NOISE MAPPING: UNCERTAINTIES

PACS REFERENCE: 43.55. Ev

Alberola Asensio, Javier [1]; Mendoza López, Jorge [2]; Bullmore, Andrew J. [2]; Flindell, Ian H. [1]
[1] Institute of Sound and Vibration Research and [2] Hoare Lea Acoustics
[1] ISVR (University of Southampton) Highfield Southampton SO17 1BJ (UK)
Tel: +44 (0)23 8059 4955
Fax: +44 (0)23 8059 2728
Email: ja@isvr.soton.ac.uk
[2] Energy House 30 Yarmouth Road Poole BH12 1TP (UK)
Tel: +44 (0)12 0254 5800;
Fax: +44 (0)12 0254 5800;
Email: jorgemendoza@poole.hoarelea.com

ABSTRACT
In recent years, noise mapping has become an increasingly useful tool for environmental noise assessment. It is not always widely appreciated that the relative accuracy of the output data depends on the amount and quality of the input data in addition to the basic accuracy of the acoustic propagation models adopted within the software. Theoretically perfect propagation models require an impossible amount of input data for large-scale mapping. Simpler empirical models are likely to be more practical but are potentially less accurate. There are also a large number of additional factors which can affect both the values and the interpretation and assessment of the output data. This paper reports an investigation of the likely uncertainties resulting from different approaches to these problems.

INTRODUCTION
Advances in computing technology and an increased understanding of sound propagation theory have helped to improve noise mapping packages and make them increasingly popular for addressing environmental noise issues. Noise mapping software packages are becoming widely used by noise professionals, government departments, and local authorities who have rapidly appreciated the potential advantages of such tools in aiding the development of planning controls and action plans to reduce noise in both rural and urban areas – as shown by both European[1] and national[2] proposals for assessing and managing environmental noise. This current trend is inevitably leading to greater social and economic pressures to predict more accurately the sound levels and other output data resulting from noise mapping. This is especially the case when the public, politicians and acousticians are increasingly relying on the calculated sound levels to justify planning, legal and compensatory decisions. Small errors or uncertainties in the precise locations of calculated noise contour lines can potentially result in millions of euros differences in costs.

Despite the many efforts made to achieve improvements in the accuracy of theoretical sound propagation models, studies into the overall validity of the outcome of noise mapping exercises have not always been properly taken into account. It is well understood that noise propagation models still require development, but there are many other sources of uncertainty which have not yet become a general concern amongst the scientific community and which can be equally or more important in determining the overall validity of the noise mapping output data. The aim of this paper is to provide an overview of such uncertainties as the first step towards the final objective of balancing the complexity of the noise mapping exercise against the accuracy requirements of the output results, which will ultimately depend on the intended use of the results.

AREAS OF UNCERTAINTIES

In this section we examine and summarise the diverse range of input data sources involved in the process of producing 'state of the art' noise maps. To maintain consistency with the noise mapping process, three distinct stages are considered: provision of input data, choice of sound propagation algorithms and the subsequent interpretation and assessment of the output data. A definition of the different uncertainties is presented for each one of these areas so as to facilitate the development of appropriate methods for estimating the magnitude of each of these different types of uncertainty. The quantification of potential uncertainty is obtained by different means according to the nature of the source of uncertainty.

We note here that long-term noise measurements might be used as a way of validating results. Even though such measurements are themselves subject to uncertainty, provided that the noise monitors are sited intelligently with regard to the relative positions of the major noise sources in the area and provided that long enough sample periods of data are obtained (measurement samples might need to be collected over total periods of one year or more to average out seasonal trends) this will usually ensure that random and seasonal trends can be properly averaged out.

Input data

The creation of an acoustical model for any environmental noise assessment requires two types of input data:

- First, accurate spatial data that configures the physical scenario is an absolute minimum requirement. This data comprises any sort of vector or raster image that represents the overall area of concern, including the positions of relevant elements within the model such as ground profile contour lines, buildings, roads, railways, airports, industries, etc.
- Second, source attribute data is required. This data includes information such as road, rail or aircraft traffic flow information, noise radiated from industrial plant, etc.

The following simple example shows the effect of different spatial resolutions of ground profile contour data. Both noise maps were calculated using the same source attribute data over the same area, and both outputs were obtained using the same commercial software (CADNA-A in this example). The only difference is that a different number of contour lines per unit area were used between the two examples. Understandably, predicted noise levels are more precise the higher the number of ground contour lines per unit area, since the model is, in this case, closer to reality (Figure 1). However, what is less well understood is the issue of how important these differences might be for practical interpretation and assessment.

Figure 2 left shows the differences between the two noise map grid point levels. The sound pressure level differences shown result solely from beginning with different qualities of ground profile input data. A maximum difference of 2 dB is obtained in areas where actual ground contour lines represent significant undulations in ground profiles.

