



User's Guide Nord2000 Road



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Foreword

In 1996 the Nordic Council of Ministers decided to initiate the development of a new generation of prediction methods for environmental noise utilising scientific development having taken place since the first Nordic methods were published in the 1970s and 1980s.

The idea was to develop a general sound propagation model and to establish source-specific prediction methods for road and rail traffic and other types of environmental noise sources. All prediction methods should be based on the same general propagation model.

The sound propagation model should be applicable for computing the sound pressure level caused by a point source, in one-third octave bands, in every normal type of weather. In the earlier models the noise levels – for historical reasons – were computed for different specific weather conditions. The new model should allow for all types of environmental noise to be computed for the same weather conditions.

Sound propagation over complicated terrain should be dealt with in the new model by means of an explicit procedure that would enable all users of the model to reach at the same result in a specific case. Earlier models take a skilled user to interpret an actual terrain profile and represent it properly in the model. Such “subjective” methods inevitably lead to unwanted variation in results obtained by different users.

The old Nordic prediction method was last revised in 1996 and has been in official use for almost 20 years. It was based on research carried out in the 1970s. Although it was revised twice, the major structure has remained unchanged. Nord2000 Road described in this User's Guide is a completely new method, and in principle there are no links to the old method. Both source data and propagation model are new. The new source model distinguishes between tyre/road noise and propulsion noise, and the new propagation model allows computations for a variety of weather conditions.

Nord2000 Road is significantly better than the old method. It can handle computation in situations where the old model was not applicable, it gives results in frequency bands, and noise levels can be computed for various weather conditions, and thus yearly average noise levels can be accurately computed.

Subsequent to the completion in 2001 of the original work on Nord2000 the source and propagation models have been adjusted in a few places. Features have been taken over from the source model of the European Harmonoise project which demonstrated that it was possible to separate tyre/road noise and propulsion noise and that it was good enough



to work with two point sources to describe a road vehicle. This new source model has been adapted and fitted to available Nordic source data.

Nord2000 Road is the first official Nordic prediction method applying the new generation of methods. The easiest way to get familiar with its behaviour is to exercise the type case software developed by SINTEF. Commercial software is expected to be available within a short time.

Although great care has been taken to test the method, errors or lack of clarity will undoubtedly be detected. Users are encouraged to inform their national road authority.

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1. Introduction

The present User's Guide is intended for persons wanting to run computations of road traffic noise levels applying software working in accordance with Nord2000 Road, the new Nordic method for predicting road traffic noise.

Software developed by SINTEF is available for type case computation. For 30 different type cases the user can compute various noise metrics after having defined the traffic and weather conditions.

Nord2000 Road is documented in the reports listed below. These reports are indispensable for developers of software for computation according to Nord2000 Road.

- H. G. Jonasson, *Acoustic Source Modelling of Nordic Road Vehicles*, SP Rapport 2006:12, Energy Technology, Borås 2006
- 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, revised Hørsholm 2006
- B. Plovsing and J. Kragh, *Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 2: Propagation in an Atmosphere with Refraction*, DELTA Acoustics & Vibration, Report AV 1851/00, revised Hørsholm 2006
- R. Eurasto, *Nord2000 for road traffic noise prediction. Weather classes and statistics*, VTT Research Report No. VTT-R-02530-06, Esbo 2005
- The present User's Guide

Equations for graphs in this User's Guide are given in the reports above.

1.1 What Can Be Calculated?

Nord2000 Road can be used to calculate L_{eq} , overall A-weighted or in frequency bands, for any combination of road vehicles provided input data are available. The maximum sound pressure level corresponding to time weighting F can be calculated, from individual vehicles or combinations of vehicles at specified positions. However, the prediction method does not give statistical methods to calculate maximum levels from passing groups of vehicles.

The assessment points should be chosen in accordance with the recommendations in [1].

The prediction method separates tyre/road noise from propulsion noise. Thus, the method can be used to estimate the effect of changing road surface or tyres. For the most common types of road surfaces default values are given. It is also possible to calculate the effect of studded tyres and of vehicle acceleration and to correct the tyre/road noise generation for



variation in air temperature. The method distinguishes between medium heavy and heavy vehicles and introduces the number of axles of heavy vehicles as an input parameter.

