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

Research Project NAN R 208: Noise Modelling

Final Report - Part 1: Project Approach

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DeltaRail Group Ltd
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1. Executive Summary

1.1 Project

Defra has let a research project on behalf of the EC Working Group on the Assessment of Exposure to Noise (WG-AEN) to determine the likely effects on the acoustic accuracy of the advice contained within the Working Group’s Position Paper “Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise exposure” Version 2 January 2006 (GPG v2).

The key objectives of the project are summarised as follows:

- To extend and build upon the work carried out in the original Research Project NANR 93, “WG-AEN’s Good Practice Guide & the Implications For Acoustic Accuracy”;
- To quantify the accuracy symbols within the GPG v2 when Toolkits 8, 9, 12, 13, 15 and 16 are used in conjunction with the UK Calculation of Railway Noise, 1995, (CRN) and the recommended adapted Interim Method for the assessment of Railway Noise based upon the Netherlands method RMR 1996 (RMR Interim);
- Provide additional practical guidance on any issues concerning the application of the Toolkits 8, 9, 12, 13, 15 and 16 in the GPG v2 relating to railway noise mapping that are uncovered whilst undertaking the study; and
- To provide practical guidance on the consequences of the accuracy of input datasets that are suitable for use with CRN and RMR Interim for noise mapping purposes, through the use of error propagation techniques.

1.2 Approach

In order to meet these objectives the project is set out in three Stages:

1. Stage 1 - Design & Planning
2. Stage 2 - Sensitivity Testing & Results Analysis
3. Stage 3 - Reporting

This Final Report is the key deliverable at the end of Stage 3 of this research project and sets out:

- the scope of the project;
• the review of the testing methodology from the previous NANR 93 research project;
• the results of a literature review to highlight any recent work in this area which has come to light since the previous NANR 93 research project;
• the approach to testing the W G-AEN GPG v2 Toolkits;
• the testing and analysis methods for assessing the acoustic accuracy implications of using the GPG v2 Toolkits;
• the testing and analysis methods used for assessing the acoustic implications of input parameter uncertainty to the CRN and RMR Interim calculation methods, both on a single parameter and multi-parameter basis; and
• the base dataset utilised for the testing, and the methods by which the test datasets will be derived from this base set.

1.3 Conclusions

This final report sets out the aims, objectives and approach of this research project to assess the accuracy implications of following the Toolkits in the W G-AEN Position Paper “Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise exposure” Version 2 January 2006 (GPG).

Using the aims and objectives as defining the requirements of the project, the approach to the project was defined, and the work tasks identified and described in detail.

The main aspect of the project was to carry out sensitivity analysis to assess the implications on the accuracy of the acoustic results from noise calculations based upon usage of the recommendations within the GPG v2 Toolkits.

Methodologies are discussed for testing and analysis of the test results, and the approach taken is set out.

The addition of DeltaRail to the project team for this research into railway noise calculation methods has enabled an independent review of the previous testing methodology to be carried out. This review has led to a number of recommendations regarding the testing approach, and the reporting of the results which have been taken into account during the research work.

A review of the recent literature publications in this area of research has been carried out, which led to several recommendations on how the Monte Carlo tools, and the input data, could be modified to provide an enhanced quality of assessment to be achieved.
To enable acoustic accuracy impact guidance to be presented alongside the GPG v2 Toolkits the requirements for sensitivity analysis were reviewed, and methodologies described for testing in line with the steps in the existing GPG v2 Toolkits.

The methodologies and approach to testing and analysis were based upon those within the previous NANR 93 research project for road traffic noise calculation methods. They were modified to take into consideration the outcome of the review of the previous research, the literature review of recent publications within this field, and particular knowledge of the individual aspects of railway noise calculation modelling.

This approach to testing, results, analysis and conclusions from the research have been presented within a Final Report consisting of eight parts

- Part 1: Project Approach (this report);
- Part 2: Error Propagation Testing of RMR Interim;
- Part 3: Error Propagation Testing of CRN;
- Part 4: Quantified Accuracy of GPG Toolkits – RMR Interim;
- Part 5: Quantified Accuracy of GPG Toolkits – CRN;
- Part 6: Data Accuracy Guidelines of RMR Interim;
- Part 7: Data Accuracy Guidelines of CRN; and
- Part 8: Executive Summary.
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2. Introduction

2.1 Background

WG-AEN was originally set up at the end of 2000 with a two year remit, which included the development of the guidance within a Good Practice Guide (GPG). GPG version 2 was issued as a Final Draft in January 2006. Version 2 of the Position Paper replaces version 1 and states within the Introduction:

“Version 1 has been revised, modified and enhanced to take account of the feedback from the consultation process and recent developments, including the results of a research project sponsored by the United Kingdom (UK) Government (see section 1.6 for further details). Readers of this Version 2, hereinafter referred to as the or this ‘Position Paper’, should note that there are significant changes between this Position Paper and Version 1, for example the way that the issue of assigning noise levels to buildings is dealt with. (This is one of the most important alterations that have resulted from the consultation process.)”

The research project referenced is the original NANR 93 project “WG-AEN’s Good Practice Guide & the Implications For Acoustic Accuracy” carried out by Hepworth Acoustics, DGMR and Acustinet and published in 2005.

The GPG v2 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 v2 are designed to provide guidance of 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.

GPG v2 provides practical advice on decision making in the absence of detailed data, and provides an indication of the acoustic accuracy implications of making the decisions only for Toolkits associated with the assessment of road traffic noise, as a result of the NANR 93 Research Project. Unfortunately this still results in the MS making choices where the uncertainty in results introduced into the process is unknown for railway noise, industrial noise, aircraft noise and weather information. This means that both the MS and the EU Commission are uncertain about the potential accuracy and robustness of these results, even when the methodology is documented and has followed the advice within the GPG v2. A second consequence, and possibly of equal importance is that this lack of quantified acoustic guidance for railways, industry, aircraft and weather datasets within the GPG v2 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. The
discussion of uncertainty in noise mapping, and the practical guidance on datasets for road traffic noise assessments help to provide a much needed introduction to the issues, but then leaves the decision makers with an incomplete set of information to deal with all of the challenges facing them.

Defra wishes to continue the study of consequential acoustic accuracy in strategic noise map results due to adopting the advice in the present version of the GPG v2, by now focusing on railway noise. The result of this study should provide practical advice and guidance on the potential acoustic accuracy implications of following the advice within the GPG v2 Toolkits 8, 9, 12, 13, 15 and 16, and thus help to inform Member States, 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 to inform 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.

2.1.1 Policy Background

The END aims to complement the EU objectives of “achieving a high level of protection of the environment and health [by initially] achieving a common understanding of the noise problem” within MS through an assessment of major noise source emissions, associated with transport and industrial activity, and then through the “adoption of action plans by Member States”. In order for this to be achieved, the Directive recognises the need to augment the current “lack of reliable, comparable data regarding the situation of the various noise sources” by undertaking an assessment of environmental noise exposure, through noise mapping, across MS and using the results as a basis for the adoption of action plans to prevent and reduce environmental noise, where required, and to aim at providing a basis for the development of community measures to reduce noise. The mapping exercise is to be completed by 30 June 2007 and reported to the EU by 30 December 2007. The Action Plans are to have been drawn up by 18 July 2008 and to be reported within 6 months, by 18 January 2009.

The objective of the Directive is to define a common approach to the assessment of environmental noise as currently a great diversity of assessment methods, criteria and policies exist across member states; not to mention attitudes to environment noise. To assist in the process a series of research projects are currently underway under the auspices of the EU Noise Expert Network, within the CALM Network1, and run by the Working Groups on “Health and socio-economic aspects”, WG-HSEA, and “Assessment of exposure to noise”, WG-AEN. This work is aimed at providing a common set of research evidence and implementation guidance on noise impact, community response, effect of mitigation measures, practicalities of noise mapping and

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1 CALM (Community Noise Research Strategy Plan) [http://www.calm-network.com](http://www.calm-network.com)
many of the other factors which need to be considered when drawing up a noise action plan to help improve community conditions. In addition to this work, other research looking into the description of noise sources, and development of new calculation methods is being carried out. The Harmonise\(^2\) work will be reported elsewhere and through the Imagine\(^3\) project will provide a common framework for the assessment of environmental noise along with guidance on its application.

### 2.1.2 Technical Background

#### 2.1.2.1 Uncertainty

In order to understand the impact of different interpretations of the standards in noise modelling software on the overall results, it is useful to 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. Estimation of uncertainty in model inputs and parameters (characterisation of input uncertainties);
2. Estimate of the uncertainty in model outputs resulting from the uncertainty in model inputs and model parameters (uncertainty propagation);
3. Characterisation of uncertainty associated with different model structures and model formulations (characterisation of model uncertainty); and
4. Characterisation of the uncertainty in model predictions resulting from uncertainty in the evaluation data.

\[\text{Figure 2.1: Four key areas of uncertainty}\]

\(^2\) HARMONOISE http://www.harmonoise.nl

\(^3\) IMAGINE http://www.imagine-project.org
For each of these four areas of potential uncertainty, it is possible to discuss some of the practical measures and processes which could be adopted as part of the noise mapping process in order to understand the magnitude of uncertainty in the results.

2.1.2.2 Uncertainty Propagation or Sensitivity

![Diagram of error propagation uncertainty flow chart]

**Figure 2.2**: Error propagation uncertainty flow chart
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 2.2 presents a flow chart showing how error propagation uncertainty is introduced into the noise mapping. In the original NANR 93 research project, the uncertainty in model outputs resulting from the uncertainty in model inputs and model parameters was studied for road traffic modelling. The study found that small errors in input data can result in large decibel errors in noise maps.

This research project aims to replicate this work, but with a focus on railway noise modelling, which has a rather different source emission mechanism from road traffic noise, and in RMR Interim and CRN there are also some differences in the way in which propagation is assessed when compared to their road traffic noise counterparts.

The original NANR 93 research explored one part of the four main areas of uncertainty in noise mapping which is the input uncertainty, relating to road traffic noise modelling. More recent research work carried out by Acustica with Hepworth Acoustics and DGMR has looked into two more areas of uncertainty. Firstly the calculation parameters within the above Figure 2.2 were investigated for five leading noise mapping software tools for road traffic noise calculations and recently reported at the Euronoise 2006 conference. In the second project, as yet unpublished, one aspect of model uncertainty was investigated when an investigation into the issues surrounding the application of CRTN, CRN and ISO 9613-2 within software systems was investigated, including the use of benchmark models across five leading commercial noise mapping software tools.

Assessment of uncertainty with noise modelling and calculations is an area where the above projects represent the leading edge of current knowledge in this area. There are many elements within the chain of uncertainty which need to be investigated and quantified before GUM style uncertainty factors can become a regular part of complex calculations. What is now becoming accepted and normal within measurements is still some way off within modelling and calculations. However, research work like this helps to make significant strides towards a complete picture of the process.

2.2 Scope of Research Project

This research project sets out to assess the implications on acoustic accuracy of following the recommended steps within the GPG Toolkits by following the processes described in detail within the following sections.

2.2.1 Aims

The Aims of the project are:
To provide practical guidance on the acoustic accuracy implications of following the recommendations within the toolkits 8, 9, 12, 13, 15 and 16 in the GPG v2, which shall be produced in a manner which is compatible with the contents of the GPG v2; and

To provide practical guidance on the consequences of the accuracy of input datasets that is suitable for use with CRN and RMR Interim for noise mapping purposes.

### 2.2.2 Objectives

The main objectives of this research project for Defra are:

- To extend and build upon the work carried out in the original Research Project NANR 93, “WG-AEN’s Good Practice Guide & the Implications for Acoustic Accuracy”;
- To quantify the accuracy symbols within the GPG v2 when Toolkits 8, 9, 12, 13, 15 and 16 are used in conjunction with the Calculation of Railway Noise 1995, (CRN) and the recommended Interim Method for Calculating Railway Noise, described within Annex II, 2.2 of the END (RMR Interim);
- Provide additional practical guidance on any issues concerning the application of the Toolkits 8, 9, 12, 13, 15 and 16 in the GPG v2 relating to railway noise mapping that are uncovered whilst undertaking the study; and
- To provide practical guidance on the consequences of the accuracy of input datasets that are suitable for use with CRN and RMR Interim for noise mapping purposes, through the use of error propagation techniques.

### 2.2.3 Objectives of Research Tasks

The tasks and objectives of the research are:

1. Briefly review the testing methodology used to determine the implications for acoustic accuracy of adopting the advice in the GPG v2 as developed during Stage 1 (NANR 93) of the research, and propose enhancements or amendments to this methodology as required;
2. Carry out quantitative testing of the accuracy symbols of the GPG Toolkits using the proposed methodology mentioned above, when used with CRN and RMR Interim;
3. Report on the acoustic implications of using the GPG v2 Toolkits as revealed by the testing methodology;
4. Carry out error propagation testing of CRN and RMR Interim in order to provide guidance on the consequences of the accuracy of input datasets that would be used with these methods;
5. Liaise throughout with the WG-AEN and Defra (by 4 weekly email updates and up to 2 meetings involving the WG-AEN) to ensure that the project develops in line with their end user requirements; and

6. Provide the following documents in a format suitable for publication both in print form and on the Department’s web site:
  - An initial report of the results of the investigations carried out under task 1;
  - A full report covering tasks 1 to 4; and
  - A final report incorporating comments from Defra and WG-AEN.

These main tasks have been analysed to develop the detailed project approach set out in section 3 below.
3. **Project Approach**

3.1 **Introduction**

A staged approach was followed which allowed the defined requirements to be highlighted at project inception and sequentially tackled in order to allow the relevant information flows to occur during the project, and feed into subsequent stages. For relevant tasks, the staged approach also allowed parallel work streams to operate which helped to ensure that the project has been delivered on time. An outline of the workflow is shown in Figure 3.1.

![Figure 3.1: Proposed workflow through the project](image-url)
The project team was able to reuse knowledge, custom developed software and noise models from the original research programme to provide the following benefits to the project:

- Time saving;
- Consistency of technical approach, development of results, and analysis were ensured by the reuse of the knowledge, software and models;
- The results, recommendations and practical guidance would be compatible with the work published within the NANR 93 research project, and help to provide a common basis for advice and interpretation.

3.2 Description of Work Stages

3.2.1 Stage 1 - Design of Testing Methodology

3.2.1.1 Task 1.1 - Inception Meeting with Defra

A project team inception meeting was held by the Consultants, in order to formalise the project initiation.

In summary the purpose of this meeting was to:

- Enable the project team members to meet and discuss the approach to the research;
- Clarify roles and responsibilities within the project team;
- Confirm the project time-plan and key project milestones; and
- Plan the research process during Stage 1.

3.2.1.2 Task 1.2 - Review the Previous Testing Methodology

The previous NANR 93 research project used two separate approaches to assess two separate parts of the noise mapping calculation system:

1. Analytical techniques were used to assess the uncertainty propagation in the non-spatial aspects of the calculation methods i.e. Monte Carlo techniques were used to investigate the source terms; and
2. The spatial aspects of the calculation methods were investigated using a modelling based approach with a series of test scenarios to investigate the effect under inspection.

The previous approach was reviewed in light of any relevant information and evidence brought to light during the literature review, Stage 1, Task 3, and any weaknesses in
the approach suggested by the evidence was assessed, and amendments to the approach were made as considered appropriate.

