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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. The result of different studies can only be combined or compared if the same indicators for noise exposure and the same assessment methods are used. It is therefore important to develop standardised methods for noise mapping. This is recognised by the DG Environment of the European Commission, who is preparing a Directive on Environmental Noise. This article illustrates and underlines the essence of standardised noise mapping tools. It also describes considerations for the development of these tools and focuses on: accuracy; cost-benefit criteria for noise measures; and presentation of uncertainties in results.

Geographical Information Systems (GIS) play an important role in noise mapping. An appropriate use of GIS in mapping noise effects makes it possible to optimise quality and efficiency of noise effect studies. Standardisation will benefit from the possibility of automating the noise mapping process in GIS. Furthermore, GIS can play an important role in estimating and exposing uncertainties.
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1. Introduction

Noise is a major factor in dissatisfaction with the environment in residential areas. This has led to the development of policies on noise control and methods of assessing the impact of noise on the environment. Particularly on noise originating from infrastructure and industry, which are the most widespread noise sources of today's developed world.

Therefore, it is important to monitor the noise effects of existing noise sources and to study the possible (decrease in) noise effects on the environment of new plans. These effect studies support the decision-making process. Based on these studies, the plan with the least environmental impact can be selected and measures can be devised by which the environmental impact is reduced.

To quantify and visualise noise effects an extended spatial database, spatial tools and computation force are needed. For that reason GIS is used in studies on the environmental impact of noise. Noise levels are computed in specially developed simulation computer models and GIS is used to quantify and visualise noise effects based on these noise levels.

At this moment, a universal method to obtain noise effects does not exist. This leads to differences in the results, as well as in quality and accuracy of different noise studies. Consequently, controversial conclusions may be drawn from different studies. Furthermore the results of different studies can not be combined or compared.

This need for standardisation is recognised by the DG Environment of the European Commission, who is preparing a Directive on Environmental Noise. An important part of this directive is noise mapping. The goal of this directive is that cities with more than 100,000 inhabitants produce noise maps and action plans and repeat this every 5 years. The European Commission, who will publish the results, will collect the outcomes. It is the intention of the European Commission to use the collected data for setting environmental targets and for developing strategies to achieve those targets (European Commission, 1996). The results originating from different member states can only be combined if all members use the same indicators for noise exposure and the same methods to calculate these noise exposure levels. Nowadays this is not the case. Comparative studies have shown dramatic differences between the outcomes of these methods (ten Wolde, 1999). Therefore the mentioned directive will include harmonised indicators for noise exposure, assessment methods *and* noise mapping.

The European Commission made a move in the right direction but the authors fear that there is not enough attention for the following three subjects (§1.1, §1.2 and §1.3).

1.1. Accuracy

It is evident that the quality of the final results depends 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.

1.2. Cost/benefit-criteria for noise measures

It is clear that the measures that will be taken against noise will influence the results of the study. However, standardised objective decision criteria do not exist for the decision whether or not the benefits of noise measures (reduction of annoyance) are enough to compensate for the costs (and other negative effects). Until now the placement of noise measures like barriers, which is part of a noise effects study is subjective.

1.3. Presentation of the uncertainties in the results

The assessment of uncertainties should also play an important part in the standardisation. Since major decisions are made based on the results of noise effect studies, an important issue is: "What is the meaning of these results?". Figures and visualisations in noise effect studies are produced by "black boxes" that give the decision-maker no insight into the methods used to quantify noise effects or their related accuracy and errors. On the other hand, the results are often accepted as being exact and true despite the mentioned lack of insight.

These three issues will be discussed in this article.

1.4. Sound and noise

Sound is formed by oscillations of the air, which can be observed by the human ear. Humans are able to hear sounds within the frequency range of 20 Hertz (Hz) to 20,000 Hz. Sound is expressed in decibels, dB(A), which is a logarithmic scale. To the human ear a sound reduction by 10 dB(A) will have the approximate effect of halving the subjective noise level (while reducing the sound energy with 90%). Faint sounds such as rustling leaves have a loudness of approximately 20 dB(A) and loud music, such as in a disco, of 100 dB(A).

Sound has multiple roles. Sound is a source of information but can also be disturbing. It can be pleasant as well as annoying. The same sound can be useful for one but unwanted for somebody else. The consequences to the health caused by noise are:

1. loss of hearing (levels exceeding 85 dB(A) and a long exposure time);
2. stress related health effects like hypertension, cardiovascular problems, influence on birth weight;
3. sleep disturbance; and
4. decreasing performance (Health Council of the Netherlands: Committee on noise and health, 1994).

Although the sound levels in the surroundings of infrastructure and industry are not that high to cause damage to hearing, the sound can be annoying and can cause stress-related health effects, sleep disturbance and decreasing performance.