The prediction method can handle various uncomplicated weather conditions whereas very strong or varying wind gradients as well as layered atmospheric conditions have been excluded. By combining results from different weather conditions, it is possible to calculate yearly average noise levels such as the L_{den} and L_{night} prescribed in the European directive on environmental noise.

The prediction method can handle any number and any combination of varying ground conditions with and without screens. The algorithms have been limited to two screens. The screens can be thin or thick with any shape.

The prediction method does not specifically deal with indoor noise. No special guidelines or data on the sound insulation of windows or facades are given. However, provided that sound insulation data are known, indoor sound pressure levels can be calculated from standard building acoustic formulae because all calculations in Nord2000 Road are carried out in one-third octave bands.

1.2 What Input Data Are Needed?

To predict $L_{Aeq,T}$ the *traffic intensity* during the time interval T must be known as well as its *speed* and *composition* (that is the percentage of different vehicle categories). It is also necessary to know the type of *road surface* and the *temperature* to be used in the calculations. To compute L_{den} the above-mentioned data must be available for each of the periods day, evening, and night.

Information is needed on the *local topography* (terrain shape, screens/buildings, and ground surface types, including the road surface).

Section 3 gives guidelines on the input data needed.

Computations can be made for specific weather conditions or long-term averages can be computed by combining results obtained for specific conditions taking into account how often these conditions occur.



1.3 How Can Input Data Be Obtained?

Data on the traffic can often be supplied by road authorities. Care shall be taken that authorities define vehicle categories in accordance with the definitions of the present prediction method. In case no information is available, default data given in the present User's Guide may be useful.

Topographical information (terrain profile and ground surface type) is obtainable from digital maps/geographical information systems. Data can be imported into computation software.

Weather statistics are available from national road authorities.



2. Noise Levels that Can Be Computed with Nord2000 Road

Due to its ability to deal with noise levels during a variety of weather conditions, Nord2000 Road is suited for computing different kinds of noise levels.

2.1 Equivalent Sound Pressure Level L_{Aeq} under Specific Weather Conditions

The equivalent sound pressure level $L_{Aeq,T}$ for the time period T can be computed for specific weather conditions such as for example slightly downwind.

2.2 Long-Term Average Noise Level

Long-term average noise levels are determined by computing the noise levels under the specific conditions occurring during the time period considered and then combining them into the average value.

According to the European directive on environmental noise [2] the yearly average values of L_{den} and L_{night} are mandatory indicators to be applied to strategic noise mapping.

The A-weighted long-term average day-evening-night noise level L_{den} is defined as

$$L_{den} = 10 \cdot \lg \frac{1}{24} \left\{ T_d \cdot 10^{\frac{L_{day}}{10}} + T_e \cdot 10^{\frac{L_{evening} + 5}{10}} + T_n \cdot 10^{\frac{L_{night} + 10}{10}} \right\} \quad (1)$$

where T_d , T_e , and T_n are the durations of the day, evening and night, respectively [h], and L_{day} , $L_{evening}$, and L_{night} are the A-weighted long-term average noise levels for the day, evening, and night period, respectively.

The day, evening, and night periods shall be defined by each Member State. Some definitions are given in Table 1.

Table 1

Definitions of day, evening and night for use when calculating L_{den} in the Nordic countries.

	Denmark (DK)	Finland (FI)	Norway (NO)	Sweden (SE)
Day	07-19	07-19	07-19	06-18
Evening	19-22	19-22	19-23	18-22
Night	22-07	22-07	23-07	22-06

The noise level for each of the time periods shall be averaged over all meteorological variations and sound emission variations that occur during the time period considered throughout a representative year.