In particular the analysis and presentation of results was reviewed with regard to the ISO/DGuide 99998 Guide to the Expression of Uncertainty in Measurements (GUM) as members of the project team, and W G-AEN, have been asked specifically about the correlation between the GUM approach and the NAN R 93 approach.

3.2.1.3 Task 1.3 - Literature Review of Alternative Methods
The consultants carried out a literature review to look for information on other possible approaches, beyond those used within the previous research project, and to develop an understanding of their relevance to the tasks required within this research project. The results of this literature review fed into Stage 1, Task 2.

3.2.1.4 Task 1.4 - Review of Calculation Standards and Basic Equations
A technical overview of the RMR Interim and CRN calculation methodologies was carried out, presenting the basic equations relating to the calculation of the source emission noise level, along with an overview of the propagation elements.

The purpose of this was:

- to present a complete description of the methods within the research reports;
- clearly set out any differences between the basic methods and the adapted versions to be utilised for END noise mapping;
- to bring to the attention of potential users any aspects of the methods of particular note; and
- to graphically present important elements of the methods which may not be graphically presented in the original documentation.

3.2.1.5 Task 1.5 - Review of Existing Toolkits
The six GPGv2 Toolkits to be tested were reviewed in the context of use with the RMR Interim and the CRN method. The Toolkits under review were:

- Toolkit 8: Sound power level of trams and light-rail vehicles
- Toolkit 9: Train (or tram) speed
- Toolkit 12: Cuttings and embankments
- Toolkit 13: Ground surface type
- Toolkit 15 Building heights
- Toolkit 16: Sound absorption coefficients for buildings and barriers
The contents of each of the Toolkits has been reviewed, with discussion on the current recommendations within the context of the GPGv2 and the knowledge on railway noise modelling within the Consultants project team.

### 3.2.1.6 Task 1.6 - Develop Testing Methodology & Models
A testing methodology to enable assessment of the acoustic implications of use of the GPGv2 Toolkits was devised for each of the following GPGv2 Toolkits:

- **Toolkit 8: Sound power level of trams and light-rail vehicles**
  - Tool 8.1: Corrections for squeal noise and impulsive noise (may be used when the calculation method does not contain such corrections)
  - Tool 8.2: Corrections for rail type and rail construction
  - Tool 8.3: Use speed dependency
  - Tool 8.4: No data known

- **Toolkit 9: Train (or tram) speed**

- **Toolkit 12: Cuttings and embankments**
  - Tool 12.1: Digital information on cuttings and embankments
  - Tool 12.2: The location and height of cuttings and embankments are not in the digital site model
  - Tool 12.3: The location and height of cuttings and embankments are unknown

- **Toolkit 13: Ground surface type**
  - Tool 13.1: Land use classification
  - Tool 13.2: Classification of urban/suburban and rural
  - Tool 13.3: No data available

- **Toolkit 15 Building heights**
  - Tool 15.1: Number of storeys available
  - Tool 15.2: No information available
  - Tool 16: Sound absorption coefficients for buildings and barriers

### 3.2.1.7 Task 1.7 - Meeting to review Draft Report with Defra
The first meeting with Defra was held during Stage 1 of the research project. The purpose of the meeting was to clarify the specific detailed requirements of the WG-AEN and Defra with regard to the project, the information to be reported and the
precise nature of sensitivity testing required and the calculation methods to be assessed. The main aims of this meeting were:

- Enable client and consultant to meet;
- Address points of clarification;
- Confirm the project time-plan and key project milestones;
- Agree a protocol for the project management (e.g. any preferences for means of communication, scheduling of subsequent meetings);
- Confirm client preferences in terms of reporting style and format;
- Reach agreement on the proposed testing methodology for the GPG Toolkits;
- Agree the method by which the error propagation testing, and the analysis of the results are to be carried out, and
- Agree on the design and specification of the dataset to be used for the testing.

Following the Interim meeting and successful agreement on the methodology of the next stages, the programme of testing was carried out.

Stage 1 delivered Milestone 1, the Stage 6 Task 1 Draft Report summarising the findings of the initial work tasks, the conclusions drawn, decisions made and recommendations for the scope and extent of work to be undertaken within the Stage 2 tasks.

### 3.2.2 Stage 2 - Testing GPG Toolkits

#### 3.2.2.1 Task 2.1 - Perform testing of GPGv2 Toolkits 8, 9, 12, 13, 15 and 16 for RMR Interim, and Task 2.2 - Perform testing of GPGv2 Toolkits 8, 9, 12, 13, 15 and 16 for CRN

Following the submission of the Draft Report, and the first interim meeting, the testing of the GPGv2 Toolkits was carried out in line with the approach set out within the Draft Report.

Specific cases were used to compare the situations where real data is available versus the situation where real data is not available and where specific defaults will be applied using the agreed method developed in Stage 1, in line with the WG-AEN GPGv2 Toolkits.
3.2.3 Stage 3 - Quantify Accuracy of GPG Toolkits

3.2.3.1 Task 3.1 - Analysis of results from existing Toolkits for RMR Interim, and Task 3.2 - Analysis of results from existing Toolkits for CRN

For Toolkits 8 and 9, statistical analysis of the results obtained from the Monte Carlo simulation was performed to obtain the mean, maximum, minimum, standard deviations, 95% confidence interval and probability distribution (PDF) of the source emission levels. The analysis provides evidence on how variation or inaccuracy in the source data could affect the source emission level.

For Toolkits 12, 13, 15 and 16, the results from the model testing was analysed statistically to obtain information such as the mean, maximum, minimum, standard deviation, range and 95% confidence interval of the error introduced due to variations of input data in the model. In addition, histograms showing the variation and statistical distribution of the error have been produced alongside difference maps to show the geometrical location of errors and inaccuracies.

3.2.3.2 Task 3.3 - Reporting of results and acoustic implications

Results have been reported as a set of GPGv2 Toolkits with the accuracy statement quantified into one of the five categories used within GPGv2.

Toolkits 8, 9, 12, 13, 15 and 16 are presented with quantified accuracy statements.

3.2.4 Stage 4 - Error Propagation Testing

Single aspect sensitivity analysis carried out on the calculation algorithms within CRN and RMR Interim has provided evidence on how variation or inaccuracy in the source data could affect the calculated noise levels in decibels. The results obtained from this stage of the study are reported in terms of a variation in range of input acceptable for dB changes in output. For example train speed input could be acceptable within 20% of the “actual” value for a 1dB accuracy limit, and say 40% for a 2dB accuracy constraint, and say 80% for a 5dB accuracy constraint.

As a follow on from the single aspect testing, further testing was then carried out to assess the sensitivity of the CRN and RMR Interim methods when several of the input datasets are varied simultaneously.

3.2.4.1 Task 4.1 - Develop Monte Carlo Tools for RMR Interim, and Task 4.2 - Develop Monte Carlo Tools for CRN

In order to carry out Monte Carlo analysis on the emission functions for the CRN and RMR Interim methods, further development was made to complete an existing CRN Monte Carlo Tool and incorporate the RMR Interim method.
### 3.2.4.2 Task 4.3 - Development of scenarios for Error Propagation testing

Following development of the Monte Carlo analytical tools, the testing procedure was finalised. As the Monte Carlo approach was used on the non-geometric aspects of the methodology, for both CRN and RMR this first required an investigation into the formulae used to calculate the source emission noise level. With this in mind, the general approach will be in three stages:

- General behaviour
- Single parameter
- Multi-parameter

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 preceding stage.

### 3.2.4.3 Task 4.4 - Perform error propagation testing on RMR source emission model, and Task 4.5 - Perform error propagation testing on CRN source emission model

Following the identification of the testing scenarios for the Monte Carlo tools, the testing was carried out.

### 3.2.4.4 Task 4.6 - Develop accuracy look-up tables for RMR 1996, and Task 4.7 - Develop accuracy look-up tables for CRN

Following the completion of the model testing and the Monte Carlo simulations a complete set of analysed results has been reported. At this stage the results could be viewed across all the tests, and interpreted to develop accuracy look-up tables for CRN and RMR Interim.

### 3.2.4.5 Task 4.8 - Meeting with Defra to discuss Draft Final Report

A second interim meeting was held with Defra on 7th February 2007 to review the contents and recommendations within the draft final report submitted in Stage 6, Task 2. There were three main aims of this meeting:

- reach agreement on the results and analysis presented in the Draft Final Report;
- reach agreement on the layout of the summarised results reporting; and
- agree any requirements for amendments to the Draft Final Report prior to submission of the Final Report.
3.2.4.6 Task 4.9 - Meeting with Defra to discuss Final Report
A final meeting was held with Defra on 16th May 2007 to review the contents and recommendations within the final report submitted in Stage 6, Task 3. There were three main aims of this meeting:

- present an overview of the project, its findings and recommendations;
- reach agreement on the approval of the submitted Final Report; and
- reach agreement on the aims of the One Page Summary Report.

3.2.5 Stage 5 - Liaison with WG-AEN

3.2.5.1 Task 5.1 - Emails and phone calls with WG-AEN
From the commencement of the project there has been liaison with the chair of WG-AEN to enable ideas, wishes, concepts, explanations and information to flow freely between the Consultants working on the research and the end users.

3.2.5.2 Task 5.2 - WG-AEN Meeting for Draft Final Report
Following the submission of the Draft Report and towards the end of the testing in Stage 2 and Stage 4 the project was presented to WG-AEN at their 19th February 2007 meeting in order to discuss the findings of the research project, and make an initial presentation regarding the results of the testing to that point. The aim was to enable WG-AEN to have early access to the project approach and results in order to provide feedback on the presentation and have input to the development of the recommendations developed from the research project.

3.2.5.3 Task 5.3 - WG-AEN Meeting for Final Report
Following the submission of the Draft Final Report, and subsequent meeting with Defra, it is proposed to have a second meeting with WG-AEN at their next available meeting to present the final results, conclusions and recommendations of the research project.

Meeting at this stage enables WG-AEN to see all the results and findings of the testing, whilst providing an opportunity for the working groups view on interpretation and recommendation to be considered when considering the publication of the Toolkits with quantified accuracy statements.

3.2.6 Stage 6 - Project Reports

3.2.6.1 Task 6.1 - Submit Draft Report
Following the design of the testing methodology and the initial development of the software tools and models for the GPG Toolkit testing and error propagation testing
the Draft Report was issued at least 5 working days prior to the agreed date for the first interim meeting with Defra.

The Draft Report was a single document setting out:

- the review of the previous testing methodology;
- proposed testing methodology for GPG Toolkits;
- proposed methodology for error propagation testing of the RMR Interim and CRN standards; and
- proposed approach to analysing the results of the tests and presenting the results.

3.2.6.2 Task 6.2 - Submit Draft Final Report

Following the completion of the testing of the GPG Toolkits, and the error propagation testing, the Draft Final Report has been issued at least 5 working days in advance of the agreed date for the second interim meeting with Defra.

The Draft Final Report is presented in several volumes, in an approach consistent with the original NANR 93 research, namely:

1. Project Approach
2. Error propagation testing of RMR Interim
3. Error propagation testing of CRN
4. GPGv2 Toolkits with Quantified Accuracy statements for RMR Interim
5. Data accuracy guidelines of RMR Interim,
6. Data accuracy guidelines of CRN
7. Executive Summary

3.2.6.3 Task 6.3 - Submit Final Report

Following the second interim meeting with Defra the draft final report was amended as agreed and issued as the Final report at least 5 working days before the final meeting with Defra.

The Final Report was submitted as updated versions of the seven documents within the Draft Final Report.

3.2.6.4 Task 6.4 - Submit One Page Summary Report

Following the submission of the Final Report a One Page Summary Report was delivered in a suitable format and style for publication on the Defra website, and for a
non-technical audience to understand the purpose, findings and recommendations of the project.

3.3 Outputs and Deliverables

3.3.1 Milestone 1 - Draft Report
- The research project provided a draft report:
  - reviewing the testing methodology from the original NANR 93 research project;
  - set out the proposed testing methodology for assessing the acoustic implications of using the GPGv2 Toolkits with CRN and RMR 1996; and
  - set out the proposed testing methodology for error propagation testing of CRN and RMR Interim.
- A Quality Assurance plan was also submitted.

3.3.2 Milestone 2 - Draft Final Report
- The draft final reports sets out:
  - the testing methodology used;
  - the results produced by the testing of the Toolkits and the error propagation testing;
  - the proposed acoustic accuracy values to be assigned to each of the stages within the Toolkits under investigation;
  - the practical guidance on the application of the Toolkits for railway noise mapping with CRN and RMR 1996; and
  - with presentation and style in a format consistent with, and suitable for use alongside, the W G-AEN GPGv2.

3.3.3 Milestone 3 - Final Report
- Following receipt of feedback from Defra and W G-AEN, the final report was produced in a print ready format suitable for easy electronic publishing.

3.3.4 Milestone 4 - One Page Summary Report
- Following submission of the final report to Defra a one page summary report was produced in a suitable format, and style, for electronic publishing, and consumption by a non-technical audience.
4. Review of Previous Testing Methodology

4.1 Introduction

DeltaRail (formerly AEA Technology Rail) joined the Hepworth Acoustics-led project team to bring rail-specific expertise to the current research project. They were also well placed to provide an audit of the methodology that was applied during the initial accuracy study, NANR 93, both because they were not directly involved in that study, and because they have previously applied Monte Carlo approaches themselves when considering the effects of rail-head roughness on rolling noise prediction for Defra.

A key objective of the original study was to carry out uncertainty analysis for the EC Interim road noise prediction method XPS 31-133 and the UK method CRTN in order to provide practical guidance on the required quality of input data, and to understand the implications for accuracy of the resultant noise maps. Various toolkits in the Good Practice Guide were then tested via this process.

4.2 Review of Analytical Approach

The two common options identified for error propagation modelling were Taylor Series Expansion and Monte Carlo Simulation. The former allows a direct assessment to be made of potential error due to input uncertainties, by considering the 1st order partial differential of the relevant functions. The latter uses random inputs based on a distribution reflecting input uncertainty, with a set of calculations yielding results that can be analysed statistically and probabilistically.

At the time it was considered that the use of either of these techniques to analyse the complete road noise modelling scenario, including propagation, would require a prohibitively complex analysis system in the context of the scope of the study. However, this decision is worth revisiting in the light of (a) the increased processing power that has become available in the two years since the original study was carried out and (b) analytical experience that has been gained by the project Team in the intervening period.

Having come to the decision that it was not cost-effective to analyse the error across the whole modelling scenario, a hybrid approach was developed. This comprised analytical techniques to assess error propagation in the source term elements of the road noise models, and a model-based approach to the spatial (sound propagation) elements, using a set of test scenarios.

The choice of analytical technique was influenced by the fact that the Taylor Series approach has disadvantages when applied to noise calculations. In particular the non-linearity of correction results within approximate answers, as errors increase in
magnitude. Therefore, the Monte Carlo approach was chosen for source term analysis.

In the absence of better information, the Monte Carlo analysis for road traffic noise has assumed that the input parameters have a normal distribution of uncertainty. This is acknowledged by the project Team as a potential source of inaccuracy within the first phase, but it is unlikely that the distributions will in reality deviate significantly from Gaussian, and hence this is not a major concern for this audit.

