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Harmonoise: simplification of comprehensive source and propagation models into an accurate and practicable engineering method

R. Nota[a], J.J.A. van Leeuwen[a], R. Barelds[a], M. Beuving[b], C. Cremezi[c], J. Defrance[d], H.G. Jonasson[e], D. van Maercke[d], G. Taraldsen[f], G. Watts[g], J. Witte[a]

[a]DGMR Consulting Engineers, P.O. Box 82223, NL-2508 EE The Hague, the Netherlands
[b]AEA Technology Rail BV, P.O. Box 8125 NL-3503 RC Utrecht, the Netherlands
[c]SNCF, 45 rue de Londres, F-75379 Paris Cedex 08, France
[d]CSTB, 24 rue Joseph Fourier, F-38400 Saint-Martin d'Hères, France
[e]SP, Box 857 SE-501-15 Borås, Sweden
[f]SINTEF, O.S.Bragstads plass N-7465 Trondheim, Norway
[g]TRL, Old Wokingham Road Crowthorne Berkshire RG45 6AU, United Kingdom

[a] [nt;ln]@dgmr.nl

Abstract [276] The Harmonoise engineering method is developed for computation of long-term noise indicators L_{den} and L_{night}. Since sound propagation effects can strongly depend on meteorological conditions, the method must be able to handle different meteorological conditions that occur during a year. In order to obtain a more accurate description of the sources, a subdivision into subsources at different heights is necessary, distinguishing different physical mechanisms: rolling noise, traction noise and, for high speed trains, aerodynamic noise. Combining such comprehensive source and propagation models into an integrated method for use in complex 3-dimensional noise maps, a balance had to be found between the accuracy of computation versus computation speed, requiring optimization and simplification of algorithms. On the other hand, for continuity of the model, additional algorithms had to be developed to improve methods that have been developed merely for 'academic cases'. The Fresnel-zone weighting principle, adopted from the Nord2000 method, can even be extended to reflecting and diffracting obstacles with finite length. Algorithms have been developed for transformation of meteorological data into an equivalent ray curvature, depending on the direction of propagation and local geometry. The resulting engineering method is flexible in such a way that it can be used both for detailed computations in case of noise assessment and for noise mapping, requiring a higher speed of computations. This computation time is saved by reduction of input data, using the same calculation engine.

1 STRUCTURE OF THE HARMONOISE PROJECT

The HARMONOISE projects consists of 7 work packages. Work package 1 has been subdivided into WP1.1 for road sources and WP1.2 for railway sources. These work packages provide physical models for an acoustical description of individual, moving vehicles. In work package 2, a reference model for sound propagation is being developed, used for validation of point-to-point computations. Work package 4 provides empirical data from different measurement sites for validation of the engineering method in practical situations.

The integrated engineering method is being developed in work package 3. Its task is to combine the improved modeling of noise generation and propagation into an engineering method that can be used for noise assessment, action plans and noise mapping. This means that the method must balance between accuracy and efficiency.

2 THE ROAD AND RAILWAY SOURCE MODEL

In road and railway source modeling, one can distinguish *vehicle models* from *traffic models*. The outcome of work packages 1.1 and 1.2 can be considered a *vehicle model*, describing the sound power output of a single moving vehicle, distinguishing different physical mechanisms such as rolling noise, traction noise and aerodynamic noise.

Figure 1 shows a moving vehicle, passing over a road segment with length L.

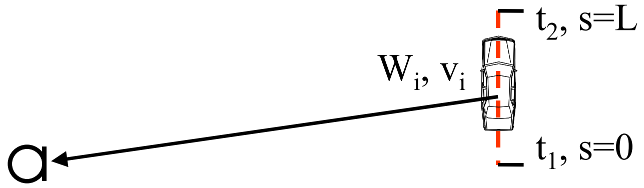

Figure 1: *sound exposure from a moving source*

Using $v_i(t) = ds_i/dt$, the sound exposure caused by a passing vehicle with sound power W_i can either be defined as a time integral or as a spatial integral [1]:

$$SEL_i = 10\lg \int_{t_1}^{t_2} \frac{W_i(t)}{W_0} A(t)\, dt = 10\lg \int_0^L \frac{W_i(s)}{W_0} A(s) \frac{ds}{v_i(s)} \tag{1}$$

where A is the total of all attenuation effects and L is the road segment length.