In order to quantify this error, a value for the reproducibility deviation σ_r must be obtained, since the repeatability of the experiment is thereby described. By repeating the same theoretical experiment at many different sites with different ground profiles, the value of the maximum sound level difference may be recorded and a probability distribution determined, from which the reproducibility deviation can then be derived.

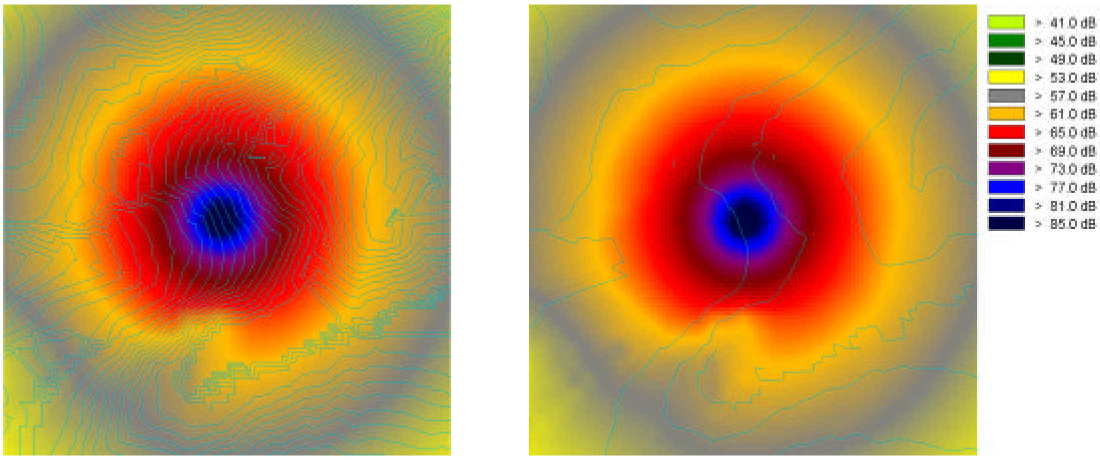

Figure 1. Two noise maps of the same site with a 120 dB point source each and a different number of contour lines per unit area.

There are many other physical elements whose relative accuracies and precisions constitute similar sources of error or uncertainty. Experiments based on fixing each input variable in turn and quantifying the effect of varying just one element at a time will throw further light on this problem, but there may also be interactions, which will need to be dealt with.

In some cases, input data must be estimated. For example, if there are thousands of buildings in a noise map, a common approach is to assign a uniform height for all buildings of the same general type because to measure the height separately for each individual building could be a very time-consuming process. There is obviously an error introduced by this estimation. In order to illustrate this we adopt the example of a fixed 1m-height point source surrounded by five buildings. Figure 2 (right) shows the difference map between the noise levels calculated by assuming building heights of 3m and then 4m, where a 2 dB additional shadow zone is revealed with the taller buildings, which extends beyond the buildings for about 500 m (Figure 2 right).

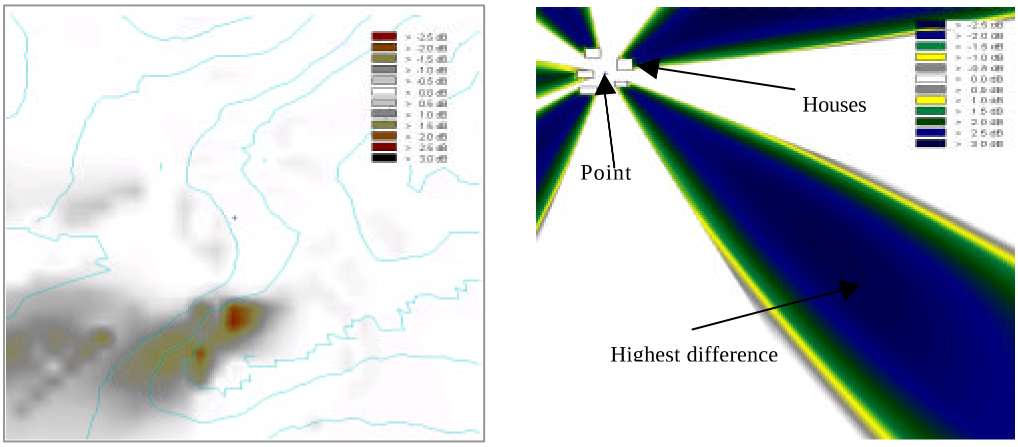

Figure 2. Left: Difference map obtained as the difference between both maps from figure 1. Right: Difference map between 4m and 3m height houses for a fixed 80 dB point source at 1m from the ground. The 2.5 dB difference extends to about 500 m from the source.

