarding maximum file size is not useful for this task (which can reach easily more than 100,000 objects when dealing with noise maps for cities). If one map could be used, many fewer steps would be needed, If the software is not used it will be expensive in time and personnel.

2 Modelling techniques

2.1 Terrain with variable height

The model of a city and all other environments is produced by combining some objects that may depend in detail on the software used. The topography with different ground heights is described by points and lines with defined absolute height. It is clearly advantageous to import these topographic objects from given databases or from GIS-systems because it is a tedious job to digitize them from a paper plan. It cannot be foreseen in the beginning of a project how many contour lines and points in the grid must be imported to the model, so it is of high priority to use software that is able to load and process a huge amount of them. Two numbers are important to describe the quality of software in this respect:

- the maximal number of contour lines in one file, and
- the maximal number of points in each contour line.

In the example shown the terrain was modelled by importing the height points from a GIS system used a federal geographic agency and by calculating contour lines using these points. These are exactly 7768 lines with about 600 points per line. The mean length of a line is about 20 km. Even for this city of only about 120,000 inhabitants with the neighbouring communities it is of tremendous advantage to use a system that can hold and process 10000 lines with 1000 points each as a minimum (Figures 1 and 2). For bigger cities these requirements are quite higher.

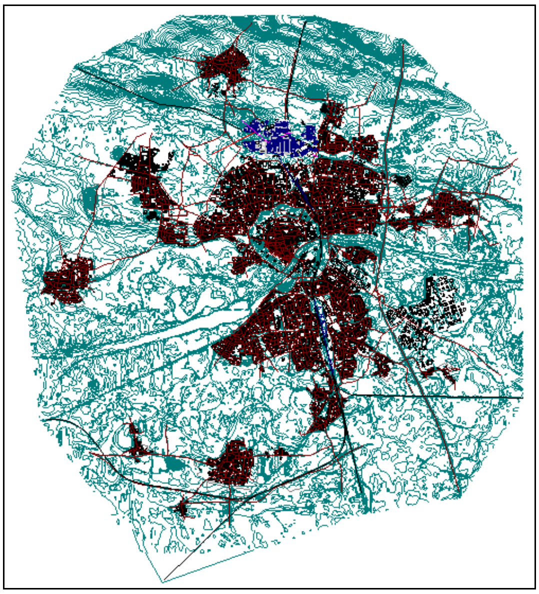


Figure 1: Digital town model for a city

Figure 2: City centre with all buildings and roads

2.2 Buildings and other objects

If the digital data of buildings, barriers, berms and other objects are imported from a GIS-system, these may be 2- or 3-dimensional data. Again it is a fundamental necessity that the software used does not set limits to the number of objects and the number of points of an object. If this is the case, it is a tedious job to subdivide the total scenery into a patchwork of sub-files that are adapted to the limitations of the software tool used. The model of figure 1 contains about 35,000 buildings that must be loaded in one sweep. With the City of Munich, where we imported the digital data directly from a 3-D digital model about 150,000 buildings are processed. If software for city-wide noise mapping is evaluated, the following information is important:

- What objects can be used to model the built up environment (e.g. buildings, barriers, berms, cylinders etc.)?
- How many objects of each type can be used?
- How many points are possible for each object?

It is clear that for professionals like consultants the possible description depth for each of these object types is also important. This is best explained with the barrier. If barriers are used to protect living areas or for other purposes, it is worth knowing the following:

- Can both sides have different absorption and can this absorption be defined as single number value and/or in frequency bands?
- Can these attribute values (spectral absorption) be imported from spread sheet or from other databases?
- Is it possible to have a gap between floor and lower edge like a billboard (floating barrier)?
- Is it possible for the upper edge to be a cantilever with correct calculation even when part of the source is under this cantilever?

