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NOISE MAPPING WITH GIS - MANAGING UNCERTAINTY HELPS PROMOTE QUALITY

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Abstract

The European Directive 2002/49/EC has presented a requirement for strategic noise mapping across Europe covering tens or hundreds of square kilometres of urban landscape. Increasing GIS functionality is being utilised to capture, store and manage large geo-spatial datasets to be utilised for noise mapping purposes. Recent work on uncertainty in noise mapping has presented an understanding of how the potential errors within these datasets can propagate through to become uncertainties in the calculated noise level. An associated challenge for the bodies responsible for noise mapping is the need to understand what a software tool means when it states "compliance" with a standard based calculation method. This paper will discuss the need for compliance test cases, the systems currently in place which could use these test cases, some of the issues associated with developing compliance test cases, and lastly propose a methodology whereby the end to end processing of data for loosely coupled noise models with GIS can be tested.

INTRODUCTION

In the recent Defra funded research in support of WG-AEN [1], the uncertainty in model outputs resulting from the uncertainty in model inputs and model parameters has been studied for the CRTN and XPS 31-133 road traffic noise models. The study found that small errors in some input data can result in large decibel errors in the calculated noise results. The WG-AEN's research [1] has not only helped to introduce the concept of uncertainty management into noise mapping, the work has also taken a significant step forward in the understanding of how input dataset variations may affect the calculated noise results.

Uncertainty in noise modelling

To understand the impact of different interpretations of the standards in noise modelling software on the overall results, it is useful to first consider the overall impact of uncertainty within the noise mapping process. Within any modelling system designed to reproduce a real world environment, there are four key areas of uncertainty to be considered:

1. uncertainty in model inputs and parameters (characterisation of input uncertainties);
2. uncertainty in model outputs resulting from the uncertainty in model inputs and model parameters (uncertainty propagation);
3. uncertainty associated with different model structures and model formulations (model uncertainty); and
4. uncertainty in model predictions resulting from uncertainty in the evaluation data.

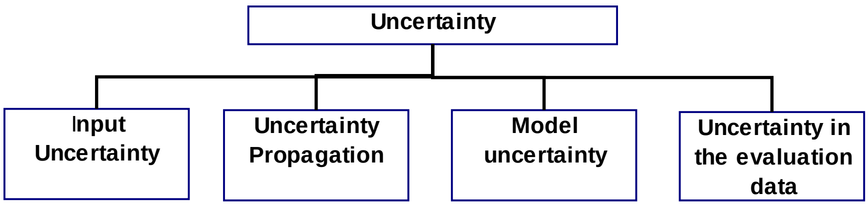

Figure 1 - Four key areas of uncertainty

The WG-AEN's research explored one part of the four main areas of uncertainty in noise mapping, that being the propagation of uncertainty. In order for a more complete level of understanding to be developed, such that professionals and public may have more confidence in the results generated, it is important that the other areas of uncertainty are more fully explored and documented.

Due to the lack of standards for noise calculation software, functionality and accuracy of the results produced can vary between products. This variability can be associated with the ways in which different software tools handle input data, and the various interpretations elements within the calculation "standard" such as ambiguous text, contradictory advice, or unsteady algorithms [2].

Model uncertainty

The characterisation of model uncertainty is a role for the owners and developers of the noise models being used. There are possibly three key areas of Model Uncertainties. The first is the ability of the computational model, or standard, to truly represent the reality being modelled. The second is associated with how a paper standard is transposed into a 3D noise calculation tool, whilst the third is related to the additional simplifications in data and the various ways of converting digital data into calculation data, along with the efficiency techniques and assumptions introduced in order to create usable real world calculation times. Figure 2 above shows how model uncertainty is introduced into the noise mapping.