Noise annoyance may be defined as a feeling of displeasure evoked by noise. It 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. The DG Environment of the European Commission has suggested to use the L_{den} and L_{night} as a indicators for noise exposure (de Vos, 2001).These indicators have a good correlation with annoyance. L_{den} is defined as:

$$L_{den} = 10 \times \log\left[12/24 \times 10^{L_{day}/10} + 4/24 \times 10^{(L_{evening}+5)/10} + 8/24 \times 10^{(L_{night}+10)/10}\right]$$

The L_{day}, $L_{evening}$ and L_{night} are the average noise levels during the day, evening and night. The definition of the durance of the night (and the other periods of the day) is left to each of the member states of the EU. Spain, for example, can include the mid-afternoon siesta in the definition of the night. In the Netherlands the night is the period from 23:00 till 07:00.

A considered use of GIS in noise effect studies can improve efficiency, data management, quality, (insight in) accuracy and presentation. This will support the standardisation and reliability of noise effect studies as will be shown in this article. First, the noise mapping process is described in detail together with considerations to improve this process in relation to its purpose. After that, the decision-making process of noise measures is described and suggestions for improvements in this process are given. Lastly conclusions are given.

2. The noise mapping process

In search for possible standardisation the authors of this paper tried to answer the questions "How can noise effect studies be more transparent, meaningful, reliable, unambiguous and how can noise effects be examined more efficient?". To give an answer to these questions they studied the whole process of noise mapping. Noise mapping is the total of the following steps:

1. collecting raw data, preparing, storing and querying of these data;
2. computing noise levels in computer models;
3. cumulating noise levels (when there are different sources);
4. determining noise contours;
5. determining noise effects; and
6. presentation of the impact of noise.

This process is shown in Fig. 1.

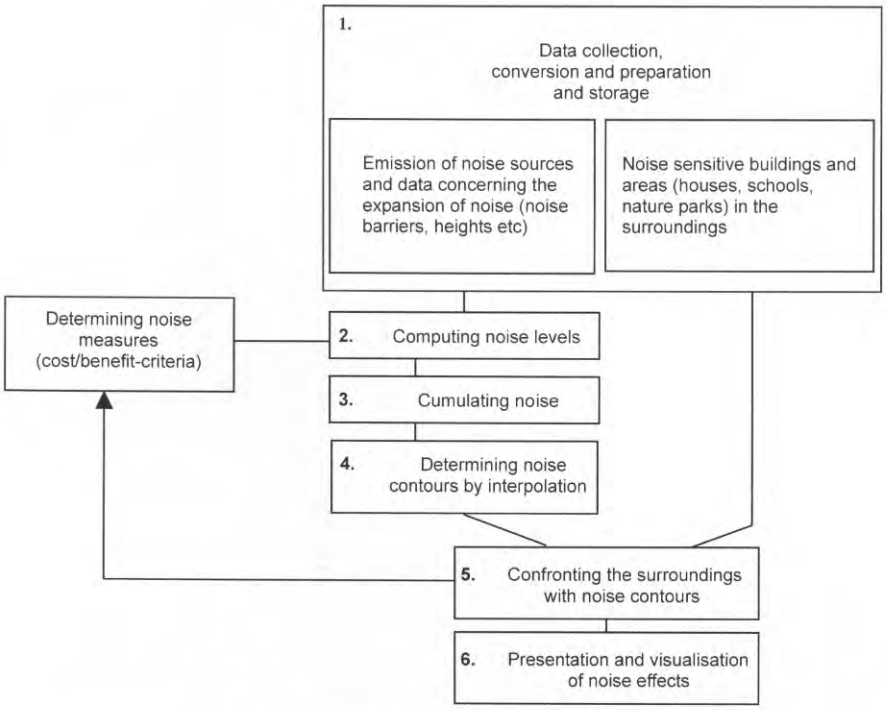


Fig. 1. Schematisation of the noise mapping process.

Noise effects are determined in GIS by combining noise levels with the location of people, animals and/or their activities (in areas, houses and other buildings) in regard to their sensitivity to noise. The study could show that noise measures are necessary. After determining the necessary noise measures, steps 2–5 will be repeated. This is an iterative (designing) process in which the benefits of the noise measures in comparison to the costs (and other negative effects like for example the disturbance of the landscape by barriers) are optimised.

The required input data and methods depend on the accuracy that one aims to achieve. This is illustrated by an example of how things should *not* be done as shown in Fig. 2.

Fig. 2 shows the determination of the number of effected houses along a railway. After the collection of the data on noise emission, the noise barriers and height of buildings, the noise level is calculated on a raster of points. These results are used to determine noise contours by interpolation and the contours are combined with polygons containing the number of houses to assess the number of noise-affected houses. The polygons containing the number of houses are a result of a conversion of ZIP code areas to squares of 100×100 m.