Having said this, it is advisable to use real distributions in such an analysis, when they are known, and it is recommended that this be done where possible during the current rail study. DeltaRail routinely measures the speed of nominally identical trains passing specific sites, and have been able to provide an indication of the nature of speed distributions. DeltaRail also has a database of rail head roughness information, acquired in terms of speed-normalised rolling noise over large sections of the UK rail network, and this can be used, in conjunction with available data from other railway administrations, to provide roughness distributions for input to the Monte Carlo analysis.

Although the end results of the error propagation analysis in non-geometric (source) aspects are presented in some detail in the reports, there is less detail regarding the set-up of the Monte Carlo models in terms of assumptions, numbers of calculations carried out etc, and also of the statistical analysis that led to the end results. To provide more confidence in the end results of the current study it is recommended that these aspects are also covered within the reporting.

4.3 Review of Model Testing Approach

The testing approach applied to the geometric, sound propagation, aspects of the road noise models, is attractive in the relative simplicity of the core methodology whilst being able to examine some complex propagation paths in a range of physical environments by building a detailed test model. Demographic data is also incorporated, despite this being somewhat labour intensive due to the need to ensure by manual intervention that address points and the buildings they represent coincide.

It is noted that the processing time required for this element of the testing limited the number of scenarios that could be carried out for each input parameter to 5. It has been acknowledged that this is not sufficient to provide definitive results. It is therefore suggested that, as with the Monte Carlo analysis for the current study, more efficient processing be sought by the use of state-of-the-art computing equipment and/or more processing time be allocated to this element. If this can be achieved, the approach has the potential for producing much useful information.

The Team were able to draw on a range of sources for data to build the “crisp” model, resulting in a comprehensive reference situation representing an area of 24 km².
4.4 Review of Testing

The indicators used to test the methods would ideally be \( L_{DEN} \) and \( L_{night} \), as required under the END. In the Phase 1 work, this has not universally been the case, with the non-geometric elements being based on either \( L_{10} \) (CRTN) or \( L_{Aeq} \) (XPS), while endeavouring to represent \( L_{DEN} \) for the geometric aspects. It is recommended that, if possible, the current study should use these indicators as a basis of the analysis, as other indicators may not behave identically to those required under the Directive.

In view of the potential time and cost that could have been required to carry out the analysis, it is clear that the Team were able to formulate a cost-effective technique for the geometric elements of the models which led to a much improved understanding of the associated error propagation.

- Toolkit 2 (traffic speed) has been analysed from Monte Carlo simulation.
- Toolkit 3 (traffic composition) has been tested analytically, examining the relationship between noise level and true, or assumed, composition, and has also been applied to the road network in the test map.
- Toolkits 6 (building height), 7 (obstacles), 8 (cuttings and embankments) and 9 (building and barrier absorption) have been assessed via the test map.
- Toolkit 17 (road surface) was tested qualitatively and via the test map.
- Toolkit 18 (junctions) has only been tested for XPS as CRTN does not correct for acceleration or deceleration, and an analytical approach has been taken here.
- Toolkits 19 (gradient), 20 (ground elevation) and 21 (ground surface) have been tested both analytically and via the test map.
- Toolkit 22 (barrier height) has been tested analytically.

In the original study, the Good Practice Guide Toolkits 1 (road traffic flow) and 12 (assignment of population data to residential buildings) were also tested via somewhat different means.

- Toolkit 1 was tested analytically to show \( L_{DEN} \) as a function of the difference between true diurnal distribution and the assumed distributions.
- Toolkit 12 was tested by running test cases for the noise map.

4.5 Conclusion

Generally, the choice of methods to analyse the various toolkits has been pragmatic and efficient, although the overall process does not always appear fully coherent. It is expected, however, that the lessons learnt during the original study will be usefully applied to the current project to address this.
In conclusion, the recommendations for revision to the testing approach for this research project are:

- The use of actual distribution within input datasets for Monte Carlo testing where available, rather than only using an assumed Gaussian distribution. These are expected to be:
  - Railhead roughness
  - Train speed
- Improved documentation regarding the setup, assumptions, and statistical analysis involved in the Monte Carlo testing;
- Investigate the possibility of increasing the number of model testing scenarios which may be processed to help provide more robust results and conclusions; and
- Ensure consistent use of the Directive \( L_{DEN} \) and \( L_{night} \) parameters.
5. Literature Review of Alternative Methodologies

5.1 Introduction

As part of the first stage of the research programme, a literature review has been carried out to establish what recent publications within the area of uncertainty and error propagation have become available which may be relevant to the research project.

The literature review has found several research reports and conference papers regarding methods for assessing uncertainty in noise mapping since the original NANR 93 study. These methods are Monte Carlo (MC) techniques, Fuzzy Logic, Fast Amplitude Sensitivity Testing (FAST) and Stochastic Response Surface Method. The review will be focused on the capabilities and limitations of each method for assessing uncertainties in the geometric and non-geometric aspects of the calculation method. This review will also assess whether any developments in uncertainty analysis since the original NANR 93 study can be used to further the testing methodology adopted in the original study.

5.2 Approach within NANR 93

In the NANR 93 study, two common methods for assessing error due to uncertainties contained within input parameters in environmental modelling have been reviewed; Taylor Series Expansion and MC simulation. Taylor Series Expansion allows analytical assessment to be made of potential error due to input uncertainties by considering at least the 1st order partial differential of the relevant functions. The method is easy to implement for low order partial differentials and computationally less intensive than MC techniques, however its accuracy is limited to linear and simple functions. For non-linear functions, the accuracy of the Taylor Series method worsens making it unsuitable for functions such as logarithms and exponentials.

MC simulation is one of the most commonly used methods of multiple parameter uncertainty analysis and error propagation. The method relies upon using random inputs taken from a distribution 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 is then analysed statistically and probabilistically to define error due to uncertainties in the input parameters. Unlike Taylor Series, MC does not require mathematical manipulation of the functions, however due to its computationally heavy nature it is best implemented within software.
In the N A N R 93 study it was decided that employing MC simulation to analyse error across the whole modelling scenario including the propagation path would require a very highly detailed based model environment, and a highly complex analysis system to be developed. An investigation into this level of detail was beyond the scope and time constraints of the study. Two separate approaches were therefore utilised to assess two separate parts of the noise calculation methods (geometric and non-geometric aspects).

- Analytical analysis techniques (Monte Carlo approach) were used to assess the uncertainty propagation in the non-geometric aspects of the calculation methods.
- A modelling based approach has been employed to assess the uncertainty propagation in the geometric aspects of the calculation methods using a series of test scenarios.

5.3 Analytical Techniques

5.3.1 Monte Carlo Techniques

Work has recently been published on using the MC simulation to carry out error propagation testing of the Harmonoise source emission model for road traffic noise. The work has been carried out as part of the IMAGINE project aimed to provide guidelines and recommendations for the modelling of road traffic in order to produce sufficiently accurate noise maps.

One design issue that has been highlighted in the study, which is applicable to this research, is the valid input range for the MC simulations. Certain parameters may not allow the generation of variates with values outside of a certain range e.g. train speed can not be negative. The study has proposed two approaches to overcome the issue by truncating the distribution at certain limit value or clamping of a variate outside of the limit range to the limit value. This issue was also encountered during the original N A N R 93 study.

The main finding of the IMAGINE uncertainty study relates to the combining of uncertainties from different noise sources. The study identified that the uncertainties associated with the dominant noise source are more likely to dominate the overall uncertainty in a combined noise level. This concept is also consistent with the analysis of Trow and Shilton.

In the Trow and Shilton study, MC testing had been applied to the Harmonoise road noise source emission model, to determine the uncertainty in the calculated source emission levels based upon the uncertainty in the input parameters. The study concluded that the propagation of uncertainty to the overall level of the sources, in both third octave bands and A-weighted levels, is dependent upon the magnitude of the relative categories contributions to the source, and their respective uncertainties.
A similar finding was also reported in a study by Fernando et al.\(^9\) which investigated the sensitivity of the calculated noise levels to the quality and precision of the geometric data available. The issue of error quantification due to multiple sources was also applicable within the context of the noise mapping carried out, because the noise level at one given point of a simulated map may be composed from the influence of several sources or propagation paths.

The study has demonstrated this by using a noise map which showed that errors in the non dominant sources only have a small effect or influence on the overall noise calculated. The opposite is observed if errors are in the dominant sources.

As a result of this, the design of datasets to an acoustical accuracy cannot be achieved by directly assessing the overall levels of each source, but must be made by assessing each categories contribution to avoid creating a multi-dimensional problem.

The study by Trow and Shilton also reported that uncertainties in differing parameters yield different characteristics in the uncertainties in the third octave band source emission levels. The application of the A-weighting curve biases the uncertainties in the overall A-weighted level towards the uncertainty within the mid-frequencies. This also means that parameters which yield greater uncertainty in the mid-frequencies will contribute more uncertainty to the overall level. This is also reported in the IMAGINE work discussed above.

These findings are applicable to the current research study for two reasons. Firstly, the RMR Interim calculation method is in octave bands, therefore the propagation of uncertainty within octave bands to an overall A-weighted level will be conceptually identical to the findings reported by Trow and Shilton and the IMAGINE work.

Secondly, in railway noise modelling, the total source emission of a rail line is a result of summing up the contribution of different vehicles, trains, or categories at different source heights. Therefore the concept of contributed uncertainty as discussed by Trow and Shilton and the IMAGINE work may also be applicable. These findings also stress the requirement for a staged testing methodology, designed to track uncertainties through the calculation methods, rather than direct assessment of the source emission level as performed in the original study.

In the ARTEMIS project (Assessment and Reliability of Transport Emission Models and Inventory Systems, an EU funded project aimed at developing a harmonised emission model for road, rail, air and ship transport to provide consistent emission estimates at the national, international and regional level.) sensitivity studies using the MC technique have been carried out to identify the sources of uncertainties in the road traffic emission models and to study how such uncertainties combine and propagate in the model\(^10\). A quantitative statement about the error ranges of emission estimates from transport (in terms of 95 % confidence interval) is then produced from the results. Unfortunately the project team have not been able to obtain a copy of the ARTEMIS project report at this time, and therefore cannot provide further details about the project or whether the research is applicable to the current study. Should
the project report(s) become available during the course of the project they will be considered.

In general the literature review has identified that the MC techniques used in the original N A N R 93 study have been widely accepted as a method for assessing the uncertainty propagation in the non-spatial aspects of noise calculation methods.

The review also found alternative methods such as Fast Amplitude Sensitivity Testing (FAST), Response Surface Testing and Fuzzy Logic Simulation which may apply for assessing the uncertainty propagation in the non-spatial aspects of the calculation methods.

5.3.2 Fuzzy Approach
The Fuzzy technique is very similar to the MC technique except the former is based on Fuzzy number inputs and a branch of Boolean mathematics, whereas the latter is based on probabilistic number inputs. De Muer and Botteldooren11 presented a theoretical comparison between MC and Fuzzy approaches and proposed that the Fuzzy technique was computationally less intensive than the MC techniques, and could handle more aspects of uncertainty. The MC techniques are preferred when the uncertainty distributions and mechanisms are well known. The Fuzzy technique is good for showing areas in the noise map where problems with accuracy may occur and the MC techniques have a general tendency to flatten out the uncertainty in areas where no single factor of uncertainty is dominant.

5.3.3 Fast Amplitude Sensitivity Testing (FAST)
Fourier Amplitude Sensitivity Testing (FAST)12, 13 is a method based on Fourier transformation of uncertain model parameters into the frequency domain, thus reducing a multi-dimensional model into a single dimensional one. The method then varies one factor at a time across a certain number of levels selected over the space of the input variables. For each variation in input, an estimate of the effect on output is computed. A statistical understanding of the distribution of uncertainty within the input datasets is formed from the outputs computed. The disadvantages of the method are the method suffers from computational complexity for a large number of inputs, and the reliability of the FAST method can be poor for discrete inputs13.

5.3.4 Stochastic Response Surface Method
The Stochastic Response Surface method14, 15, 16 selects a subset of important model input parameters and performs multiple runs of the computer model using specific values and pairings of these input parameters. A general polynomial model is then fitted to the model data using a least square method. The fitted response surface is then used as a replacement for the computer model and all inferences related to sensitivity / uncertainty for the original models are derived from the fitted model.
The disadvantage of the Stochastic Response Surface method is that the response surface is calibrated to data generated from the original model therefore the valid domain of applicability of the response surface model will be limited to the range of values used to generate the calibration data set. As most response surface studies are based on fewer inputs than the original model, the effect of all original inputs on the sensitivities cannot be evaluated in Stochastic Response Surface method. In general, Stochastic Response Surface method and FAST try to attempt to form a statistical understanding of the distribution of uncertainty within the input datasets using a limited number of values hence significantly reduce the number of iterations required to obtain a stable result. This improvement in computational speed is at the expense of accuracy.

5.3.5 Analytical Techniques for Analysis of Geometric Aspects

The NANR 93 study did not use MC to assess uncertainty within the geometric aspects of noise modelling due to the excessive complexity and computational load this would have resulted in. The literature review found very little published or documented evidence regarding the application of analytical techniques to the assessment of uncertainty in the geometric aspects of the noise calculation methods. The study carried out by De Muer and Botteldooren, on methods for quantifying the uncertainty in noise mapping, has indicated that it is possible to use the MC technique and a Fuzzy approach for probabilistic modelling in noise mapping. Their work goes further than the previous accuracy study by including the propagation path within the assessment and in addition, performs the uncertainty analysis within a geometrical noise model. The work identified that a comprehensive assessment of uncertainty from source to receiver can be achieved.

The study reported that the Fuzzy technique is computationally less intensive, can handle more aspects of uncertainty and good for showing areas in the noise map where accuracy may be of concern. The MC technique is preferred when the uncertainty distributions and mechanisms are well known and the method has general tendency to flatten out the uncertainty in areas where no single factor of uncertainty is dominant. This research is a starting point for including measures of uncertainty within actual noise maps and has clearly supported the previous conclusion that for practical purposes, a move away from pure MC techniques is required due to computation time.

Even with the recent progress on computer processor speeds, and the increased availability of distributed computing features within noise mapping software, the IMAGINE study concluded that the potential increase in the speed of performing MC simulations for propagation aspects has not yet reached a point where it would be practical to use this approach.
In the IMAGINE uncertainty study a modelling based approach, similar to those in the original NANR 93 study, has been employed to investigate the spatial importance of microscopic traffic parameters in a realistic situation (including the propagation of sound). This shows that this method has been widely accepted as a method for assessing the error propagation in the geometric aspects of the calculation methods.

An alternative approach could be to use a simple point to point model and run MC simulations for a restricted set of simple model situations. However this is unlikely to lead to a sufficiently wide ranging and robust set of simulation situations without the computational load reaching a significant level, and thus largely negating the potential benefit of the approach. It is also likely to prove complicated to simulate an extensive series of complex propagation scenarios, such as those typical in the noise mapping calculation models used for the tests in the NANR 93 research.

5.4 Others Approaches

In addition, the literature review found a small number of papers which have been published looking at input dataset uncertainty or error affecting noise level results, however generally they are quite simplistic in approach, such as case-to-case comparisons.

Kurze et al.\textsuperscript{17} used a data base comprising about 10,000 entries of sound emission data, obtained from pass-by trains at distances of 7.5 metres to 25 metres. The measurements were evaluated for the purpose of establishing a new German Guideline for the prediction of railroad noise. The study found that uncertainties in train types/categories and railhead roughness can introduce significantly large uncertainty in the train emission prediction.