2.3 Contributions from Other Roads or Lanes

When the software is only able to compute the noise level from one road or lane, then a manual addition of noise levels from the traffic in different lanes or on different roads can be made using Eq. (2) or Figure 1.

$$L_{Aeq,tot} = 10 \cdot \lg \left[10^{\frac{L_{Aeq,1}}{10}} + 10^{\frac{L_{Aeq,2}}{10}} \right] \quad (2)$$

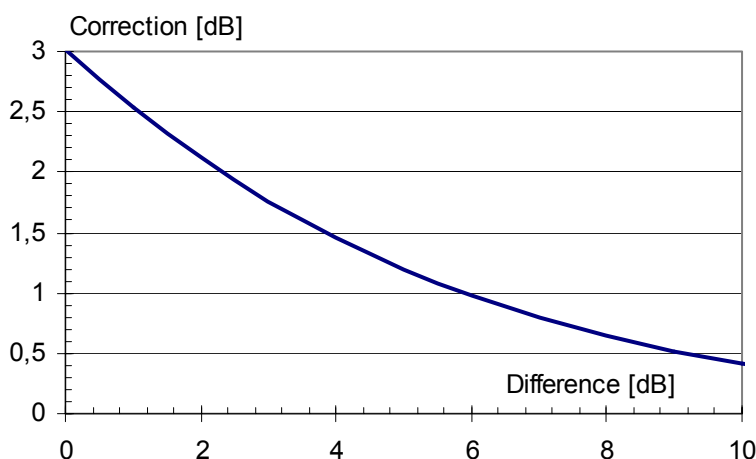


Figure 1

Adding noise levels: Add a correction to the highest noise level.

Example: $L_{Aeq,1} = 53$ dB; $L_{Aeq,2} = 47$ dB; Difference = 6 dB; Correction = 1 dB; $L_{Aeq,tot} = 53 + 1 = 54$ dB

2.4 Maximum Noise Levels

Also the maximum noise level L_{AFmax} with time weighting F during the pass-by of an individual vehicle can be computed.

At present this metric is not applied to road traffic noise in Denmark and Finland. In Norway it is defined as the level exceeded by the noise from 5% of the vehicles in the actual category. In Swedish regulation the requirement is that a certain value of L_{AFmax} must not be exceeded more than a certain number of times during a specified time period. Procedures for determining these maximum noise levels are described in Section 4.1.



3. Input Parameters

3.1 Traffic and Road

3.1.1 Source Positions

In Nord2000 Road a vehicle is represented by noise sources situated at different heights (0.01 m, 0.30 m, and 0.75 m). The sound power level of each source is calculated using equations with input parameters selected by the user. The sound power contributions are derived from tyre/road noise and propulsion noise. Heavy vehicles with high exhaust have an extra source at 3.5 m height. The horizontal position of all sources is presupposed to be at 1 m from the vehicle centre line, in the direction to the receiver.

3.1.2 Traffic Intensity

The input parameter is the total number of vehicles per lane per unit of time.

3.1.3 Traffic Composition and Vehicle Parameters

If more reliable data are not available, the default parameter values given below may be applied. The default traffic composition, vehicle speed, and traffic distribution are based on, but not identical with, available data from the Nordic countries. Analyses have shown that the variation between data from different countries only leads to minor differences in computed noise levels taking the expected accuracy into consideration.

3.1.4 Traffic Composition

The percentage of each category of vehicle (or the number of vehicles per category per unit time) is an input parameter in Nord2000 Road.

The vehicle categories in Nord2000 Road are summarized in Table 2. Category 1 includes cars and delivery vans. The categories in the table are operational definitions often used in traffic counts and noise prediction. When collecting data on vehicle noise emission, the classification in Table 16 (in Appendix 3) should be used.

Table 2

Short form characterization of the categories of vehicles in Nord2000 Road.

Vehicle category no.	Short description	Maximum gross weight [kg]	Vehicle length [m]	Characteristics
1	Light	3,500	< 5.5	Additional input parameters: Studded tyres Wet surfaces
2	Medium	3,500 - 12,000	5.6 – 12.5	2 axles, 6 wheels
3	Heavy	> 12,000	> 12.5	3 or more axles Additional input parameter: Average no. of axles

When more reliable data are not available, the default values of the percentage heavy vehicles in Table 3 may be applied. These data are not representative of roads with special traffic such as heavy transport of wood in parts of Finland or Sweden.

Table 3

Default traffic composition on various types of road.

