Noise Prediction Models and Geographic Information Systems, a sound combination

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ABSTRACT

The design and development of large infrastructure projects, like rail- and highways, demand good environmental management. GIS is increasingly important in the study on the possible effects of planned infrastructure on the environment.

When planning new infrastructure, noise is one of the most important factors to be considered. Noise has a widespread spatial influence and the effects can be very drastic. GIS can be a very useful tool to monitor the noise effects on the environment. The use of GIS can increase the quality of the study on noise pollution. This will support environmental management.

At the Delft University of Technology, Faculty of Civil Engineering and Geosciences, we are working on a research project to integrate noise prediction models and GIS (Geographic Information Systems). The aim is to improve the study on noise effects supporting the environmental management and to reduce the costs of these studies as well.

Keywords and phrases: environmental management, spatial analyses, integrating spatial models and GIS, interoperability, noise prediction models

1.0 INTRODUCTION

New infrastructure influences the surroundings. It is important to study the possible side effects on the environment. These effect studies support the decision making process. Based on these studies, the design with minimal effects on the environment can be selected and measures can be schemed by which the influence on the environment is reduced.

Geographical Information Systems (GIS) are becoming more important in the study on the possible side effects of planned infrastructure. The possibilities of GIS to analyse and present geographical data improve these studies. This is particularly the case in the study on noise pollution, since noise transmission and the effect of noise on the environment have many spatial components.

Noise pollution is one of the most important factors to be considered in the study on new infrastructure. It is a major factor of dissatisfaction with the environment, especially in the Netherlands where space is limited and the population density is high.

In the Netherlands noise levels are calculated in noise prediction computer models. Until now GIS is only used as pre- and post-processor in the study on noise pollution. GIS facilitates the visual presentation of the effects and is an additional tool in analysing the results. Since there is no far-reaching integration of GIS and the noise prediction models, the following shortcomings and problems are met:

- Much data conversion is needed between the noise prediction models and GIS. This causes confusion about the actuality and validity of the data.
- The differences in scale, format and accuracy of the data endanger the quality of the results. A control system to tackle this problem is absent.

- The lack of a standardised method for assessing the noise effects on the environment using GIS gives ambiguous analysing results.
- At the present day some systems integrate noise and GIS. Yet they are distinctive solutions and demand specific data formats and offer only specific analysing possibilities. Examples are the Noise Cadastre of the Swiss Federal Railways (Oertli and Wassmer, 1995) and the Geographical Railway Noise system of the Dutch Railways (Elbers, 1998).

Far reaching integration of GIS and noise prediction models will give a solution to the problems mentioned. Such a system is an appropriate monitoring tool on noise effects and will help to control the long-term effects.

At the Delft University of Technology, Faculty of Civil Engineering and Geosciences, we are working on a research project to integrate the Dutch noise prediction models and GIS. As will be shown in this paper the integration of GIS and noise pollution models improves the study on noise effects. Furthermore such a powerful system offers a controlling instrument to support the legislation on noise pollution and reduction. In this phase our work focuses on the Dutch legislation and prediction models.

The issue of noise pollution is country specific since the used noise models and the legislation on noise pollution is different for each country. A further development of the project can aim to combine the country specific developments on GIS and noise pollution. This can serve as a start to make the issue of noise pollution more general and support standardisation of prediction models and legislation, which is desirable in the European Community. Developments on the integration of noise models and GIS in other countries can be found in the references of this paper.

Section 2 describes the occurrence of sound and noise pollution. In which way GIS can enrich the study on noise pollution is explained in section 3. In this process controlling the quality and accuracy of the data is an important issue as is described in section 4. Section 5 gives a description of the way GIS and noise prediction models are incorporated into one system to improve the study on noise effects. Section 6 contains the conclusions of the project and our views on future developments.

