Noise mapping - State of the art -
Is it just as simple as it looks?

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Summary
Noise pollution is subjective. Decibel values give a quantification of noise levels. Contour lines with equal noise levels and filled areas of noise classes seem to be useful for citizens and decision makers to oversee the situation.
Contour lines and filled areas of noise classes are okay at first glance, but as soon as we do simple analyses a step more in detail, the limitations must be clear. Some aspects: grid size, interpolation techniques, noise levels at façades, counting number of dwellings and citizens, down wind conditions, tunnels and viaducts, the effect of the height of grid points, low flow roads, effect of noise measures, other noise sources.
This paper summarizes the state of the art of important noise mapping aspects and gives explanations on limitations and constraints of a noise map.

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1. Introduction

The European Noise Directive aims to “define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise”. For that purpose several actions are to be progressively implemented. It furthermore aims at providing a basis for developing EU measures to reduce noise emission by major sources, in particular road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery.

One principle of the Directive is 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.

2. Purpose of noise maps

Strategic noise maps have to provide practical information and presentation of information to the public. The noise maps are an information tool and a diagnosis of the sound environment for decision-making regarding territorial development. They are used to have a global vision, at a given time, of the sound impact of road and rail vehicles, airplanes and of industries. After having drawn up these strategic noise maps, they have to initiate noise abatement actions in areas considered as critical according to this diagnosis and identify and protect “quiet” areas. In the end this process documents the evolution of the sound situation along the years and its impact on populations.

3. Noise level at the façade versus the noise level at an arbitrary grid point

In the END [1] it is described that the results on a certain noise map should be a number of people in certain noise classes (for example between 65 and 70 dB) or the number of dwellings in certain noise classes. For this determination of the quantities we have to calculate the highest noise level at a façade. This is the incident noise level, so without a reflection on the façade. You should compare this with the noise energy coming into a room with an open window. With regard to this discussion we have to realise that a façade level is not the same as the noise level in front of a façade. The noise level in front of a façade is including the reflection on the façade and in most cases this is 2.5 to 3 dB higher than the incident noise level.

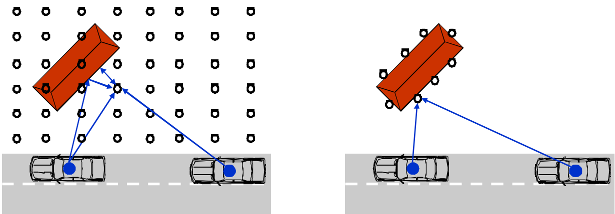

Figure 1: Noise level at the façade versus the noise level at a arbitrary grid point.

A noise map is the noise level in the street and is not the incident noise level at a façade. One other important aspect is the calculation height at 4 m above street level. For dwellings in the countryside it is realistic, but in dense populated areas this calculated noise level is used for complete high rise apartment buildings. In general this leads to an over estimation of the number of exposed people. An under estimation occurs when we deal with road or railway tracks with noise barriers. It is rare when a barrier shields nearby high-levelled dwellings.

The phenomenon of the noise level in the street versus the incident noise level at a façade is even more important when calculation quiet façades e.q. façades at the non road side of a building. Interpolation of grid points at both sides of a dwelling gives wrong results by definition. Calculation models without reflections are also incapable to calculate the quiet façades.

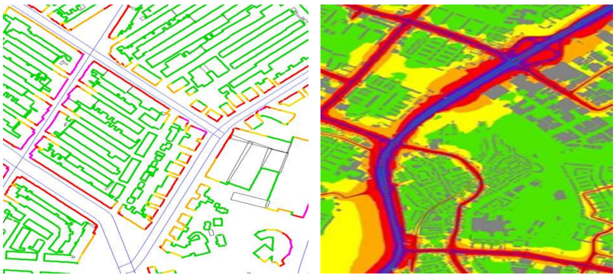

Figure 2: An example of the presentation of noise levels in the open air / in the street and noise levels as incident level at the façade.

So in general it is important to realise what you want to show on your noise maps. On general a strategic noise maps over a very large area, does not bother on noise levels within a 2 to 5 dB. More detailed noise maps will focus on these smaller inaccuracies so the calculation method is much more relevant. An explanation of what is described on the map is inevitable. Moreover if you want to investigate the effect of noise measures, you need to have a relative accuracy within the effect of the noise reduction measure.