It will be clear from Fig. 2 that the result will not be very accurate. Although a lot of effort was put in the calculation of the noise levels (the Dutch standard calculation

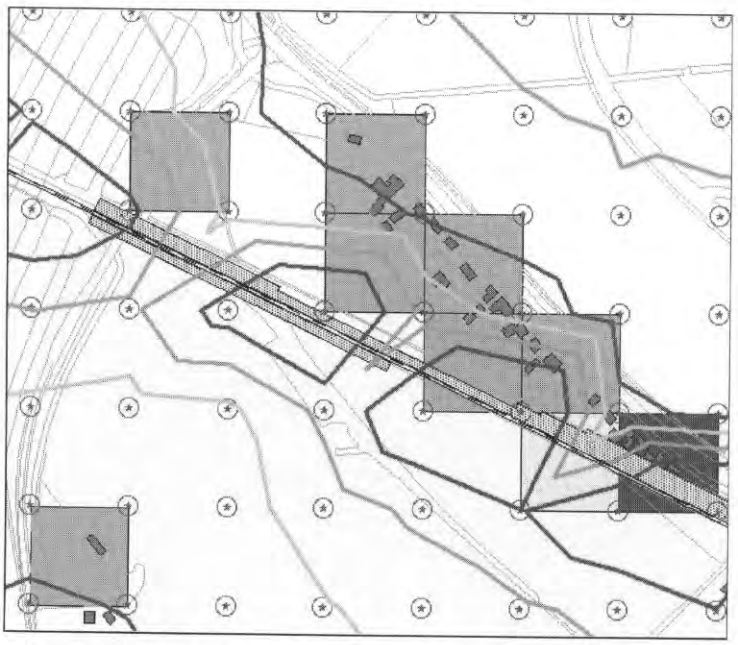


Fig. 2. Example of an inaccurate method to determine noise-effects (for the presentation the noise barriers are drawn flat on the surface).

method was used which is accurate but takes a lot of modelling and calculation time), this accuracy is lost in the following steps.

The overall accuracy in this example would have been improved if part of the effort, time and money which was put in the first calculation step had been used to improve the interpolation method for generating the noise contours or to obtain more accurate geographic data on the location of the houses. The handicaps are evident but still this noise mapping method is frequently used. This explains the fear of the authors for the lack of attention for these problems.

In order to answer the question as stated in the beginning of this paragraph, all steps in the noise mapping process (collecting raw data, storage and querying data, computing noise levels and contours, determining noise effects in GIS, determining noise measures and presentation of the results) were studied and will be described one by one in the following paragraphs. The focus will be on their influence on the quality, accuracy and duration of the study.

2.1. Step 1: data collection, storage and conversion

A noise effect study requires a central spatial database with the required data and the possibilities to process these data in a GIS. As is shown in Fig. 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 like the height of buildings); and
2. the location 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 result of the) two data sets.

Scale and level of detail of the data need to be sufficient to reach the proposed accuracy of the study. However, too much detail might be too much for the purpose it has to serve. Too much detail in relation to the purpose must be avoided in order to limit time needed for collection, preparation and computation.

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. This principle is illustrated in Fig. 3, which shows a dramatic improvement in the results in relation to the "standard" method shown in Fig. 2.

