The Department for Environment, Food and Rural Affairs (DEFRA)

Research Project NANR 93: WG-AEN’s Good Practice Guide And The Implications For Acoustic Accuracy

Final Report:

Sensitivity Analysis for Noise Mapping

Document Code:
HAL 3188.3/3/2
DGMR V.2004.1300.00.R007.1

May 2005
The Department for Environment, Food and Rural Affairs (DEFRA)

Research Project NANR 93: WG-AEN's Good Practice Guide And The Implications For Acoustic Accuracy

Final Report:

Sensitivity Analysis for Noise Mapping

Document Code:
HAL 3188.3/3/2
DGMR V.2004.1300.00.R007.1

May 2005

Hepworth Acoustics Ltd
DGMR Industrie, Verkeer & Milieu B.V.
Acustinet SL
The Department for Environment, Food and Rural Affairs (DEFRA)

Research Project NANR 93:
WG-AEN’s Good Practice Guide
And The Implications For Acoustic Accuracy

Final Report:

Sensitivity Analysis for Noise Mapping

Document Code:
HAL 3188.3/3/2
DGMR V.2004.1300.00.R007.1

May 2005

Hepworth Acoustics Ltd
DGMR Industrie, Verkeer & Milieu B.V.
Acustinet SL

Main Contributors
Simon Shilton CEng, BEng, MIOA, MAES
Head of Software & Mapping
Hepworth Acoustics Ltd

Hans van Leeuwen
Division Manager
DGMR Industrie, Verkeer & Milieu B.V.
DGMR Consultants for traffic, environment and software

Issued by
Simon Shilton

Checked by
Peter Hepworth

Hepworth Acoustics Ltd
5 Bankside
Crosfield Street
Warrington
WA1 1UP
Tel: 01925 579100
Fax: 01925 579150
Email: simon.shilton@hepworth-acoustics.co.uk
Ref: 3188.3/3/2

Copyright Hepworth Acoustics 2005

The ideas and proposed method of working contained in this proposal remain the intellectual Copyright of Hepworth Acoustics (The Company) and may not be used, without prior agreement of the Company, for any purpose other than assessing this proposal from the Company.
1. Executive Summary

1.1 Project
Defra has let a research project in support of the European Working Group – Assessment of Exposure to Noise (WG-AEN) to determine the likely effects on the acoustic accuracy of the advice contained within the Working Groups’ Position Paper “Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise exposure” Version 1 December 2003 (GPG).

The key objectives of the project are summarised as follows:

- Provide potential additional GPG Toolkits for issues not currently covered within existing guidance for EU Member States (MS) dealing with the Environmental Noise Directive (END);
  - Devise six new Toolkits for: road surface type, road junctions, road gradient, ground surface elevation, ground surface type and barrier height; in a format compatible with the existing GPG Toolkits;
- Quantify the accuracy symbols within Version 1 of the GPG when Toolkits 1, 2, 3, 6, 7 and 8 plus the new road surface Toolkit, are used in conjunction with CRTN and the recommended Interim Method for roads XPS 31-133;
- Provide practical guidance on the acoustic accuracy implications of following the recommended toolkits within the WG-AEN GPG;
- Provide practical assistance to MS and professionals dealing with data management and procurement across the EU in relation to the END;
- Liaise closely with WG-AEN to ensure that the views and requirements of the EC and member states are taken into consideration during the project.

1.2 Sensitivity Analysis for Noise Mapping
In order to quantify the accuracy symbols within Version 1 of the GPG, and also to help develop practical guidance on the acoustic accuracy implications of using the WG-AEN Toolkits, it is important to develop an understanding of how changes in input data to the noise mapping calculations can affect the results generated.
This report sets out to present the following aspects of the research project:

- an introduction to uncertainty analysis as utilised within other areas of predictive modelling,
- a review of uncertainty analysis and error propagation related to noise mapping, and
- design and development of the testing methods and tools for assessing the acoustic accuracy implications of using the GPG Toolkits.

The results and conclusions drawn from using the testing methods developed are covered in other reports associated with this research.

1.3 Conclusions

To enable acoustic accuracy impact guidance to be presented alongside the GPG Toolkits, the requirements for sensitivity analysis have been reviewed, and methodologies for testing in line with the steps in the existing and newly proposed GPG Toolkits have been developed.

To enable practical guidance on input dataset quality requirements to be provided, a review of the input data requirements of CRTN and XPS 31-133 Interim has been carried out to establish guidance for applicability, accuracy of results and sensitivity to error in the input data. This review has lead to a list of required input data objects, and attributes for those objects. Both single and multi-input attribute testing schemes have been developed to investigate the error propagation through the noise calculation methods in order to estimate the effect of uncertainty in the input data sets resulting in uncertainty in the calculated result.

The results from the tests and the interpretation of those results are presented in other reports associated with this research.
## Contents

1. Executive Summary
   1.1 Project
   1.2 Sensitivity Analysis for Noise Mapping
   1.3 Conclusions

2. Background
   2.1 Background
   2.2 Scope of Research Project

3. Introduction to Sensitivity Analysis
   3.1 Sources of Uncertainty
      3.1.1 Input Uncertainties
      3.1.2 Uncertainty Propagation or Sensitivity
      3.1.3 Model Uncertainties
      3.1.4 Uncertainty of Evaluation Data
   3.2 Glossary of Terms

4. Uncertainty Analysis for Noise Mapping
   4.1 Testing methodologies
   4.2 Analysis of the results from the testing

5. Testing methodology for non-geometric aspects
   5.1 Analytical testing methodology
   5.2 1st Order Taylor Series
   5.3 Monte Carlo Simulation
   5.4 Developing Monte Carlo Tools
   5.5 Approach to the analytical testing
6. Testing methodology for geometric aspects
   6.1 Mapping model testing methodology
   6.2 Developing the test models

7. Designing other testing & analysis methodologies
   7.1 Traffic flow
   7.2 Assignment of people to properties
   7.3 Methodology for testing the interaction between noise & people Toolkits

8. Testing methodology for GPG Toolkits
   8.1 Testing Toolkit 1: Traffic flow
   8.2 Testing Toolkit 2: Traffic speed
   8.3 Testing Toolkit 3: Composition of road traffic
   8.4 Testing Toolkit 6: Building heights
   8.5 Testing Toolkit 7: Obstacles
   8.6 Testing Toolkit 8: Cuttings & embankments in the site model
   8.7 Testing Toolkit 9: Building and barrier absorption coefficient
   8.8 Testing Toolkit 12: Assignment of population data to residential buildings
   8.9 Testing new Toolkit 17: Road surface
   8.10 Testing new Toolkit 18: Road junctions
   8.11 Testing new Toolkit 19: Road gradient
   8.12 Testing new Toolkit 20: Ground elevation
   8.13 Testing new Toolkit 21: Ground surface type
   8.14 Testing new Toolkit 22: Barrier height
   8.15 Method for testing multiple GPG Toolkits simultaneously
   8.16 Method for testing the interaction between noise & people Toolkits

9. Conclusions

   iv

2. Background

2.1 Background

In its capacity of support for the chair of the European Working Group – Assessment of Exposure to Noise (WG-AEN), Defra has let a research project to determine the likely effects on the acoustic accuracy of calculated noise levels, of following the advice contained within the Working Groups’ Position Paper “Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure” Version 1 December 2003 (GPG).