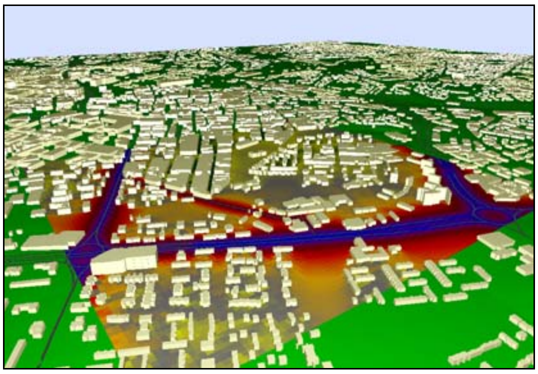


Figure 3: 3D-Special view of a town, horizontal noise grid projected to the terrain

The more or less photo-realistic view shown in figure 3 is not only a nice presentation but also very helpful to control the correctness of the model. This is especially true if data are produced or modified by the user of a mapping program. Many mistakes can be avoided if the model is reviewed with this 3D-view after a complicated object has been produced. To be used in this way as a tool to control the model during input, it must be very easy and quick to switch to this presentation. Otherwise it slows down the work and will not be used. If the program allows the user move around in the model or to virtually drive along a road, this can be done without any difficulty. This moving around in a model of the city with real time presentation needs extremely fast graphic processing and therefore such requirements should be taken into account when hardware is chosen.

3 Calculation and assessment of noise impact

Noise maps produced according to the European Directive on Environmental Noise are based on the calculation of the noise indicators L_{den} and L_{night} at immission points distributed on a grid [1].

Depending on the selected appearance each rectangle representing one grid point is colored according to the level or the lines of equal noise level are generated by interpolation between the grid points in a selectable step width (in noise mapping in steps of 5 dB). By experience, noise maps with progressive colors being red and blue for high noise levels and yellow and green for low noise levels are best suited for information purposes meant for the public and of decision makers. The calculation points should have preferably a grid width of 10 m and a height of 4 m above the ground. The time required to calculate noise maps depends on the area of the project, on the kind of software used, on project specific circumstances, and on the individual settings in the configuration of the calculation.

3.1 Acceleration techniques

The dependance on the area is trivial – doubling the area will require twice the calculation time assuming the same type of building distribution and arrangement of sound sources. Reducing the grid width to the half – e.g. from 10 to 5 m – will multiply the calculation time by the factor 4. Intelligent software applies numerous possibilities to accelerate the calculation. Areas with approximately free sound propagation and a minor number of screening or reflecting objects are calculated considerably faster than high-density areas with extended sources. In case the sound level in an area is governed by just some dominating sound sources, the calculation is considerably faster as it is with many sources with similar noise contribution. If you allow some specifiable maximum error of the final result, the calculation can be much faster. In order to reduce calculation time a special pre-sorting strategy is applied which ranks all contributions for each receiver point. Only dominating sources in the vicinity are considered while the remaining sound sources contributing just to an extent lower than the maximum tolerable error are ignored. This maximum tolerable error can be defined by the user and is in large scale noise mapping situations typically 0.5 to 1.0 dB.

But, based on the emission of a single source, one can't determine if it is relevant to the total contribution at a receiver point. A pre-sorting process must occur for each calculation point, the result of which has to be updated after each contribution has been calculated. Then some sources, based on error allowed, can be neglected.

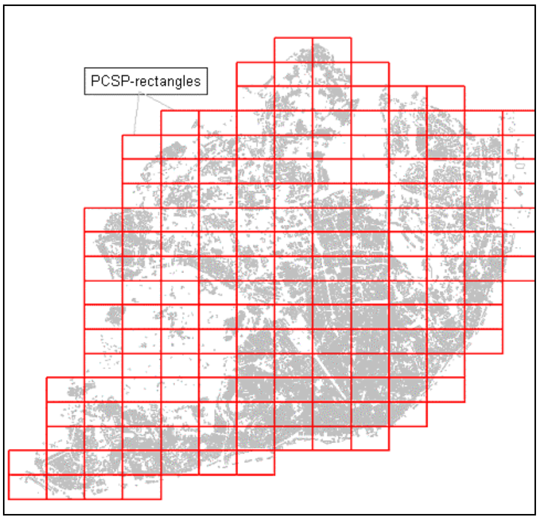


Figure 4: City area divided into rectangles of equal size for subsequent PCSP-calculation