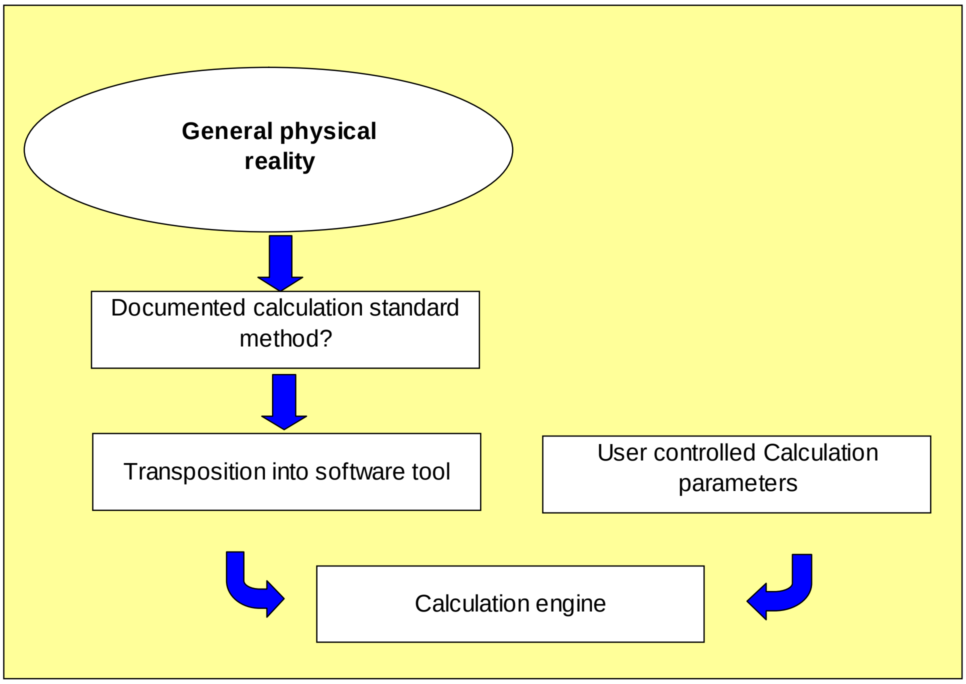

Figure 2 - Model uncertainty flow chart

IMPLEMENING STANDARD IN 3D MAPPING SOFTWARE

The majority of current calculation methods in use across the EU are based on a semi-empirical approach to mathematically describe the sound propagation. The methods were not written to be transformed into a software environment. As a result of this, the different noise mapping software have been produced according to the developer's understanding of the guideline text, the interpretation of imprecision, the experience in using a specific guideline, the general understanding of outdoor noise propagation, and the mathematical possibilities and limitations of current calculation methods and guidelines [2,3,4]. Even before the advent of commercial noise prediction and noise mapping software, acoustic engineers produced calculations that varied in their precision because of the issues stated above. The use of software added another layer of complexity. The developers produce a code based on their understanding of the calculation method, and the end-user tends to rely blindly on the calculations produced by the software [4].

In several reference [2,3,5,6,7,8,9,10] some of the issues related to the implementing calculation methods have been discussed. Some test cases have been created to investigate the issues. Hill and Tompsett [7] have discussed their experiences and problems encountered in implementing CRTN into a software environment. They have discussed issues related to ground, gradient, opposite façade, surface correction, retained cut and multiple screening. Probst and Huber [8,9] and Brittain and Marlund [6] have discussed some issues of transposing ISO 9613-2 to a software environment. For rail noise, the current literature search shows no study on this subject has been carried out for CRN. However there have been a number of studies carried out on comparing railway noise prediction methods used in Europe [11].

Fausti and Pompoli have carried out an inter-comparison of computer traffic noise simulations [12]. The study aims to compare the results given by different programs and by different users of the program. The study showed that a difference of 8dB with a standard deviation of 2.7dB is shown in the results. Although there is no mention of the prediction method tested, the large difference in the results suggests that different prediction methods have been used by different users or programs.

Overall there is both documented and hearsay evidence to suggest that the transposition of documented standards into noise mapping software introduces variance between solutions, and therefore uncertainty in the results obtained.

USER CONTROLLED CALCULATION PARAMETERS

Calculation time is an important consideration when performing 3D noise mapping calculations of large areas. Efficiency techniques are one of the factors that affect calculation time. Intelligent software can apply numerous options to accelerate calculation time. However, some of the efficiency techniques do affect the accuracy of the noise map and without a detailed understanding of the impact of these techniques; there is an increased risk of producing erroneous results.

It is therefore important to understand the impact on the results which the different user settings, and efficiency techniques, have when used within the calculations carried out by noise mapping software systems. Kang and Huang carried out work [13] which examined the efficiency and accuracy of results obtained from some 3D model simplification and some calculation configurations. In their study, the software calculated results have been validated against benchmark results which were obtained using the image source method. Carruthers et al. [14] investigated what input data and output grid resolution is consistent with an achievable calculation in terms of computer time, and results within a known accuracy. A 500m x 500m area surrounding a busy London roundabout was taken as a test area for a detailed noise mapping study in order to consider these issues.

Hepworth *et al.* [15] have recently studied the impact on time and accuracy of a number of user calculation settings across five leading noise mapping systems. The results obtained are compared to the time taken, and results obtained for “benchmark” settings designed to produce the most accurate result from each software system, regardless of time taken. From the results presented it is clear to see that the inappropriate use of some of the available settings within the software could introduce uncertainty in excess of 5dB(A) 95% CI. This is of concern in the context of noise mapping applications, and the potential compound level of total uncertainty from data quality, methodology transposition and user settings.

APPROACHES TO COMPLIANCE

The most complete compliance cycle currently published is arguably the Nordtest Method [16]. Some practical experiences of using this approach have been reported recently for a number of different calculation methods by Manvell *et. al*. [17], which has highlighted the lack of test cases for many commonly used calculation methods, SRM2, ISO 9613-2 and ECAC Doc 29 being the most prominent for the END mapping.

For the calculation methods where published test cases are available, they have come about via a verity of routes. As examples, the UK CRTN and CRN methods contain examples within the Annexes, although recent work [18] suggests many of these contain unclear or ambiguous issues, or are possibly incorrect. Other sets of test cases, such as those in Austria have been developed in coordination with the software developers to avoid ambiguous descriptions. In Germany there are standardised test cases available, and the recently published Harmonoise [19] method has been developed with test cases.