The GPG sets out a series of Toolkits which can be used by EU Member States (MS), and their designated competent authorities, whilst fulfilling the requirements of Directive 2002/49/EC, the Environmental Noise Directive (END). The Toolkits within the GPG are designed to provide guidance on potential steps to be taken, or assumptions to be made, when the dataset available to the MS falls short of the coverage or detail required for the large scale wide area noise mapping required by the END.

Whilst the GPG provides practical advice on decision making in the absence of detailed data, there is currently no corresponding indication of the acoustic accuracy implications of making the decisions. This will result in the MS making choices where the level of resulting uncertainty introduced into the process is unknown, and therefore both the MS and the EU Commission are uncertain about the potential accuracy and robustness of the results, even when the methodology is documented and the process followed the advice within the GPG.

A second consequence, and possibly of equal importance, is that this lack of acoustic guidance within the GPG does not help MS with a data shortage make informed decisions on the relative importance of the various datasets which would help focus (finite) resources in the procurement of missing data.

Defra wish to study the consequential acoustic accuracy in strategic noise map results of adopting the advice in the present version of the GPG, focused at this point on road traffic noise. This project aims to result in practical guidance on the potential acoustic accuracy implications of following the advice within the GPG Toolkits, and thus help to inform MS, competent authorities and the EU Commission as to the robustness of the results submitted in 2007 under the END framework.

The guidance should also help assist MS to produce their own guidance regarding the relative importance of the various datasets required to carry out END compliant noise mapping, and thus help to manage any budget available for data procurement towards the datasets which will provide the most benefit to the acoustic accuracy of the results.
2.2 Scope of Research Project

This element of the research project sets out to develop an understanding of uncertainty analysis, the methods used and the applicability to noise mapping. The use of uncertainty analysis to establish the error propagation of the noise mapping system will help to develop an understanding of the relationship between input data variations and the receptor noise result calculated.

Having identified techniques and methodologies for investigating the error propagation of the noise mapping system, this report then goes on to describe the design of each of the testing methods employed within the research, as well as outline the means by which the results were analysed to identify the effects reported.

The results and conclusions drawn from the use of the testing methods developed are covered in other reports associated with this research.
3. Introduction to Sensitivity Analysis

3.1 Sources of Uncertainty

For any mathematical engineering model of a real world event the calculated result may only be described as a best estimate of the real situation. This is particularly true in the field of outdoor noise predictions based upon empirical models dating back several decades.

Whenever a quantity of interest is calculated from a series of other quantities there will be uncertainty in the calculated value. Kirchner\(^1\) suggests the following possible sources of uncertainty within a calculation procedure:

i. statistical error / random variation of replicate measurements
ii. spatial and temporal variability
iii. systematic error (bias)
iv. imprecise definitions or unrepresentativeness of samples
v. uncertainty in the form of the function relating the result to the inputs

In noise mapping the propagation model can be biased because some important influences could be omitted, such as meteorological effects, which will introduce a source of uncertainty. For other inputs there may only be partial knowledge of the source data, such as traffic speed where “travel time between junctions” is often known, but genuine vehicle speeds are not. Similarly with the ground or façade reflection effects, uncertainty is introduced due to imprecise information.

In this study we are interested in how the uncertainty in the calculated result in dBs, may be related to uncertainty, errors, or assumptions in the input parameters. A study of this nature is generally referred to as an “error propagation” analysis.

To understand how this form of study is useful in noise mapping, and also how it may help to build up an understanding of the complete picture, we shall consider the work by Isukapalli and Georgopoulos\(^2\) who stated that there are normally 4 stages involved in the uncertainty analysis of a model:

---


1. estimation of uncertainties in model inputs and parameters (characterisation of input uncertainties);

2. estimation of the uncertainty in model outputs resulting from the uncertainty in model inputs and model parameters (uncertainty propagation or sensitivity);

3. characterisation of uncertainties associated with different model structures and model formulations (characterisation of model uncertainty), and

4. characterisation of the uncertainties in model predictions resulting from uncertainties in the evaluation data (uncertainty of evaluation data).

It is important to understand that the current project is only investigating uncertainty propagation through the CRTN and XPS 31-133 calculation methods via two different sets of step changes, (1) in line with the GPG Toolkit steps, both individually and in combination and (2) as individual input parameter variations across the range of probable input values, both individually and in combination.

Below is a brief discussion of each of the four factors listed above.

3.1.1 Input Uncertainties

Characterising input uncertainties would involve a study of each of the various types of data required to construct a finished noise map. These uncertainties arise from various sources including: measurement; management, factoring and assimilating of the actual captured information prior to reporting. To form an understanding for each type of input dataset there would probably need to be liaison with domain specialists such as data providers, owners and managers, in order to seek an understanding of how the uncertainties of the input values are distributed. There would also need to be detailed analysis carried out to quantify the scale and distribution of these uncertainties in the delivered dataset.

MS and noise mapping agents should be aware of the need for characterisation of input uncertainties but it will vary from country to country, dataset to dataset, and each data owner or manager will need to be interviewed regarding this aspect. When known, this information can be used in combination with the results from this current project to help understand how these input uncertainties will affect the final result from the model. Figure 3.1 below presents a flow chart showing how input uncertainty is introduced into the noise mapping. There are two types of input uncertainties, one is related to raw data and the other is related to data handling.

In this current project, it has been assumed that each input dataset has a normal distribution of uncertainties.
3.1.2 Uncertainty Propagation or Sensitivity

Uncertainty Analysis (UA) allows the assessment of model response uncertainties associated with uncertainties in the model inputs. Sensitivity Analysis (SA) studies how the variation in model output can be apportioned to different sources of variations, and how the given model depends upon the information fed into it. Figure 3.2 below presents a flow chart showing how error propagation uncertainty is introduced into the noise mapping.
The work within this current project is centred on assessing the means by which uncertainties, error or assumptions within the input datasets of noise maps propagate through the calculation tools to produce uncertainties or errors in the decibel results obtained. The aims set out above propose that the analysis will be undertaken in two forms to provide results to inform two types of guidance.