3.2 Segmented processing of areas

When calculating a noise map for a large area it is always the required calculation time that determines the level of accuracy (by considering the number of reflections, application of the projection method etc.). The solution to this problem, a technique named "Program Controlled Segmented Processing" (PCSP) subdivides the complete project area into rectangles of equal size (Fig. 4) and saves this project in a special sub-directory. When the noise calculation software is run in a network each of these client-PCs will load one of these rectangles considering a certain overlapping length, calculate the noise map of this rectangle, save it and proceed with the next available rectangle. The program feature PCSP enables the program to be interrupted at any time e.g. if a computer is required for other purposes. The part of the noise map already been calculated will be stored automatically and another computer will continue with the calculation of the not finalized noise map at the last point of the rectangle where the interrupt occurred.

3.3 Number of residents in classes

According to annex VI of the EU-Directive, the estimated number of residents living in buildings has to be evaluated which are exposed at 4 m height to a L_{den} in dB on the loudest facade in the range of 55-59, 60-64, 65-69, 70-74, > 75 dB. These figures have to be evaluated for road noise, railway noise, aircraft noise and industrial noise separately. A similar statistic, just for different level intervals, is for the night time making use of L_{night}. Finally, both statistics have to be evaluated for such buildings which are exposed to a fairly moderate noise level. A facade of a building is considered to be "relatively quiet" if the sound level at a 2 m distance from the façade is at least 20 dB lower than the highest sound level at another façade.

To assess the noise load of residential buildings the calculation has to carried out preferably at the facades themselves – the so-called "building evaluation." This method has been proven to be an effective tool to handle various tasks in acoustical planning. For the relevant buildings receiver points are placed at a predefined distance from the facade on all floors and in a predefined horizontal maximum distance. For the purpose of EC-noise mapping, the receiver points are placed at a height of 4 m above the ground. By this building evaluation procedure, the analysis can be performed by the noise calculation program more efficiently. To this end, the number of residents is assigned to each building, thus, becoming an attribute of the buildings. The assignment can be done in different ways. For instance, the residents per building can directly be imported to the noise calculation software from a database on residential data. Alternatively, if the residential data are not available the number of residents can be estimated automatically from the base area of the building and the number of floors or the building height. When the total number of residents within a certain area is known, the estimated values can be normalized to the real total number of inhabitants. It should be mentioned that the number of residents estimated in this way for each building can also be assigned to any area on the basis of residents per km². Based on these data, the analysis can be performed without any problems. When computing for all buildings, the number of residents is summed up if the loudest level is within the predefined level interval and if, if required, the lowest level is more than 20 dB below the highest value (Figures 5 and 6).

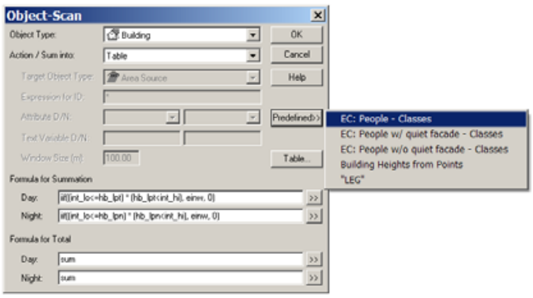
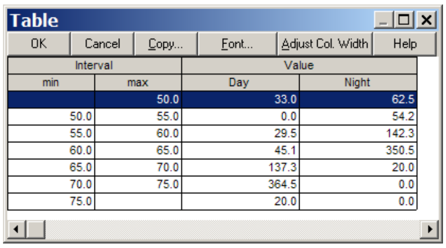