To compound the uncertainty of the situation, some test cases state acceptable tolerances from the stated result which still constitute compliance, whereas other do not, or possibly imply it by the use of precision within the stated results. The use of tolerances within the results possibly comes about due to a desire to accept different routes to a software solution, e.g. ray tracing or method of projection, or possibly because there is almost no documented guidance on how to set up models or software appropriately in order to be compliant with the standards. Only a report from Australia [20] could be found which has followed this route.

In general the availability of test cases, or documented modelling requirements to ensure compliance, could be described as patchy at best and probably better described as inadequate. A review of software "support" for a number of calculation standards [18] also indicates that the software tools currently available do not entirely enact all aspects of the standards, with the documentation of these deviations form the standard being somewhat obscure.

PRACTICAL MANAGEMENT OF UNCERTAINTY

The discussion on compliance procedures, test case models and documented guidance on constructing compliant models has an important place within the overall scheme of managing uncertainty. The one potential restriction is that these steps all appear to focus on small issue specific cases, rather than management of uncertainty within a wider urban noise mapping project.

Recent work carried out for Defra as part of the "Noise Mapping England" project involved generating acoustic results sets for the Manchester, 1400km^2, Merseyside, 750km^2 and Stoke-on-Trent, 400km^2, project areas. The supplied 3D datasets came from the Central Data Service (CDS), a large national coverage GIS dataset prepared for noise mapping by InfoTerra. The supplied datasets were very large, many tens of GBs in total, and contained a large amount of redundant data, when viewed in the context of noise mapping calculations. The large model areas and requirement for quickly obtaining the results also focused attention onto the user selectable calculation settings within the LimA calculation kernel. These two aspects combined meant that there was a desire to economise the datasets to help reduce calculation time, and also to configure the calculation settings to best reduce the calculation time.

These dual requirements can be seen to introduce two potential sources of uncertainty; model uncertainty would be affected by the user calculation settings, whilst propagation of uncertainty would be introduced by reducing the quality of the input datasets by economisation. It was determined that the uncertainty would be managed by an end to end process which would balance reduction in calculation time with uncertainty in order to produce a processing time acceptable to the project team, and a management of uncertainty in the calculated results acceptable to the client.

By starting with a calculation over a $25km^2$ sample area, using original CDS datasets and the most accurate calculation settings a set of benchmark results was generated. Various options for dataset economisation were investigated by processing elements of the sample dataset, and a series of meta-models created and each calculated to produce a complete set of results. Likewise, a number of the calculation settings were identified as being most appropriate to help reduce calculation time, and settings for each were tested by calculating the complete sample model.

The result sets for each of the these test runs could then be compared against the benchmark results, and statistically analysed to identify maximum change, standard deviation and 95% confidence interval. This process enabled a cost/benefit relationship to be established, benefit being reduction in calculation time, cost being level of uncertainty introduced into the results. This lead to an overall solution which was partially created by economisation of some datasets to a specific extent, and partially by the careful use of the calculation settings.

The combined results was an 87% reduction in total calculation time, whilst maintaining an overall uncertainty of 1.4dB(A) 95% CI when compared to the benchmark results. Importantly, the final datasets utilised were not heavily simplified, and were of a level of resolution suitable for use in action planning and detailed analysis.

The key feature of the approach is the traceability and transparency of the decision process, and the technical evidence to support the data economisation carried out, and the calculation setting utilised. This leads to an enhanced level of confidence in the results generated, and provides decision makers with a robust and defensible process for generating the noise results.

CONCLUSIONS

The lack of standardization within noise mapping applications has lead to a situation where accuracy of results, compliance with standards, and documentation of uncertainty have largely taken second place within a feature driven competitive market place. The outcome of the recent research for WG-AEN has provided a common discussion framework to address the various aspects of the noise modeling process which need to be managed in order to ensure quality and reliability are outcomes of the END noise mapping process.

Two specific aspects associated with model uncertainty have been reviewed, each having the potential to introduce significant levels of uncertainty if not properly documented and managed.

With regard to the current situation regarding compliance mechanisms and test cases, it is considered that the Nordtest approach could be utilized successfully for other calculation methods, with test cases required to cover both specific issues, and the use of software for large model area, as in noise mapping of cities. Secondly, it is considered that users should be provided with publicly available guidance and documentation regarding known issues or aspects of the methods which must be modeled in a particular way to ensure compliance. As well as a greater degree of transparency from software developers regarding any non-complaint aspects of the software to the standards “supported”.

With a view to the practical application of noise mapping, an end to end process suitable for the management and documentation of the various aspects impacting upon results uncertainty during the modeling and calculation stages has been proposed. This methodology has been successfully used and proven during three recent agglomeration mapping projects in England where it was found to provide the client with results of a documented uncertainty, without impacting upon timescales or budgets for the project.

The proposed project process is aimed to complement and enhance the certification and validation process set out within the Nordtest Method, and other similar approaches, to help extend the management of uncertainty into real world mapping projects.

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