1. There will be step changes to the input data type and quality in accordance with the guidance set out in the GPG Toolkits

2. There will be an investigation into the sensitivity of the method to variation in the input attributes in order to assess a ranking order for input data quality, and develop a practical specification for noise mapping datasets.
Combining data, digital datasets, raw data

Optimisation, data reduction, simplification in order to create usable real world calculation times

Geometric model and attributes (Input for the software)

Calculation engine

Calculations

Calculated noise levels ($L_{\text{den}}$)

Noise contours

Number of people

Figure 3-2: Error propagation uncertainty flow chart.

3.1.3 Model Uncertainties

The characterisation of model uncertainty is the responsibility of the owners and developers of the noise models being used, as they are in a position to effect change to the model if uncertainty is identified and quantified.
As Kragh\textsuperscript{3} stated:

\begin{quote}
Many empirical methods have been applied to outdoor noise prediction, from inter- and extrapolation of a few measurements results to \textquote{\textsuperscript{semi-empirical models}} based on an understanding of the mechanisms involved, but choosing simple algorithms to cope with the lack of computational power.\
\end{quote}

Within the current noise mapping situation there are probably two main sub-elements to noise mapping uncertainty:

1. The issue of how accurate is the prescribed calculation standard at representing the real world situation and what uncertainties it introduces due to the (necessary) simplifications made in order to present a solution which is relatively simple to implement, and;

2. The secondary issue of how the documented standard is transposed from a paper document into a 3D noise calculation tool, and how the tool's additional simplifications, efficiency techniques and assumptions introduce further uncertainties into an uncertain methodology in order to create usable real world calculation times.

Figure 3.3 below shows how model uncertainty is introduced into the noise mapping.

There is previous work published in this area, as well as ongoing work such as the proposed DIN standard, to assess the use of efficiency techniques on accuracy. It is considered that having agreed test cases for each of the standardised methods to be enacted within the noise modelling tools would help to promote consistency and reduce uncertainty.

\footnotesize{\textsuperscript{3} "News and needs in outdoor noise prediction" J.Kragh, InterNoise 2001, The Hague.}
3.1.4 Uncertainty of Evaluation Data

The evaluation data is that used to confirm the accuracy of the calculated noise level, is in itself open to uncertainty due to its means of capture. In relation to the calculation of noise levels Kragh’s statement presents the fundamental nature of this issue:

“The uncertainty of a predicted noise level is an interval in which the true value lies. It is difficult to quantify the uncertainty of a calculated noise level because the true value is unknowable……. A measured noise level may deviate from the calculation result due to the influence of weather, variation in source operating conditions, background noise etc. during the measurement.”

This issue has also been researched in detail by Craven & Kerry whose work suggested that you were doing well if repeat measurements were within 5dB(A) at the same site, for the same source, on different days.

---

Having said that, it is also possible, as an alternative approach, to assess the uncertainty of the calculated noise level against the true value of the calculation. If one considers the situation where all the relevant input data is known with certainty and precision, this can be said to provide a true calculated result, even if it differs from a measured result. Muer & Botteldooren\textsuperscript{5} suggested that:

“A lack of quality and imperfection of models and input data can either be caused by uncertainty or imprecision. Uncertain information can be characterised by the partial knowledge of the true value of a statement. Imprecise information is linked to approximate information or not exact information.”

Evaluation data uncertainty flow chart presented in Figure 3.4 below shows how the uncertainty is introduced into the measurement.

The above four uncertainties are inter-related to each other as shown in Figure 3.5 below. It is therefore important that the different types of uncertainties should be taken into account when evaluating the decibel error in the noise mapping result.

DEFRA
WG-AEN’s Good Practice Guide And The
Implications for Acoustic Accuracy
Final Report – Sensitivity Analysis for Noise Mapping
3188.3/3/2 – May 2005

Reality actual noise level

Measurement of source factors (Flow, Speed, etc)
Measurement of noise level
  Noise source
  Transmission path
  Receiver
Measurement of propagation factors
  (meteorology e.g. temperature, Humidity, wind)

Corrections

Noise levels (L_{Aeq})

Figure 3-4: Uncertainty of evaluation data flow chart.
Figure 3-5: How different types of uncertainties are inter-related to each others.
### 3.2 Glossary of Terms

Below is a brief summary of some of the terms used in these reports in connection with uncertainty analysis.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>95 % CI</td>
<td>A statistical calculation indicating the degree of certainty that any given result calculated is within the range identified. For the 95% CI it can be stated that from the 100 noise values 95 are within the confidence interval limit.</td>
</tr>
<tr>
<td>Accuracy</td>
<td>The ability of a measurement, or calculation, to match the actual value of the quantity being measured, or calculated.</td>
</tr>
<tr>
<td>Actual noise level</td>
<td>Theoretical value of the noise level. A measurement can give a good estimate of this noise level. The quality of this estimate is very much dependent on the sound power fluctuations of the source, and the variations of the noise propagations due to meteorological effects, and variation in vegetation. In special cases for the $L_{den}$ or $L_{night}$ it could be confirmed by measurement over a period of at least a year, provided that meteorological, vegetation and ground cover effects are representative of a several year period.</td>
</tr>
<tr>
<td>Attribute</td>
<td>Property of a geographic object or location e.g. the traffic flow is an attribute associated with a road centreline.</td>
</tr>
<tr>
<td>Computational method</td>
<td>Method describing the mathematical calculations within a computational model. These methods are (typically) standardised in guidelines or (national or international) standards. Often used as a simulation model for the actual situation and future situations.</td>
</tr>
<tr>
<td>Computational model</td>
<td>Mathematical representation of reality; computational models can be classified into logical, empirical and conceptual (physically-based) models.</td>
</tr>
<tr>
<td>Dwelling</td>
<td>A single self-contained housing unit.</td>
</tr>
<tr>
<td>Error</td>
<td>Difference between reality and our representation of reality; it includes not only “mistakes” or “faults” but also the statistical concept of “variation”.</td>
</tr>
<tr>
<td>Error propagation</td>
<td>Occurs when the errors of the input attributes to a calculation cause errors on the output of the operation.</td>
</tr>
<tr>
<td>Input error</td>
<td>Error in the inputs to a calculation.</td>
</tr>
<tr>
<td>Method error</td>
<td>Error of a computational method.</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>Noise mapping</td>
<td>The use of calculation software to produce noise results using computational methods and sampled representations of the physical reality.</td>
</tr>
<tr>
<td>Noise modelling</td>
<td>The use of noise calculation software to evaluate the computational model, or method.</td>
</tr>
<tr>
<td>Operation</td>
<td>To derive new attributes from existing attributes e.g. calculation of noise emission from the source term attributes such as flow, speed, gradient, surface etc</td>
</tr>
<tr>
<td>Output error</td>
<td>Error in the output of a calculation.</td>
</tr>
<tr>
<td>Physical reality</td>
<td>Real 3D physical world.</td>
</tr>
<tr>
<td>Precision</td>
<td>The extent to which a measurement may be specified exactly e.g. number of valid decimal places.</td>
</tr>
<tr>
<td>Slope</td>
<td>Rate of change of an incline in the ground model.</td>
</tr>
<tr>
<td>Software error</td>
<td>Error introduced by the software implementation of a computational method.</td>
</tr>
<tr>
<td>Software model</td>
<td>The realisation of a computational method within a software tool, to assess the results based upon the spatial model of the physical reality.</td>
</tr>
<tr>
<td>Standard error</td>
<td>The standard deviation of the sampling distribution of that statistic. Standard errors are important because they reflect how much sampling fluctuation a statistic will show.</td>
</tr>
<tr>
<td>Spatial modelling</td>
<td>Computational modelling which includes geographic location information within the model</td>
</tr>
<tr>
<td>Speed</td>
<td>Mean driving speed for a vehicle class. It is NOT the distance divided by time to travel from one point to another. The speed may be different for cars, light vehicles, light trucks and heavy trucks. Some calculation methods enable vehicles classes to have individual speed, others do not.</td>
</tr>
<tr>
<td>Transmission path uncertainty</td>
<td>A result of the propagation from source to receiver. Uncertainty in factors such as distance, wind speed &amp; direction, temperature, ground cover, propagation height all contribute.</td>
</tr>
<tr>
<td>Variability</td>
<td>Refers to variations that are present in the attributes; exists</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Uncertainty</strong></td>
<td>Synonymous with error; the uncertainty of an attribute is affected by the variability and the procedure used</td>
</tr>
</tbody>
</table>