2.0 NOISE

2.1 Sound and noise pollution

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, 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. Annoying sounds are considered as noise and can also be harmful to the health at lower volumes. The consequences to the health caused by noise are:

- loss of hearing (levels exceeding 85 dB(A) and a long exposure time)
- stress related health effects like hypertension, cardiovascular problems, influence on birthweight
- sleep disturbance
- decreasing performance

(Health Council of the Netherlands: Committee on noise and health, 1994)

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. 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. In the Netherlands studies have been done on the response of people to different kinds of sources resulting in response functions (Miedema, 1992).

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. 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.

2.2 Dutch legislation on noise pollution

In the Netherlands there are several policies on noise pollution. The following policy levels can be distinguished:

- National: Long term policy aims to limit the overall growth in noise pollution.
- Covering the total plan and route: Plan makers are obliged to search for a solution that has a minimum effect on the environment (for example alternative routes, tunnels, noise barriers and less noisy asphalt).
- Local: New infrastructure must comply with maximum noise levels.

In order to control the noise problem the Dutch law requires noise studies that show the possible effects on the environment. The noise levels caused by new infrastructure or industry must be calculated with a specific prediction calculation method (further explained in section 2.3). It also has been defined which effects have to be considered and in what way.

The study for the design with a minimum effect on the environment must show:

- the design of the new infrastructure and accompanying noise contours
- areas that are effected by noise (residential areas, recreational areas, hospital grounds, animal habitats like nature parks)
- the number of houses effected by noise
- the number of annoyed people
- the number of effected buildings that are especially sensitive to noise (hospitals, schools, universities)

These effects must be shown in absolute figures but also relative to the present situation and the future situation without the new infrastructure.

An extensive spatial database with (spatial) analysing and presentation possibilities is needed for the study on noise effects.

2.3 The prediction of noise levels

Calculating noise levels is to be preferred instead of measuring noise levels. Modelling has the following major advantages:

- Modelling is relatively easy. Measurements have to be very extensive. Many observation points are needed to supply a complete picture of the noise effects. Furthermore measuring has to be done over a long period to average weather effects, background sounds and even seasonal effects.
- Modelling is possible even if the noise source is not present at the time, like new infrastructure.
- Several solutions to the noise problem can be calculated (noise barriers, less noisy concrete)

A (prediction) calculation method for noise levels is made in the Netherlands following extensive measurements of noise and noise transmission caused by traffic and industry in the seventies and eighties. Based on this method a computer model can be made of infrastructure and industry by which noise levels can be predicted. The parameters in the models are the noise emissions from the noise sources and the transmission of the noise to the surroundings.

Noise emission
Engines, contact between tires and the road or contact between the train wheels and the rail induce the noise emissions. At high speeds there is also aerodynamic induced sound. In the prediction models the emission of infrastructure is determined by the sort of transport (types of trains and cars) and the intensity of the transport.

Noise transmission
The noise transmission and the noise level at an observation point is related to the distance to the source (noise level reduces quadratic with distance), absorption by air, absorbing or reflecting (ground-)surfaces, the direction of the wind, temperature gradients and objects which obstruct the transmission path like buildings and noise barriers. These parameters are used in the prediction models to calculate noise levels on observation points.

3.0 GIS AND THE STUDY ON NOISE EFFECTS

Monitoring the effects of noise is only possible with an extensive spatial database and spatial analysing tools. Furthermore computation force is necessary. GIS forms a powerful set of tools for storing and retrieving, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986).

A preliminary study on the integration of noise and GIS has been done on a test area containing a highway and a railroad (see figure 1). This study has shown that GIS can enrich the study on noise pollution. The following paragraphs give a description of the experiences. The accompanying figures are based on this study area.