Tellado et al.\textsuperscript{18} have carried out a study to assess the applicability of the Dutch SRM II trains noise characterisation method in Spain. In the study, an applicability assessment has been carried out; starting from the most complete measurement procedure through to the simplest one. The assessment took into account technical difficulties, economical cost and inaccuracies in noise emission when using one or other method. All the simplifications in the procedure will imply a lower cost, but large uncertainty in the noise maps. The study also concluded that uncertainties in train types and railhead roughness can introduce significantly large uncertainty in the train emission prediction. Following these findings, in the current study, the effect of uncertainties in train types/categories and railhead roughness on rail source emission will be assessed with additional attention with the use of realistic input distribution.

The BUMP (Birmingham Updated Noise Mapping Project) project has identified more than 100 different train types running in and out of Birmingham\textsuperscript{19} whilst in CRN there are only 35 available train types. In addition, the rolling stock presented in CRN Table A1.1 are now either phased out, or being phased out, of general service. This leads to a general problem associated with selecting CRN categories for new types of rolling stock, if a detailed understanding of CRN correction factors is not available. When
CRN correction factors are not known a user must make a judgment call and manually filter this new stock into the existing CRN train categories.

This problem is analogous to the problem faced by EC Member States using the RMR Interim method who may not have the time or resources to undertake an extensive measurement programme to correctly identify the RMR Interim emission factors, but rather make manual selection of train category based upon knowledge of local rolling stock.

Parts of the current research study are to assess the uncertainty involved by generalising the unknown trains into the ‘like’ categories proposed in the study. To take this into consideration, the current study will involve not only continuous inputs (train speed) but also discrete inputs (e.g. train categories). The statistical tool will need to be able to consider both types of inputs.

Probst proposed using the concepts within the GUM to define uncertainty in the prediction of environmental noise and in noise mapping. The GUM is a documented and internationally accepted standardised method of assessing uncertainties within measurements. The concept has been used in noise measurement; however its principles are yet to be applied or refined for use in noise calculations. Probst presents an approach to estimating the uncertainty of the calculated noise level from the uncertainties of the emission values of all sources, taking into account the uncertainty of the propagation calculation. However the method is only valid by assuming all the sources are uncorrelated, which is at odds with the findings of the NANR 93 research, which demonstrated through multi-parameter MC testing that this did not appear to be the case.

5.5 Conclusion

The following summarises the main findings from the literature review which are relevant to the current research:

- MC analysis has been widely accepted as a method for assessing the uncertainty propagation in the non-geometric aspects of the calculation methods;
- Alternative methods such as Stochastic Response Surface method, FAST and Fuzzy approach may also be applicable in the current study for assessing uncertainty in the non-geometric aspects of the calculation methods. However each method has its advantages and limitations in terms of accuracy and computational speed. It is also considered that these methods will comprise consistency with the results derived from Monte Carlo and model mapping methods during the previous study;
- De Muer and Botteldooren have discussed the possibility of a Fuzzy approach for assessing uncertainty in the geometric aspects of the calculation methods;
• Studies by Tellado et al. and Kurze et al. have reported that uncertainties in train types/categories and railhead roughness can introduce significantly large uncertainty in the train emission predictions; and

• Trow and Shilton, and Fernanda et al. have found that in the case of multiple sources combined together, the uncertainty of the total source emission is dominated by the uncertainties of the dominant sources. The design of the datasets to an acoustic accuracy therefore cannot be achieved by directly assessing the overall uncertainty of the source but must be made by assessing each individual source.

The review has shown that within noise mapping, the MC technique remains the most applicable method, when compared to the other methods reviewed in this study, for assessing uncertainties in the non-geometric aspects of the calculation methods. Therefore, the MC technique should still be the preferred approach for the current study to investigate the error propagation in rail source emission due to uncertainty in the input parameters.

Although research has suggested that it is possible to use a Fuzzy technique for a complete assessment of uncertainty in noise mapping (source and propagation), to apply the method in the current study will require highly complex analysis system to be developed, which might jeopardise the project timescales. The modelling based method is therefore proposed for testing uncertainties in the non-geometric aspects of the calculation methods.

Employing the same basic MC approach as to that adopted in the previous study will also maintain consistency in the results, as well as saving in project time and cost from re-use of previous tools and test scenarios. Both approaches have previously been successfully employed to study uncertainties associated with both the interim computational method for road traffic noise, and the Harmonoise methodology, which demonstrates that the approach can be migrated to different calculation standards, and is not limited to those investigated during the previous study.

The following summarises the improvements to the testing approach proposed within this research study due to information brought to light during the literature review:

• Ensure that valid input data ranges are maintained for the MC testing;

• Consideration of continuous (e.g. train speed, flow) and discrete (e.g. train categories) inputs for the MC testing;

• Revision of the testing methodology and assessment method to consider the contribution and propagation of uncertainty from individual railway vehicle sources, and not just the overall source emission levels; and

• The use of actual or realistic distributions within input datasets for the MC testing. This is particularly applied to railhead roughness and train types or categories as studies reported that uncertainties in train types/categories and
railhead roughness can introduce significantly large uncertainty in the train emission predictions.
6. Review of Existing Toolkits

6.1 Introduction

The six GPGv2 Toolkits for which quantified accuracy statements are to be established are reviewed below in the context of use with the RMR Interim and the CRN method. These include Toolkits 11 (ground elevation) and 14 (barrier height), for which testing is not a specified aim of the research project, however the project team are expecting to be able to provide quantified accuracy statements for them, based upon the results which will be produced by the proposed testing.

Since both the source spectrum and the source heights for railway sources differ from road traffic sources, the accuracy symbols in Toolkits that may be used both for road traffic noise and railway noise modelling, will potentially be different from those determined within the framework of NANR 93. The current accuracy study will provide a separate Toolkit report that applies specifically to the RMR 1996 method. It is WG-AEN’s decision whether the accuracy symbols in the toolkits that address propagation related issues (toolkits 11-16) should cover both Interim Methods or require a distinction between the two.

6.2 Toolkit 8: Sound power level of trams and light-rail vehicles

<table>
<thead>
<tr>
<th>Available information (Note. It may be necessary to use more than one tool)</th>
<th>applicable tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustical sound power level per unit of rolling noise, squeal noise and impulsive noise on the used rail network as a function of speed and for the different used rail constructions and the representative rail roughness.</td>
<td>no further action</td>
</tr>
<tr>
<td>Acoustical sound power level per unit of rolling noise, on the used rail network as a function of speed and for the different used rail constructions and the representative rail roughness are known. Correct for squeal and impulsive noise.</td>
<td>Tool 8.1</td>
</tr>
<tr>
<td>Acoustical sound power level per unit of rolling noise, on the used rail network as a function of speed and Correct type and rail construction</td>
<td>Tool 8.2</td>
</tr>
<tr>
<td>Acoustical sound power level per unit of rolling noise, on the used rail network at a certain speed.</td>
<td>Tool 8.3</td>
</tr>
<tr>
<td>No data known</td>
<td>Tool 8.4</td>
</tr>
</tbody>
</table>
### Tool 8.1: Corrections for squeal noise and impulsive noise (may be used when the calculation method does not contain such corrections)

<table>
<thead>
<tr>
<th>Method</th>
<th>Complexity</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make observations during a representative dry period on curves with a radius &lt; 100 metres</td>
<td>△</td>
<td>△</td>
<td>↓</td>
</tr>
<tr>
<td>If no squeal noise: no correction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squeal noise occurs: correction of up to +12 dB(A) if it occurs with all vehicles (a smaller correction should be applied if it occurs less often). This is a correction (based on experience), which should be applied to the normal source emission level. The correction to be applied over the section of the curve where squeal noise occurs.</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
</tbody>
</table>

Where rail joints are found:
- If no impulsive noise: no correction
- Impulsive noise occurs: correction of +3 dB(A). This is a correction (based on experience), which should be applied to the normal source emission level. The correction to be applied for the line source 30 metres before and after the rail joint.

### Tool 8.2: Corrections for rail type and rail construction

<table>
<thead>
<tr>
<th>Method</th>
<th>Complexity</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular rail in ballast: no correction</td>
<td>△</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grooved rail in ballast: correction +2 dB(A)</td>
<td>△</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail in asphalt or concrete (as shown below): correction +3 dB(A)</td>
<td>△</td>
<td>\</td>
<td></td>
</tr>
<tr>
<td>(Note. Propagation calculations may need to take account of the reflective surface in which the rail is placed)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Tool 8.3: Use speed dependency

<table>
<thead>
<tr>
<th>Method</th>
<th>Complexity</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make corrections for the actual vehicle speed on different track sections. For calculating the sound level use 30 Log ( \frac{V_{\text{actual}}}{V_{\text{ref}}} ) or for calculating the equivalent emission/emission use 20 Log ( \frac{V_{\text{actual}}}{V_{\text{ref}}} ).</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
</tbody>
</table>
The GPG makes a distinction between regular, ‘heavy’ railways, light rail transport (LRT) and tram-type vehicles which may be considered as road traffic. The tools in Toolkit 8 refer to LRT and tram-type vehicles only, however the GPG recognizes that it may be difficult to decide what is an LRT system and what is a “regular train” system.

Further guidance on this distinction is considered useful, especially when the RMR Interim method is to be used in Member States where the rolling stock differs in acoustic terms from the Dutch noise emission categories.

The two main issues when considering this toolkit are that neither CRN nor RMR Interim have a facility for modelling squeal noise, and that the track types and rail head roughness that are assumed within the method are not “representative” for LRT. Corrections are available already for e.g. jointed track, slab track (but not embedded track).

In Toolkit 8, special attention is paid to squeal noise and impulsive noise as they are considered to be a potentially serious problem in agglomerations. The principle of observation is a good approach for this source, because of the difficulty of prediction, but it may be more realistic to suggest absolute default levels rather than enhancements. It is not clear whether this 12 dB enhancement contains any element of probability of occurrence over the year. In IMAGINE the default probability for squeal on curves is 50%. CRN already includes a 2.5 dB(A) enhancement for rail joints, and therefore the advice in the GPG does not give any benefit.

---

**20** The difference between the formulas $30\log \left( \frac{\nu_{total}}{\nu_{ref}} \right)$ and the $20\log \left( \frac{\nu_{total}}{\nu_{ref}} \right)$ has to do with the exposure time. The sound power has an empiric relation to the speed with a $3^\text{rd}$ power ($v^3$). For a receiver point of view a moving vehicle passing on a higher speed the exposure time will be shorter. This relation is -$10\log (T)$ where $T$ is the exposure time. A shorter exposure time will result in a (relative) lower equivalent noise level. This (lower) has an empiric relation to the speed of $(30-10)\log \left( \frac{\nu_{total}}{\nu_{ref}} \right)$. 

---

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure the acoustical sound power level per unit of rolling noise,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>as a function of speed and for the different rail constructions and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the representative rail roughness.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measure the acoustical sound power level per unit for squeal noise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and impulsive noise on the rail network as a function of speed and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>for the different used rail constructions. (Measurement on squeal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>noise are very complicated and they take a long time)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For regular rail in ballast use an SEL at 25 m of 70 dB per bogie (2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>axles)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For grooved rail in asphalt or concrete: use an SEL at 25 m of 70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dB per bogie (2 axles), independent of the rail construction, and use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the correction given in Tool 8.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For both rail constructions and for no regular maintenance of the rail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>roughness: make a correction of +2 dB</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CRN does not currently account for grooved rail in ballast, or embedded rail, and therefore the advice in tool 8.2 could be beneficial. The advice for speed dependency tallies with the SEL/speed relationship in CRN.

The tools in Toolkit 8 refer to different types of noise emission measurement (noise emission for reference speed and reference track, measurement of speed dependence, track type corrections and squeal noise). Reference to measurement methods would be helpful since this may give more detailed information on complexity and cost of the measurements, and to further specify the accuracy of the tools.

RMVR 2002 and CRN present methods for acquiring source terms for new vehicles or track types, and therefore the advice to measure tallies with this, with the only difference being to use “representative” rail roughness. The question here is how to determine whether the site chosen has roughness that is representative. It is agreed that squeal noise measurement is very complicated and time-consuming, as suggested in the GPG. The suggested SEL per bogie of 70 dB (assumed to be dB(A)) at 25m does not have a speed associated with it. A 2dB correction for no regular maintenance is possibly an underestimate, but may be sufficient in global terms over a year.

6.3 Toolkit 9: Train (or tram) speed

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable train speeds are available from the owner of the tracks</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Reliable train speeds are available from the operators of the trains</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Measure train speeds</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Use timetables and distances to calculate an average speed (may not be possible for freight trains)</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Take the minimum of the following two values:</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>• maximum train speed</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>• maximum track speed</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
</tbody>
</table>

The issue of train or tram speed is dealt with at different levels of detail, ranging from a very detailed description (from track owners or operators) to roughly assigning maximum speed values. However, the spatial and temporal resolution is not addressed in the Toolkit. Near stations, the average train speed may vary strongly along the track, and between tracks.

In the testing of the toolkits, it is assumed that speed measurement is either carried out:
• for a limited number of train passages along the railway network (yielding uncertainty to whether or not these passages are representative for all passages on the entire railway network), or;

• for a limited number of locations over a statistically robust set of train passages (yielding uncertainty to the speed variation along the tracks in the entire network).

With respect to the assignment of train movements to different tracks in a multi-track corridor, WG-AEN recommends that the number of trains be assigned to the different tracks based on local knowledge or, as a last resort, in a uniform manner i.e. the same number of trains on each track. A similar consideration would apply to train speeds. The geometrical model testing of Toolkit 9 should provide an answer to the question of what the acoustic implications are associated with such assumptions.

Although track owners and/or operators may provide the most reliable information on train speed, this data will nevertheless hold a certain level of uncertainty. Available probability distributions of train speed will be used in order to determine the associated potential error in the sound power output.

Alongside this sensitivity testing, it is considered useful to provide practical guidance on speed data acquisition, based on experience in the UK and the Netherlands, in order to assist Member States in setting up datasets that cover an entire railway network.

### 6.4 Toolkit 11: Ground Elevation Close to the Source

Testing of this Toolkit is not a specified aim of the research project, however the project team are expecting to be able to provide quantified accuracy statements for this toolkit based upon the results which will be produced by the proposed testing.

<table>
<thead>
<tr>
<th>Available information</th>
<th>Applicable Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital terrain model including cuttings and embankments</td>
<td>no further action</td>
</tr>
<tr>
<td>GPS height of a road</td>
<td>Tool 11.1</td>
</tr>
<tr>
<td>Cross sections</td>
<td>Tool 11.2</td>
</tr>
<tr>
<td>Default height of embankment</td>
<td>Tool 11.3</td>
</tr>
<tr>
<td>No data available</td>
<td>Tool 11.4</td>
</tr>
</tbody>
</table>
The guidance provided by this Toolkit assumes that the elevation of the surrounding terrain is either flat or unknown and refers to the relative height of the sources. From that point of view it may be worth considering to merge toolkits 11 and 12 into a single Toolkit.