regardless of how the attribute is mapped
4. Uncertainty Analysis for Noise Mapping

4.1 Testing methodologies

It is possible to carry out uncertainty analysis by running the model with varied input factors (one factor at a time) and comparing the resulting outputs with the nominal estimate (obtained with the nominal input value). Whilst this approach has an advantage of being simplistic in design and execution, these one at-a-time techniques (OAT) do not allow a simultaneous exploration of the domain of the input factors, so they cannot capture interaction effects. They also rely upon the model behaving in a linear manner, as the approach is based upon differential analysis.

Testing multiple inputs simultaneously requires the construction of an error propagation model. Error modelling requires the consideration of input parameters 'measured values' and their respective uncertainties. An error model has the ability to create an output uncertainty based upon the uncertainties of its respective inputs.

In Environmental Modelling there are two methods most commonly used for assessing multiple inputs. Taylor Series Expansion, or finite order analysis, provides an approximate yet direct assessment of potential error due to uncertainties contained within input parameters. The most commonly used method of multiple parameter testing is Monte Carlo Simulation (MCS). MCS relies upon using random inputs distributed according to the nature of the input uncertainty. A model is continuously calculated over a number of samples to obtain a probability distribution of the model output. The output can then be analysed statistically and probabilistically.

To use these techniques to analyse the error across the whole modelling scenario, including the propagation path, would require a very highly detailed base model environment, and a highly complex analysis system to be developed which is beyond the scope of this current research.

For these reasons two separate approaches are being utilised to assess two separate parts of the noise mapping system:

i. Analytical analysis techniques are being used to assess the uncertainty propagation in the non-spatial aspects of the calculation methods i.e. the source terms;

ii. The spatial aspects of the calculation methods are being investigated using a modelling based approach with a series of test scenarios to investigate the effect under inspecting.

These two approaches are discussed in detail in the subsequent sections of this report.

The work by Muer and Botteldooren has indicated that it is possible to use Monte Carlo or a Fuzzy Approach for probabilistic modelling, with the inclusion of the propagation path for the assessment of uncertainty in noise modelling. Experience in other disciplines also indicates that techniques such as Fourier Amplitude Sensitivity Testing (FAST), or Response Surface Methods
may be applied to noise mapping models. Following the publication of this current research work, it may be considered appropriate to carry out further investigation of uncertainty propagation in the spatial aspects of noise modelling via these advanced methods.

4.2 Analysis of the results from the testing

As there have been two distinctly different forms of testing undertaken, analytical and model mapping, there has been some variation in how results analysis was performed, dependent upon the testing method used.

Results analysis has been carried out using universally recognised descriptors such as maximum and minimum values within a results set, mean and standard deviation. For analytical results it will also be possible to use traditional statistical approaches to assess the standard deviation, variance and probabilistic distribution in order to access whether the error forms a classic distribution shape. An example can be seen in Figure 4.1 below.

![Figure 4-1: Example of probability distribution from a Monte Carlo analysis for CRTN.](image-url)
Results from the model mapping tests generated sets of grid results for the crisp model and each of the metamodel runs. The analysis of these was carried out in order to generate a series of difference maps, and the spread of results across the sets of difference maps assessed for each of the tests under consideration. An example of an assessment of hard/soft ground “default” options for CRTN is shown in Figure 4.2 above.

The results grids were also analysed to assess the hard boundaries such as maximum and minimum difference, alongside mean and RMS difference.

The results of the testing, and the analysis and interpretation are presented in other reports associated with this research.
5. Testing methodology for non-geometric aspects

5.1 Analytical testing methodology

The two most popular means of carrying out uncertainty analysis are via the Taylor Series Expansion (or finite order analysis) and the Monte Carlo analysis techniques.

The Taylor Series expansion provides an approximate yet direct assessment of potential error due to uncertainties contained within input parameters. The method relies upon taking the 1st order partial derivative of a function. A first order derivative is the rate of change of the function due to the input parameter at any value which is essentially its sensitivity.

Unlike the Taylor Series methods Monte Carlo does not provide a direct analytical link between input and output uncertainties but allows more statistical and probabilistic analysis of uncertainties. The idea behind Monte Carlo Simulation in the context of uncertainty analysis is to compute the outcome of a model repeatedly using input values which have been randomly sampled from a series of possible input values according to its associated distribution.

The main assumption which has been made as part of this project work is that the distribution of uncertainties in the input attributes all follow a normal distribution. As mentioned above, it is envisaged that further work in this area would need to be carried out in order to assess whether this assumption is acceptable. Further details regarding the two uncertainty analysis are presented in sections below.

5.2 1st Order Taylor Series

Taylor Series Expansion or finite order analysis provides an approximate yet direct assessment of potential error due to uncertainties contained within input parameters. The method relies upon taking the 1st order partial derivative of a function. A first order derivative is the rate of change of the function due to the input parameter at any value which is essentially its sensitivity. All that is then required in implementation is a nominal input value and its associated error or uncertainty, i.e:

\[ Q = 25,000 \pm 10\% \text{ or } \pm 2,500 \]

Example: 18 Hour Basic Noise Level (CRTN)

\[ BNL = 10 \log(Q) + 29.1 dB \]

As discussed before, the sensitivity of this is at any value of Q is the partial 1st order derivative of BNL to Q:
i.e. $\frac{\partial BNL}{\partial Q} = \frac{10}{Q \ln(10)}$

Using this equation, we can plot the sensitivity of the correction with respect to increasing values of $Q$. This gives a graphical demonstration of sensitivity and can aid decisions. It can be seen in the example that the sensitivity of the correction is higher at lower values of traffic flow.