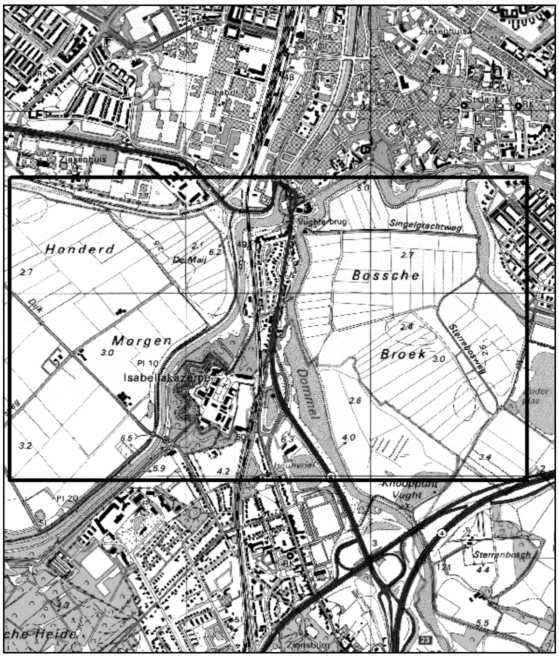

Figure 1. Study area for the preliminary study on the integration of noise and GIS.

3.1 The use of a spatial database management system

GIS contains a database management system designed for spatial data and is therefor a very good system for managing geographic data. GIS offers the same possibilities as other database management systems (DBMS) like:

- the possibility to manage the data (setting authorisation, integrating data, version managing, verifying data, controlling and supervising accuracy and quality)
- ensuring the integrity and consistency between data
- rapid access to the data
- the availability of the data stored in the DBMS to many users and different kinds of applications

(Bernhardsen, 1999). Furthermore GIS offers tools and datastructures to deal with the spatial component of the data.

To do a complete study on noise effects geographical information about the noise sources, the noise transmission and the areas and buildings that are sensitive to noise as described in section 2.2 should be gathered, stored and managed in the database. Apart from this data, photographs, videos and noises stored in the database can also be very useful in noise studies for presentation of the data. Some of the possibilities of a spatial database management system in noise studies are illustrated in the following example (figure 2) in which a number of GIS-layers are combined. It concerns four GIS data layers: the location of houses, the location of the railway, the location of noise barriers and the computed noise contours (lines of equal noise level).

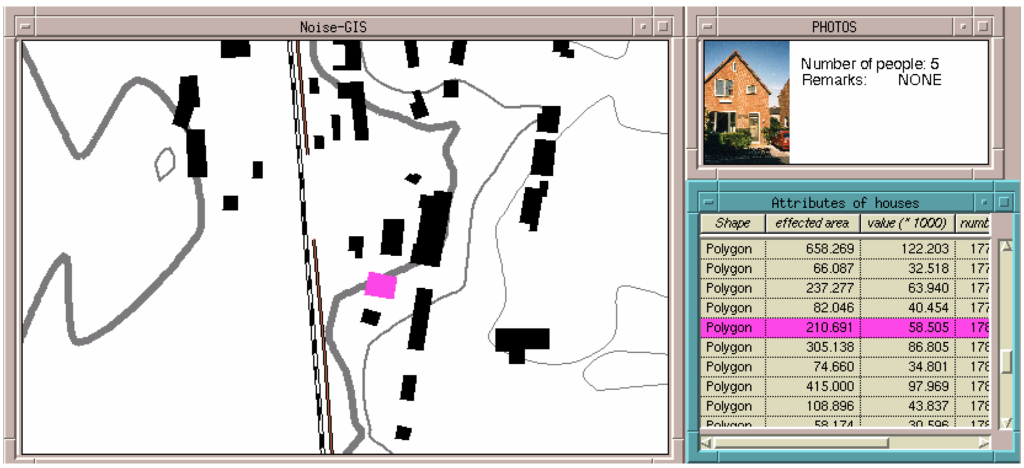

Figure 2: An example of combining data stored in a spatial DBMS (spatial and additional data).

The combination of the layers shows a number of noise effects like the area which is effected by noise and the number of houses for which the noise exceeds a certain level. As is described in section 3.3 with GIS it is possible to quantify the noise effects by mean of the data stored in the database.

A substantial part of the noise study is usually gathering and digitising the needed information. However this information is already digitally available with designers, agencies or with external and commercial data suppliers. GIS offers a digital door to this information. With a GIS Database Management System it is possible to collect, store, control, standardise and manage this data with differences in format, scale and accuracy.