---

**Tool 11.1: GPS height of a road**

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>The road height can be determined by measurement. This can be combined with an estimation of global ground height to determine the height of the embankment or cutting.</td>
<td>![ ]</td>
<td>&lt; 0.5 dB</td>
<td>![ ]</td>
</tr>
<tr>
<td>The height of objects which can screen noise propagation should be determined, this can also be done by measurement or alternatively by visual estimation of the height above local terrain.</td>
<td>![ ]</td>
<td>&lt; 0.5 dB</td>
<td>![ ]</td>
</tr>
</tbody>
</table>

**Tool 11.2: Cross sections**

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>If cross sections from a road are available, the road height can be determined from these cross sections.</td>
<td>![ ]</td>
<td>1 dB</td>
<td>![ ]</td>
</tr>
</tbody>
</table>

**Tool 11.3: Default height of embankment**

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>In a more or less flat situation the main parameter is the height of the road above or under local terrain, this is the height of the embankment or cutting. This height can be determined by visual inspection. The default height of an embankment crossing a road or a railway is given in the table below.</td>
<td>![ ]</td>
<td>2 dB</td>
<td>![ ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>crossing item</th>
<th>height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railroad</td>
<td>8.0 metres</td>
</tr>
<tr>
<td>major road</td>
<td>6.0 metres</td>
</tr>
<tr>
<td>local road</td>
<td>4.0 metres</td>
</tr>
</tbody>
</table>

---

30 Methods such as GPS trajectory surveys, airborne laser scanning (LIDAR), remote sensing and photogrammetry could be utilised.

**Tool 11.4: No data available**

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources are situated on an embankment with a default height e.g. 1.5 metres. The individual Member States can decide on a default value. The surrounding terrain is considered (approximately) flat</td>
<td>![ ]</td>
<td>&gt; 5 dB</td>
<td>![ ]</td>
</tr>
</tbody>
</table>
The results from the accuracy study NAN R 93 for road traffic, which apply to the XPS 31-133 Interim method, show that the tools in this Toolkit provide a variety of tools with a large spread in accuracy.

The most detailed method of obtaining height information is to take heights from a digital terrain model in order to produce an accurate acoustic model near to sources that are elevated or in cutting. Other methods that may be employed include the use of Global Positioning Systems, lidar, photogrammetry or manual surveying and visual inspection. Most of such data cannot be used directly in noise modelling software, but requires conversions or economizations. The Toolkit 11 model testing will address this issue by comparison between different modelling techniques.

### 6.5 Toolkit 12: Cuttings and embankments

<table>
<thead>
<tr>
<th>Available information</th>
<th>Applicable tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital information on cuttings and embankments</td>
<td>Use Tool 12.1</td>
</tr>
<tr>
<td>The location and height of cuttings and embankments but these are not in the digital site model</td>
<td>Use Tool 12.2</td>
</tr>
<tr>
<td>The location and height of cuttings and embankments are unknown</td>
<td>Use Tool 12.3</td>
</tr>
</tbody>
</table>

**Tool 12.1: Digital information on cuttings and embankments**

**Method**

- Incorporate information on cuttings and embankments in digital site model and then use 3D visualising tools to carefully check for inconsistencies and discontinuities

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 0.5 dB</td>
<td></td>
</tr>
</tbody>
</table>

**Tool 12.2: The location and height of cuttings and embankments are not in the digital site model**

**Approach for cuttings:**

- Digitise contour lines along the top of the cutting, on both sides, to model the nearby area.
- Digitise contour lines along the bottom of the cutting, on both sides, to model the railway or road area

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 0.5 dB</td>
<td></td>
</tr>
</tbody>
</table>

**Approach for embankments:**

- Digitise contour lines along the top of the embankment, on both sides, to model the railway or road area.
- Digitise contour lines along the bottom of the embankment, on both sides, to model the nearby area

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 0.5 dB</td>
<td></td>
</tr>
</tbody>
</table>
CRN provides guidance on the assessment of the acoustic effect of these features once the dimensions of the “equivalent barrier” are known. It does not, however, assist in the determination of these dimensions, and therefore Toolkit 12 provides a valuable resource to accompany the application of CRN.

The accuracy symbols in the current version of this toolkit do not give information on the potential error of ignoring cuttings and embankments if they do contain relevant sources. The geometrical model testing will however provide this information.

As mentioned in the previous section, integration of this toolkit with Toolkit 11 may improve the comprehensibility and practicability of both toolkits.

### 6.6 Toolkit 13: Ground surface type

<table>
<thead>
<tr>
<th>Available information</th>
<th>Applicable tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed geometry of reflective and absorptive surfaces</td>
<td>no further action</td>
</tr>
<tr>
<td>Land use classification</td>
<td>Tool 13.1</td>
</tr>
<tr>
<td>Classification of urban/suburban and rural</td>
<td>Tool 13.2</td>
</tr>
<tr>
<td>No data available</td>
<td>Tool 13.3</td>
</tr>
</tbody>
</table>
This Toolkit refers to situations when there is little information on ground properties across the noise model. The three tools within the GPG can all be directly applied to the current calculation methods, and are considered to be a useful enhancement to the process, provided the accuracy implications outlined in the GPG are recognised.

With regard to small areas of land with differing ground surface characteristics to larger surrounding or adjacent areas, the GPG recommends ignoring these areas when they are less than 250 m$^2$. It may also be appropriate to ignore long, narrow areas of land, for example roadside verges in agglomerations, where the typical width is less than 3 metres, or narrow roads in open country. These geometric criteria are not fully reflected by the tools in the toolkit and may need more specific definitions of statements such as “small” and “narrow”. It should be noted that areas of substantial dimensions may be composed of a large number of “small” and “narrow” sub-areas that would not fall into the minimum requirements for their dimensions individually.
In addition, the toolkit may be improved by investigating the effect of a distinction between ground properties in the vicinity of the sources and those in other parts of the noise map. Special attention may need to be paid to aspects that are specific to certain methods, such as the CRN correction for propagation over ballast, when traffic on any track other than the one closest to the reception point is being considered.

6.7 Toolkit 14: Barrier Heights near Railways

Testing of this Toolkit is not a specified aim of the research project; however the project team are expecting to be able to provide quantified accuracy statements for this toolkit based upon the results which will be produced by the proposed testing.

<table>
<thead>
<tr>
<th>Toolkit 14: Barrier heights near roads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available information</strong></td>
</tr>
<tr>
<td>Height of the barrier above the road</td>
</tr>
<tr>
<td>Height of the barrier above ground height at the barrier</td>
</tr>
<tr>
<td>Visual estimation of barrier height</td>
</tr>
</tbody>
</table>

### Tool 14.1 Height relative to road

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtract the height of a road above or the ground height at the barrier to get the height of the barrier above road level</td>
<td></td>
<td>&lt; 0.5 dB</td>
<td></td>
</tr>
<tr>
<td>Derive the height of a barrier from a drawing with a cross section</td>
<td></td>
<td>&lt; 0.5 dB</td>
<td></td>
</tr>
</tbody>
</table>

### Tool 14.2: Visual estimation of height

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual inspection of the barrier height relative to the road surface (preferably from roadside)</td>
<td></td>
<td>1 dB</td>
<td></td>
</tr>
<tr>
<td>Divide barriers into classes and take the default barrier height from the classification</td>
<td></td>
<td>2 dB</td>
<td></td>
</tr>
</tbody>
</table>

**Example:**

<table>
<thead>
<tr>
<th>class</th>
<th>height</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>1.5 metres</td>
</tr>
<tr>
<td>medium</td>
<td>3.0 metres</td>
</tr>
<tr>
<td>high</td>
<td>6.0 metres</td>
</tr>
</tbody>
</table>

Since barriers along railways are generally placed at shorter distance from the source than road noise barriers, the effects of applying this Toolkit may differ strongly from the results in the previous research for road traffic noise. The toolkit provides
guidance only on the barrier height, and does not give answers to questions related to barrier length and position.

Further guidance on different methods of determining the barrier height and position from different types of datasets and different digital techniques would further improve the practicability of the Toolkit. The accuracy study will address relevant aspects of such modelling techniques with respect to acoustic accuracy.

6.8 Toolkit 15: Building heights

<table>
<thead>
<tr>
<th>Toolkit 15 Building heights</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available information</strong></td>
</tr>
<tr>
<td>Building heights</td>
</tr>
<tr>
<td>Number of storeys</td>
</tr>
<tr>
<td>No information</td>
</tr>
</tbody>
</table>

**Tool 15.1: Number of storeys available**

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiply number of storeys with the average storey height (e.g. 3 metres)</td>
<td>〇</td>
<td>1 dB</td>
<td>〇</td>
</tr>
</tbody>
</table>

**Tool 15.2: No information available**

<table>
<thead>
<tr>
<th>Method</th>
<th>complexity</th>
<th>accuracy</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use aerial photos to estimate height</td>
<td>〇</td>
<td>&lt;0.5 dB</td>
<td>〇</td>
</tr>
<tr>
<td>Make on-site visits and count storeys, then use Tool 15.1</td>
<td>〇</td>
<td>1 dB</td>
<td>〇</td>
</tr>
<tr>
<td>Use aerial photos to estimate number of storeys then use Tool 15.1</td>
<td>〇</td>
<td>1 dB</td>
<td>〇</td>
</tr>
<tr>
<td>Use default heights for different types of buildings&lt;sup&gt;31&lt;/sup&gt;</td>
<td>〇</td>
<td>2 dB</td>
<td>〇</td>
</tr>
<tr>
<td>Use a default height for all buildings (e.g. 8 metres)</td>
<td>〇</td>
<td>3 dB</td>
<td>〇</td>
</tr>
</tbody>
</table>

<sup>31</sup> To identify different building types use the surface area covered by the building and the property boundaries or make site visits

This GPG Toolkit is considered to provide sufficiently differentiated tools to the noise mapping software’s end users. More detailed guidance on the practical aspects of dataset management in order to obtain the required information would nonetheless be valuable. For example, if building heights are to be obtained from advanced digital techniques such as lidar or photogrammetry, this requires advanced post-processing of
crude data which may affect the accuracy of the result. It is recommended to make reference to e.g. the IMAGINE-project in which these issues were dealt with.

6.9 Toolkit 16: Sound absorption coefficients for buildings and barriers

| Toolkit 16: Sound absorption coefficients $a_v$ for buildings and barriers |
|-----------------------------|---------------|-------------|-------------|
| **Method**                  | **Complexity**| **Accuracy**| **Cost**    |
| Use absorption coefficients if known | $< 0.5$ dB     | $< 0.5$ dB | $\triangleleft$ |
| Measure absorption coefficients      | $< 0.5$ dB     | $< 0.5$ dB | $\triangleleft$ |
| Use nationally defined default absorption coefficient values | $2$ dB       | $\triangleleft$ |
| Use the following default values:  |                |            |             |
| **Structure**                | **Suggested $a_v$** |
| Completely reflecting (e.g. glass or steel) | $0.0$         |             |
| Plane masonry wall, reflecting noise barrier | $0.2$         | $1$ dB      |
| Structured masonry wall (e.g. building with balconies and oriel) | $0.4$         | $\triangleleft$ |
| Absorbing wall or noise barrier | See manufacturer's data. If unavailable use $0.6$ |             |

The tools in Toolkit 16 provide only a limited set of suggested sound absorption coefficients. However, for road traffic noise the accuracy study showed that the effects of this are acceptable and do not give reason for further refinement.

In certain calculation methods (e.g. CRN), buildings are assumed to be fully reflective and therefore there is no simple method for incorporating alternative acoustic characteristics into the model. For this reason the guidance in the GPG for buildings cannot be usefully applied. For barriers, there may only be two categories, being reflective or absorptive. Therefore, the suggestion within the GPG to use manufacturer’s data or, as a default, $0.6$, would again be of no relevance to these standards.

For railway noise, a special case should be addressed since reflective barriers near the sources will cause multiple reflections between the reflective barrier and the train body. This issue will be looked into in conjunction with the geometrical model testing for toolkit 12, where a cutting with vertical, reflective walls be considered. The specific modelling guidelines for CRN and RMR Interim will be assessed in this case in order to provide information on the uncertainty in noise levels associated with possible uncertainty in input data.
7. Testing Methodologies

7.1 Introduction

The literature review carried out as part of the current research study concluded that Monte Carlo (MC) techniques remain a preferred approach for investigating error propagation in rail source emission models due to uncertainty in the input datasets. For the non-geometric aspects of the noise calculation methods, the modelling based method was also considered as the preferred approach. The literature review identified several recent pieces of research using the testing methodology adopted in the previous study as a foundation. Therefore the testing methodology used within the previous study has been accepted. The use of the same basic testing methodology also allowed consistency between the current study and the previous NAN R 93 study.

The following section details the recommendations and improvements to the testing methodologies which were made during this research study. This follows the information and improvements brought to light during the current literature review, and lessons learned from the NAN R 93 study.

7.1.1 Non-geometric aspects testing

- The use of actual distribution within input datasets for Monte Carlo testing where available, rather than only using an assumed Gaussian distribution. These have been available for:
  - Acoustic Track Quality (ATQ); and
  - Vehicle speed.
- Ability to perform analysis and track uncertainty at each individual source contribution, and summation, rather than directly assessing the overall source emission level;
- Ensure valid input range for the MC testing - some parameters can not have negative values;
- Consideration of continuous (e.g. train speeds) and discrete (e.g. train categories) inputs;
- Improved documentation regarding the setup, assumptions, and statistical analysis involved in the Monte Carlo testing; and
- Ensure consistent use of the Directive L_{DEN} indicator for results.
7.1.2 Geometric aspects testing

- Ensure consistent use of the Directive $L_{DEN}$ indicator for results; and
- Increasing the number of model testing scenarios to help provide more robust results and conclusions.

7.2 Testing Methodology for GPG Toolkits

7.2.1 General approach

As discussed in Section 7.1 above there are two distinct approaches which have been taken for the testing, analytical MC testing of the parameters and modelling tests. It is considered that each of these two types of techniques have had an appropriate role to play within the overall research project.

For the sensitivity testing, the two methods utilised were:

- Monte Carlo simulations based on uncertainty in parametric non-geometrical aspects of the two methods considered; and
- Single parameter and multiple parameter testing based on a representative noise map, using acoustic calculation software.

The behaviour of the CRN and RMR Interim methods has been examined by Monte Carlo simulation in cases when variations of a source output parameter have a direct connection to the variations in the computed $L_{DEN}$ and effects will not vary e.g. as a function of distance. The results have been presented in graphs showing the variation in dB as a function of the variation in the input parameter.

When the accuracy of results depends on a number of variables, which includes geometrical information and hence depends on the actual geometry, a graphical representation of the error is not practicable any more. For example, the accuracy of assumptions on building height will vary from one location to the other, and the acoustic effect of such inaccuracies will depend on several factors such as the position of the reception point, the source elevation and spectrum.

Therefore, the implications of such Toolkits in the GPG have been examined with the use of test maps and test models, starting with a situation where input data is very detailed. Subsequently, the level of certainty is decreased stepwise, according to the tools in the GPG Toolkits.

For this purpose, a representative set of test noise maps have been produced with sufficient relevance and a large number of assessment points. The noise map includes various items, relevant for noise computations and assessment of noise levels:

- Urban and suburban cases;
- With and without barriers/embankments;
With varying number of tracks;
In flat terrain and hilly environment;
With demographic data of different kinds.

More detailed information on the development of the proposed base noise map is available in section 7.6 below.

The test noise map computations have been carried out using Predictor 5.0 and LimA 5.04 software, in compliance with the CRN and RMR Interim methods, and at 4 m above local terrain.

