Harmonoise WP 2 – Reference sound propagation model

Foort de Roo, Ingrid M. Noordhoek
TNO TPD, P.O. Box 155, 2600 AD Delft; Email: deroo@tpd.tno.nl

Introduction

The European Environmental Noise Directive 2002/49/EC specifies an obligation for member states to draw up noise maps of major agglomerations, roads, railways and airports starting from 2007. After a period of using national or interim methods, European harmonised assessment methods will be made available from 2012 for the computation of these noise maps. These harmonised methods are being developed in the European FP5-IST project Harmonoise. Due to budgetary restrictions the Harmonoise project focuses on road and rail traffic noise and disregards the methods needed to calculate noise impact caused by aircraft and industrial sources.

Harmonoise employs a rigid philosophy stating that the source and the propagation models should be separated. This will guarantee a universal interfacing between the source and propagation models that allows various propagation models to be used with the same source characterisation without affecting the correctness of the total noise impact model.

Furthermore Harmonoise will deliver two noise impact prediction models: an Engineering model intended for everyday use and a Reference model that will serve as a calibration base for the Engineering model and may remain available after the development period as a model of high accuracy for complex propagation problems that cannot be solved in a satisfying way with the Engineering model. Both models will include the same source characterisation model, but the propagation module will differ considerably. In the Reference model the aim of the development is focussed on achieving the highest possible accuracy, without too much concessions to flexibility of use or short computation times. The Engineering model focuses exactly on these last aspects and does not aim for the highest but for an acceptable accuracy.

The Harmonoise Reference model will be based on theoretical physical modelling methods. The idea behind this is that any model based on empirical data loses its validity in situations that are not covered by the measured data. Extrapolation outside the validated range will be risky. For theoretically based models this not the case: if the applied theory has a sufficiently general validity the model will be valid also in ranges that cannot be covered by validation measurements. This is the reason that the Harmonoise set-up uses a double validation system for the Engineering model, based on measured data from WP 4 as well as on Reference model computations.

Comparatively the Reference model will emphasise high accuracy in situations of physically complex propagation and relatively simple geometry. The Engineering model will emphasise flexibility of use in complex geometries and physically not too demanding propagation conditions.

The objectives of the Reference model with respect to the prediction accuracy are:

- Up to 100 m distance:
  95 % confidence interval = $\pm$ 1 dB(A);
- From 100 m up to 2000 m; flat terrain:
  95 % confidence interval = $\pm$ 2 dB(A);
- From 100 m up to 2000 m; hilly terrain:
  95 % confidence interval = $\pm$ 5 dB(A).

Tasks of the Reference model work package

The Reference model development is divided into 11 tasks:

1. Definition of the physical problem;
2. State of the art of modelling;
3. Benchmark testing of existing models;
4. Choice of basic reference propagation models;
5. Numerical implementation of Reference model (new algorithms and modelling solutions);
6. Development of a prototype of the Reference model;
7. Evaluation and testing of prototype;
8. Validation against measured data;
9. Final implementation of Reference model;
10. Delivery of final model;
11. Final report.

The development will reach the start of task 6 by the beginning of May 2003. The tasks 2.1 to 2.5 all have resulted in technical reports of which the report [1] of task 2.2 is available to interested parties outside the Harmonoise consortium.

The development of new or adapted modelling solutions and simulation algorithms is concentrated in task 2.5.

State of the art of modelling

In the work package "State of the art of modelling" an inventory of theoretical modelling methods was made. Table 1 gives an overview of the models that were studied and described.

The report gives for each model an overview of the basic physical assumptions, the mathematical equations, the input and output parameters, the way the ground and the meteorological influences are treated, the validation and the available operational versions.

Furthermore three general modeling aspects that are relevant for sound propagation modelling are described: modelling of meteorological influences, impedance models and Fresnel zone interpolation.

Benchmark test computations

Each of the models mentioned in the previous chapter was tested in a systematic series of benchmark tests. These tests configurations consisted of the following elements:

- three source heights (0.05 m, 0.5 m, and 5 m);
- three horizontal source-receiver distances (20, 200, and 2000 m);
- four types of surfaces (rigid, grassland, porous asphalt, and porous concrete);
- transitions from one type of ground surface to another;
- eight different atmospheric conditions (including range-dependent sound-speed profiles and turbulence);

- four barrier types (rectangular barrier, trapezium, T-shaped barrier, and tilted barrier);
- four terrain profiles (ridge, trench, elevated road, and depressed road);
- a forest or a city.

In addition, various modeling approximations were tested to investigate their usefulness for the Reference model:

- coupling of models;
- two-dimensional approximation for oblique propagation over a barrier;
- Fresnel-zone interpolation for heterogeneous ground.