Traffic case	Description	Composition [%]		
		Cat. 1	Cat. 2	Cat. 3
A	Motorway 100-130 km/h	85	5	10
B	Urban motorway	85	5	10
C	Main road 80-90 km/h	85	10	5
D	Urban road 60-70 km/h	90	5	5
E	Urban road 50 km/h or feeder road in residential area	95	5	0
F	Residential road 30-40 km/h	100	0	0

3.1.5 Vehicle Speed

The average vehicle speed per category is an input parameter in Nord2000 Road. Default average speeds are given in Table 4. These data were used in the type case computations [3] to limit the number of cases, and they do not necessarily represent the actual average speed on an individual road in a certain class. When known, the actual average speed should be used.

Table 4
Default average vehicle speed on various types of road.

Traffic case	Description	Speed [km/h]		
		Cat. 1	Cat. 2	Cat. 3
A	Motorway 100-130 km/h	120	90	90
B	Urban motorway	90	85	85
C	Main road 80-90 km/h	85	75	75
D	Urban road 60-70 km/h	70	65	65
E	Urban road 50 km/h or feeder road in residential area	50	50	50
F	Residential road 30-40 km/h	35	35	35

3.1.6 Traffic Distribution on Time of Day

The number of vehicles or the percentage of the traffic (per category; per lane when needed) during the day, evening, and night, respectively, are input parameters in Nord2000 Road. Default traffic distributions are given in Table 5. Different definitions of day, evening, and night apply in the Nordic countries, so the given default data cannot be valid everywhere. When actual data are available, these should be used.

For computation of $L_{eq,24h}$ the diurnal traffic distribution is not relevant.

Table 5
Default traffic distribution on day, evening, and night on various types of road.

Traffic case	Description	Distribution Cat. 1 [%]			Distribution Cat. 2 [%]			Distribution Cat. 3 [%]		
		Day	Eve.	Night	Day	Eve.	Night	Day	Eve.	Night
A	Motorway 100-130 km/h	80	10	10	75	10	15	70	10	20
B	Urban motorway	80	10	10	75	10	15	70	10	20
C	Main road 80-90 km/h	80	10	10	85	5	10	80	5	15
D	Urban road 60-70 km/h	80	10	10	85	5	10	75	10	15
E	Urban road 50 km/h or feeder road in residential area	80	10	10	85	5	10	75	10	15
F	Residential road 30-40 km/h	80	10	10	85	5	10	75	10	15

3.1.7 Road Surface

Recent investigations have shown that the sound power levels of vehicles in the Nordic countries are not identical. The coefficients given in [4] specifying the sound power levels of tyre/road noise refer to the following reference conditions:

- Road surface: Average of dense asphalt concrete (DAC 11) and stone mastic asphalt (SMA 11) with maximum aggregate size 11 mm, at an age of more than 2 years, but not at the end of its life span
- Air temperature: 20°C
- Country: DK (FI, NO, and SE have an additional road surface correction)

For all other cases corrections have to be made, and further input is required.

For normal asphalt road surfaces the input parameters in Nord2000 Road are:

- 1) Country (DK, FI, NO, or SE)
- 2) Maximum aggregate size (*D*)
- 3) Dense asphalt concrete (DAC) or stone mastic asphalt (SMA)
- 4) Air temperature

For these surfaces there is no correction for age unless one wants to correct for surface age less than two years. The corrections $\Delta L_{\text{surface}}$ given below are frequency-independent corrections valid at all vehicle speeds. The correction in Figure 4 for porous surfaces is valid where studded tires are not used.