3.2 (Spatial) insight in the data

Noise is not visual in the real world. However noise levels (on observation points or noise contours) and the effects of noise on the environment can be visualised by using GIS. This provides an extra tool in noise studies. The visualisation of noise levels clarifies the data (see figure 2, 3 and 4). In addition the visualisation of input data and computed values adds an extra check to discover errors during the noise modelling process.

In noise prediction models noise levels are computed at discrete sample points surrounding the noise sources. By spatial interpolation of these points in a GIS, a spatial continuous picture of the noise spreading can be created, giving more insight in the (nature of the) data.

Noise contours can be generated based on the interpolated spatial noise model. Noise contours are isolines connecting locations with equal noise levels. The Dutch acoustic software packages also offer the possibility to calculate noise contours but these packages have a number of drawbacks:

- It is not possible to generate a continuous spatial model of the noise levels. This makes it impossible to do further analysing besides presenting the contours. Data conversion is needed for further analysing.
- Simple interpolation techniques based on a regular raster of observation points are used. Higher accuracy can only be obtained with an overall increase in density of observation points (quadratic increase in calculation time). Usually a compromise is made between accuracy and computation time.
- It is impossible to use extra information, beyond the sample points, like information about the noise emission, the quadratic decrease of the noise level with distance and information about objects that lead to discontinuities in the noise transmission.

These disadvantages can be overthrown by the use of spatial interpolation in GIS. With this less sample points are needed. Moreover the quality of the noise contours can be improved in comparison with noise contours generated by existing noise software. To find the optimal method for generating a spatial noise model, further research needs to be carried out. Insight in the spatial properties of noise and incorporating these properties in the interpolation will increase the quality of the obtained continuous spatial noise model.

Figure 3 is the visualisation of a spatial noise model. The height represents the noise level caused by the railway. The levels are high close to the railway. Further away the noise fades out. Locations that not have enough observation points can be traced (the contours show unnatural squared shapes related to the observation point raster). Discontinuities in the predicted noise levels indicate errors. The noise expert can use this information to improve the noise prediction model.

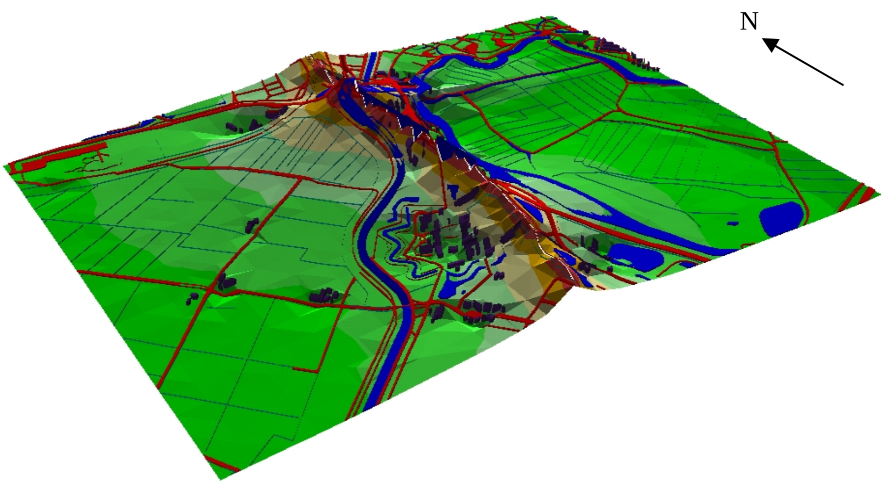

Figure 3: Spatial noise model of the study area.

3.3 Quantifying the effects of noise on the environment using spatial analysis

GIS contains a set of computer tools for analysing spatial data. These tools can be used on the information stored in the spatial database to quantify the noise effects when new infrastructure is planned (see also figure 2). The following analyses can easily be implemented in GIS:

- computing the area, which is effected by noise
- determining the number of noise sensitive buildings where a certain noise level is exceeded
- determining the area of natural parks where the noise-level will be higher than the norm value
- determining the number of citizens who are annoyed by noise

A GIS application for quantifying the noise effects makes it possible to easily calculate and quantify the influence of several different designs. Such an application will ensure that all infrastructural alternatives can be objectively compared.