If we consider N events during a time interval T, road segment's contribution to the equivalent sound pressure level is given by:

$$L_{eq} = 10\lg \int_0^L \left(\frac{1}{T} \sum_{i=1}^{N} \frac{W_i(s)}{W_0 v_i(s)} \right) A(s)\, ds \tag{2}$$

In the integrated engineering method, the sound power of individual vehicles W_i in the *vehicle model* are combined into a *traffic model* yielding the equivalent sound power output *W'(s)* of a traffic flow consisting of N vehicles per unit time.

$$\begin{aligned} W'(s) &= \frac{1}{T} \sum_{i=1}^{N} \frac{W_i(s)}{v_i(s)} \\ L_{eq} &= 10\lg \int_0^L \frac{W'(s)}{W_0} A(s)\, ds \end{aligned} \tag{3}$$

The traffic model deals with the fact that on a certain road/railway-section, individual vehicles of different types may move at different speeds and under different driving conditions. The traffic model yields the sound power for the road/railway which is equivalent to the total noise emission of individual vehicles. Especially for urban roads (near intersections) and railways (near stations) these variations in vehicle speed and driving conditions can be significant.

For the definition of propagation paths from roads or railways, the source lines need to be split up into source segments, represented by mutually incoherent point sources. Such segmentation of noise sources can be done in several different ways, yielding different results

The aim for the engineering method is to have an unambiguous method of source segmentation, with sufficient accuracy, but without generating an unnecessarily large number of propagation paths. A typical case to consider is when the receiver is in line with (a part of) the source. This is illustrated by the example below, where a source line is segmented by a fixed viewing angle.

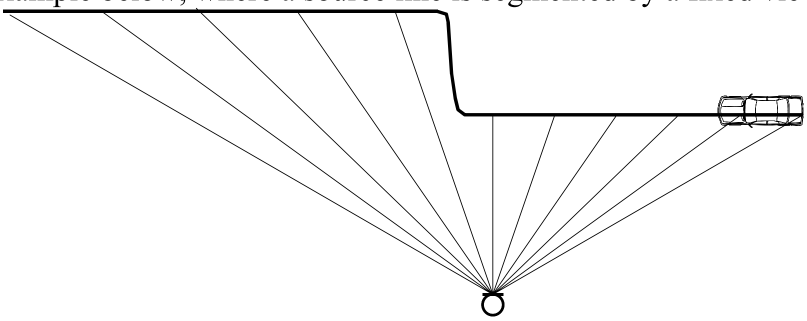

Figure 2: *example of fixed angle source segmentation*

Figure 2 shows that angular segmentation will lead to errors when a receiver is (approximately) in line with the source. On the other hand source segmentation by a fixed length may lead to a large number of remote point sources that have a small contribution to the total noise level. Therefore, the integrated engineering method uses a variable segment length, based on the 'optical length' of the source segment. This 'optical length' is a function of a standard viewing angle and the shortest distance between the source segment and the receiver [2].

3 THE NOISE PROPAGATION METHOD

The total noise attenuation is primarily composed of geometrical divergence, atmospheric absorption and excess attenuation. If reflected propagation paths occur, a correction is made for the effectiveness of each successive reflection.

Primarily, all computations are done by 1/3 octaves, but reduction into 1/1 octaves is considered to be an option for reduction of computation time.

The attenuation by atmospheric absorption is computed according to ISO 9613-1 [3], with ambient temperature, ambient pressure and relative humidity as input parameters.

The computation of excess attenuation can be considered as the major 'building block' of the engineering method. Although it is described in detail in [4], a brief outline is given in this paper as well.

For the computation of excess attenuation, the development of the Nord2000 prediction method [5] has proven to be very valuable. Several principles have been adopted from this method and some have been developed further. The method uses the model of Chien and Soroka [6] for computation of excess attenuation over flat, homogeneous ground, based on the spherical reflection coefficient Q. This principle has been extended to inhomogeneous ground by using Fresnel-weighting of contributions from different ground segments.