![Sensitivity of Basic Noise Level to Traffic Flow](image)

Figure 5.1: Relationship of basic noise level and traffic flow.

Where, $\partial BNL$ is theoretically the change in the BNL correction. An equation for the change in the correction for any change in $Q$ at any value of $Q$ can then be established:

$$i.e. \quad \partial BNL = \frac{10}{Q \ln(10)} \partial Q$$

Using this equation we can apply to different traffic scenarios. For example, A-road has a traffic flow of 25,000 vehicles.

We know $Q = 25,000$, but we have an uncertainty or error $\pm 2500$, we can then work out an associated error.

$$\partial BNL = \frac{10}{25,000 \ln(10)} \times 2500 = 0.43\text{d}B$$
Therefore we can conclude that an error of ±10% at a Q of 25,000 vehicles yields an error of ±0.43 dB. In addition to this, we can alter the equation to yield uncertainties or acceptable errors from desired dB error. This is achieved by rearranging the error equation.

\[
\frac{\partial BNL}{10} Q \ln(10) = \partial Q
\]

Hence, if we require an error of 1 dB in the correction, we can identify the uncertainty in Q. Taking the example above of 25,000 vehicles; we can identify the uncertainty of Q which would yield a 1 dB error.

\[
\partial BNL = 1\, dB \\
Q = 25000
\]

i.e.

\[
\frac{1}{10} 25000 \ln(10) = 5756.46
\]

In terms of a relative percentage error, this is:

\[
\frac{5756.46}{25000} \times 100 = 23\%
\]

Therefore this method allows a direct relationship between input and output errors to be drawn as the method is purely analytical. It also does not require a significant amount of computation; however the derivatives of some attenuations may be complex. Despite this the method does have some distinct disadvantages.

Due to the non-linearity of correction within noise calculation methods, the use of the method gives approximate answers. The main reason for this is the method creates a straight line approximation of the function at a point. As a result of this, the method works very well for small error and uncertainties but becomes less accurate as these become larger. In the case where a correction is highly non-linear, the method breaks down significantly, however it should be noted that for linear functions this method is entirely accurate.

To increase the accuracy of the method it is possible to include higher order derivatives but it has been found that the mathematics of the method becomes more complex and the benefits of this are hard to justify.

This method is not limited to single parameter calculation but can also be applied to multiple inputs. By equating the first order derivatives of functions or corrections throughout the process, the overall error from input errors or uncertainties can be defined however the same concerns from the single parameter analysis remain. For these reasons it was decided not to use this approach in the uncertainty testing. The discussion is preserved to help present the design
process, and to illustrate that the method may be suitable for simple analysis where a straightforward linear process is under consideration.

5.3 Monte Carlo Simulation

The name “Monte Carlo” was given to a class of mathematical methods developed by scientists working on nuclear weapons in Los Alamos in the 1940’s. As the name suggests the method is theoretically ‘games of chance’ with mathematical models to study their behaviour. Although Monte Carlo Methods are themselves a whole branch of mathematics, the underlying principles can be used for the assessment of uncertainties within inputs of mathematical models. In terms of Environmental Modelling, Monte Carlo has been used in the assessment of multi-parameter Air Quality and Water Resource Models.

As mentioned before, the Taylor Series methods Monte Carlo does not provide a direct analytical link between input and output uncertainties, but it allows more statistical and probabilistic analysis of uncertainties.

The idea behind Monte Carlo Simulation in the context of uncertainty analysis is to compute the outcome of a model repeatedly using input values which have been randomly sampled from a series of possible input values according to its associated distribution.

The output can then be displayed in a histogram which then defines the probability distribution of the output allowing for the calculation of statistical parameters such as standard deviation and variance. The method also allows probabilistic determinations such as upper quartiles and inter-quartile ranges. In addition to viewing the tendencies of the model with respect to errors the method allows for stepped transitions in calculation methodology.
Overall, Monte Carlo Simulation is essentially easy to implement and gives a high level of accuracy as long as the correct input distributions are known. The method uses the model as function of inputs which gives more focus on the output and not the underlying function therefore there is a strong argument to assess the individual function by other means such as Taylor Series methods. Monte Carlo suits itself to software and coding therefore opening the possibility to including the method within software. The downside of the method in this respect is the required computation load. Figure 5.1 shows the process flow of the Monte Carlo Tools.

![Monte Carlo Tools Process Flow](image)

### 5.4 Developing Monte Carlo Tools

In order to carry out Monte Carlo analysis on the emission functions for the CRTN and XPS 31-133 methods it was necessary to develop a software tool to automate the process of running the analysis.
The Monte Carlo tools compute the outcome of the functions set out in the methods repeatedly using input values which have been randomly sampled from a series of possible input values according to its associated distribution. It is important to note that the function under investigation is the complete development of the emission sound power, or basic noise level, this way the decibel uncertainty result has a linear relationship to the receptor noise level. Since there is currently no information regarding the distribution of the input parameters, a normal distribution has been assumed for all the input attributes.

The outputs are then displayed in a histogram to define the probability distribution of the output, and to calculate the statistical parameters such as standard deviation and variance. The method also allows probabilistic determinations such as upper quartiles and inter-quartile ranges. In addition to viewing the tendencies of the model with respect to errors the method allows for stepped transitions in calculation methodology.

The Monte Carlo Simulation has been straightforward to implement utilising Matlab, and Fortran and will obtain a high level of accuracy provided the input datasets actually do have a normally distributed uncertainty and a large sample size is taken.

Figure 4.2.3.1 illustrates the analysis workflow through the tools developed to carry out the Monte Carlo analysis.

5.5 Approach to the analytical testing

Following development of the Monte Carlo analytical tools, the testing procedure was designed. As the Monte Carlo approach was to be used on the non-geometric aspects of the methodology, for both CRTN and XPS 31-133 this resulted in an investigation of the formulas used to calculate the source emission noise level. With this in mind, the general approach was in three stages:

1. General behaviour
   a. investigate the general behaviour of the source emission function across a range of traffic flow values likely in noise mapping projects, and
   b. identify scenarios to use within the subsequent tests.

2. Single parameter
   a. using the scenarios as the crisp condition, run Monte Carlo simulations varying each input parameter individually,
   b. assess the resulting uncertainty in the calculated noise level and
   c. develop a ranking order for the input datasets based upon the magnitude or results uncertainty they introduced.

3. Multi-parameter
a. select the three most significant input parameters, run Monte Carlo simulations varying all three input parameters simultaneously,
b. assess the resulting uncertainty in the calculated noise levels,
c. compare and contrast with single parameter tests.