3.4 Cumulating noise levels originating from different sources

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. The influence of new infrastructure depends on the existing noise level.

Regarding cumulating noise, the possibility to bundle infrastructure is an important issue in the process of planning infrastructure. Bundled noise sources will result in less noise pollution than sources over a widespread 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.

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 can be calculated (see figure 4).

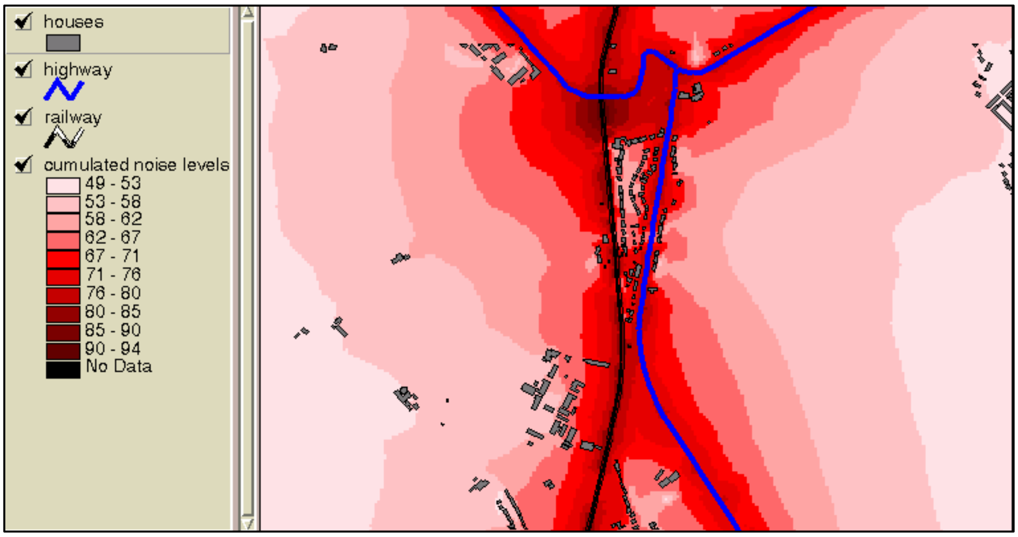

Figure 4: Cumulating noise levels originating from different sources.

3.5 Noise studies, 3D GIS and Virtual Reality

A new development in GIS is the storage of geo-objects as 'world-alike' 3D-objects. The location and geometry of these 3D-geo-objects is determined by x, y and z-co-ordinates. The transmission of noise is influenced by the height of the surroundings (for example obstruction by surrounding terrain, buildings and objects). 3D-information is therefor necessary in order to calculate noise levels. Consequently linking GIS and noise models has many possibilities.

At our department, a 3D GIS Virtual Reality system has been developed. (See also in *International Journal of Geographical Information Science* vol. 13, no. 4; Verbree *et al.*). With this system it is possible to create a 3D-model based on a GIS-database (figure 5). This could be a noise model. The system uses VR-techniques to visualise the (3D) GIS data. In addition to visual presentation the simulation of noise caused by passing trains or road traffic will make Virtual Reality models more realistic. A Virtual Reality world with 'real' sound can help the designers and can play an important role in the communication process with the community.