Figure 5: Dialog box Object-Scan: setting-up scanning for residents



Interval		Value	
min	max	Day	Night
	50.0	33.0	62.5
50.0	55.0	0.0	54.2
55.0	60.0	29.5	142.3
60.0	65.0	45.1	350.5
65.0	70.0	137.3	20.0
70.0	75.0	364.5	0.0
75.0		20.0	0.0

Figure 6: Façade points with noise levels

4 Calculation of air pollutants

The evaluation of air pollution resulting from traffic or industrial sources is already a task in city planning for several decades. While in the past mostly measurements and atmospheric dispersion calculations based on the simple Gaussian plume approach have been used to study the air pollutants impact, nowadays more advanced computational methods are applied to evaluate and assess the exposure to air pollutants.

In Germany, for example, the calculation model AUSTAL2000 developed by the German Environmental Protection Agency (UBA Umweltbundesamt Berlin) calculates the air pollutants distribution from traffic and industrial sources based on the Lagrange Particle Model [2]. The work has been initiated by a European Council Directive on ambient air quality assessment and management [3]. This directive defines and establishes objectives for ambient air quality in the European Community and intends to avoid, prevent or reduce harmful effects on human health and the environment. This is determined by a common assessment of the ambient air quality in the Member States on the basis of common methods and criteria resulting in information on ambient air quality open to the public.

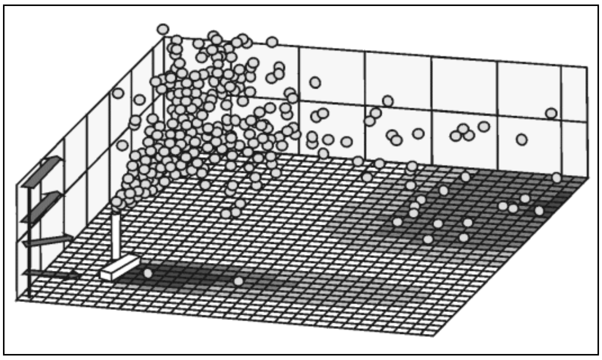


Figure 7: Principle of the Lagrangian Particle Model

The Lagrangian Particle Model in AUSTAL2000 is developed on the basis of time series of meteorology (wind speed, wind direction and stability of the atmosphere) and emission time series resulting in concentration time series as calculation result (Figure 7). Such particle models allow to account for time-dependent emission, variable wind field above height, and amount of atmospheric stability. Lagrangian Particle Models account for the effect of terrain structure and obstacles on the local wind field. For particulates the sedimentation in the vicinity of the source is modelled.

In comparison, Gaussian plume models are restricted to constant emission rates, time and location invariant wind field, constant diffusion parameters. Also a flat terrain assumed with no obstacles disturbing the wind field. For emitted particles the sedimentation effect is ignored.

For the final representation of results obtained with the AUSTAL2000-model the time series are evaluated for average or maximum concentrations for the time periods hour, day, or year. The influence of the topography on the wind field and thus the dispersion can be taken into account provided that annual meteorological data is available. This enables

- the calculation of air pollutants emission and immission by roads in cities and urban areas,
- the prognosis of air pollutants emission and immission to assess mitigation plans for road traffic,
- the assessment of measures in the context of noise and air quality mitigation plans, and
- the prognosis of air pollutants emission and immission of industrial sources.

Software programs basically developed for noise prediction and noise mapping purposes enable users to calculate the air pollutants impact even for larger areas, such as whole towns [4]. The digital town, already been set-up for the noise calculation, can also be used to calculate maps on air pollutants exposure (e.g. nitrogen oxides NOx, carbon monoxide CO, ash particulates, fine particulates PM10, hydrocarbons HC). Figure 7 shows the distribution of nitrogen dioxides resulting from road traffic in the city of Munich (area 500 km²).