This approach was designed to produce a logical progression through the stages, such that the design of subsequent stages could always be influenced by any important effects discovered during the proceeding stage.

This approach and process were carried through in two parallel streams, using two sets of Monte Carlo Simulation tools, or dealing with the CRTN method and the other with the XPS 31-133 method.

Details of the calculation methods under investigation can be found in other reports associated with this research project.
6. Testing methodology for geometric aspects

6.1 Mapping model testing methodology

Analytical analysis techniques can be used to assess uncertainty propagation when there is a direct relationship between the input data and the result through the formula used. However, when the accuracy of results depends upon a number of variables which include location information, and hence depend upon the actual geometry, an analytical approach becomes so much more complex as to no longer be practicable within the confines of this research project.

As an example, the uncertainty propagation due to building height change will vary with change in building height, but also in a second dimension as the location of that change in building height varies within the geometry of the model, these two degrees of uncertainty then form a part of the propagation path, which even in a very simple case will need to include uncertainty in the spatial location, as well as height, of both the source and the receptor.

For this reason another approach has been used for the analysis testing of input data with a geometrical aspect. The accuracy implications of such datasets have been examined by the use of a test map, starting with a situation where input data is very detailed; this is known as the crisp model. Subsequently, the level of certainty was decreased stepwise, according to the tools in the GPG Toolkits to produce a series of metamodels. Each metamodel is a copy of the crisp model for which the detailed data within the crisp model, for a particular dataset or attribute, has been reduced in quality, or simplified, inline with the likely effects of using a GPG Toolkit step.

The development of the crisp model and metamodels is discussed in detail in other reports associated with this research project.

The crisp model and metamodels were then calculated using noise mapping software packages to produce a series of grid results. Predictor v5 was used for the XPS 31-133 calculations, and LimA v4.2 for the CRTN versions of the models. The results sets were then analysed to assess the effect upon the results for the metamodels compared to those from the crisp model.

For each input parameter under investigation a number of metamodels were produced in order to create a spread of uncertainty. Each was then calculated to produce a series of uncertainty propagations, and finally the series of results sets were analysed together against the crisp model results to estimate the impact upon the accuracy which has been introduced.

This method is conceptually quite simple, and the metamodel development was made manageable by the use of GIS tools to manage the step changes in input parameter data; however the downside is that the time it takes to run each series of grid calculations required to achieve a spread of results for each input uncertainty. For this reason it was only proposed to carry out 5 scenarios for each input parameter under investigation. This has not lead to definitive
results; however it is believed to have provided an understanding of the uncertainty propagation suitable to inform the use of the GPG Toolkits. Figure 6.1 shows a three-dimensional view of the test model.

Figure 6-1: 3D view of the test model

6.2 Developing the test models

A representative test noise map was required to set as the base *crisp model*. The model needed to be produced with sufficient relevance, and a large enough number of assessment points to enable a spread of typical geometrical scenarios to be assessed simultaneously within one calculation run, with the assessment of results taken across the whole model. The noise map utilised needed to include various items, relevant for noise computations and assessment of noise levels:

- Urban and suburban cases;
- With and without barriers/embankments;
- With motorways, secondary roads and different types of urban roads;
• In flat terrain and hilly environment;
• With demographic data of different kinds.

Consideration was given to utilising an existing noise model from work previously carried out by members of the project team. Consideration was also given to the creation of a specific geometrical dataset, amalgamated from other available data, in order to build a crisp model with complete notional datasets for all the input attributes to be tested.

It was determined that the model should be composed of several sub models each having a sufficiently high level of detail, making it possible to test the recommendations in the GPG Toolkits.

The crisp model was built up from a number of sub areas, for which the data has various origins. Road traffic flow was partly determined by automotive traffic counts (with distinction between light vehicles and heavy vehicles) and partly by traffic flow modelling. In certain sub areas, buildings have been generated from laser altimetry whereas in other sub areas, they were digitized from scale 1:1000 maps and building height was taken from on site visual inspection.

The model area is approximately 6km by 4km which will provide a calculation grid of approximately 240,000 points.

Although detailed data on vehicle speed is not available in the test maps, this is not a problem since the effect of uncertainties in the vehicle speed will be determined analytically. Data on the road surface type has partly been provided by local and national authorities and by on site visual inspection.

The demographic data has been derived either from digital files from the postal service containing individual addresses, or from ZIP-code files (points) that have been allocated numbers of dwellings and residents using demographic data (polygons) from the Dutch National Statistics Service.

Since the buildings and the demographic data originate from different sources, the geographical match is not perfect and it has to be checked manually (see Figure 6.2 below; some address points are several metres away from the building that they belong to).
Using ZIP-code files combined with the demographic data (polygons) from the Dutch National Statistics Service, there is a better distinction between dwellings and other addresses (for instance office buildings, commercial functions) but the need for a manually achieved geographical match is even stronger. This is illustrated by Figure 6.3 below, where the grey surfaces represent the buildings in the noise map and the circles represent ZIP-code points (the larger the point, the higher the number of residents). The underlying polygons have a darker colour when they represent more residents. The example illustrates that these ZIP-code points may represent multiple buildings, which requires a manual check.

Receivers will be situated in a grid with a 10 m grid spacing at 4 m above the ground level. This means that in areas where the ground level varies, the absolute receiver height will vary as well.
Test map 1
Test map 2

Test map 3
Test map 4

Figure 6-4: 3D view of the test sub models.
7. Designing other testing & analysis methodologies

In addition to carrying out sensitivity testing in line with the GPG Toolkits on a case by case basis, the project also investigated the uncertainty introduced into results for a number of other aspects of the required modelling and analysis work associated with the END.

7.1 Traffic flow

The GPG Toolkit 1 for road traffic flow presents recommendations for the treatment of traffic flow data when it is not supplied in a format suitable for direct use in END noise mapping calculations.

The main purpose of the tests was to analyse the potential uncertainty introduced by factoring day/night, or 24 hour total flows into the required day, evening and night periods required for the END.

Mathematical analysis of the diurnal split derived from detailed traffic flow data was supplemented by some noise map calculation tests to investigate the effect across a noise map.

7.2 Assignment of people to properties

For testing the GPG Toolkit 12, a noise map has been used in which the number of people and buildings are known for each individual building. Since the number of storeys are known for all buildings as well, the toolkit can be used in two dimensions (without the knowledge of the number of storeys) as well as in 3D (distribution of the numbers of residents and dwellings for each storey). In order to test the implications of using Toolkit 12, the crisp data was then reduced to more global data by assignment of the population data to sub-areas. In a second step, this was further amalgamated to the whole mapping area. This is illustrated in the scheme below.
7.3 Methodology for testing the interaction between noise & people Toolkits

A fundamental objective of carrying out noise mapping for the END is to identify the number of people exposed to various noise levels. These results can be influenced by the uncertainty in two aspects:

i. the acoustic noise level calculated at each most exposed façade, and

ii. the number of people assigned to the property with the exposed façade, which will be effected by the method of assignment chosen.