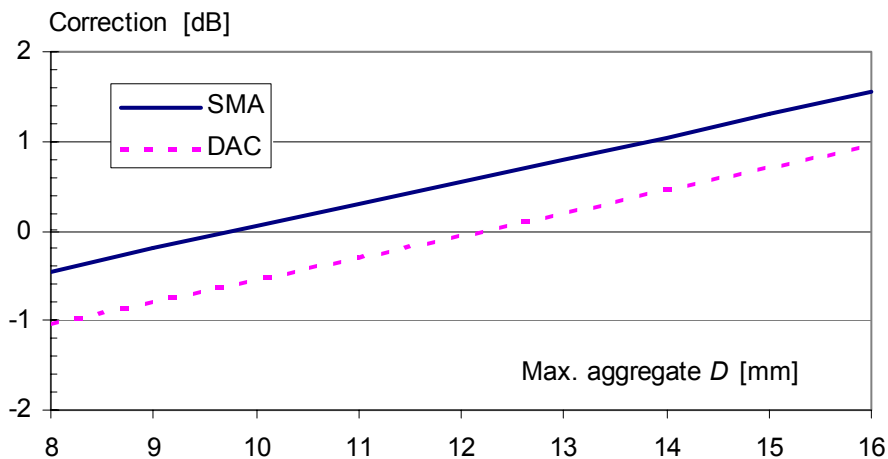


Figure 2
Correction $\Delta L_{\text{surface}}$ for maximum aggregate size.

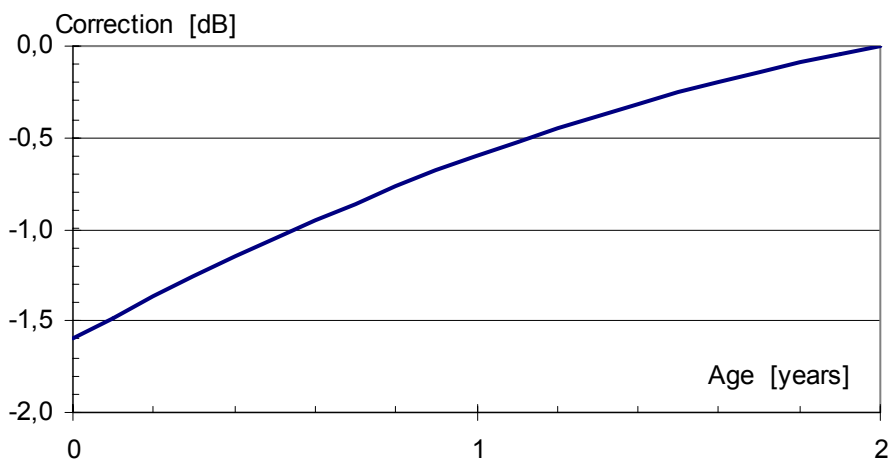


Figure 3
Correction $\Delta L_{\text{surface}}$ for DAC or SMA surface aged less than 2 years.

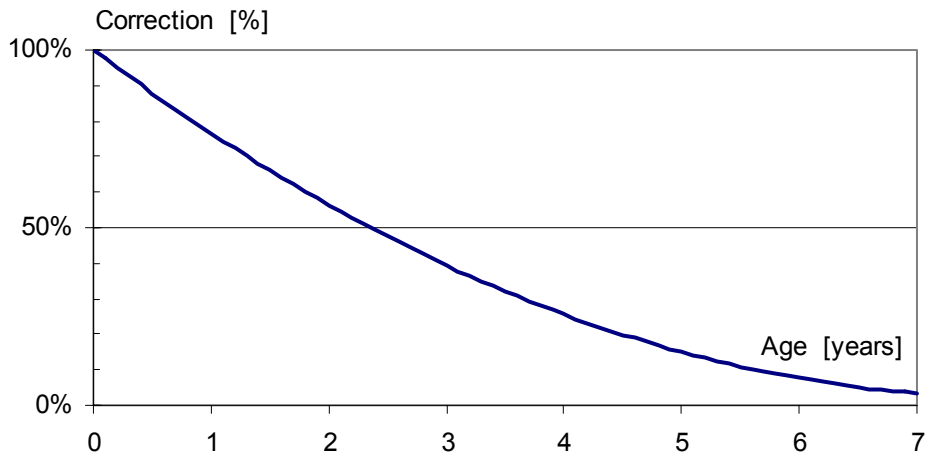


Figure 4
Correction $\Delta L_{surface}$ for porous surface age = the percentage of its original dB-value at the new surface. Valid for roads where studded tyres are not used.