The uncertainty on the computed noise levels have been reported both graphically and in statistical terms. Further details of the means of analysis are detailed in section 7.6 below.

7.2.2 Railway traffic scenarios
For both the CRN and RMR Interim methods, four different traffic scenarios have been developed for carrying out the Monte Carlo Simulation as well as the geometrical model testing.

The RMR Interim traffic scenarios are:
1. Utrecht Central Station - low speed urban traffic;
2. Noordoost Groningen - diesel passenger trains with low traffic flow;
3. Venlo - lower speed intercity & freight trains;
4. Zwijndrecht - higher speed intercity & freight trains.

The CRN traffic scenarios are:
1. West Coast Main Line (Fenny Stratford) - higher speed intercity;
2. Trans Pennine (Edale) - diesel passenger trains with low traffic flow;
3. Midland Main Line (Duffield) - lower speed intercity;
4. North London Line (East of Hackney C Station) - freight trains.
The scenarios are presented in more detail in Appendix A for the RMR Interim traffic scenarios, and Appendix B for the CRN traffic scenarios.

The Dutch railway scenarios have been derived from the Dutch National Railway Database (ASWIN), providing detailed data on vehicle speed and track construction for each single track.

The CRN railway scenarios have been derived from the Network Rail ACTRAFF Database, providing detailed data on vehicle movements for each single track.

Initially, each of the four railway traffic scenarios for each of the two calculation methods were applied to one of the four different geometrical models. In order to achieve a more statistically relevant and robust set of test model results, further combinations were then subsequently tested, as discussed in section 7.6.2 below.

7.2.3 Testing Toolkit 8: Sound power level of tram and light rail vehicles

Toolkit 8 provides guidance on how to obtain emissions of trams and light rail vehicles if information on noise levels produced by trams and light rail transport (LRT) is not available. Tool 8.3 of Toolkit 8 recommends using speed dependency to define the emission level of an unknown rail vehicle. The tool recommends to use 30 \( \log(V/V_{ref}) \) to calculate the sound power level and 20 \( \log(V/V_{ref}) \) to calculate the equivalent emission. The main difference between the two formulas is because of the exposure time.

Toolkit 8 could not be tested using Monte Carlo simulations as it is non-parametric in nature; however it has been tested by investigating the behaviour of the equations within the Toolkit and cross referenced to the results from the Monte Carlo testing for train vehicle speeds for Toolkit 9.

7.2.4 Testing Toolkit 9: Train and tram speed

The GPG Toolkit for train and tram speed has been tested by Monte Carlo simulation, yielding diagrams with the spread in source emission level as a function of the true vehicle speed, as a result of an assumed probability distribution. These simulations have been completed for each of the different railway traffic scenarios defined for CRN and RMR Interim.

Secondly, the effect on the predicted \( L_{den} \) has been considered taking operating conditions (CRN: diesel locomotives under full power; RMR Interim: coasting versus braking trains) into account.

The final tool in Toolkit 9 provides guidance on assigning speed data to trains (or trams) when detailed information on the exact speed of travel is unknown. The last tool in Toolkit 9 suggests that when actual train speeds are unknown, the minimum value of either the “maximum train speed” or “maximum track speed” should be assigned to the train. As this approach is non-parametric in nature it has not been possible to test it using Monte Carlo simulations, however it has been investigated.
using the flow scenarios for RMR Interim and CRN and analysing the resultant uncertainty introduced.

7.2.5 Testing Toolkit 12: Cuttings & embankments in the site model

Toolkit 12 gives guidance on dealing with the geometry and location of cuttings and embankments when accurate information is not available. In order to investigate uncertainty introduced by making assumptions about cuttings and embankments, a number of different ground models have been developed for model 2.

In this test noise map, a railway is situated on an embankment or in a cutting, and results are compared with a crisp model where the rail embankment is level with the surrounding terrain. For the cuttings, two possible cross-sections are considered: with inclined walls or with vertical, reflective walls. The latter case requires a special source height modelling for RMR Interim, and hence was of particular interest.

The effect of embankments has additionally been examined for cases with a 1.5m, 3m and 6m high barrier along the railway in line with Toolkit 14, and comparisons were made with crisp models including these barriers as well. These results have been presented within the final report for Toolkit 14.

The considered cuttings and embankment cases are given in Table 7.1.

<table>
<thead>
<tr>
<th>Table 7.1: Considered cutting depths and embankment heights</th>
</tr>
</thead>
<tbody>
<tr>
<td>depth / height</td>
</tr>
<tr>
<td>cuttings (inclined walls)</td>
</tr>
<tr>
<td>cuttings (vertical walls)</td>
</tr>
<tr>
<td>embankments</td>
</tr>
</tbody>
</table>

Both a quantitative description and a qualitative analysis of the results have been given (relative to a case without embankment or cutting).

In addition to the GPG Toolkit testing, the effect of using 3D polyline strings along a rail corridor, rather than projecting the railway sources onto iso-contour lines (e.g. from a DTM) has also been investigated, in order to quantify the possible benefit of including such model items. This developed into a series of tests investigating Toolkit 11, which was outside the original scope of the project, but as Toolkits 11 and 12 were considered to be closely related it was considered appropriate to test both.

7.2.6 Testing Toolkit 13: Ground surface type

A sensitivity study has been carried out for the CRN and RMR Interim methods with respect to ground surface properties between source and receiver and for all four railway traffic scenarios. The testing has been carried out by application of the GPG Toolkit 13 to test models 1 and 2. A comparison of each individual result has been
made with the results obtained from the crisp model. Statistics and noise level difference maps have been generated.

Results have been presented in a graphical format, alongside recommendations for the usage of Toolkit 13.

7.2.7 Testing Toolkit 15: Building heights
The tools in Toolkit 15 have been examined by running three test cases in comparison with a crisp model formed from building heights derived from laser altimetry (Lidar):

1. Multiplication of the number of storeys with the average storey height of 2.8 m (tool 15.1);
2. Assignment of building heights based on a building classification (tool 15.2a);
3. Assignment of a default building height to all buildings (tool 15.2b).

Table 7.2 shows the logic taken for assigning building heights based on building classification.

Table 7.2: 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>

7.2.8 Testing Toolkit 16: Building and barrier absorption coefficient
For testing the tools in Toolkit 16 it was not possible to build a crisp models using genuine absorption coefficients for the buildings, since detailed data on absorption coefficients was not available, as has always found to be the case. The crisp models therefore used a default absorption coefficient of 0.2.

In order to quantify the effect of more detailed information on absorption coefficients as suggested in Toolkit 16 of the GPG, the noise level contributions by reflections were separated from the contributions from direct propagation paths for each individual grid point. For this purpose, calculations were run in all four crisp noise maps without reflections from buildings. This corresponds to applying an absorption coefficient of 1 to all buildings.
As CRN follows a rather different approach for the assessment of reflection effects, the crisp and meta-models developed for RMR Interim were modified to suite CRN.

### 7.2.9 Method for testing multiple GPG Toolkits simultaneously

As the GPG Toolkits were tested separately, it was appropriate that the combined application of multiple GPG Toolkits simultaneously was also tested, as it is acknowledged by the project team that many toolkits are likely to be used at once. For this, the inaccuracies in the calculated noise levels arising from the input uncertainties are considered mutually independent, taking their probability distribution into account.

Testing was carried out using test model 2 with four different combinations of three Toolkits used simultaneously, and each comparison compared to the crisp model. From this, the effects of combined application have been determined by combination of the output uncertainties, and comparisons drawn with the use of Toolkits in isolation.

### 7.3 Other testing & analysis methods

Alongside the testing of the GPG Toolkits, further testing to access the uncertainty propagation of the input data attributes through the CRN and RMR Interim calculation methods has also been made.

#### 7.3.1 Method for testing the single parameter acoustic constraints to the CRN & RMR Interim methods

Spatially located data, relevant to the propagation effects, has been tested using a model based testing method with possible variation in data being handled by the construction of a series of meta models to cause variance to a base crisp model in order to provide multiple results sets across a range of input uncertainties.

#### 7.3.2 Method for testing multiple CRN & RMR 1996 Interim inputs simultaneously

Railway traffic composition, vehicle speed, track type and operating conditions are relevant parameters for determining the total source emission level. For testing the sensitivity of the calculation methods to uncertainties in their input parameters simultaneously, the following combinations have been tested:

- railway traffic composition & vehicle speed;
- railway traffic composition, vehicle speed & track type;
- railway traffic composition, vehicle speed & operating conditions.
For the calculation of propagation effects, the following basic input is considered most relevant:

- source-receiver distance, gives input to attenuations due to geometrical spread, atmospheric absorption and ground effects;
- source elevation, significant for determining ground effects and (in case of barriers) screening effects;
- ground absorption factor, an input parameter for the ground effects; and
- barrier/obstacle height, gives input to the attenuation due to screening and possible contributions by reflections.

For testing the sensitivity for the propagation effects to uncertainties in input parameters simultaneously, the following combinations will be tested:

- source-receiver distance & source elevation;
- source-receiver distance & ground absorption factor;
- source elevation & ground absorption factor;
- source elevation & barrier/obstacle height.

These combinations have been tested with the assistance of the test models. Each basic input has been considered when studying the models from each of the toolkits.

### 7.4 Monte Carlo Simulations

The sensitivity testing in line with the GPG Toolkits has a vital role to play in understanding and correlating the level of uncertainty in the results obtained within the MS noise mapping processes when the GPG Toolkits have been followed.

Single aspect sensitivity analysis has been carried out on the source term algorithms within CRN and RMR Interim to provide evidence on how variation or inaccuracy in the source data could affect the calculated noise levels in decibels. The results obtained from this stage of the study have been reported in terms of a variation in range of input acceptable for dB changes in output. For example, for CRN, a train speed input within 10% of the “actual” value will yield an uncertainty of 2dB.

Further testing has been carried out to assess the sensitivity of the CRN and RMR Interim methods when several of the input datasets are varied simultaneously.
7.4.1 Developing Monte Carlo Tools

In order to carry out Monte Carlo analysis on the emission functions for the CRN and RMR Interim methods, further development will be made to complete an existing CRN Monte Carlo Tool and incorporate the RMR Interim method. As a result of this, the Monte Carlo tools will not need to be developed from the ground up. The tool will also be programmed so that automated analysis can be carried out.

The Monte Carlo tools will 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 an 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. If there is no information regarding the distribution of the input parameters, a normal distribution will be assumed for all the input attributes.

7.4.2 Testing Procedure

Following finalisation of the Monte Carlo analytical tools, the testing procedure will be finalised. The general approach will be in three stages:

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

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

- **Multi-parameter**
  - select the three most significant input parameters, run Monte Carlo simulations varying all three input parameters simultaneously;
  - assess the resulting uncertainty in the calculated noise levels; and
  - compare and contrast with single parameter tests.
This approach is 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 preceding stage.

In order to test the error propagation in the non-geometric aspects of the CRN and RMR Interim methods the Monte Carlo analysis software tools will run scenario testing against the CRN and RMR Interim methodologies for assessing the basic source emission level.

As there are a multitude of possible combinations of the input parameters for which the uncertainty analysis may be carried out, it is important within any study to first identify a limited number of typical situations to investigate, from across the range of possibilities, in order to assess the type of response generated.

In order to run scenario testing it is first necessary to identify the traffic flow parameters that will be used for the benchmark cases. In the previous NANR 93 research work this was achieved by analysing key aspects of the parameters which contribute to the calculation of the emission level. Two aspects were used to determine the scenarios to be used:

- the calculation of emission was mapped across the range of several key parameters; and
- previous experience of carrying out many projects noise modelling and mapping projects provided insight into real world traffic parameter values.

Within this research project it is proposed to use the same two sets of four traffic flow scenarios within the MC and model testing, as described in Section 7.2.2 above.

7.4.3 Input uncertainty distribution

In the original NANR 93 study, due to absence of better information, the MC analysis for road noise has assumed that the input parameters have a normal distribution. The project team acknowledges this as a potential source of inaccuracy and improvement. Therefore, in the current study, if available, a real distribution of input uncertainty will be used for the MC simulation to enhance the robustness of the results. For input parameters with unknown distribution, a Gaussian normal distribution will be assumed.

Kurze et al.\textsuperscript{17}, and Tellado et al.\textsuperscript{18} found that uncertainties in train types/categories and rail roughness can introduce significantly large uncertainty in the train noise emission. In the current study, for train categories/types, the MC tools will not be used, rather an analytical approach outlined in Section 7.6 below will be taken. For the railhead roughness correction, an actual distribution obtained from DeltaRail’s research into UK rail roughness\textsuperscript{23} will be used. In order to take this into consideration, the MC tool will need to be able to consider different input distributions.
7.4.4 Input Range

In generating random input for the MC simulation, certain parameters may only allow generation of values within a certain range, for example train flow and speed can only be positive. In the IMAGINE uncertainty study\(^7\), two approaches have been suggested to overcome the issue:

1. Truncation of the distribution at certain limit values - the distribution is re-sampled until a variate is obtained within the limit values; and
2. Clamping of a variate outside of the limit range to a limit value.

The study found that both truncation and clamping significantly alter the mean value and standard deviation of the distribution. This has significant implications on the accuracy of the MC simulation especially when input parameters are assigned large uncertainty values as there will be a tendency for calculated mean noise emission levels to drift and the overall magnitude of uncertainties will be suppressed. In the current study, the above two approaches will be investigated and the best approach will be adopted in the development of the MC tool as well as the potential for re-sampling and clipped distribution.

7.4.5 Result Indicators

The indicators used to test the methods ideally should be \(L_{den}\) and \(L_{night}\), as required under the Directive. In the original study, this has not universally been the case, with the non-geometric elements being based on either \(L_{A10}\) (CRTN) or \(Leq\) (XPS), while endeavouring to represent \(L_{den}\) for the geometric aspects. For the current study, \(L_{den}\) and \(L_{night}\) will be used as a basis of the analysis, as other indicators may not behave identically to those required under the Directive.

A testing method will also use the same principles and assessment techniques used for assessing the combination of different sources to assess the interaction of uncertainty within the \(L_{day}\), \(L_{evening}\) and \(L_{night}\) indicators to \(L_{den}\).
Figure 7.1: Improved process flow of the previous MC tool.
7.4.6 Combine Sources

In railway noise modelling, the total source emission level is a result of summing up the contribution of different train vehicles at different source heights.

As discussed in Section 5 above recent research has found that in the case of multiple sources are combined together; the uncertainty of the total source emission is dominated by the uncertainty of the dominant source\textsuperscript{7, 8, 9}. Therefore the design of the datasets to an acoustic accuracy cannot be achieved by directly assessing the overall uncertainty of the source emission level but must be made by assessing the uncertainty of each individual source and its relative level. For the current study, the MC tool will take this into consideration by outputting results of the combined and individual sources so that the correlation between the individual results to the overall result can be assessed.

7.4.7 Final MC Testing Process Flow

In conclusion Figure 7.1 presents an improved process flow of the previous MC tool taking into consideration the amendments and improvements detailed in this section above.

![Figure 7.2: Screenshot of a CRN Monte Carlo Tool under development.](image)

7.4.8 Results Analysis

The outputs of the MC tools are 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.

As discussed in 7.4.5 and 7.4.6 above, analysis will also be carried out at intermediate
stages in the assessment in order to gain an understanding of the relationship between
uncertainty within the intermediate results, such as $L_{\text{day}}$, and the final results, i.e. $L_{\text{DEN}}$.