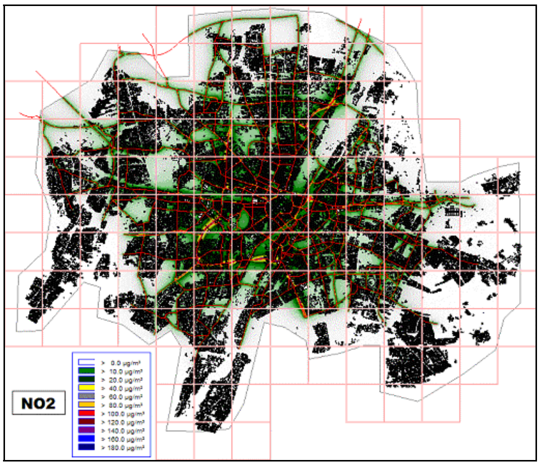


Figure 7: Exposure map for nitrogen dioxide resulting from road traffic in the City of Munich

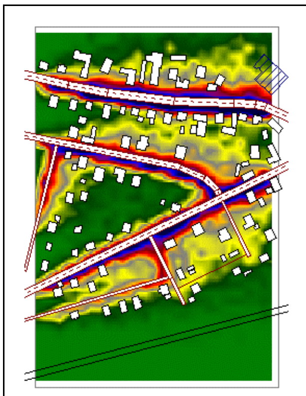
The same techniques as with noise calculations - such as PCSP for tiling the project area - are available also for calculation of air pollutants.

4.1 Air pollution by road traffic

In order to study the air pollutants impact by road traffic the emission factors from a joint publication by the German, Swiss, and Austrian Environmental Protection Agencies (HBEFA Handbuch Emissions-faktoren des Strassenverkehrs - Manual for Emissions Factors of Road Traffic) can be applied [5]. The emission factors depend on the mean daily traffic densities (MDTD), the percentage of heavy vehicles, and the speed limit which are by default available from road noise calculations. Alternatively, the individual emission factors for certain scenarios can be imported as time series via the clipboard.

In urban planning the calculation tool allows to study the distribution of air pollutants resulting from road traffic. The horizontal grid maps show the concentrations of nitrogen dioxide (NO2), fine particulates (PM10), benzene (C6H6) and sulphur dioxide (SO2) in micrograms per cubic metre. The exposure to further air pollutants can be calculated as well provided that emission data per hour is available.

An example for the effect of wind direction on the distribution of nitrogen dioxide caused by road traffic is shown in figure 8. The calculation covers the time period of a day, the receiver height is 1.5 m. For West wind of 10 m/s the air pollutants are concentrated along the roads axis. As the roads are extending mainly from West to East the local concentration increases. In comparison, the result for the same situation with southerly wind of 10 m/s the pollution is more spread towards northern areas covering a larger total area, but with lower local concentration. For both calculations the effect of the buildings on the local wind field was not accounted for.

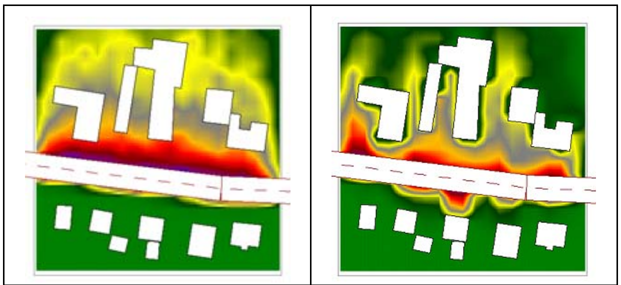


(a) West wind 10 m/s

(b) South wind 10 m/s

Figure 8: Influence of wind direction on the NO2-distribution of roads (evaluation period: 1 day)

In a further step, the effect of the terrain and/or buildings on the local wind field can be considered. In this setting, the wind field vectors for each grid point in the calculation area have to be calculated first. Based on this vector field the distribution of air pollutants is calculated in a second step. As the calculation of local wind fields by the AUSTAL2000-module is – as already for small sized areas – a time-consuming computation task it should not be applied for whole town, or even not for parts of it, but just for local situations. An example is shown in figure 9.