4. Uncertainty and accuracy

4. 1 The uncertainty analysis of a model

Estimation of the uncertainty in model outputs is mostly based on the uncertainty in model inputs. However the uncertainty of the model itself is also an important aspect. E.g.:

- *How accurate is the standard at representing the real world situation and what inaccuracies does its (necessary) simplifications introduce*
- *How clearly is the standard described? Is it possible to use and implement the formulas and text of the standard in an unambiguous manner?*
- *How to convert general purpose GIS data into data formatted according to the formulas in the standard.*
- *What is the effect of uncertainty in the input data on the results? An uncertain ground absorption factor e.g. can cause a spreading of more than 10 dB.*
- *What is the calculation inaccuracy caused by optimisation settings of the software tool in order to reduce calculation times?*

Figure 4 presents the inter-relationship between different types of uncertainty.

4. 2 Inaccuracy in relation to measurements

Lots of investigations and research studies include comparisons between noise measurements and calculations. In most cases these comparisons are done for a very limited number of points and for limited situations. One has to realise (depending on the calculation method) that comparisons should be done for the L_{den} calculations. This means for the yearly average meteorological situation. So short-term measurements can give some reservations, and a limited number of microphones will also give shortcomings. The yearly average noise level is not the same as the noise level at the average situations. For example, and this is obvious, the average noise propagation is not the propagation at the average wind situation. Other examples are the average temperature, the average driving speed, the average car tyre, the average car condition, the average rail roughness, etcetera.

4. 3 What is accuracy in practice

For a typical user of a noise map, for example an inhabitant, the only relevant issue is the accuracy at one point, mostly his own house. For this single point, making the prediction calculations will differ case by case. E.g.:

- Close to the road
- At a façade at the first line
- At a façade at the 2nd, 3rd and further lines of buildings
- In free field

Specifically for these ‘single point accuracies’ it should be noted, that there will always be a possibility that the diversion from the real value is very high. These outliers always occur and the overall quality of a noise map cannot be assessed by measurements on a limited number of points. It will be much better to have a statistical approach for this accuracy. For example it is realistic to analyse that all points has a 95% confidence level.

Regarding the quality of measurements another point of concern can be raised. In noise maps we are handling the L_{den} and L_{night}. Measurement of the pure L_{den} or L_{night} are rare, as are measurements of a real yearly average. And doing these measurements one has to fine-tune and document all the relevant parameters like traffic flow, speed, average temperature etcetera.

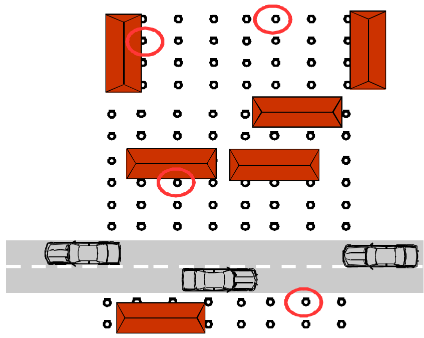

Figure 4: Accuracy for different grid points at various locations from the source.

4. 4 Line to point sources

An underrated aspect when making noise maps is the segmentation of the source line. This beside the subdivision of a road in separated source lines, representing the lanes. The segmentation of the source is inevitable because the necessary point to point calculations need a virtual point starting the calculation. The most accurate is to subdivide the source line in short source segments but this will dramatically increase the computer calculation time. Large steps for these source segments will give fast calculations but due to this concentrated virtual starting point, details like reflective surfaces, diffraction (or gab in the diffraction) will give inaccurate results.