Finally, another source of noise-mapping uncertainty, which relies on the accurate definition of input data, arises from the quality of attribute data. Road and railway traffic flow figures depend on the time interval for which they were measured. Depending on the year, season, month, day of the week, and even time of the day, there will be different traffic flows. Therefore, noise maps cannot predict noise levels with such accuracy for shorter periods of time unless the input data really is available to the required degree of accuracy, and this is another reason why noise maps may need to be validated against long-term measured data, with the relationships between assumed and actual attribute data carefully examined.

Sound propagation models

Noise mapping software is inevitably based on noise prediction models that have been carefully designed and validated by different national and international standards organisations. A wide range of these models, classified by types of noise sources, is available for use in noise environmental assessments. Some of the most popular ones are:

- Road traffic noise: CRTN (UK), RLS90 (Germany), OAL (Austria), NMPB (France).
- Railway noise: CRN (UK), Schall 03 (Germany), SRMII (The Netherlands), Semibel (Switzerland).
- Industrial noise: ISO 9613, Norforsk 32 (Nordic Prediction Method).
- Aircraft noise: AzB/AzB-L (Germany), INM (USA).

As models improve, their structures tend to become more homogeneous. At present, the most popular general trend is the one followed by ISO 9613 [3]. However, each separate model will be constrained by the type of source considered, as well as by national regulations. However, the core of the calculation method should probably be similar to that adopted in the ISO standard. Bearing this in mind, the nucleus of ISO 9613 [3] relies on the following equation:

$$L_p = L_w - \sum \Delta_{propagation\ factors} \qquad (1.)$$

where L_p is the predicted noise level, L_w is the sound power level of the source and the last term is the sum of all attenuation and propagation corrections. This general formula clearly specifies that the prediction model can be split into two main parts. The former takes into account the source description, whereas the latter considers all relevant attenuation and amplification factors in noise propagation.

In the determination of uncertainty associated with the predicted noise level L_p, the linearity of equation (1) together with the independence of its terms allows the overall uncertainty to be determined from the separate uncertainties of both source noise level and propagation factors. The uncertainty quantification of the first element, L_w, has different approaches according to its nature. Industrial noise source levels, for instance, are calculated through standardised measurement procedures [4-5], which provide standard deviations of reproducibility and repeatability, that is to say, direct expressions of the uncertainty. Contrarily, road traffic, railway and aircraft noise levels are calculated through empirical formulae adopted by the aforementioned models. This means that the accuracy of results depends upon both these formulae and how realistic their input variables are (i.e. traffic flows, %HGV for road traffic, Noise-Performance-Distance curves for aircraft). In these cases, the determination of uncertainty turns out to be more complex, since the quantification methods for attribute input data described in the first section might be combined with the uncertainties linked to the empirical equations.

The second term in (1) is mainly composed by the following parts:

- $Ä_{div}$ the attenuation due to geometrical divergence
- $Ä_{atm}$ the attenuation due to atmospheric absorption
- $Ä_{gr}$ the attenuation due to the ground effect
- $Ä_{bar}$ the attenuation due to a barrier
- $Ä_{meteo}$ the correction due to meteorological effects (present but, not clearly adopted in reference 3)

A detailed examination of the above attenuation factors reveals a high agreement between models when the first two are considered. This convergence arises from the current well-advanced understanding of the physical mechanisms involved in both processes, as reviewed by Piercy et al[6]. Uncertainties regarding geometric divergence can arise from the spatial distribution and directivity of the noise source, while atmospheric conditions are rarely as homogeneous as assumed by any simplified calculation method. In practice, uncertainties in these factors are often neglected, since their magnitude is often smaller than the rest.

In contrast, different models predict the remaining three attenuation factors in many different ways, and consequently agreement is seldom reachable. The theoretical justification for this disparity can be explained by the individuality with which the three factors are treated within models. Prediction methods assume an initial independence between propagation factors in order to simplify calculations and consequently, relevant interactions when these factors operate together, are often ignored. In the presence of a barrier, for instance, the dominant sound source position is moved up above the ground to the top of the barrier. Therefore ground effects as well as meteorological factors affect propagation in a different way than for the original source. Nevertheless, equation (1) sums up separately the effects of each factor and no considerations of virtual sound sources at the top of the barrier are present.

Significant uncertainties are thus linked to the prediction of these processes and error quantifications are required. Usually, models are expected to attach calibration or validation tests to accompany predictions. Even though some models conform to this expectation [3], many others show only weak correlations between measurement and prediction [7] and quantification of uncertainties should be made through our own calibration samples.

Use of output data

The output of a noise mapping exercise may be used in a variety of ways, ranging from supporting policy decisions towards the development of regional or national noise management action plans, to establishing the noise levels affecting a specific property, perhaps for planning or compensatory purposes. In some instances the important consideration is the identification of properties subjected to noise levels above a certain absolute threshold, such as the UK's 68dB $L_{A10,18hr}$ criterion for statutory entitlement to mitigation against increased road traffic noise. In these instances reducing the uncertainties associated with the noise mapping input data and calculation procedures becomes increasingly important.

