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NOISE MAPPING AND GIS;

OPTIMISING QUALITY AND EFFICIENCY OF NOISE EFFECT

STUDIES

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Abstract
Noise caused by industry and infrastructure is a major source of dissatisfaction with the environment in residential areas. In order to assess and monitor the influence of noise, policies on noise control have been developed in most European countries. Noise effect studies are carried out to support these policies. Since significant decisions are based on the results of noise effect studies it is important to develop standardised methods for the noise mapping process. Moreover, it is not only important to obtain results, but also to have information on the quality and the reliability of the results. And yet, the need for this information is often discarded. The quality and reliability depend on the quality of the data and models used.
An appropriate use of Geographical Information Systems (GIS) in mapping noise effects makes it possible to optimise quality and efficiency of noise effect studies by automating the modelling process, by estimating and exposing uncertainties and by developing and applying standardised methods to study and quantify noise effects.

Résumé
Le bruit causé par l'industrie et par les infrastructures est une source majeure de mécontentement dans les zones résidentielles. Afin d'évaluer et de surveiller l'influence du bruit, des politiques de gestion du bruit ont été développées dans la plupart des pays européens. Des études sur les effets du bruit sont menées pour contribuer à ces politiques. Comme des décisions importantes reposent sur ces études sur les effets du bruit il est important de développer des méthodes standardisées pour le processus de cartographie du bruit. Qui plus est, il ne s'agit pas uniquement d'obtenir des résultats, mais il importe également d'obtenir une information sur la qualité et la fiabilité de ces résultats. Néanmoins ce besoin n'est pas souvent pris en compte. La qualité et la fiabilité dépendent de la qualité des données et des modèles utilisés.
Une utilisation appropriée des Systèmes d'Information Géographique (SIG) pour la cartographie des effets du bruit permet d'optimiser la qualité et la fiabilité des études, en automatisant le processus de modélisation, en estimant et en représentant les incertitudes, en développant et en appliquant des méthodes standardisées pour l'étude et la quantification des effets du bruit.

Keywords: decision support, environmental modelling, error-sensitive GIS, uncertainty analysis

- computing noise levels in computer models
- storage and querying of these data
- determining noise effects in GIS by combining noise levels with the locations of people, animals and/or their activities (in areas, houses and other buildings) in regard to their sensitivity to noise
- presentation of the impact of noise on the surroundings by means of visualisation tools in GIS

Noise computer models and GIS are often used as two independent separated systems. Hence, data exchange and conversion between those systems is often needed. This is a potential source of errors since it causes confusion about the actuality and validity of the data and it may introduce conversion errors.


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│  │ Emission of noise │  │ Noise sensitive  │    │
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│  │ expansion of noise│  │ schools, nature  │    │
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│  │ heights etc)      │  │ surroundings     │    │
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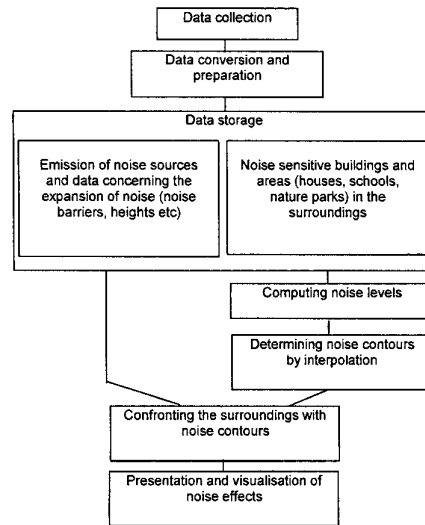
Fig. 1: schematisation of the noise mapping process

It is evident that the quality of the final results depend on the quality of the data and the methods used in every step of the noise mapping process. In order to improve the efficiency the level of detail of the complete noise mapping process should be adapted to the purpose and desired level of detail of the entire noise effect study. This also means, finding a balance in the level of detail and the exactness between the different steps in the noise mapping process. It makes no sense to put a lot of effort in the accuracy of one step while another step in the process is done with less detail, loosing the earlier obtained details. In conclusion, the accuracy of the methods and input data used should be in balance and adapted to the desired level of detail of the final results.

To give a more valuable meaning to the results, insight in the quality of the results is needed. For example: the calculated number of annoyed people should be presented together with the variation

in this number. This variation is caused by limitations and uncertainties of the methods and input data used.

All steps in the noise mapping process and their influence on the quality, accuracy and duration of the study are described in the following paragraphs. The authors hope to contribute to the discussion on standardisation and harmonisation of noise mapping.