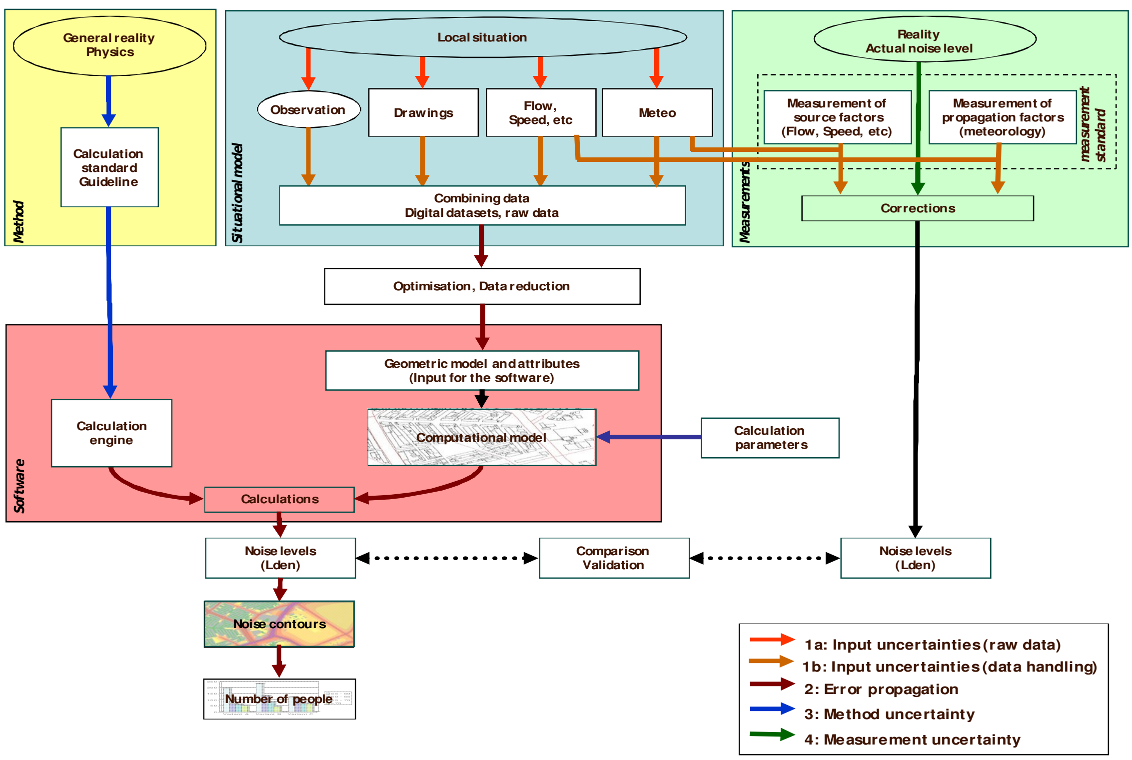

Figure 3: Inter-relationship between different types of uncertainty from literature. [5] and [6]

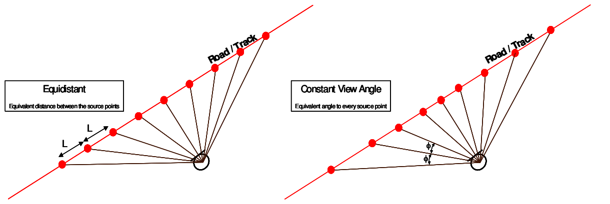

Figure 5: Two primary examples of segmentation of a source line. Equidistant and constant angle approach.

Beside the awareness of source segmentation for receiver points alongside a road line, there is also a situation where this source segmentation will give incorrect results. This is the situation where the receiver is in line, or almost in line, with the source line. This is the case for T junctions and for tunnel entrances. These calculations will even give a larger error when making calculations for railway noise using a dipole radiation. And this is the case using the EU interim calculation method based on the Dutch railway noise calculation method. Literature [3].

4. 5 Simulation of crossings/intersections.

For detailed noise maps, it might be relevant to do an extra investigation on the L_{eq} and the maximum noise level in relation to the annoyance for inhabitants close by. In figure 6 you find an example of the calculation of a car passing by and an accelerating car. These calculations are possible using the Harmonoise calculation method. Zee also literature [4]4

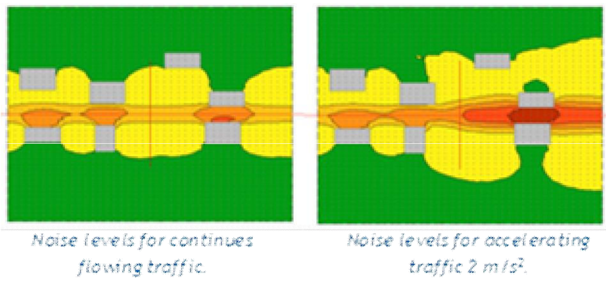

Figure 6: Maximum noise levels nearby some dwellings calculated with a single car passing by with constant speed and an accelerating car passing by.