7.4.9 Validation

Before running any simulations, the output from the MC tool was validated against the
results calculated by a commercial noise mapping software, in the case of RMR Interim
using Predictor 5.0, to ensure that all formulas and equations were implemented
correctly within the MC tool.

Figure 7.3 presents a comparison chart showing the total train emission level
calculated at the railhead by Predictor 5.0 and by the MC tool. These calculations have
been made with no uncertainties or errors within any of the input parameters for flow
scenario 3.

Good agreement is shown between the two results to within 0.1 dB(A), indicating that
all the formulas have been implemented correctly in the MC tool. These small errors
of less than 0.1 dB(A) are believed to be a result of different rounding procedures
between the MC tool and within Predictor 5.0.

To ensure that the MC tools were performing the random number generation,
statistics and random sampling elements of the MC method, additional code was
developed in the MATLAB programming language by a different programmer. This
validation MC code was designed for CRN and a small selection of the train vehicles
supported by the standard. A series of test cases was created and calculated within
both the proposed MC tool and the validation code. The tests revealed that for
calculations with the same settings and input parameters, the validation tool and MC
tool produced the same statistics for full MC calculations with different levels of
uncertainty. These tests showed that the MC tool was performing the MC method
correctly.

Although these tests have only been performed for the CRN method, the MC tool
uses the same sub-routine for RMR Interim. Therefore, the MC elements of the RMR
Interim MC tool have been validated.
Figure 7.3: A comparison chart showing the total train emission calculated at the railhead by the noise mapping software and by the MC tool, Flow Scenario 3. Results are only presented for train category 1 and 2 with different track types. Hatched bars are software calculated results and dotted bars are MC tool calculated results.

7.4.10 Convergence
Prior to running the complete set of MC simulations, initial testing was undertaken to assess the point at which convergence was reached. Convergence is an important consideration when creating any statistical factors from the MC method or any random or stochastic process. The concept of convergence is to identify the number of samples required so that the statistics produced by the MC simulations become stable and do not vary between like calculations.

The aim of this stage of the research was to define the number of iterations which were required to achieve stability in the statistical output. For the study, simulations
were run with 1000, 2000, 3000, 4000, 5000 and 9000 iterations for 100% uncertainties in train flow and speed. Using a large value of uncertainty ensures that statistics are reliable and as a result, smaller uncertainties also produce reliable and stable statistics.

**Figure 7.4:** Difference between the uncertainty parameter (95%CI) obtained for a given number of iterations compared to those obtained for 9000 iterations.

Figure 7.4 presents the difference between the uncertainty parameter (95%CI) obtained for a given number of iterations compared to those obtained for 9000 iterations. Figure 7.4 shows that 3000 iterations gives a good compromise between the calculation time and accuracy. The results show that 3000 iterations were sufficient for stability to 1 decimal place of output. Obtaining stability for a higher number of decimal places is not worthwhile for two reasons. Firstly, noise levels are reported usually to an accuracy of 0.1 dB. Secondly, obtaining stability to a second decimal place for large uncertainties such as in the convergence testing may never be possible unless a very
large number of iterations are adopted. This has a knock on effect on calculation time and is only beneficial when assessing very large uncertainties.

As a result of the convergence testing, 3000 iterations were adopted.

### 7.5 Other Non-Geometrical Aspects

Monte Carlo simulations are an appropriate tool for assessing error propagation in the non-geometric source terms of RMR Interim and CRN for those aspects of the source term derived by the use of equations, i.e. they are parametric in nature. However, there are some aspects of the source terms, and some aspects of Toolkits 8 and 9, as discussed above, which are non-parametric in nature, and thus cannot be investigated using Monte Carlo simulations.

Other testing methodologies and approaches have been devised and utilised for the following aspects of the source model:

- Train vehicle category selection
- Source enhancements i.e. track types and supports
- Toolkit 9 vehicle speed derived from the minimum value of either the “maximum train speed” or “maximum track speed”
- Use of Toolkit 8.3 sound power level equations

The approach to testing Toolkits 8.3 and 9 are discussed above, and the approach to testing train vehicle category selection is discussed in section 7.7 below.

### 7.6 Geometric Model Toolkit Testing

As discussed in Section 7.2 a testing methodology to enable assessment of the acoustic implications of use of the GPGv2 Toolkits have been devised for each of the following GPGv2 Toolkits:

- Toolkit 12: Cuttings and embankments
  - Tool 12.1: Digital information on cuttings and embankments
  - Tool 12.2: The location and height of cuttings and embankments are not in the digital site model
  - Tool 12.3: The location and height of cuttings and embankments are unknown
- Toolkit 13: Ground surface type
  - Tool 13.1: Land use classification
o Tool 13.2: Classification of urban/suburban and rural
o Tool 13.3: No data available

- Toolkit 15 Building heights
  o Tool 15.1: Number of storeys available
  o Tool 15.2: No information available

- Toolkit 16: Sound absorption coefficients for buildings and barriers

These toolkits have been tested geometrically as they have implications on propagation of noise. Propagation effects are mainly determined by the presence and height of barriers and buildings and by ground altitude variations (including the height of a road cuttings or embankments). Secondly, the noise levels are determined by the acoustical properties of the ground and reflective properties of noise barriers and building facades. Thirdly, meteorological data will affect the propagation between source and receptor.

The outcome of noise computations does not only depend on the available data, but also on the geometrical modelling of a true physical situation. The sensitivity analysis describes briefly the effects of such simplifications, both in the horizontal plane (source position) and vertically (ground altitude variations).

Figure 7.5: A view of the crisp model containing equal height contours with a 5m vertical interval. The model has terrain heights ranging from 0m - 160m.

Toolkits 11, 12, 13, 14, 15 and 16 have been investigated using the model testing method developed within the original NANR 93 research. Identical geometrical noise
models as used in the previous research into the CRTN and XPS 31-133 road traffic noise methods have been used in this research. This has been done to help to provide results and recommendations which will be consistent with the previous research study and avoid any variance introduced by adopt different geometrical environments. These models have been amended to incorporate railway source objects (discussed further in 7.6.1 below). Figures 7.5 to 7.8 illustrate the test models used for this CRN and RMR Interim research.

Due to the differing definitions of the acoustic parameters required by CRN, in comparison to RMR Interim, the RMR Interim models were created as the master versions, and then adapted to fit the requirements and definitions within CRN. This was particularly the case with regards to reflecting barriers. In RMR Interim, barriers can have absorption coefficients assigned at octave band frequencies, however in CRN a barrier is simply either reflective or not. All barriers and buildings were defined as being reflective apart from the test cases for when reflections are not considered. The same logic has been applied for ground cover objects. Where ground cover objects in RMR Interim have intermediate values of 0.5 (which are not supported in CRN), these have been assumed to be completely absorbing.

7.6.1 Dataset for sensitivity testing purposes

The geometrical models developed in the framework of Research Project NANR 93, “WG-AEN’s Good Practice Guide & the Implications for Acoustic Accuracy” form the basis for testing the GPGv2 Toolkits within the scope of the current research. In each of the four geometrical models, the road sources have been replaced by railway sources running through the centre of each of the models. Source emission levels have been calculated for RMR Interim and CRN using the railway traffic flow scenarios described in Section 7.2.2 above.

These test maps start with a situation where the input data is very detailed. These crisp models were built up from a number of sub areas, for which the data has various origins. In certain sub areas, buildings have been generated from laser altimetry, whereas in other sub areas they were digitized from 1:1000 scale maps, and building heights taken from on site visual inspection.

Subsequently, the level of certainty is decreased stepwise to form meta-models, in line with the tools in the GPGv2 Toolkits.

The total model area is approximately 12 km by 8 km which provides a calculation grid of approximately 260,000 points.

The Dutch railway scenarios have been derived from the Dutch National Railway Database (ASWIN), providing detailed data on vehicle speed and track construction for each single track.

Receivers have been situated in a grid with a 10 m grid spacing at 4 m above ground level. This means that in areas where the ground level varies, the absolute receiver height will vary as well.
**Figure 7.6:** Model 3 Containing contours determining the start and end height of key ground model features of major acoustic significance.

**Figure 7.7:** Three-dimensional view of Test map 1
Figure 7.8: Three-dimensional view of Test map 2

Figure 7.9: Three-dimensional view of Test map 3
7.6.2 Number of Scenarios

In the NANR 93 study, the testing approach applied to the geometric, sound propagation, aspects of the road noise models is attractive due to the relative simplicity of the core methodology, whilst being able to examine some complex propagation paths in a range of physical environments by building a detailed test model.

Within this current research programme, the same test models have been utilised, with the addition of some further meta-models to investigate cuttings with vertical sides. The testing carried out commenced with a series of one-at-a-time testing scenarios, where one input dataset, or one Toolkit is tested in isolation, will all other aspects remaining fixed.

Following collation and review of these results, multiple input datasets, or multiple Toolkits, have been varied simultaneously to establish the effect of having several input datasets with less than ideal data quality, or to assess the effect upon the results of utilising multiple GPGv2 Toolkits simultaneously.

It is noted that the processing time required for this element of the testing in the previous research limited the number of scenarios that could be carried out for each input parameter to 5. It was acknowledged that this was not sufficient to provide definitive results. As a result, as with the Monte Carlo analysis for the current study, more efficient processing has been utilised with the use of state-of-the-art computing equipment which has significantly greater processing power than that used during the first research project.
It is considered that by increasing the number of scenarios and tests, increased robustness and reliability of the results has been achieved.

**Table 7.3:** Proposed testing matrix for model testing

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.3 illustrates the four geometric test models in a matrix with the four flow scenarios to be used for the CRN and RMR Interim testing. Highlighted in blue is an initial combination of traffic flows with test models to illustrate one pass through the testing process. The testing was run in Tiers. Within each Tier, each traffic flow scenario was matched to one test model. Upon completion of tests the traffic flow scenarios were each moved to different test models and the tests run for a second time. For the RMR Interim testing it was possible to complete three Tiers of testing, whilst for the CRN testing it was possible to complete four Tiers of testing. This provides a substantially larger results evidence base compared with the NANR 93 road testing. Compared with 4 sets of results for NANR 93, the current project resulted in 12 combinations for RMR Interim and 16 combinations for CRN.

Table 7.4 illustrates the approach to testing the GPG Toolkits, and presents a view on which of the test models will provide results useful to the determination of the quantified acoustic accuracy statements for the each Toolkit being tested.

After the first pass through the model testing, the traffic flow scenario in each model has been changed to the next traffic flow scenario within the matrix illustrated in Table 7.3. This process is proposed to continue after each round of model testing is completed, with the aim of completing four full rounds of model testing, once with each of the four traffic flow scenarios.

This will provide a total of 16 sets of model testing, which will provide a much more robust evidence base than the 5 sets of tests carried out within the previous NANR 93 research project.
7.6.3 Result Indicators

For the current study, $L_{den}$ and $L_{night}$ have been used as the basis of the analysis as recommended by the review of the previous research project.

7.6.4 Methodology for analysis of testing results

The noise model calculation runs produced a series of results datasets to be analysed. Statistical analysis of the results generated by the testing has provided information such as standard deviation, mean, range, maximum, minimum, 95% confident interval, skewness and kurtosis in the output due to uncertainty in the input.

The results of the model testing were analysed using a tool developed in-house which was able to read in LimA or Predictor grid results files for the crisp model and meta-models for each scenario under test. Figure 7.11 shows the layout and explains the main features of the statistical analysis tool.

Before the statistical analysis was carried out, the result datasets were filtered to form the ‘acoustically relevant’ footprint, where the noise level is more than 45 dB, for the indicator under review, for all of the scenarios considered, crisp and meta-models. This filtering of grid points ensures that the results of the statistical analysis are not contaminated by a potentially large number of grid points for which the noise levels are significantly below the noise level classes set out in the END.
The tool filtered the results and undertook statistical analysis on the grid results which remained after filtering comparing each meta-model in turn with the results from the crisp, or benchmark, model. Figure 7.12 shows the tool in use comparing one crisp results file for Lden with six meta-model results files.

![Figure 7.12: Statistical analysis program in use](image)

In addition to the results produced by the statistical analysis tool, histograms showing the variation and statistical distribution of the error were produced, alongside difference maps to show the geometrical location of errors and inaccuracies. Figures 7.13 and 7.14 show examples of the histograms and maps produced.
**Toolkit 15 - Height from Building Type Classification**

![Chart](chart.png)

**Figure 7.13:** 15.2a: Distribution of results - Lden.

**Figure 7.14:** Toolkit 15: Difference map - Height from Building Type Classification vs. Crisp Model (Model 2, Flow Scenario 4 on left and Model 4, Flow Scenario 1 on right)
7.7 Discrete Inputs: Train Categories and Types

CRN and RMR Interim work by treating trains on an individual basis and summing the individual contributions from each train type to obtain a total source emission level. In CRN there are 35 different train types modelled with 45 different corrections, including Eurostar rolling noise and fan noise in a separate supplement to describe the different aspects of the train operation. In RMR Interim, different train types are allocated to the nine train categories based on their propulsion system, wheel brake system or maximum speed.

The BUMP (Birmingham Updated Noise Mapping Project)\textsuperscript{19} has identified that there are more trains in the current rail network than those considered in CRN Table A1.1, and some of the trains in CRN are now either phased out or being phased out of general service. To support these new rolling stocks, a view must therefore be made to how new stocks can be filtered into the existing train categories. One option available to the project is to draw upon a study that was carried out by DeltaRail (when AEA Technology Rail) for Defra in 2004\textsuperscript{22}. This involved the consideration of a set of vehicle classes that were comparatively numerous and that were not included within the CRN 1995 document, or later supplement. CRN source term corrections were derived either from new or existing measurement data, or by prediction, covering an additional 32 vehicle classes.

This general process also applies to EU Member States which employ the RMR Interim method where a view must be taken on how to filter their national trains into those in the interim methods.

In general, for CRN to be used as designed the trains in CRN are sub-sectioned based on factors such as number of axles, braking systems and engine type, as shown in Table 7.4.