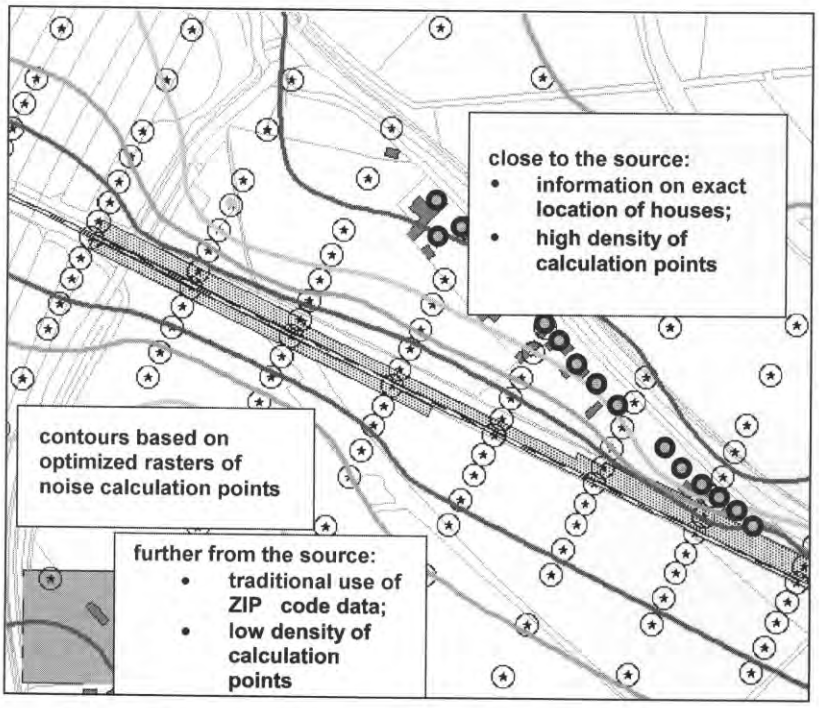


Fig. 3. Improving accuracy by optimising information density (exact location of houses near the source and improved contours by using an optimised raster of points for interpolation).

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 process of data collection, data storage and data conversion, which is needed to prepare the (available) data for noise effect studies.

2.1.1. Using available data

At present, there is an extensive collection of digital geographical data available, which could be used in noise effect studies. For example: large scale topographical information and 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 for the computer simulation models of noise transmission. Height information is relevant, since buildings and other obstacles obstruct noise. At this moment, the height 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 (Fig. 4). The preparation of the input data for the noise computer model no longer depends on time-consuming work and subjective insights of the acoustic expert. This increases the efficiency and standardisation of noise effect studies.

2.2. Step 2: Computing noise levels

In noise effect studies noise levels are computed and not measured. Computation of noise levels instead of measuring them has advantages. In the first place, a future situation cannot 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.

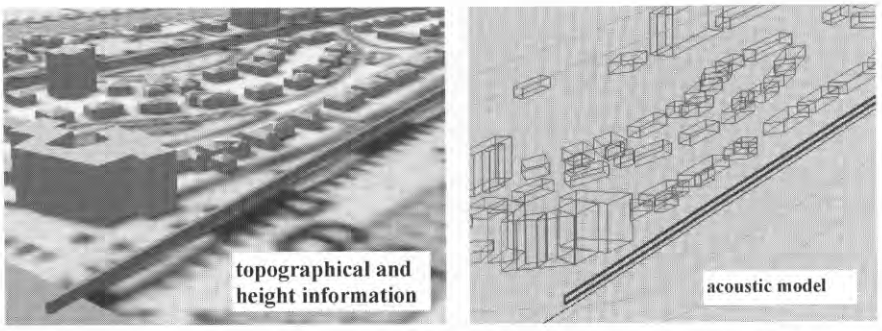


Fig. 4. (a and b) An acoustic model automatically generated based on topographical and 3D information.

In the Netherlands, the computation takes place in specially developed computer models based on extensive measurements done in the 1970s and 1980s (VROM, 1981, 1997, 1999). 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. Dutch law dictates a standard accurate computation method, which has to be used in these studies. In plan studies and studies supporting noise policies this accurate calculation method is not needed, although it is often also used since other methods are not available. For example, for alternative studies: not the exact information on noise levels is needed, but only the differences in the overall acoustical situation resulting from different designs are needed to be able to make a choice between alternatives.

Furthermore, as stated before, it is senseless to obtain accurate noise levels while in most cases these values are combined with less accurate data. An example of this was shown in Fig. 2, in which the accurate noise levels are combined with less detailed information like the location of house-areas based on ZIP code data (an average number of houses is used instead of using the exact locations of individual 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.

In conclusion, the computation method of noise levels should be adapted to the required level of detail. This is recognised by the Dutch Ministry of Housing, Spatial Development and the Environment who has started the research to develop a special noise calculation method for mapping purposes. More details on the calculation methods can be found in the following paragraph.

2.2.1. Dutch noise calculation methods

In the Netherlands the calculation of noise must follow one of the official calculation methods. Nowadays there are two official methods, which are called Standard Calculation Methods 1 and 2. The first method is a simple method which takes into account the emission of the source, the distance to the source, the absorption of noise by the ground, the effect of wind and temperature (yearly averaged), and a simple reflection term but which does not consider the obstruction of noise by objects. In other words Standard Calculation Method 1 calculates the noise transmission for a flat landscape (Fig. 5a). This simple method can only be rarely used, because in most cases the obstruction of noise by buildings is an important factor. For these situations Standard Calculation Method 2 was developed. With this method the obstruction and diffraction by objects and/or heights in the landscape are also calculated. To do so "noise paths" are defined form the source to each calculation point (schematically shown in Fig. 5c). The angles between these paths as seen from the calculation point are 2°. Then the contribution of each path is calculated and cumulated to get the overall noise level on the calculation point. The contribution of first (as shown in Fig. 5c), second and third order reflections can also be calculated. The calculation of these reflection paths is very difficult and time consuming (the location of "mirror" noise sources must be found). Nowadays it is thought that another, less time consuming but for noise mapping purposes equally accurate, approach can be used. This method will become the Dutch Standard