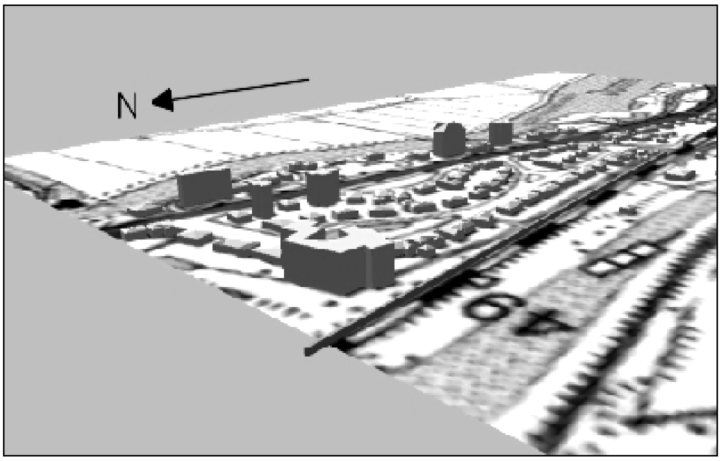

Figure 5: An example of a 3D-visualisation based on a GIS-database.

4.0 QUALITY AND ACCURACY OF THE DATA IN NOISE STUDIES

Chapter 3 has described the possibilities of GIS to support the study on noise. Besides these possibilities the preliminary study also showed a number of aspects that has to be considered carefully in order to make the integration successful. These aspects concern scale, detail and the accuracy of the data.

4.1 Scale and detail

The accuracy and quality of noise studies depend on the scale and detail of the input data. An accurate result of the study can only be obtained if the information density is high enough. Nevertheless redundant information should be avoided reducing the computation time. The needed information density is dependent on the fluctuation of the noise levels. The noise level fluctuates in a geographical manner. The noise levels reduce 'quickly' on the following locations:

- near the noise source (noise level reduces quadratic with distance)
- behind objects like noise barriers or buildings
- near changes in ground-reflection or absorption like water surfaces

The noise levels reduce 'slowly' or not at all:

- at a great distance from the source (without obstructing objects)
- parallel to the road or railway

A high information density is needed on locations where the noise levels change ‘quickly’ (geographically) and not necessary at locations where the noise levels change 'slowly'.
Two sets of input data can be distinguished in the study on noise effects:

- noise levels calculated at a number of observation points (from which a continuous spatial picture of the noise transmission can be generated)
- the areas and buildings that are sensitive to noise in the surroundings

Figure 6 shows the noise model in which the density of the observation points is considered as described above (high density close to the source and behind objects, low density parallel to the track and further away).

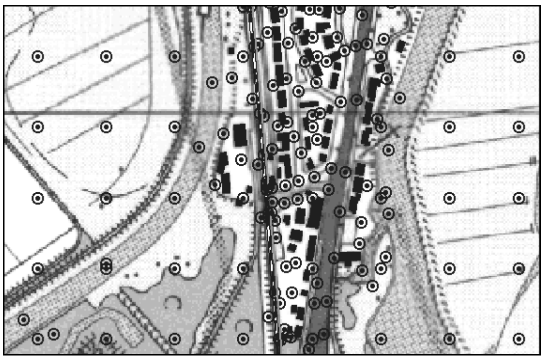

Figure 6: Density of observation points dependent on the variation in noise-levels.

The density of the observation points is not the only scale factor that has to be considered. The scale and detail of the information of areas and buildings sensitive to noise are also very important. Similar conclusions can be drawn as made for the density of the observation points. For example the location of the houses and other buildings that are sensitive to noise must be very accurate near the source. Less detail is required further away. Data on population density in polygons of 100 x 100 meter will be accurate enough far from the source, but will not be sufficient close to the source where exact locations of houses are needed.

4.2 Acknowledging the inaccuracies in the data

Since there are a lot of variables determining the final noise level, the computed noise levels are fuzzy (not exact). Important decisions are made based on the predicted noise levels, like the insulation or removal of houses and the placement of noise barriers. GIS can support this decision-making process by the use of fuzzy logic and spatial explorative data analyses. With fuzzy logic it is possible to describe data not with a discrete model but with boundaries presenting the spatial variation and uncertainties in the data. With spatial explorative data analysis it is possible to look for irregularities and errors in the data. Fuzzy logic and spatial explorative data analysis lead to more insight into the meaning and validity of the computed noise levels.