Diffraction effects are taken into account by the Deygout-approximation [7]. If multiple diffraction points occur, the convex hull is constructed over all diffracting edges. Secondary diffraction points below this hull are taken into account to a limited extend. Much attention has been paid to continuity of the model, e.g. in case of very low barriers on flat ground.

For convenience, the ‘curved ground-analogy’ [8] has been adopted by inverse curving of the terrain rather than curving sound rays for assessment of meteorological refraction.

3.1 Meteorological module

In the meteorological module, the radius of curvature is determined for each propagation path, based on wind speed, wind direction and a general description of the atmospheric stability in terms of the degree of cloud cover and period of the day.

For assessment of the meteorological refraction, a combined linear/logarithmic sound speed profile is assumed [9]:

$$c(z) = c_0 + A z + B \log\left(\frac{z}{z_0}\right) \tag{4}$$

in which both the linear coefficient A and the logarithmic coefficient B are composed of a thermal and an aerodynamic component.

$$\begin{aligned} A &= A_T + A_W \\ B &= B_T + B_W \end{aligned} \tag{5}$$

The four terms A_T, A_W, B_T and B_W have physical quantities such as the friction velocity, temperature scale, and Monin-Obukhov length as their basic input parameters. For convenience, default values are provided for (combinations of) 25 combinations of wind speed and atmospheric stability.

The linear term and the logarithmic term in equation (4) are each represented by a radius of curvature R_A and R_B. These are determined by simple approximations, based on an estimation of the maximum height of the ray path [10].

$$\begin{aligned} R_A &= \frac{A}{|A|}\sqrt{\left(\frac{c_0}{|A|}\right)^2 + \left(\frac{D_{sr}}{2}\right)^2} \\ R_B &= \frac{B}{|B|}\frac{1}{8}\sqrt{\frac{2\pi c_0}{|B|}}\, D_{sr} \end{aligned} \tag{6}$$

Where c_0 is the atmospheric sound speed and D_{sr} is the horizontal distance between the source and receiver. Both curvatures are combined into a single “equivalent ray curvature”.

$$\frac{1}{R} = \frac{1}{R_A} + \frac{1}{R_B} \tag{7}$$

Obstacles such as buildings and forests disturb the sound speed profile in open terrain, given by equation (4). Therefore, a correction is applied to the maximum ray path height for “mesoscale” meteorological effects.

3.2 Reflected propagation paths

For a reflected propagation path, the contribution to the noise level is corrected for the effective energy reflection coefficient of the obstacle and for the size of the reflecting surface S_{refl} relative to the Fresnel-zone S_{Fz}. The Fresnel-zone is defined by the intersection between the plane of reflection and the Fresnel ellipsoid around the sound ray from the image source to the receiver.

$$A_{refl} = 10\,\log(\rho_E) + 20\,\log\left(\frac{S_{refl}}{S_{Fz}}\right) \tag{8}$$

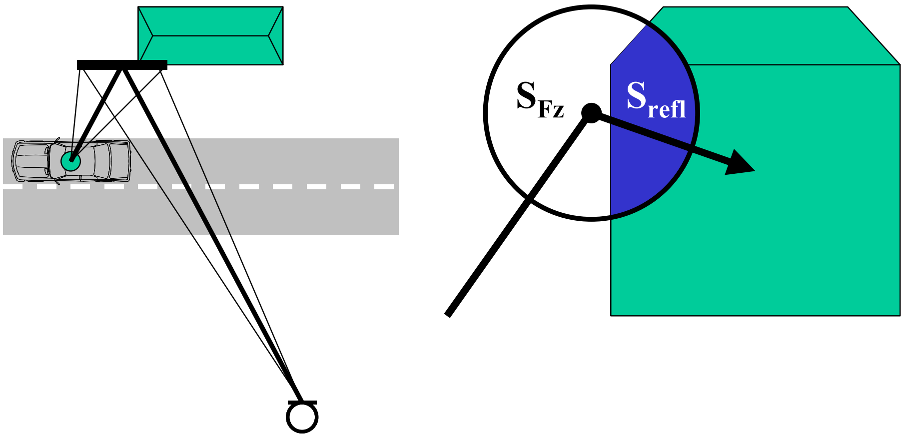

Figure 3: *size of the reflecting surface relative to the Fresnel-zone*

4 COMPUTATION OF LONG TERM AVERAGE NOISE INDICATORS

For the calculation of the yearly average noise indicators L_{den} and L_{night}, the engineering method must take the dynamic characteristics of both noise emission and noise propagation into account. Simulations [11] have pointed out that for each source-receiver pair, variations in the excess attenuation can be described as a function of the resulting relative sound speed gradient *a* as shown in figure 4.