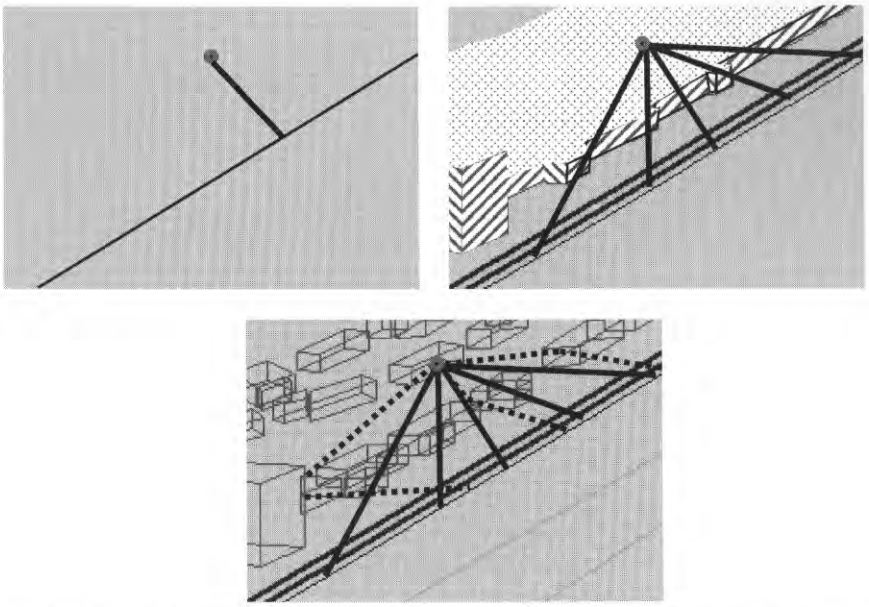


Fig. 5. (a–c) Schematic overview of the Dutch Standard Noise Calculation Methods, from left to right Standard Noise Calculation Method 1, 11/2 (proposal) and 2.

Calculation Method 11/2 (Fig. 5b). The first author of this article is working on a proposal for this method for Railway Noise under contract of the Dutch Ministry of Housing, Spatial Development and the Environment. The current proposal for Standard Calculation Method 11/2 assumes a diffuse sound field between the buildings in a area with more then 10 buildings per 10.000 m^2. Parameters in this method are (1) the height and the average "openess" of the first row of buildings between the noise sources and the calculation point as seen from the source and (2) the average space between the buildings in the area. After approval by the Ministry and by a commission of recommendation the method will be published at the beginning of 2002 and this will be the calculation standard for mapping purposes or railway noise in the Netherlands. It is possible that this method will also be used by other European countries since the Dutch Railway noise calculation method will become the European standard interim method for countries without a calculation method. This until this interim method will be replaced by a new harmonized European method.

Obviously the basis of each noise calculation is information on the emission of noise by the source. In the Netherlands the emission of road and railway noise can be calculated with the noise Standard Noise Calculation Methods. Parameters are the number of vehicles per hour, the type of vehicles (motorcycles, cars, light lorries including busses or heavy lorries or with railways the type of train), the speed and the road surface or for railways the track type. These emission functions are based on extensive measurements, which are repeated periodically. From these measurements one can see for example that since the 1970s lorries have become quieter (van

Blokland, 2001), as a consequence of new technology development enforced by stricter European noise legislation for lorries. Although for cars quiet technology is also available it is not enforced and therefore not used by the producers of cars or bought by the consumers. Fortunately also new "quiet" road surfaces, railway tracks and trains are being developed. New types are measured and the calculation method will be accordingly adapted.

There are no standard calculation functions for the noise emission of industry. These emissions are very dependent on the activities of each company. For the calculation of noise from industries, measurements of the noise emission at each separate company and even at the individual noise source of these companies are required.

2.2.2. *Integrating GIS and noise computer models*

The noise computer models and GIS are often separate systems. 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.

The calculation method should have different levels of detail, so we can estimate noise levels and noise effects and indicate possible solutions to noise problems without the need to use complex computer models.

Implementing the noise calculation method in GIS and "replacing" the existing software could be difficult since the existing (complex) noise computer models have a status of confidence.

2.3. *Step 3: cumulating noise*

A harmonised standard on noise mapping will be incomplete without a chapter concerning the cumulating of noise caused by different sources. This is an important factor in the study on noise effects, since usually the overall annoyance to noise is determined by more than one noise source. It is also evident that the influence of new (or the changing of) noise sources depends on the existing noise level. 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.