(a) buildings ignored	(b) buildings relevant

Figure 9: Disturbance of wind field by buildings effecting the NO2-distribution of roads

In figure 9a there is no effect by the buildings on the NO2-distribution while in figure 9b the local wind field causes as distinct impact on the distribution. Both grid maps have been generated with southerly wind of 10 m/s for an evaluation period of one day. For buildings south of the road the NO2-concentration raises as eddies develop behind the obstacles in downwind direction. This results in more particles in the local volume and thus a higher concentration than with not considering the buildings as obstacles. To the north of the road the distribution "follows" the border lines of the buildings causing lower concentration at close proximity of the facades due to the accumulation of air. To summarize, the effect of buildings and terrain must be considered when studying local effects of air pollutants distribution. Otherwise, reasonable errors may occur as the local wind field has strong impact on the concentration.

4.2 Air pollution by Industrial sources

According to German national environmental law, the emission of air pollutants by industrial sources, such as stacks or cooling towers, has to be modelled and assessed to receive the final technical approval. The calculation model AUSTAL2000 is the official model to be used to comply with the decree TALuft, forming part of the German clean air act BImSchG [6]. For modelling the emission, the height of the source and the emission rate in grams/hour for each relevant pollutant is entered. The increase of plume height due to thermal boost can be accounted for by entering the heat flux. In figure 10 the NOx-distribution resulting from 3 stacks (25 m height of emission) with wind from the Southeast shown for a receiver height of 1.5 m projected to the ground. The constant emission rate is 2000 g NOx/hour. The plume raises significantly above ground in close vicinity of the plant. Higher immission occurs at more distant locations where the plume falls down touches the ground due to the governing wind. The specific distribution of air pollutants in the resulting immission map depends also on the assessed time interval (hour, day, year). As the Lagrangian particle model is a stochastic model results for short time intervals (hour, day) may differ from one calculation run to another, while long term evaluations (year) cause invariable results.

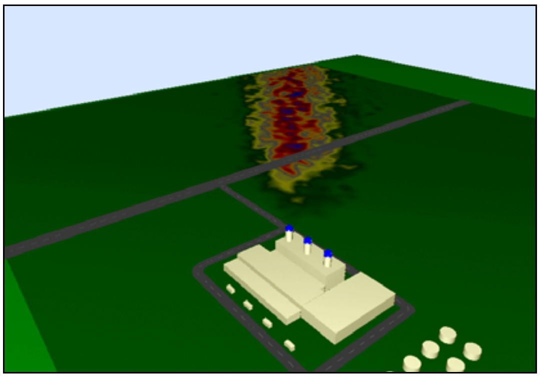


Figure 10: NOx-distribution caused by 3 stacks, height 25 m, with SE-wind

References

[1] Directive 2002/49/EG of 25 June 2002 relating to the assessment and management of environmental noise, Official Journal of the European Communities L 189/12 dated 18.7.2002.

[2] http://www.austal2000.de

[3] Council Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management (Air Quality Framework Directive), EC-Official Journal L 296 , 21/11/1996 P. 0055 – 0063.

[4] http://www.datakustik.de

[5] The Handbook Emission Factors for Road Transport (HBEFA), Version 2.1 (02-28-2004), http://www.hbefa.net/

[6] Erste Allgemeine Verwaltungsvorschrift zum Bundes– Immissionsschutzgesetz (Technische Anleitung zur Reinhaltung der Luft – TA Luft) vom 24. Juli 2002 (GMBl. 2002, Heft 25 – 29, S. 511 – 605).