3. Data collection, storage and conversion

A noise effect study requires a central spatial database with the needed data and the possibilities to process these data in a GIS. As is shown in figure 1 two sets of data can be distinguished:

1. data needed to compute noise levels (noise emission of the noise source and aspects influencing the transmission of noise)
2. the locations of people, animals and/or their activities (in areas, houses and other buildings) in regard to their sensitivity to noise

Noise effects are determined by combining the two data sets when the computed noise contours are confronted with the surroundings.

Scale and level of detail of the data need to be sufficient to reach the proposed accuracy of the study. On the other hand, too much detail in the data must be avoided in order to limit computation time and storage capacity. Although nowadays storage capacity is a less important factor, less detailed data make data better workable.

High variations in spatial information can only be reproduced adequately if the density of the sample points (measuring or observation points) is high enough. In noise effect studies, this means that a high density of information is needed on locations where noise levels reduce fast with distance. These are the locations, which are close to the noise source or behind noise obstructing objects. On locations where noise levels vary little, like far away from the noise source or parallel to the source, less detailed information is needed.

The level of detail of input data should be adjusted to these presumptions as well as to the purpose of the study. This is the essence of the conversion, which is needed to prepare the (available) data for noise effect studies.

At the moment there is an extensive collection of digital geographical data available which could be used in noise effect studies. For example: large scale topographical information, intensities of rail and road traffic.

The available digital data are not (yet) adequate in all cases. This is caused by differences in standards, data definitions, scales and formats. Therefore fieldwork can still be necessary. An example of this is the preparation of height information. Height information is relevant, since buildings and other obstacles obstruct noise. At this moment, these data are mostly measured in the field. Based on maps and this collection of heights an acoustic expert prepares the data to serve as input in the noise computer model. This conversion and accompanying generalisation is done by hand.

By the availability of accurate laser scanning data, this time consuming process can be automated (see figure 2). This increases the efficiency and standardisation of noise effect studies, since the preparation of the input data for the noise computer model is no longer dependent on the subjective insights of the acoustic expert.
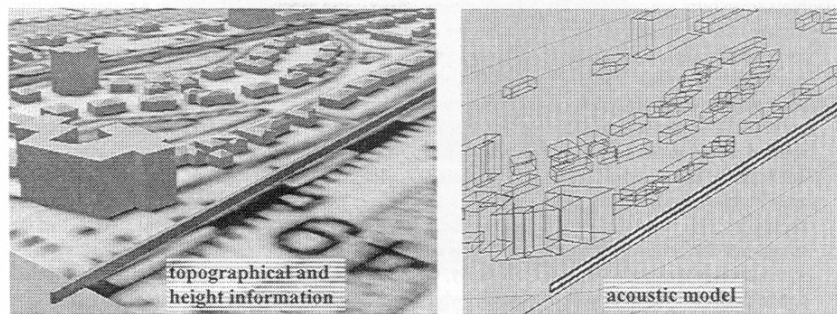
topographical and
height information

acoustic model

Fig. 2: an acoustic model automatically generated based on topographical and 3D information

4. Computing noise levels

In noise effect studies noise levels are computed and not measured. In the Netherlands, the computation takes place in specially developed computer models based on extensive measurements done in the seventies and eighties. Dutch law dictates the computation methods to be used.

Computation of noise levels instead of measuring them has advantages. In the first place, a future situation can not be measured. In the second place for most studies, the measuring is practically impossible since many measure points are needed to obtain a complete picture of the noise situation. Finally, the legal security of the parties involved is higher, since the results do not vary with measuring errors.

The computation methods are designed to give an accurate result on the scale of individual houses, for example in order to calculate the needed insulation. In studies supporting noise policies and in plan studies these accurate calculation methods are often also used, although the purpose of these studies does not require this level of accuracy. Not the exact noise levels are needed to serve these purposes, but only the differences in the overall acoustical situation resulting from two different designs to be able to make a choice between two alternatives.

Furthermore it is senseless to obtain accurate noise levels while in most cases these values are combined with less accurate data. For instance to determine the impact of noise on the environment, the locations of residential areas with average numbers of houses are used instead of the individual locations of houses. Computers are processing for days, while a sufficiently accurate result with a less detailed model and less detailed data could be reached in a few minutes.

The computation method of noise levels should be adapted to the required level of detail. The adapted noise calculation method could be implemented in GIS making conversion and exporting data between the systems unnecessary. Existing GIS techniques and functions to process spatial data could be used to optimise the calculation process, although this needs further research. With parts of the noise calculation method in GIS we can estimate noise levels and noise effects and indicate possible solutions to noise problems without the need to use complex computer models. However

the existing (complex) noise computer models have a status of confidence. Therefore it will be hard to replace them.