Annoyance is also related to many non-acoustic factors of a social, psychological or economic nature (PBNA, 1995). Moreover the average annoyance (individual reactions differ) 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. Studies have been done on the response of people to different kinds of sources resulting in response functions (Fig. 6; Miedema, 1992). These response functions are going to be used for the European noise mapping studies in the future.

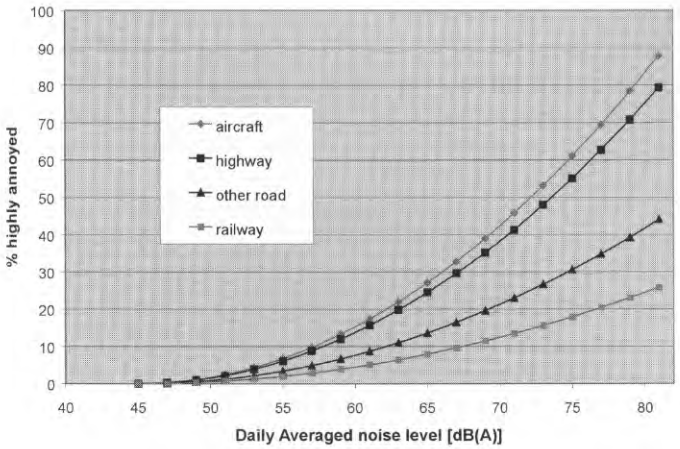


Fig. 6. The percentage of interviewed people who were seriously annoyed depends on the noise level and the kind of noise source.

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 (Fig. 7).

2.4. Step 4: determining noise contours

Noise contours are computed in GIS by interpolating noise levels computed on a raster of points (Figs. 2 and 3). Until now, no standards exist for the used interpolation method or for the density of the raster of calculation points. This is left to the subjective judgement of the "researcher". This is not optimal, since significant decisions are based on these contours, which makes it important that these decisions are 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.

2.4.1. Decreasing calculation time

Most of the Dutch commercial acoustic software is capable of determining noise contours by interpolation. However, this software needs a regular raster of calculation points. The used density is often based on a compromise between accuracy and

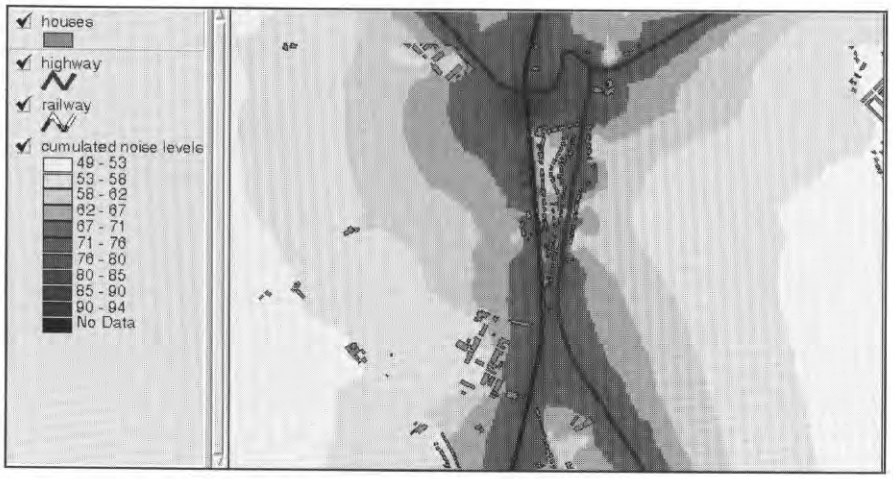


Fig. 7. Result of cumulating noise levels originating from highway and railway.

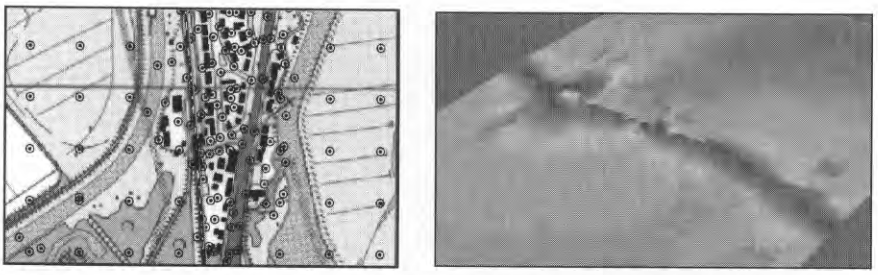


Fig. 8. (a and b) Continuous picture of noise levels after interpolation of calculation points.

computation time. A better option would be to adjust information density to fluctuations in noise levels, like argued before.