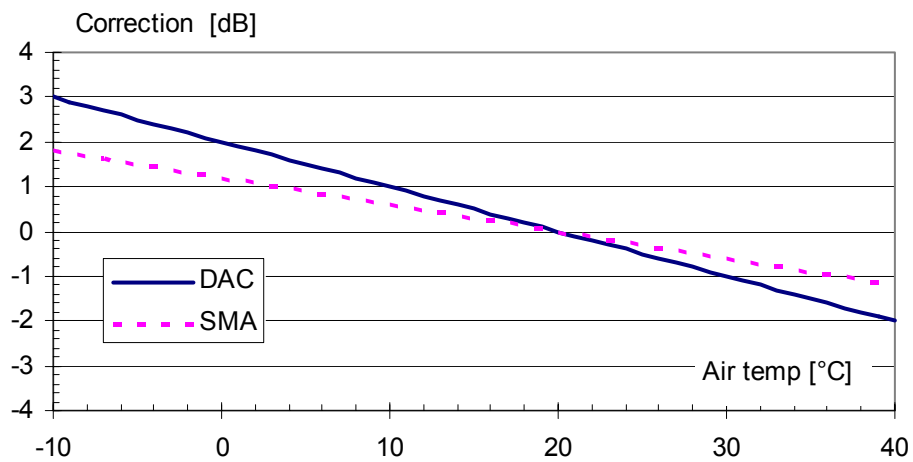


Figure 5
Correction $\Delta L_{surface}$ for air temperature.

It is also possible to input user-defined road surfaces yielding a correction $\Delta L_{surface}$ in relation to a defined road surface among the normal DAC and SMA surfaces with maximum aggregate size in the range 8-16 mm. This correction may be different for light and heavy vehicles, cf. Appendix 2.

For some other road surfaces typical corrections $\Delta L_{surface}$ are given in Table 6. These corrections are valid in cases where studded tyres are not used. There is a need for determining corrections for more types of road surface.

Table 6
Examples of $\Delta L_{surface}$ [dB] from [5].

Road surface type	Identifier	Vehicle category no.	
		1	2 or 3
Asphalt concrete	DAC 11	0	0
Porous asphalt 0/08, less than 3 years	PAC 8	-5.8	-3.7
Porous asphalt 0/11, less than 3 years	PAC 11	-3.1	-3.7
Porous asphalt 0/16, less than 3 years	PAC 16	-2	-3
Cement concrete, longitudinally brushed	CCB lo	1.3	1.7
Cement concrete, transversely brushed	CCB tr	3.7	2.1
Even pavement stones	PS even	3	2
Uneven pavement stones	PS uneven	6	4

The road surface corrections described above are typical values, and they are not necessarily correct in a given situation. The values have been simplified to be speed- and frequency-independent, and there will be a certain spread in data from one site to another.

The road surface affects the sound propagation, and its acoustic impedance is needed. For porous road surfaces it should be determined by measurement in each case. When no better information is available, the default values in Table 7 may be used.

Table 7
Default values of road surface impedances.

Type of road	Flow resistivity [kPas/m ²]
Very hard road surface	200,000
Normal road	20,000
ISO surface	2,000
Porous road	Hamet model [6]

Temperature affects the generation of tyre/road noise, and the air temperature is an input parameter. For computing yearly average noise levels the mean temperature per meteorological class shall be used. These temperatures are available from national road authorities.

For information some yearly average temperatures are given in Table 8.

Table 8
Yearly average temperatures.

Country	Yearly average air temperature [°C]		
	Day	Evening	Night
DK	9	8	6
FI	N/A ¹⁾	N/A ¹⁾	N/A ¹⁾
NO	N/A ²⁾	N/A ²⁾	N/A ²⁾
SE ³⁾ Range	7.4 -2 - +9	7.0 -3 - +8	4.8 -5 - +6

¹⁾ The yearly average air temperature in Finland (1971-2000): northern part: -2 - 0°C; central part: +1 - +2 °C; southern part: +5 °C

²⁾ The yearly average daily temperature is 1.0°C, the range is -0.5 - +3.7 °C depending on region.

³⁾ The averages given are for Stockholm; the ranges show the variation between regions.

Corrections may be made to take into account the influence of a film of water on the road surface [4]. This correction is valid for light vehicles only, and it has not been possible to show a similar relationship for heavy vehicles. In order for this correction to be applied, it is not enough that the surface looks wet. It literally has to be covered with a distinct film of water.