5. Determining noise contours

Noise contours are computed in GIS by interpolating noise levels computed on a raster of points. Figure 3 shows part of a noise model with the calculation points used to calculate noise levels caused by a railway. The way this interpolation is done is not standardised, neither is the density of the raster of calculation points. Therefor the location of noise contours depends on subjective factors. This is not desirable since important decisions are based on these contours, while these decisions should be unbiased. The development of directives for the density of the used raster and for the interpolation method would increase the standardisation of noise effect studies.

An accurate and complete picture of the noise situation in the surroundings of a noise source can only be obtained if the density of points is sufficiently high. Like mentioned before the density should be high close to the noise source and near noise obstructing objects, while parallel to the source and further away from the source less calculation points are needed and desired. This results in a decreased computation time. Obviously, the needed density of calculation points also depends on the desired level of detail of the study, which is dictated by the purpose of the study.
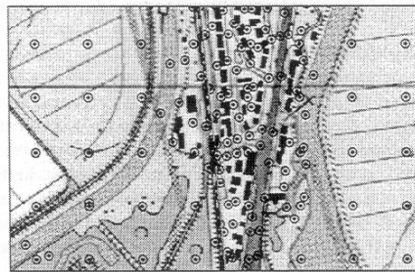

Fig. 3: density of calculation points dependent on the expected variation in noise levels

The Dutch acoustic software is capable of determining noise contours by integration. However, this software needs a regular raster of calculation points. The used density is often based on a compromise between accuracy and computation time. A better option would be to adjust information density to fluctuations in noise levels, like argued before. Computation time is reduced while a higher level of accuracy is achieved.

Interpolation in GIS does not require a regular raster of calculation points. From a pilot study, in which noise contours were calculated in GIS, it can be concluded that 90% of calculation points and accompanying computation time could easily be saved (see figure 3). The continuous picture of figure 4 is based on the noise model partly shown in figure 3. About 1,000 calculation points were used in total for an area of 3 by 2 kilometre (600 calculation points in a regular raster of 100 by 100 meter, with 400 extra points to increase the density near the source and near noise obstructing objects). GIS-functionalities can automatically determine appropriate locations for calculation points. In acoustic software, the same result can be obtained with a raster of 25 by 25 meter with 9,600 calculation points in total. This would lead to a ten times higher computation time.

Another optimisation is to increase the quality of noise contours. Further going optimisation is possible with advanced interpolation methods available in GIS which take the properties of spatial spreading of noise into account.
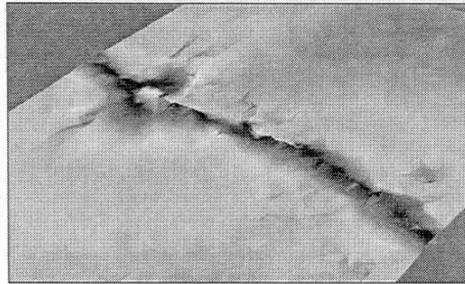

Fig. 4: continuous picture of noise levels after interpolation of calculation points

6. Quantifying and visualising noise effects

Noise effects are quantified and visualised by confronting the obtained noise contours with information on the surroundings, such as locations of houses and other buildings and/or areas with activities sensitive to noise (see figure 5). Functions available in GIS (see figure 5) are used in this process.

Quantifying noise effects includes:
- computing the area, which is affected by noise
- determining the number of citizens who are annoyed by noise
- determining the number of buildings with activities sensitive to noise exceeding a desired noise level (schools, hospitals)
- determining the areas within nature parks where a desired noise level is exceeded
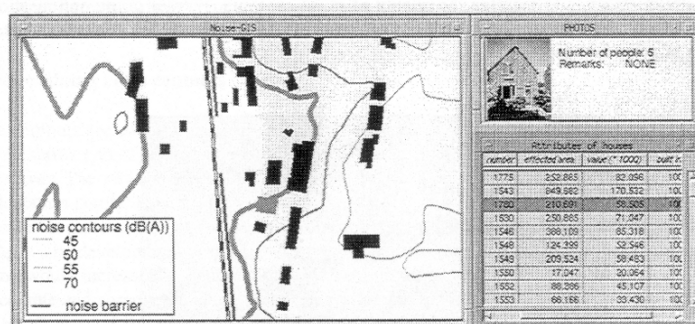
Fig. 5: determining the number of houses where the dictated noise level is exceeded by combining noise contours with the locations of houses

The presentation of the results is not complete without a presentation of the quality of the results. As mentioned before, the reliability of the results depends upon the accuracy and quality of the input data and the validity and accuracy of the computation methods used.