4.3 Unlocking the accuracy of the analysing results

Since important decisions are made based on the results of these analyses, it is not only important to have the results, but also to have information about the quality and the reliability of the results. Reliable decisions can only be made if the level of the prediction errors is sufficiently low. This problem is often discarded. The quality of the results of noise studies depends on the quality of the data used. GIS can control and supervise the quality of the results by taking the quality of the input data into account. Techniques of error propagation should therefor be implemented in the system that links GIS and noise prediction models.

5.0 INTEGRATION OF GIS AND NOISE PREDICTION MODELS

In the previous sections the way noise studies can be improved by the use of GIS is described. In this section it is explained how an optimal integration between GIS and noise prediction models can be achieved. To realise the integration between GIS and noise prediction models, interoperability and Open GIS have to be basic principles.

An important issue in new GIS-developments is interoperability. Interoperability focuses on the ability to move data easily from one system to another, by means of exchanging formats, conversion, interfaces and the database model (Sondheim, Gardels, Buehler, 1999). Standardising (GIS) functions allows a standard language and a higher degree of mobility between systems. Users on any computer and under any operating system can use these functions (Clarke, 1999). Another important new development in GIS is Open GIS. In an ideal situation there should be a national and global information infrastructure in which geodata and geoprocessing resources move freely and fully integrated with the latest computing technologies (Salgé, 1999). Developing a standard for spatial data gives the possibility to move the data directly into any GIS with all stored characteristics, topology, attributes and graphics completely intact. Datasets can migrate between software packages without losing the resolution, accuracy or descriptive poignancy.

A core system consisting of a spatial database management system, (spatial) tools and noise prediction software is built to allow the interaction between noise software and GIS functions and to give the facility to use the same data in both systems. Figure 7 shows a schematic picture of the system. Through this core system, different applications are able to communicate with each other. Different users have the possibility to use the same data, without the need to copy or convert the data. This avoids the risk of working with different versions of data and increases the effectiveness, the reliability and the quality of the studies and decreases the costs.

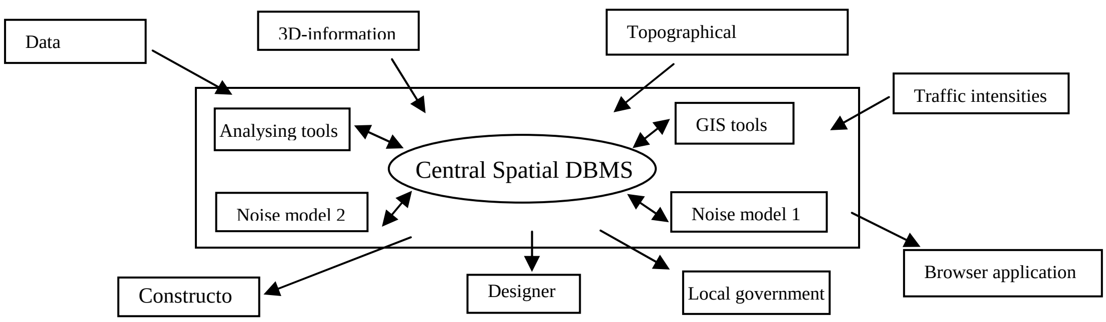

Figure 7: Interoperability between GIS, databases and Noise Prediction Models.

5.1 The central spatial DBMS

The need of a spatial DBMS in the study on noise effects has already been emphasised in the previous sections. In this section it is explained how this DBMS as central system contributes to noise studies as well as to noise prediction models.

The noise prediction models in the Netherlands have several limitations:

- There are two accepted models, which are used for noise prediction. Between those models no data exchange is possible and therefor these models can not be combined in any way.
- The input data for these models are usually digitised because the models need the data in special formats and under special conditions. Information that is already digitally available can not be used in these models directly.
- The input data for these models is very divers. It concerns noise emission data, data about the design and surroundings, all with a different scale, format and accuracy and coming from different sources and suppliers. It takes a lot of effort to collect and prepare the input data for the models.