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 the calculation points and the accompanying computation time could easily be saved (Fig. 8a). The continuous picture of Fig. 8b is based on the noise model partly shown in Figs. 4b and 5c. In total 1000 calculation points were used for an area of 3×2 km (600 calculation points in a regular raster of 100×100 m, 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 (close to the source) can only be obtained with a raster of 25×25 m with 9600 calculation points in total. This would lead to a computation time 10 times longer.

Further optimisation is possible with advanced interpolation methods available in GIS which take the properties of spatial spreading of noise into account.

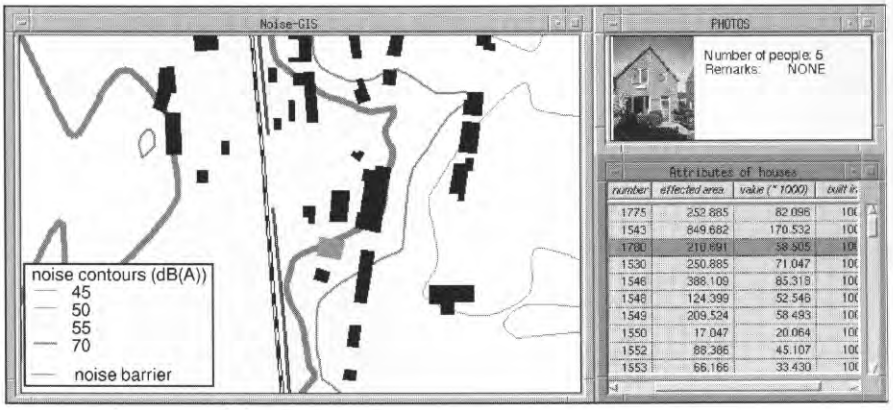


Fig. 9. Determining the number of houses where the dictated noise level is exceeded by combining noise contours with the location of houses.

2.5. Step 5: determining noise effects

Noise effects are quantified and visualised by confronting the obtained noise contours with information on the surroundings, such as location of houses and other buildings and/or areas with activities sensitive to noise (Fig. 9). Functions available in GIS are used in this process.

Quantifying noise effects includes:

1. computing the area, which is affected by noise;
2. determining the number of citizens who are annoyed by noise;
3. determining the number of buildings affected by noise (buildings with activities sensitive to noise exceeding a desired noise level like schools, hospitals etc.); and
4. determining the areas within nature parks affected by noise.

2.6. Step 6: presentation of the impact of noise

To give a more valuable meaning to the results, insight and presentation of 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.

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:

1. taking the errors in the data and the models into account by methods of error propagation [e.g. Monte Carlo simulation (Openshaw, Charlton, & Carver, 1991) or other error propagation methods in spatial modelling (Heuvelink, Burrough, & Stein, 1990)];

2. exposing the quality of the results by estimating and quantifying potential errors;
3. replacing visualisation of exact noise contours by contours with uncertainty bandwidths; and
4. replacing exact figures by gradual judgements.

Furthermore the presentation should be standardised (de Kluijver, 2001; Popp, 2000) and simulations of noise with virtual reality systems will help laity to understand the acoustical consequences of plans (Dubbink, 2000).

3. Noise measures: the complexity of the decision-making process

It is mostly thought that law dictates the need for noise measures. This is only partly true; law in most European countries dictates noise levels (outside the houses), which are preferably not to be exceeded.

Noise measures could be noise barriers, "quiet" concrete road surfaces, "quiet" rails etc. However, if costs of noise measures are too high or if other negative effects, like the disturbance of the landscape, are too serious, higher noise levels will be permitted and these kind of noise measures will not be taken. In this case the houses will be insulated and the noise levels outside the houses will remain high.

There are no standardised cost/benefit-criteria, which regulate these cost/benefit-judgements. For example the decisions about the placement of noise barriers are left to the advisors and are from then on a constant subject of debate. Since subjective aspects are involved, this is a complex, non-transparent decision process. Obviously, this is a major factor of uncertainty in the outcome of noise effect studies. This also means that studies can only be comparative if cost/benefit criteria are part of the standardization. The European Commission, which works on harmonisation of the methods for noise effect studies, should also pay attention to these aspects.

The lack of standardised cost/benefit-criteria has led to the development of a variety of criteria. There are almost as many criteria as there are studies (de Kluijver, 1998, 2001; Janssen, 1997; VROM, 1987a, 1987b; Waterman, 1998). Most criteria focus on the balance between the effect of a noise measure (e.g. the number of houses, which benefits from the measure and the reduction of the noise level achieved) and the cost of the noise measure (measured in money). Until now criteria, which also take other negative effects into account, are not or seldom used like the effect on free sight and landscape, the feeling of safety (for example, a train platform enclosed by barriers) and the forming of a social barrier between two neighbourhoods by a noise barrier.