Techniques for dealing with data inadequacies and for disclosing the quality of the results should be applied in noise effects studies. These techniques include:

- taking the errors in the data and the models into account by methods of error propagation
- exposing the quality of the results by estimating and quantifying potential errors
- replacing visualisation of exact noise contours by contours with uncertainty bandwidths
- replacing exact figures by gradual judgements

7. Cumulating noise

Cumulating noise levels originating from different sources is a very important factor in the study on noise effects. Usually the overall annoyance to noise is determined by more than one noise source and therefore the influence of new infrastructure depends on the existing noise level as well. Cumulating noise sources is also an important issue in regard to "bundling noise sources". Bundling noise sources will result in less noise pollution than spreading sources over a wide area. For example: a new highway next to an existing railway is, from an acoustic point of view, better than designing these noise sources parallel but wide apart. In conclusion, cumulating noise should be considered in noise studies. The analysing possibility in GIS to cumulate noise levels originating from different noise sources is therefore an improvement in noise effect studies.

The annoyance to noise depends upon many variables, like sound intensity, frequency and variation in time. Several studies on noise show a correlation between the time averaged noise level and annoyance. Annoyance is also related to many non-acoustic factors of a social, psychological or economic nature (PBNA, 1995). It is found that the average annoyance (averaged individual reactions) is related to the type of noise source. For example, aeroplanes tend to be more annoying than trains even if the noise levels are the same. Dutch studies on the response of people to different kinds of sources have resulted in response functions (Miedema, 1992, see figure 6).
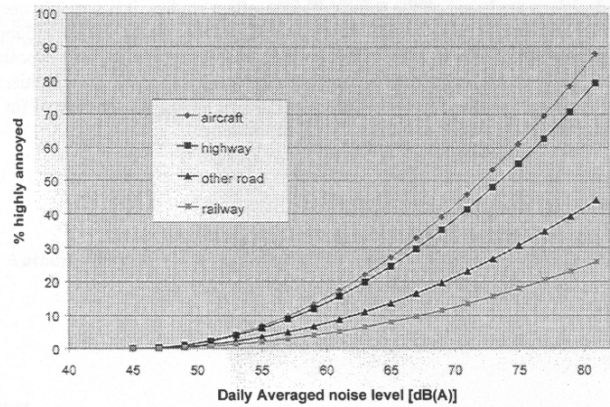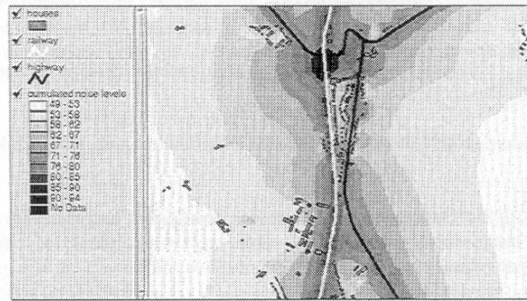
Fig. 6: the percentage of interviewed people who were seriously annoyed depends on the noise level and the kind of noise source

By taking all the noise sources and their respective annoyance factors into account and implementing these response functions in GIS the total "cumulated" acoustic situation and related annoyance in the area can be calculated (see figure 7).

Fig. 7: result of cumulating noise levels originating from highway and railway

8. Conclusion

An appropriate use of GIS in mapping noise effects makes it possible to optimise quality and efficiency of noise effect studies.

A universal method to map noise effects is lacking. The standardisation of noise effect studies will be enhanced when the methodology and the level of detail to quantify noise effects will be laid down in directives. These procedures can be implemented in a GIS-application. The aim is to obtain an unambiguous device to uniquely quantify noise levels, so results will no longer vary with the used methods.

Since significant decisions are based on the results of noise effect studies, it is not only necessary to have the results themselves, but also to have information about the quality and the reliability of these results. A proper use of GIS in noise effect studies, enables estimating and exposing the uncertainties of the results based on the data and methods used. An important issue in this, is that the efficiency and meaning of noise effect studies are served by letting the purpose of the study dictate the level of detail of the results and the allowed uncertainties.

References

European Commission, (1996), Green Paper on "Future Noise Policy", COM(96)540 final, 1996.

Miedema, H.M.E., (1992), Response functions for environmental noise in residential areas, Leiden NIPG-TNO, Report 92.006, 1992.

PBNA, (1995), Geluid en geluidhinder, Miliekunde en Milieutechniek, Koninklijke PBNA, Arnhem.

Wolde, T., Ten, (1999), "Outlines of future European noise policy", *Proceedings of International conference on noise and vibrations from road, rail, aircraft and industry*, 11 November 1999, Rotterdam, pp. 8-11.

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