However, in many instances noise mapping output data is used to provide a strategic overview of the general noise environment in a given region. Armed with this knowledge, action plans may be developed aimed at improving overall quality of life in the mapped region through the reduction of the numbers of people exposed to unacceptably high levels of noise. In these instances the practical usefulness of numeric quantifications of noise exposure, whether presented as tables of values or noise contour plots, is more limited. This is not least because of the general lack of understanding of acoustical terminology by the public and decision makers alike. The utility of large scale strategic noise mapping for the development of noise action plans can be enhanced by linking calculated noise levels with other socio-economic or demographic data to provide 'real' answers as to whether proposed changes will result in the overall noise situation becoming better or worse.

As a first step towards this goal, it is necessary to calculate the numbers of people or residents affected within specified noise contour levels, and to quantify how these people may be affected. This stage of the process requires the mapped noise levels to be overlaid onto geographic features such as homes, schools or hospitals, or onto other noise sensitive areas such as recreation spaces. However, even this step of linking noise levels to geographical features is still not sufficient to meaningfully assess changes in noise impact, as environmental noise can only have a meaningful impact where it is heard, and to be heard people must be present. Thus the crucial stage involves linking noise data with population and other socio-demographic information. However, this in itself introduces yet more potential sources of uncertainty in the process, be this in the definition of the numbers of occupants in each residential property, or the numbers of in-patients at hospitals or numbers of pupils at a given school and the extent of time these people are exposed to the calculated noise levels (for example, are they at home all day, what proportion of their time do they spend inside/outside, how often are their windows open, what activities are they undertaking etc?). To add to this, most dose effect relationships for noise are themselves based on statistical data and consequently introduce additional levels of uncertainty. The point we make here is that the uncertainties associated with noise mapping exercises do not stop with the calculated noise levels, and extensive efforts made to increase the ‘accuracy’ of calculated levels may be of limited value unless the additional factors such as those just considered are also taken into account. The important factor is to realise the limitations at the outset of any noise mapping exercise and to plan the entire exercise proportionately to balance the accuracy and uncertainty limits at all stages of the process, from input data to the eventual utility of the output data.

PROPOSED RESEARCH LINE

Current research is being undertaken in order to quantify as many as possible of the different uncertainties involved in noise mapping and thereby to assist in minimising any resulting errors in practical applications [8-9]. Resulting from the initial concerns already identified, further work is now in progress to improve the definition of all uncertainty elements associated with each noise mapping stage as well as finding more reliable quantification procedures. Once this task is completed, statistical models can then be constructed which will allow all previously quantified uncertainties to be combined in meaningful ways. The direct results obtained by these models could then be implemented straight into the prediction software, with the estimated uncertainties included as additional output layers in any resulting noise maps. This will provide an improved method for standardisation and quality control comparison between different noise mapping exercises carried out by different operators or over different areas of ground.

CONCLUSIONS

Preliminary work carried out to date has already demonstrated the potential for significant uncertainties to arise in noise mapping outputs where industry standard or conventional assumptions and estimates of source attribute, sound propagation and output interpretation data are applied. Further work will quantify as many of these sources of uncertainty as possible, eventually leading to more reliable statistical methods of predicting actual uncertainty in practical applications.

REFERENCES

[1] ‘Directive of the European Parliament and of the Council relating to the Assessment and Management of Environmental Noise’. 2000/0194(COD).

[2] ‘Towards a National Ambient Noise Strategy’ A Consultation Paper from the Air and Environmental Quality Division. November 2001. DEFRA (Department for Environment, Food and Rural Affairs).

[3] ‘Attenuation of Sound During Propagation Outdoors’ ISO 9613-2.

[4] ‘Determination of Sound Power Levels of Noise Sources Using Sound Pressure’ ISO 3744.

[5] ‘Determination of Emission Sound Pressure Levels of Sound Sources’ ISO 11201- ISO 11205.

[6] ‘Atmospheric Propagation of Sound: Progress in Understanding Basic Mechanisms’ Piercy, J.E., Embelton, T.F.W., Daigle, G.A. 11th ICA Paris (1983).

[7] ‘Implementation of the Dutch railway noise model for use in noise mapping’ Manvell, D. The IOA’s Autumn Conference 2001.

[8] ‘Matching Noise Maps With Reality – Reducing Error Through Validation and Calibration’ Manvell, D. et al. The IOA’s Conference: Noise Mapping – Which way now? (February 2002).

[9] ‘The Uncertainty of Sound Pressure Levels calculated with Noise Prediction Programs’ Probst W., Donner U., ACCON GmbH. Cadna A web page.