4. 6 Modeling points at the receiver

Within the discussion of accuracy there is also a discussion of the correct and representative noise level at a façade. This regarding small variations along a façade. Of course this is only relevant when making very detailed noise maps, mostly on small areas.

When making noise calculations everyone comes to the point where the calculation model comes to its limits. So, detailed noise maps can result, at the first glance, in strange results. Going into more detail small effects can give correct calculations. The challenge is to determine when the calculation is incorrect, or when the calculation method comes to the limitations on the field of application. One example is the situation where we have “hit or miss” reflections. Some receiver points can have higher levels due to reflections but a meter further away this reflection is not existing or is shielded.

To avoid these random results it is advisable to calculate an average noise level over the surface of a façade or use a more advanced method like Harmonoise [4] that uses Fresnel zones. This will determine a more representative target value.

4. 7 Grids and interpolation

The principle of determining a noise map is to define a large number of grid points and to calculate the acoustical propagation from the different sources to these grid points. Most of the time these grid points are defined on a regular grid of 10 by 10 m. For a large city this adds up to millions of grid points with long calculation times. The determination of the noise level at one receiver point needs a calculation for all sources in the neighbourhood and to compute for each octave band the attenuation for geometrical spreading, for ground, barrier and air attenuation. The noise sources will consist of a large number of source points.

Once calculated the noise levels at the different grid points, the interpolation routine can do its work. The interpolation will give the nice continuous colourful pictures that we expect from noise maps. The question is: when/where is it incorrect to make these interpolations. Because interpolating over relative larger areas and/or over objects can give incorrect results.

4. 8 Interpolation

As already indicated at the discussion on the quiet façades, it is not allowed to interpolate separate grid points when they are, in principle, not comparable. Such as grid points on both site of a barrier, a building, the edge of a typical ground surface, grid point at both sites of a noise source and at different receiver heights. The solution to this is to calculate a more finer set of grid points, to get the correct noise levels on these positions.

We can conclude that grid points, types of grid and interpolations techniques are crucial when calculating noise levels. Interpolated noise levels are not the same as calculated noise levels on exact positions. Interpolations are much faster than calculations of noise propagation so commercial software developers flaunting with fast calculation times will use more interpolations even in situations where this is doubtful.

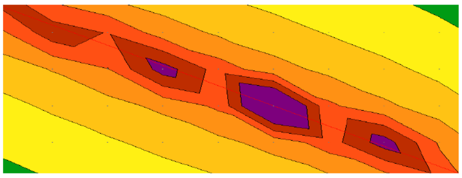

Figure 7: Example of noise contours with incorrect interpolations

4. 9 Height of grid points

In the END it is defined that the height definition of the receiver points is at 4 meter above the ground level. A practical problem is the definition of ground level. Even in a flat country as the Netherlands we have dwellings where the ground level at the front side of a building is not the same as the ground level at the back side. And what about ditches and water surfaces. There is no definition of the height of a grid point.

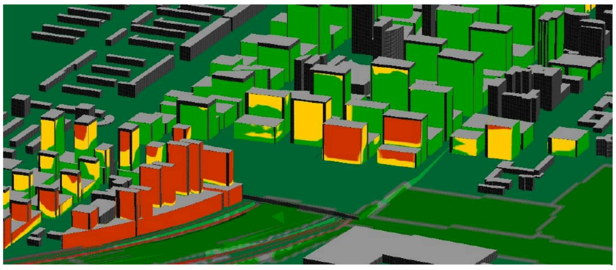

Figure 7: Example of vertical grids.