Sensitivity testing of the GPG Toolkit methods for assigning numbers of people to buildings has been carried out in order to provide information to MS on the impact of using the different Toolkit methods.

In the methodology described in the GPG, buildings form the link between the calculated noise levels and the people exposed to these noise levels. Uncertainties in the number of people exposed have therefore been determined by the combined uncertainties in the computed noise
levels, in the building geometries and in the assignment of people to these buildings. These aspects were taken into account in testing the interaction between noise & people Toolkits.

It should be noted that the EU directive states that noise levels should be calculated at 4 m above the ground. In areas with flats or other multi-storey dwellings, this will obviously lead to inaccuracies in the calculated noise levels. Therefore variable receiver height for each dwelling was also taken into account additionally.

The tools in Toolkit 12 have been examined by running test cases for the test noise map. Demographic data of different types and resolution has been used in an area where the number of dwellings is known for each separate building and the number of inhabitants has been estimated accurately.

The total number of dwellings in the area is approximately 6000. In order to apply the tools of the GPG, the area has been divided into multiple sub-areas.

There is also an important third aspect to be addressed, which is to discover and understand how these two sets of uncertainties interact in producing an uncertainty in the reported “number of people exposed” figures. It is considered that this information is relevant to the MS and to the Commission in understanding the robustness of the reported data, and to help to inform decision making with regard to future data development or policy decisions.
8. Testing methodology for GPG Toolkits

Below is a brief summary discussion on the testing methodology utilised for each of the GPG Toolkits under investigation.

8.1 Testing Toolkit 1: Traffic flow

The GPG Toolkit for road traffic flow was tested analytically, yielding diagrams with the difference in $L_{den}$ as a function of the difference between the true diurnal distribution of traffic flow and the error in the assumed distributions.

For this purpose, a number of diurnal distributions have been considered (see Table 8.1):

<table>
<thead>
<tr>
<th>period</th>
<th>distribution 1</th>
<th>distribution 2</th>
<th>distribution 3</th>
<th>distribution 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>70 %</td>
<td>75 %</td>
<td>80 %</td>
<td>85 %</td>
</tr>
<tr>
<td>evening</td>
<td>18 %</td>
<td>15 %</td>
<td>12 %</td>
<td>9 %</td>
</tr>
<tr>
<td>night</td>
<td>12 %</td>
<td>10 %</td>
<td>8 %</td>
<td>6 %</td>
</tr>
</tbody>
</table>

The difference in $L_{den}$ was determined as a function of the relative error on the day period traffic flow and the night period traffic flow, ranging from -50% to +100%. The error on the evening period traffic flow follows from the error on the day and night periods.

For the assessment of uncertainty on the distribution between weekday traffic flow and the traffic flow during weekends, a graphical representation was produced of the error on the $L_{den}$ as a function of the relative error on the weekend traffic flow.

Additionally, the application of the tools in Toolkit 1 to the road network in the test maps has been examined in order to give insight into the combined effects for different roads in a realistic case.

8.2 Testing Toolkit 2: Traffic speed

The GPG Toolkit for road traffic flow has been analysed with reference to the results of the Monte Carlo simulations. The level of traffic speed uncertainty introduced by following a recommendation in the Toolkit has been estimated. The results of the Monte Carlo tests for this uncertainty level have then been assessed in order to determine the likely uncertainty in the resulting noise level.
8.3 Testing Toolkit 3: Composition of road traffic

The GPG Toolkit for road traffic composition have been tested analytically, yielding diagrams which show the difference in noise level as a function of the difference between the true road traffic composition and the assumed compositions i.e. ratios of light to heavy vehicles. These computations were carried out and reported for different vehicle speeds.

Secondly, the application of the tools in Toolkit 3 to the road network in the test map will be examined in order to give insight into the combined effects for different roads in a realistic case.

8.4 Testing Toolkit 6: Building heights

The tools in Toolkit 6 were examined by running test cases for the test noise map, with varying storey height and default height for all buildings. A crisp noise map was used which was produced by laser altimetry.

In an intermediate step, building types were identified and given a typical building height as shown in Table 8.2 below.

Table 8-2: Building types and typical height

<table>
<thead>
<tr>
<th>building type</th>
<th>typical height</th>
</tr>
</thead>
<tbody>
<tr>
<td>dwelling</td>
<td>8 m</td>
</tr>
<tr>
<td>urban apartment block, flats</td>
<td>15 m</td>
</tr>
<tr>
<td>industrial building</td>
<td>15 m</td>
</tr>
<tr>
<td>office building, hospital</td>
<td>15 m</td>
</tr>
<tr>
<td>high rise building</td>
<td>50 m</td>
</tr>
<tr>
<td>farm house</td>
<td>8 m</td>
</tr>
<tr>
<td>barn, greenhouse</td>
<td>3 m</td>
</tr>
</tbody>
</table>

8.5 Testing Toolkit 7: Obstacles

The tools in Toolkit 7 were examined by running test cases for the test noise map, which contained a large number of various buildings, and different barriers and embankments. A quantitative description and a qualitative analysis of the results are presented in other reports associated with this research.

8.6 Testing Toolkit 8: Cuttings & embankments in the site model

The tools in Toolkit 8 were examined by running test cases for the test noise map. In this noise map, the embankment height and cutting depth for a motorway were varied in order to compute the effect on noise levels in the noise map. Additionally, the effect of embankments was examined for a number of cases with barriers.
The considered cuttings and embankments are given in Table 8.3.

**Table 8-3: Considered cutting depths and embankment heights**

<table>
<thead>
<tr>
<th></th>
<th>Depth / height</th>
<th>barrier height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuttings</td>
<td>-1 / -3 / -5 / -10 m</td>
<td>0 m</td>
</tr>
<tr>
<td>Embankments</td>
<td>+1 / +3 / +5 / +10 m</td>
<td>0 / 2 / 4 m</td>
</tr>
</tbody>
</table>

Both a quantitative description and a qualitative analysis of the results are presented in other reports associated with this research (relative to a case without embankment or cutting).

### 8.7 Testing Toolkit 9: Building and barrier absorption coefficient

For testing the tools in Toolkit 9, the influence of reflections in the test noise map was determined by subtraction of the noise levels with *reflections switched off* from the computed noise levels including reflections.

The effect of absorption coefficients can then be computed for each individual grid point.

### 8.8 Testing Toolkit 12: Assignment of population data to residential buildings

A fundamental objective of carrying out noise mapping for the END is to identify the number of people exposed to various noise levels. In addition to being affected by the accuracy of the noise predictions, the results reported back to the Commission will be affected by the method used for assigning numbers of people to properties. For this reason, sensitivity testing of the GPG Toolkit methods for assigning numbers of people to buildings has been carried out, to provide information to MS on the impact of using the different Toolkit methods.