The central spatial database management system serves as a collector, supervisor and provider for the input data for the noise models. In addition a tool built upon this DBMS is able to generate and supply the input data for the acoustic models automatically.

Additional conditions which are met in the spatial DBMS in the integrated system noise-GIS are the following:

- In the spatial DBMS all relevant data can be collected, stored, controlled, standardised and managed.
- The quality and accuracy of the data is guarded by the system.
- The (spatial) data is stored in a kernel and can be retrieved independent from the software that is used. The system acts like an interpreter between different databases, software and models.
- The use of the central GIS DBMS supplies the tools to make it possible that everyone who works with the data uses the same and most actual data, without the need to copy and convert data.
- The output data of the noise models can also be stored in the central DBMS. In this way other applications and users can get access to these data as well, so the data becomes available for different authorities. This will ensure legal security for all parties (owners of the infrastructure and the people living in the surroundings).

5.2 Integrating GIS utilities and Noise Prediction Models

In section 2.0 it is mentioned that noise has spatial components. The study on noise can be improved and enriched, not only by using a spatial database management system, but also by the possibility of applying spatial tools for performing tasks as described in section 3 (cumulating noise levels, deriving a spatial noise model etc.). Since fundamental studies have been done to build the existing noise models, it is not availing to replace these noise models totally in a GIS. Instead the integration of GIS utilities and noise prediction models mainly takes place by being able to access and process the same data. GIS utilities are in this way expansions and enhancements of noise studies.

In the integrated noise-GIS system the following tools are built:

- A tool that implements the communication between GIS utilities and noise prediction models. The tool is used to access and use the output data from noise prediction models in GIS and vice versa.
- A control tool is incorporated which supervises the use of the correct data (version, accuracy, scale etc.).
- A tool for visualisation the data of the noise prediction models during the modelling process. With this visualisation tool it is possible to perform a visual analysis on the information giving an extra control on the input data and computed values.
- A GIS-application for monitoring and quantifying the noise effects on the environment for different scenarios, giving an unambiguous instrument to support the decision process in infrastructure planning.

6.0 CONCLUSIONS

The use of GIS in noise studies increases the quality of the studies on noise pollution and decreases the costs. Integration of GIS and noise prediction models has a number of advantages:

- GIS can form a link between geographical and geometrical information of the surroundings and the noise prediction models. The integration makes it possible to generate noise models automatically based on the available geographical data, information about the design and information concerning the noise source(s).

- In GIS it is possible to calculate the impact of noise on the environment with data based on the noise levels computed in the noise models combined with information of the sensitivity of the surroundings to noise. A GIS-application for monitoring and quantifying the noise effects for different scenarios provides an unambiguous instrument to support the decision making process in infrastructural planning. Besides that such an instrument can assist to control and preserve the noise emission of the existing infrastructure.
- GIS contains additional tools for storing, managing, analysing and presenting the needed geographical data and noise effects.
- The quality of the data used is a determining factor in the quality of the results of noise studies. GIS can manage the quality of the studies by detecting and dealing with uncertainties in the data and by quantifying and visualising these uncertainties in the results.

In the future, a link will be made to a 3D GIS-VR system, to support the modelling process and to make a better representation (visual and audible) of the planned infrastructure.
Further research has to be done on implementing parts of the noise calculation method in GIS. With simplified noise calculation tools available in GIS, it is possible to indicate possible solutions to noise problems without the need to use the complete noise calculation method for obtaining precise results.

To make the integration successful not only the technical part of the system should be considered. Since different disciplines have to work together to make the integration tool functional, effort should be made to prepare the organisation where the system will be incorporated. Another point that should be considered in the integration process is that users frequently expect digitally obtained, computed and managed data to be of a high quality, especially if fabulously presented. In general advanced digital systems are capable of processing data precise, but their overall accuracy still depends on the accuracy of the source data and in noise studies on the models used. Therefor users working with the integration system of GIS and noise prediction models should be aware of this.

7.0 ACKNOWLEDGEMENTS

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