The acoustical cost/benefit criteria, that are used till now, can be distinguished in three groups:

1. best guess method;
2. cluster definition; and
3. iterative criteria.

3.1. Best guess method

The first solution is the easiest. A cost/benefit-criterion is set. The acoustic advisor suggests a noise measure and the decision-maker checks if the measure fulfils the criterion. The drawback of this solution is that one never knows if the most optimal measure within the bands of the cost/benefit-criterion is reached. In other words, it is difficult to determine whether another possible measure would reduce more annoyance.

3.2. Cluster definition

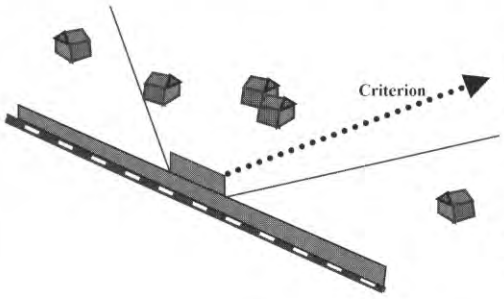
The second solution is also easy to understand. It is evident that a noise barrier in a city will reduce the number of annoyed more than the same barrier in the open country where it will cause a reduction in noise levels for two or three farms. Clusters of houses are defined based on the density of houses. Noise measures will be taken to reduce noise levels for the clusters. No noise measures will be taken for houses outside the clusters. The drawback of this method is that no noise measures will be taken for houses which lay just outside a cluster and for which only a little extension of the noise measure (and costs) is needed to make a lot of improvement.

3.3. Iterative criteria

The problems met by cluster definition can only be solved by a criterion that iteratively extends the noise measure and compares benefits and costs for each step. The noise measures grow step by step and the effects of each step are compared to the costs (Fig. 10).

An example of the first group of criteria is a criterion of the Dutch government to decide whether to subsidise noise barriers requested by the local governments or not. The local governments have to fill in a form with the benefits (number of houses and the expected noise reduction based on results of a noise model) and the costs. No alternative solutions are needed in this request.

The second criterion is successfully used by the Dutch Railways to calculate the overall need for noise measures and related costs for predefined cluster of houses in



Can the barrier be increased with a "step" of 25 m. in length and 1 m. in height?

Yes if:

$$\frac{\text{cost}}{\Sigma_{\text{houses}}\,\Delta\text{dB}} \leq \$\,25.000,-$$

Otherwise no!

$\Sigma_{\text{houses}}\,\Delta\text{dB}$ = sum of the noise reduction

Continue with next step.

Fig. 10. Example of an iterative barrier criterion.

the Netherlands (different scenarios for different levels of ambition). This criterion is part of an integrated noise/GI-system and automatically calculates the noise measures that are needed (Janssen, 1997). This system is among others used for a study on a European scale. This study involved different kinds of noise measures and their related costs. It showed that on a European scale it is much cheaper to make trains silent than to place barriers. These kinds of studies show the relevance of noise/GI-systems and integrated automated cost/benefit-criteria for noise measures. The costs of these systems and studies are only a fraction of the costs of the needed noise measures.

An example of the third criterion has successfully been used in a noise study on different designs for the new high-speed railway from Amsterdam (the Netherlands) to Frankfurt (Germany; de Kluijver, 2001). This criterion was also integrated in a noise/GI-system. It automatically calculated the needed noise barriers for the whole railway in a matter of seconds. The use of the criterion guaranteed that different designs for the railway were judged equally by the noise experts, that the results were comparative and, as a consequence, that the best solution could objectively be chosen. The iterative approach guarantees that the most optimal solution within the bands of the criterion is reached. This will prevent endless discussions about other locations and heights for barriers of which one or the other claims to be better.

The Dutch government recognises the essence of an objective cost/benefit criterion on the placement of noise barriers. The Ministry of Housing, Spatial Development and the Environment and the Ministry of Transport, Public Works and Water Management have planned to standardise the decision-making process for noise measures during the coming years.

4. Conclusions

A universal method to map noise effects does not yet exist. The results of noise effect studies can therefore not be compared. In this article the need for standardisation of noise mapping was argued to make comparing possible. It also gave considerations for the development of standardised noise mapping tools.

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. A relevant 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. Essential hereby is to look at the noise mapping process as a whole and to see each step in this process in relation to each other.

Important in noise effect studies is the decision on noise measures against noise. This article described suggestions to objectify, to clarify and to improve the decision-making process concerning noise measures.

The influence of noise on the environment is becoming significant important in areas with an increased pressure on land. Many citizens as well as decision-makers are or will be involved. Therefore, (legally) secure and standardised noise mapping should get more attention.

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