3.1.8 Driving conditions

All default sound power coefficients in [4] refer to free-flowing traffic at constant speed. The propulsion noise from Category 2 and 3 vehicles can be corrected for acceleration/deceleration on long road gradients according to Figure 6. In urban traffic and start/stop situations the propulsion noise should be corrected with +3 dB.

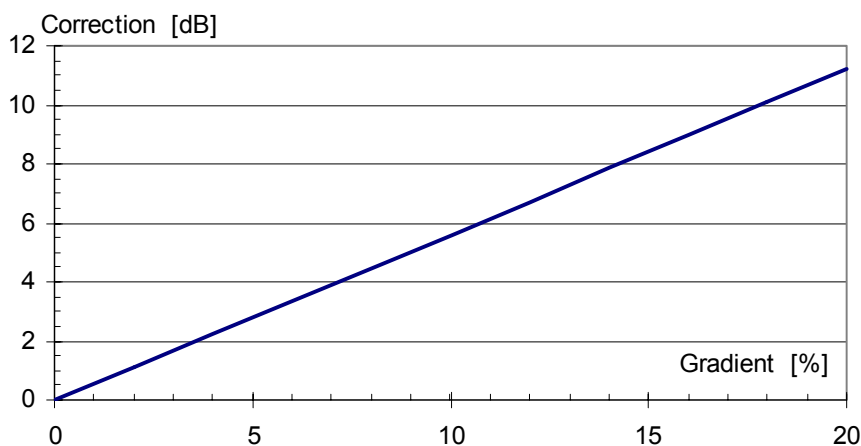


Figure 6
Correction of propulsion noise from Category 2 and 3 vehicles on long gradients.

3.2 Propagation

3.2.1 Computation Point Height

The computation point (receiver) height is the height above the local terrain. Guidelines, regional or national, if any, will decide the height of the computation point. If no such rules exist, use the following:

- 1) 4 m outdoors according to the European directive on environmental noise [2]
- 2) Recommended height: 1.5 m above ground, for use in outdoor recreational areas and in areas with one-storey housing. The EU Directive [2] allows the noise level at a height of 1.5 m as an additional indicator.
- 3) Reference for indoor levels: 2 m above floor level or $\frac{2}{3}$ up the window; whatever is highest.

3.2.2 Propagation Path

The attenuation of sound during propagation along the path from source to receiver depends on the shape of the terrain and on the ground type (impedance) and terrain roughness [7]. The attenuation also depends on the weather conditions as described in Section 3.2.3 and in [8].

Simplification of Terrain

In Nord2000 Road the prediction of the sound pressure level at the receiver is based on the vertical terrain cross section from source to receiver simplified to a broken line (a chain of straight-line segments). Figure 7 shows how such a segmented terrain may look for three categories of non-flat terrain.

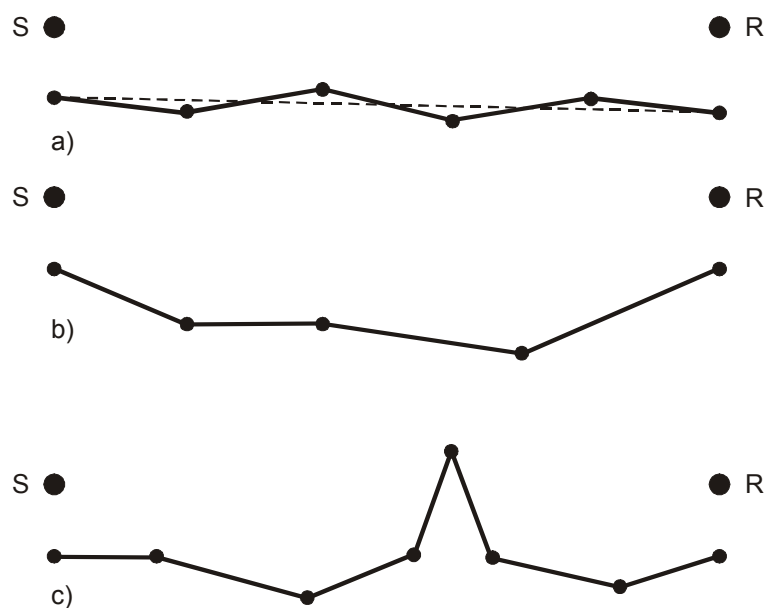


Figure 7
Examples of segmented terrain: a) moderately non-flat terrain, b) valley-shaped terrain, c) terrain with a screen.