Evaluation of theoretical propagation models

The state-of-the-art sound propagation models were evaluated on three items: accuracy, applicability, and computational effort (see Table 1). Accuracy is based on deviation from the 'true' solution. Applicability refers to limitations of the set of situations the model can be applied to. Computational effort refers to computing times and memory.

Table 1: Appraisal of the sound propagation models.

MODEL	Accurate in …	Applicability	Computational effort
Linearised Eulerian model	most cases	no limitations, except for an approximate representation of ground impedance	very large
Boundary Element Model (BEM)	most cases	limited to a non-refracting (homogeneous) atmosphere	large
Meteo-BEM	many cases	(presently) limited to linear sound speed profiles	large
Parabolic Equation method (PE)	most cases	limited to axisymmetric cases, maximum propagation angles between 35 and 70 degrees, forward propagation, rectangular obstacles, and a flat ground	large
Generalised terrain PE	most cases	see PE, but applicable to arbitrary terrain profiles with a maximum local slope of 30 degrees	large
Fast Field Program (FFP)	many cases	limited to axisymmetric cases, a layered atmosphere, no obstacles, and a flat homogeneous ground	large
Straight Ray model	many cases	limited to a non-refracting (homogeneous) atmosphere, dimensions of obstacles and distances to diffraction edges that are large compared to wavelength, and obstacles that consist of flat surfaces	small
Curved ray model	some cases	see SRAY, but not limited to a non-refracting atmosphere; limited to linearised sound speed profile	small
Statistical scattering models	not determinable	limited to a non-refracting atmosphere and randomly distributed scattering objects that are small compared to wavelength	small

Results of the tests of the modeling approximations show that:

- Hybrid models (SRAY+PE and BEM+PE) are accurate in cases investigated. A disadvantage is that refraction in the source region is neglected.
- The accuracy of the two-dimensional approximation for oblique propagation over a barrier varies with the angle between the source-receiver line and the normal to the barrier. For most traffic noise cases, integration over the angle results in an error les than 1 dB.
- The Fresnel zone interpolation is accurate in some of the cases investigated, but inaccurate in other cases.

Proposed design of the Reference model

From the model evaluation it was concluded that the Euler model would be the favourite basis for a Reference model, if the required computational effort were manageable. The same would apply for the 3-dimensional PE method. Because of this difficulty the 2-dimensional PE method was chosen as the general basis for the Reference model. As the PE method cannot handle shielding objects with a non-rectangular shape, it can be replaced in the source region by the straight ray or the boundary element method. In those cases the straight ray and the BEM model will be coupled to the PE model to take care of the propagation outside the source region, where the influence of an inhomogeneous atmosphere will be relevant. This coupling can be realised by computing the complex sound pressure for a vertical stack of intermediate receiving points and using these sound pressure values as a starting vector for a PE model simulation.

This choice of possible models enables the input of single and double barriers in the source region, as well as elevated and depressed (rail)roads and (rail)roads situated on a hillside. Reflections between vertical surfaces can be taken into account by carrying out computations in several propagation planes and summing the contributions in the receiving point. Outside the source region the permissible geometrical and geographical variability is governed by the modelling possibilities of the PE model. In this region the model can handle one shielding obstacle of rectangular shape, a terrain profile with a maximum local slope of 30 degrees and one or more ground impedance transitions. Figure 1 shows an example of the modelling possibilities of the combined modelling methods.

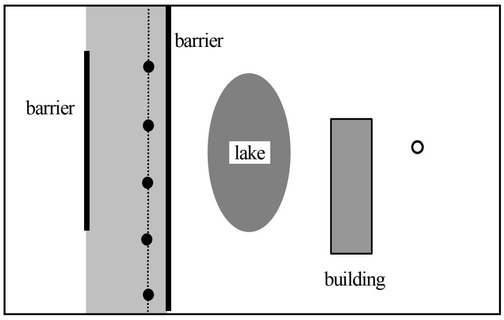

Figure 1: Example of the complexity of the configurations the reference model can handle.

Further developments

The modelling design discussed above is now being implemented in modelling solutions and algorithms, that are aimed at: elaboration of the concept of propagation planes, incorporation of source directivity, meteorological classification, development of a catalogue of ground and terrain types with suitable modelling parameters, development of a modelling method for barrier tops and a unification of numerical modelling methods and parameters. The next step will be to combine the various partial models and algorithms into a working prototype.

[1] Noordhoek, I.M. e.a., Harmonoise Work Package 2 – Reference model – Task 2.2: State of the art of modelling, Harmonoise Technical Report nr. HAR22-TR020220-TNO11, TNO TPD, Delft, 19 November 2002.