In terms of data capture, to practically obtain data to this level of detail will require in-depth knowledge of different rolling stock, which cannot always be guaranteed. Therefore the train categories can be simplified further based on a general description of the rolling stock as detailed in Table 7.5 to more closely reflect the type of information which may result from a field survey data capture exercise.
Table 7.4: Trains in CRN based on number axles, braking systems and engine

<table>
<thead>
<tr>
<th>CRN Category</th>
<th>Range in Correction Factors dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Tread braked passenger coaches (4 axles)</td>
<td>9.6</td>
</tr>
<tr>
<td>2 Disc braked passenger coaches (4 axles)</td>
<td>5.3</td>
</tr>
<tr>
<td>2a Disc braked light railway passenger coach (6 axles)</td>
<td>0</td>
</tr>
<tr>
<td>2b Disc braked light railway passenger coach (8 axles)</td>
<td>0</td>
</tr>
<tr>
<td>3 Tread braked freight vehicles (2 axles)</td>
<td>0</td>
</tr>
<tr>
<td>4 Tread braked freight vehicles (4 axles)</td>
<td>0</td>
</tr>
<tr>
<td>5 Disc braked freight vehicles (2 axles)</td>
<td>0</td>
</tr>
<tr>
<td>6 Disc braked freight vehicles (4 axles)</td>
<td>0</td>
</tr>
<tr>
<td>7 Locomotives</td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>3.2</td>
</tr>
<tr>
<td>Electric</td>
<td>0</td>
</tr>
<tr>
<td>8 Diesel locomotives under full power</td>
<td>5</td>
</tr>
<tr>
<td>9a Eurostar (rolling noise)</td>
<td>0</td>
</tr>
<tr>
<td>9b Eurostar (fan noise)</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7.5: Generalised train categories based upon CRN categories

<table>
<thead>
<tr>
<th>Generalised Category</th>
<th>CRN Categories</th>
<th>Range in Correction Factors dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Coaches</td>
<td>1, 2</td>
<td>10.7</td>
</tr>
<tr>
<td>Light Railway Passenger Coaches</td>
<td>2a, 2b</td>
<td>0.9</td>
</tr>
<tr>
<td>Freight Vehicles</td>
<td>3, 4, 5, 6</td>
<td>7.5</td>
</tr>
<tr>
<td>Diesel Locomotives</td>
<td>7 (diesel)</td>
<td>3.2</td>
</tr>
<tr>
<td>Electric Locomotives</td>
<td>7 (electric)</td>
<td>0</td>
</tr>
<tr>
<td>Eurostar Trains</td>
<td>9</td>
<td>0</td>
</tr>
</tbody>
</table>
Using a similar approach, the nine general vehicle categories within RMR Interim, detailed in Table 7.6, can be generalised further into four categories, detailed in Table 7.7.

**Table 7.6: RMR Interim - nine train categories**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Tread braked conventional electric passenger trains and (international) wagons of the German railways DB for a typical speed between 60 and 130 km/h (1 unit = 2 bogies);</td>
</tr>
<tr>
<td>Category 2</td>
<td>Disc braked combined with additive tread braked electric passenger trains and (international) wagons of the SNCF and TEE with an electric locomotive for a typical speed between 80 and 140 km/h (1 unit = 2 bogies);</td>
</tr>
<tr>
<td>Category 3</td>
<td>Disc braked electric commuter trains for the shorter range with noticeable electric engine noise for a typical speed between 60 and 120 km/h (in or around urban areas, 1 unit = 2 bogies);</td>
</tr>
<tr>
<td>Category 4</td>
<td>Tread braked freight trains for a typical speed between 40 and about 80 km/h (all kind of freight wagons, 1 unit = 2 axles);</td>
</tr>
<tr>
<td>Category 5</td>
<td>Diesel passenger trains with tread brakes for a typical speed between 40 and about 80 km/h (1 unit = 2 bogies);</td>
</tr>
<tr>
<td>Category 6</td>
<td>Diesel passenger trains with disc brakes for a typical speed between 40 and about 120 km/h (1 unit = 2 bogies);</td>
</tr>
<tr>
<td>Category 7</td>
<td>Disc braked urban subway, trams and Light-rail vehicles for a typical speed between 40 and about 80 km/h (1 unit = 3 bogies);</td>
</tr>
<tr>
<td>Category 8</td>
<td>Disc braked modern and state of the art electric passenger trains (also double deck train) for a typical speed between 40 and about 160 km/h (1 unit = 2 bogies); and</td>
</tr>
<tr>
<td>Category 9</td>
<td>Disc braked and tread braked high speed trains – TGV-PBA and Thalys for a typical speed between 150 and about 250 km/h (1 train = 2 power units + 8 coaches = 13 bogies).</td>
</tr>
</tbody>
</table>

**Table 7.7: Generalised train categories based upon RMR Interim categories**

<table>
<thead>
<tr>
<th>Generalised Category</th>
<th>RMR Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger trains</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>Freight trains</td>
<td>4</td>
</tr>
<tr>
<td>Diesel trains</td>
<td>5, 6</td>
</tr>
<tr>
<td>Inner city trains / trams</td>
<td>7, 8</td>
</tr>
<tr>
<td>High speed trains</td>
<td>9, 10</td>
</tr>
</tbody>
</table>
The testing methodology utilised for dealing with train vehicle categorisation and discrete inputs, is different to that used for the other non-geometrical aspects of the calculation methods. The major reason for this is that uncertainty within the selection of railway vehicles is not a continuous problem or the result of a mathematical equation, but instead is a set of discrete selections which may be assumed or informed. As a result of this, Monte Carlo simulation is an inappropriate method of analysis as an incorrect selection or misinformed judgement cannot be defined by a statistical distribution.

In both RMR Interim and CRN, the modelling of trains is performed by cumulatively considering the noise from a series of different train vehicles. This means that the modelling is performed on an individual train or vehicle basis. For example, in the case of CRN, although individual train vehicles are categorised based on propulsion, axles and braking systems, the modelling requires each modelled rail vehicle to be known in terms of rolling stock. This requirement for detailed train vehicle information means that where data has not been captured to the same resolution as required by the calculation standard, assumptions must be made.

The project team have identified three levels at which it is possible to capture rail vehicle information:

1. **Crisp Vehicle Capture** - rail vehicles are captured by their model or class (e.g. Class 465 EMU);
2. **Technical Capture** - rail vehicles captured based on propulsion systems, braking systems and axles (e.g. tread braked passenger coach);
3. **General Capture** - rail vehicles captured based on general description of the train with factor such as type and propulsion system or photography (e.g. electrically powered passenger train).

Using these three levels of data capture, Tables 7.4 and 7.6 relate to train data collected by a Technical capture. Tables 7.5 and 7.7 can be related to a general capture.

As the calculation standards require trains to be defined in terms of specific rolling stock, the testing methodology concentrated on how generalised data could be allocated and filtered into specific rolling stock, i.e. how data capture using the descriptions in Tables 7.4 to 7.7 could be transformed and filtered into actual rail vehicles. The testing methodology also used the process in reverse to assess the decibel error introduced for a range of supplementary scenarios when crisp captured information is simplified according to filters.

Figure 7.15 gives an example of filtering based on the three resolutions of data capture as discussed previously.
It can be seen in Figure 7.15 that for this limited example in CRN, a series of inputs required by the calculation method can be sought. In the example in Figure 7.15, capturing train flow by vehicle based on a generalised description of “Diesel Multiple Unit Passenger Coach” can lead to six possible train vehicles.

The project team drew up categorisation diagrams such as in Figure 7.15 for all modelled rail vehicles within CRN and RMR Interim.

On completion of the categorisation diagrams, the project team used crisp detailed vehicle data, including all other non-geometrical factors such as flow and speed, and filtered it into the technical and generalised capture descriptions. This provided both crisp data and two more simplified data variants.

A decibel error for using these techniques was obtained by comparing the results of the crisp data calculations with the calculation made using the techniques.
8. Conclusions

This final report sets out the aims and objectives of this research project 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 2 January 2006 (GPG).

Using the aims and objectives as defining the requirements of the project, the approach to the project was defined, and the work tasks identified and described in detail.

The main aspect of the project was to carry out sensitivity analysis to assess the implications on the accuracy of the acoustic results from noise calculations based upon usage of the recommendations within the GPG Toolkits.

Methodologies are discussed for testing and analysis of the test results, the approach taken is set out.

The addition of DeltaRail to the project team for this research into railway noise calculation methods has enabled an independent review of the previous testing methodology to be carried out. This review has led to a number of recommendations regarding the testing approach, and the reporting of the results which have been taken into account during the research work.

A review of the recent literature publications in this area of research has been carried out, which has led to several recommendations on how the Monte Carlo tools, and the input data, could be modified to provide an enhanced quality of assessment to be carried out.

To enable acoustic accuracy impact guidance to be presented alongside the GPGv2 Toolkits the requirements for sensitivity analysis were reviewed, and methodologies described for testing in line with the steps in the existing GPGv2 Toolkits.

The methodologies and approach to testing and analysis were based upon those within the previous NANR 93 research project for road traffic noise calculation methods. They were modified to take into consideration the outcome of the review of the previous research, the literature review of recent publications within this field, and particular knowledge of the individual aspects of railway noise calculation modelling.
### Appendix A: RMR Interim Railway Traffic Flow Scenarios

#### Scenario 1
**Utrecht central station.**
**Low speed city**

| vehicles categorie & omschr. | dag | avond | nacht | scenario 1
|-------------------------------|-----|-------|-------|--------------
| 1 MAT16                      | 95.37 | 90.51 | 27.26 | short
| 2 ICRC/CM                    | 143.57 | 126.04 | 26.09 | long
| 3 SGM                        | 32.06 | 32.39 | 10.56 |
| 4 CARGO                      | 20.35 | 30.79 | 20.25 |
| 5 DE                         | 0.05 | 0.06 | 0.02 |
| 6 DH                         | 0 | 0 | 0 |
| 7 STAD                       | 0 | 0 | 0 |
| 8 RMM/DM                     | 60.06 | 117.75 | 31.9 |
| 9 Thals                      | 0 | 0 | 0 |
| 10 ICE 3M                    | 7.73 | 9.28 | 0 |

bowenbouwode 2 voegloos spoor met houten dwarsligger (of zigzag) en ballastbed track construction track with joints and wooden sleeper, and ballast...

#### Scenario 2
**Noordoost Groningen, Diesel passenger**
**Low intensity line**

| vehicles categorie & omschr. | dag | avond | nacht | scenario 2
|-------------------------------|-----|-------|-------|--------------
| 1 MAT16                      | 0 | 0 | 0 | short
| 2 ICRC/CM                    | 0 | 0 | 0 | long
| 3 SGM                        | 0.16 | 0.01 | 0.08 |
| 4 CARGO                      | 0.99 | 0.13 | 1.27 |
| 5 DE                         | 0 | 0 | 0 |
| 6 DH                         | 0.87 | 4.52 | 1.47 |
| 7 STAD                       | 1 | 0 | 0 |
| 8 RMM/DM                     | 0 | 0 | 0 |
| 9 Thals                      | 0 | 0 | 0 |
| 10 ICE 3M                    | 0 | 0 | 0 |

bowenbouwode 2 voegloos spoor met houten dwarsligger (of zigzag) en ballastbed track construction track with joints and wooden sleeper, and ballast...
### Scenario 3
**Vealo**

**Lower speed InterCity**

<table>
<thead>
<tr>
<th>vehicles categorie &amp; omschr</th>
<th>dag</th>
<th>avond</th>
<th>nacht</th>
<th>speed non braking trains gaand (km / u)</th>
<th>speed braking trains pend (km / u)</th>
<th>fraction braking dag</th>
<th>avond</th>
<th>nacht</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MAT64</td>
<td>10.15</td>
<td>9.69</td>
<td>4.52</td>
<td>40</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>2 ICR/ICM</td>
<td>20.88</td>
<td>20.32</td>
<td>3.26</td>
<td>40</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>3 SGM</td>
<td>19.26</td>
<td>13.33</td>
<td>5.48</td>
<td>40</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>4 CARGO</td>
<td>45.54</td>
<td>46.5</td>
<td>40.27</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5 DE</td>
<td>0.49</td>
<td>0.53</td>
<td>0.56</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6 DH</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7 STAR</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>8 IRM/DM</td>
<td>3.38</td>
<td>4.06</td>
<td>0.22</td>
<td>40</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>9 Thalys</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10 ICE 3M</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**bovenbouwcode**
3 voegerspoor met dwarsslagers en doorgaand ballastbed

**track construction**
track with joints and sleepers and ballast

---

### Scenario 4
**Zwijndrecht**

**Higher speed InterCity**

<table>
<thead>
<tr>
<th>vehicles categorie &amp; omschr</th>
<th>dag</th>
<th>avond</th>
<th>nacht</th>
<th>speed non braking trains gaand (km / u)</th>
<th>speed braking trains pend (km / u)</th>
<th>fraction braking dag</th>
<th>avond</th>
<th>nacht</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MAT64</td>
<td>23.4</td>
<td>17.27</td>
<td>8.6</td>
<td>120</td>
<td>84</td>
<td>0.5</td>
<td>0.4</td>
<td>0.35</td>
</tr>
<tr>
<td>2 ICR/ICM</td>
<td>62.33</td>
<td>55.6</td>
<td>11.77</td>
<td>120</td>
<td>70</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3 SGM</td>
<td>3.45</td>
<td>3.59</td>
<td>3.1</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4 CARGO</td>
<td>79.95</td>
<td>89.18</td>
<td>72.37</td>
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</tbody>
</table>

**bovenbouwcode**
E voegers wissel

**track construction**
E track without joints, switches
Appendix B: CRN Railway Traffic Flow Scenarios

Hepworth/WG-AEN Accuracy Study
CD47135

Sensitivity analysis at four sites, three based on those used in the Defra Roughness Study and the Bureau Veritas Mapping Spec work, and one based on Silverlink info.

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<tr>
<th>Sites</th>
<th>1</th>
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<td>Trans</td>
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<td>MML</td>
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<td>Stratford</td>
<td>Edale</td>
<td>Duffield</td>
<td>Hackney Station</td>
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Effect of ATQ on CRN correction
For "Smooth" wheels, ie predominantly disc-braked or composite tread-braked,

\[
\text{Correction} = (\text{M} \cdot \text{ATQ} + \text{"CRN"}) \times \text{the complete ATQ range}
\]

("CRN" = standard value, ie where ATQ = 0.0)

For "Rough" wheels, ie predominantly cast-iron tread-braked

\[
\text{Correction} = \text{"CRN" for ATQ}=0.0, \text{ or (M} \cdot \text{ATQ} + \text{"CRN"}) \text{ for ATQ} \geq 0.0
\]

<table>
<thead>
<tr>
<th>Short Code</th>
<th>Description</th>
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<tr>
<td>DP</td>
<td>Diesel locomotive-hauled passenger</td>
</tr>
<tr>
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<td>Electric locomotive-hauled passenger</td>
</tr>
<tr>
<td>DMU</td>
<td>Diesel multiple unit</td>
</tr>
<tr>
<td>EMU</td>
<td>Electric multiple unit</td>
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<tr>
<td>DF</td>
<td>Diesel locomotive-hauled freight</td>
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RRKJ, 23/11/06

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<tr>
<th>Site 1</th>
<th>WCL</th>
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<th>Annual vehicle flows</th>
<th>Speed km/h</th>
<th>Vehicle rolling</th>
<th>Loco on power</th>
<th>Gradient, M</th>
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DP = HST 2+8
EP = CI 90+8+DVY
DMU = CI 153 single car
EMU = CI 325 12 car
DF = CI 60 + 14 Roadstone Hoppers
EF = CI 90 + 20 Freighliner flats
### Site 3

**Trans Pennine**

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DMU = Cl 170 3 car
DF = Cl 66 + 20 Freightliner flats

### Site 5

**MM/L**

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DP = HST 2+8
DMU = Cl 150 2 car
DF = Cl 60 + 10 TIA 46T + 14 TIA 80T
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</table>

DMU = CI 313, 3 car

Freight data, for this site, has been obtained from Actraff and is broken down into numbers of locomotives and wagons per annum.
Appendix C: References


7. IMAGINE - Development of Strategies for the use of traffic models for noise mapping and action planning. W P2 - Demand and Traffic Flow Modelling.


18 Uncertainty analysis in trains’ noise emission characterisation due to simplification in official procedures. Tellado, N., Aspuru, I. and Eguiiguren, J.L., Managing Uncertainties in Noise Measurements and Prediction, Symposium Le Mans (France), 27-29 June 2005