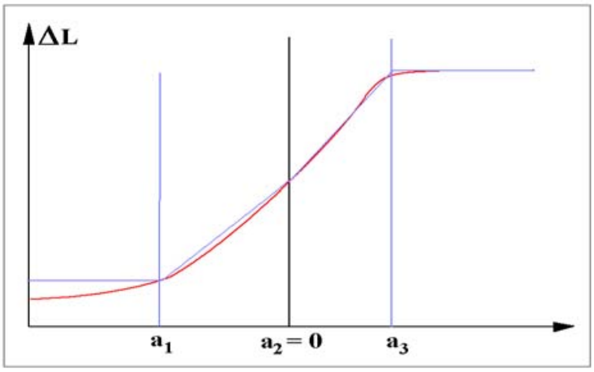

Figure 4: *typical behaviour of excess attenuation as a function of the relative sound speed gradient*

This implies that if three representative values for the ray curvature can be found (strongly favourable to sound propagation, strongly unfavourable and neutral), all noise levels can be derived by interpolation. The long-term average noise level is obtained by combining the noise levels under specific meteorological conditions with their relative occurrence and the corresponding sound power output of the sources.

5 VALIDATION OF THE METHOD

Validation of the method is done at different levels. As a major 'building block', the point-to-point excess attenuation has been compared with reference computations in over 25,000 geometries for homogeneous meteorological conditions. Using a standard road traffic source spectrum, the results are evaluated on dB(A) level. Examples of validation results are shown in figures 5 and 6. A full presentation of the comparisons is given by [12] and [13].

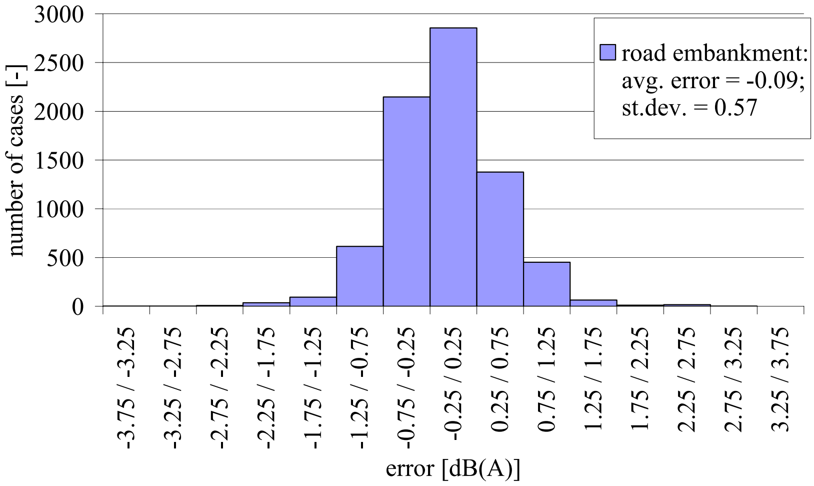

Figure 5: *Histogram of the difference between reference computations and P2P-results for the 'road embankment' (reflective ground near the source)*