Even much more relevant is the calculation of the grid points at multi-level apartment buildings and high rise apartments. In the centre of Paris almost all dwellings are on the 2nd floor or higher, so grid point calculations at 4 meter height are not applicable. As we know that the ground attenuation and shielding effects will rapidly decrease for higher floor levels, we all know that the noise levels at apartment building are strongly underestimated. A solution to this is to make vertical grids to elaborate the variation of the noise level over the façade surface

4. 10 Accuracy at several distances (1)

An aspect for all calculation methods that is not handled with care. This is the aspect that downwind noise level and reflections on façades and other objects are only calculated under downwind. The calculations are always done for the downwind situation. Because the calculations are made with the use of an imaginary receiver, the wind will blow in the direction towards the reflecting façade but also away from this façade. Literature [4].

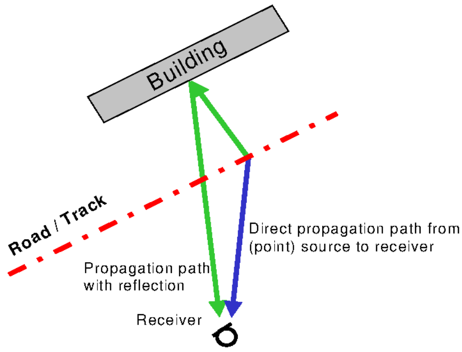

Figure 8: Reflections and downwind propagation.

4. 11 Accuracy at several distances (2)

One other aspect that is overshadowed is the calculation distance of the separated sources. One can realize, that the areas of influence of a small road is only a few blocks away. The effect on the total L_{den} or L_{night} of the large motorway is much more. This is even more relevant with huge junctions with high flyovers etc, etc,. The calculation of the higher L_{den} levels is, for this discussion aspect, not so difficult. But for the lower noise levels, e.g. the 50 dB L_{den} or the 40 dB L_{night} one has to realize that the contribution of, let's say 100 source points (road segments) of 20 dB will lead to this 40 dB L_{night}. The definition of the so called fetching radius is on crucial influence when calculation the lower noise levels contours.

5. Accuracy versus small noise reduction measures

The accuracy of a noise map must be in relation of the purpose of the map. A strategic noise map is more general in relation to the accuracy of maps for action plans. For example if we want to calculate the effect of a noise reducing aspect of 2 dB(A), the accuracy must be higher otherwise the effect of this small noise reduction measure cannot be calculated. Even more for strategy reasons a small noise reduction measure should be presented as positive initiative.

6. Presentation of a noise map

The presentation of a noise map is the last factor which can affect the public for the seriousness of the situations. Literature [12] gives a result of a study on this. One of the conclusions is that a noise map without any colours is seen as not correct and inaccurate calculated, while the noise map without red colours will not give any indication to noise annoyance.

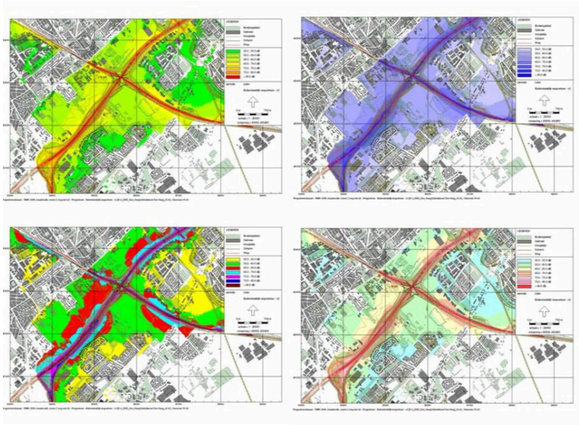

Figure 9: An example of four various presentations of a noise map.

7. Summery and conclusion

The interpretation of noise levels in the street or in the field, is different in relation to façade levels, on which regional and nationals legislation is based on.

The END prescribes noise contour lines at 4 m height. We must realise how this will work out for high raised apartments. Also in relation to these high raised apartments, we have to pay attention to dwellings behind noise barriers.

Grid points, types of grid and interpolations techniques are crucial when calculating noise levels. Interpolated noise levels are not the same as calculated noise levels on exact positions.

The accuracy of a noise map must be in relation of the purpose of the map.

Accuracy in relation to noise measurements is important. Some single noise measurements are substantially insufficient for these validations.

Some calculation models only make calculations for downwind situations. One has to realise what downwind is and how will this work out in urban areas.

The impact of the presentation of a noise map is adjustable. So red colours gives more impact on annoyance and the green colour gives quietness.

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