The tools in Toolkit 12 have been examined by running test cases for the test noise map. Demographic data of different kind and resolution was used in an area where the number of dwellings was known for each separate building, and the number of residents can be estimated accurately.

### 8.9 Testing new Toolkit 17: Road surface

The tools in this toolkit were tested partly in a qualitative way and partly by the use of a test map.

In the first place, typical examples of CPX measurement results were used to analyse the variations in the noise emission of a road surface within each class, based upon the acoustical road surface parameters. Local disturbances in the noise generation that have a weak effect on the equivalent noise levels should not have dominated the outcome of such analyses. Therefore,
the roads were divided into sections of 20 m and the variation between the equivalent noise levels for each road section was considered.

The effect of variance in the road surface type, and texture depth for CRTN, were also investigated using the Monte Carlo Simulations, with the error propagation identified the step changes suggested by the Toolkit could be assessed from the results.

The classification in tool 17.3, based on the type of road, and the general assumption of dense asphalt in tool 17.4 will be tested against the roads in the test noise map. The road surface corrections according to CRTN and XPS 31-133 will be taken into the computations.

8.10 Testing new Toolkit 18: Road junctions

Since the CRTN method does not provide corrections for decelerating and accelerating traffic, the testing was carried out for XPS 31-133 computations only.

The effect of junctions has been examined analytically as a function of the percentage decelerating and accelerating traffic. As the method has different corrections for light and heavy vehicles, the effects are described for the two vehicle types separately, as well as for four different traffic compositions, with 5%, 10%, 15% and 20% heavy vehicles.

8.11 Testing new Toolkit 19: Road gradient

The assessment of road gradients has a different approach in the CRTN and XPS 31-133 methods. In the CRTN method, the road gradient correction is a linear function of the road gradient, whereas in XPS 31-133 it works like a boolean expression, with a constant correction for any road gradient of more than 2%.

Road gradients will only be relevant when the height difference is substantial. Different values for this threshold have been considered.

In order to test the tools in this Toolkit, a test noise map was used with roads on bridges and inclines in flat terrain as well as roads in hilly terrain. Both positive and negative gradients have been considered.

As the road gradient may also be considered a non-geometric aspect when the dataset is input from other sources, it has also been assessed with the analytical tools.

8.12 Testing new Toolkit 20: Ground elevation

An analytical, single parameter sensitivity study has been carried out for the CRTN and XPS 31-133 methods regarding ground elevation variations between source and receiver, for both reflective and absorbing ground types. Results are presented in graphical output, alongside with recommendations for relevant ground elevations to be taken into account.
Secondly, the application of the tools in this Toolkit to the ground elevations of sources and receivers in the test map has been examined in order to give insight into the effects in a realistic case. In order to test the tools in this toolkit, a test noise map was used with roads on viaducts in flat terrain as well as roads in hilly terrain.

8.13 Testing new Toolkit 21: Ground surface type

An analytical, single parameter sensitivity study has been carried out for the CRTN and XPS 31-133 methods with respect to ground surface properties between source and receiver, over a flat ground with varying elevation of the source. Results are presented in graphical output, alongside recommendations for relevant variations in the ground surface properties to be taken into account.

Secondly, the tools in this Toolkit are applied to the ground surface properties in the test map and examined in order to give insight into the effects in a realistic case. In order to test the tools in this Toolkit, a test noise map is used with a high resolution of modelling of the acoustically absorbing and reflective grounds.

8.14 Testing new Toolkit 22: Barrier height

An analytical, single parameter sensitivity study has been carried out for the CRTN and XPS 31-133 methods with respect to barrier height, for a number of receiver positions (50, 100, 200 and 500 m from the road centre line) and different road configurations (2x1 to 2x4 lanes). Results are presented in graphical output.

Secondly, the tools in this Toolkit have been applied to the barrier heights in the test map, and the results examined in order to give insight into the effects in a realistic case. In order to test the tools in this Toolkit, a test noise map is used with various noise barriers.

8.15 Method for testing multiple GPG Toolkits simultaneously

After the GPG Toolkits have been tested separately, the combined application of multiple GPG Toolkits simultaneously was tested. For this, the inaccuracies in the calculated noise levels arising from the input uncertainties are considered mutually independent, taking their probability distribution into account.

One should take into consideration that some assumptions often have general effects on the outcome of the noise mapping (e.g. standard distributions of the traffic flow among the three assessment periods, standard road traffic composition) whereas other assumptions may have a very local or spatially varying effect on the calculated noise levels (e.g. building and barrier height).
A summary of the results for applying the GPG Toolkits separately is given in tables, with distinction between general effects and local effects. The results include:

- minimum and maximum difference; and
- standard deviation on the output (relative to the standard deviation on the input).

From this, the effects of combined application can be determined by combination of the output uncertainties, taking the probability distributions into account.

8.16 Method for testing the interaction between noise & people Toolkits

Since uncertainties in the number of people exposed are determined by the combined uncertainties in i) the computed noise levels, ii) the building geometries and iii) the assignment of people to the buildings, the variation in the number of residents within specific noise bands was tested by:

- Gradual increase and decrease of all noise levels. This way, the effect of uncertainties in the source strength on the number of exposed residents was evaluated for each noise band. Variations between -3 and +3 dB(A) were considered;
- Random variations in the noise levels. These variations represent the compound uncertainties of both the input variables and the calculation methods. Since the overall uncertainty in the calculated noise levels increases with distance from the source, a linear relationship between the random error and the shortest distance to a source was assumed, with a maximum of 5 dB(A) at 100 m distance;
- Random variations in the building geometries. The sensitivity of the assignment of population data to the accuracy of modelling the buildings was tested by Monte Carlo simulations. In these simulations it was assumed that the position of the first vertex of each building had a precision of 1 m and that the building length and width both have a precision of 10%;
- Random variations in the distribution of dwellings and residents among the buildings. The total number of dwellings and residents within each area was kept constant.

Additionally, the effect of using a standard receiver height of 4 m above the ground (as stated in the EU noise directive) was tested against a noise map with receiver height specific for the dwelling. This means that for flats or other multi-storey dwellings, the number of residents was distributed among multiple receiver heights.
9. Conclusions

This research project sets out to assess the accuracy implications of following the Toolkits in the WG-AEN Position Paper “Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise exposure” Version 1 December 2003 (GPG).

In order to assess the acoustic accuracy effect of using the Toolkits it is first necessary to understand how analysis of uncertainty is carried out within environmental modelling systems. This report sets out an introduction to uncertainty analysis and error propagation methodologies and presents a means of using these techniques in the context of noise mapping.

Methodologies for testing and analysis of the test results are discussed and presented. The details of the results obtained and further analysis can be found in other reports associated with this research.