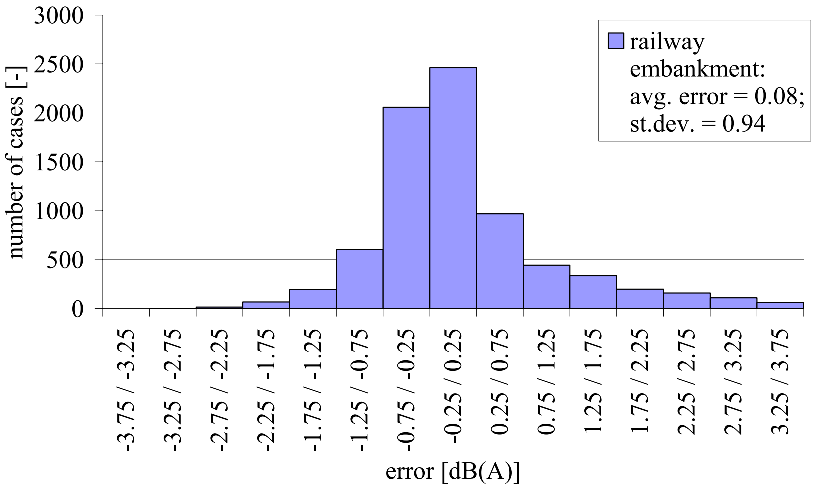

Figure 6: *Histogram of the difference between reference computations and P2P-results for the 'railway embankment' (absorbing ground near the source)*

For cases with meteorological refraction, close to 900 geometries have been defined. Since these geometries comply with those without meteorological refraction, the accuracy of the meteorological module can be evaluated separately.

As the second level for validation, 20 three-dimensional maps have been defined for comparison with the WP2 reference model. Not only direct propagation from the source to the receiver, but also reflected contributions to the total noise level are taken into account. By averaging over a number of meteorological events and by simulation of a traffic flow, the validation will be done by L_{den}.

The validations that form the biggest challenge will be carried out based on empirical data from 7 test sites in Germany and France. Both railway noise and road traffic noise measurements will be evaluated, making it possible to validate the source models as well. Again, the validation will be done by L_{den}.

6 CONCLUSION

The HARMONOISE engineering method combines the physical description of road and railway sources with a flexible and thoroughly validated propagation model. It includes a meteorological module that is based on similar lin-log sound speed profiles as used in reference models.
Solutions have been chosen such that discontinuities in the computed noise levels, that may occur by small changes in the geometry, are avoided.

The method is developed for both detailed studies and for large scale three-dimensional modelling. Optimizations and validations of the method are still under study, in order to increase the computation speed without unacceptable loss of accuracy.

REFERENCES

[1] D. Van Maercke, HAR31MO-020930-CSTB01 “Source description & integrated models”, 2002.

[2] R. Nota and R. Hordijk, HAR30MO-031007-DGMR01 “Noise source segmentation”, 2002.

[3] ISO 9613-1:1993(E), “Acoustics - Attenuation of sound during propagation outdoors- Part 1: Calculation of the absorption of sound by the atmosphere”, 1993.

[4] D. Van Maercke, “Fast and accurate prediction of outdoor noise propagation in the Harmonoise engineering model” in *Proceedings of Internoise 2004*, Prague, 2004, paper n. 475.

[5] B. Plovsing and J. Kragh, “Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 1: Propagation in an Atmosphere without Significant Refraction”, DELTA Acoustics & Vibration Report AV 1849/00, Lyngby 2001.

[6] C. F. Chien and W. W. Soroka, “A note on the calculation of sound propagation along an impedance boundary”, *J. Sound and Vibration* **69**, pp. 340-343 (1980).

[7] J. Deygout, “Multiple knife-edge diffraction by microwaves”, *IEEE Trans.Antennas Propagat.* **14**(4), pp. 480-489 (1966).

[8] M. Almgren, “Simulation by using a curved ground scale model of outdoor sound propagation under the influence of a constant sound speed gradient”, *Journal of sound and Vibration* **118**(2), pp. 353-370, (1987).

[9] D. Heimann, HAR25MO-031121-DLR01 “A unified meteorological classification”, 2003.

[10] D. Van Maercke, “Meteo effects in the engineering model”, 2004.

[11] P. Hernandez, “How to calculate day/evening/night weighted yearly average of road traffic sound pressure levels”, *SP Rapport* **2003:03**, 2003

[12] D. Van Maercke, F. Gaudaire, N.Noe, “Harmonoise WP3: integrated model. Test case3: 3-Plane valley”, 2003.

[13] R. Nota, HAR30MO-040428-DGMR02 “ Comparison of the engineering model with reference results”, 2004.