The way for the user to define the propagation path depends on the type of software used for the calculation. It is not possible to foresee all user interfaces of software, but most likely the procedure will depend on whether the software is single receiver software or mapping software.



Single Receiver Software

It is presupposed that in single receiver software the user shall (“manually”) define the vertical terrain cross section from the road to the receiver. The user may have to simplify the terrain profile into the broken line representation and assign a ground surface type and a ground roughness to each segment.

The user shall input parameters to define the terrain cross section as illustrated in Table 9. Each row corresponds to a point of discontinuity in the terrain profile (the beginning or end point of a straight-line segment). Such a point is assigned a horizontal distance x , a vertical height z , a ground type GT , and a ground roughness GR . GT and GR represent the surface properties of the line segment from the point to the next point (with a higher index). The first point is below the source and the last point below the receiver. The values of x shall be in ascending order.

Table 9

Terrain definition for a terrain with $n-1$ straight-line segments (corresponding to n segment beginning/end points).

Ground point no.	Distance x	Height z	Ground type	Ground roughness
1	x_1	z_1	GT_1	GR_1
2	x_2	z_2	GT_2	GR_2
...
$n-1$	x_{n-1}	z_{n-1}	GT_{n-1}	GR_{n-1}
n	x_n	z_n	-	-

Mapping Software

In mapping software the vertical terrain cross sections are automatically determined from a digital terrain model and then simplified by the software. The task of the user is to find and import digital terrain data or to digitize terrain contours if such data lack. Ground surface types are most likely to be included by defining areas with a specified ground surface type and areas with a specified ground roughness. The rest is taken care of by the software.



Ground Type

The ground surface type is defined by the flow resistivity of the ground surface. The ground type may be specified directly by the flow resistivity or indirectly by using the classes *A* to *H* defined in Table 10.

In simplified computations where it is possible only to distinguish between “soft” and “hard” ground, it is recommended to use the ground types *D* and *G*, respectively. The road is represented by ground type *G* in such calculations.

Table 10
Classification of ground type.

Impedance class	Representative flow resistivity σ [kPas/m ²]	Description
<i>A</i>	12.5	Very soft (snow or moss-like)
<i>B</i>	31.5	Soft forest floor (short, dense heather-like or thick moss)
<i>C</i>	80	Uncompacted, loose ground (turf, grass, loose soil)
<i>D</i>	200	Normal uncompacted ground (forest floors, pasture field)
<i>E</i>	500	Compacted field and gravel (compacted lawns, park area)
<i>F</i>	2,000	Compacted dense ground (gravel road, parking lot, ISO 10844 asphalt)
<i>G</i>	20,000	Hard surface (most normal asphalt)
<i>H</i>	200,000	Very hard and dense surface (dense asphalt, concrete, water)

Absorbing Screen

A screen is a part of the terrain cross section. The properties of a sound-absorbing screen are classified according to EN 1793 [9]. The sound absorption class can be translated into an equivalent flow resistivity or Nord2000 Road ground class using Table 11.



Table 11
Flow resistivity class of sound-absorbing screens.

Screen class no.	Attenuation of reflected sound [dB]	Flow resistivity [kPas/m ²]	Recommended Nord2000 Road class
A0	Not tested	200,000	<i>H</i>
A1	< 4	20,000	<i>G</i>
A2	4 - 7	250	<i>D</i>
A3	7 - 11	80	<i>C</i>
A4	> 11	40	<i>B</i>

Ground Roughness

In Nord2000 Road each segment of the terrain profile is assumed to be perfectly flat. In most cases this is a reasonable assumption when a real terrain has been appropriately approximated by a segmented terrain. However, in some cases the terrain height may fluctuate strongly along a segment. These fluctuations are supposed to take place within a short range, otherwise the terrain profile should be further subdivided. Such fluctuation can be handled in Nord2000 Road by specifying a ground roughness (unevenness). The ground roughness is the rms-value¹⁾ of the ground height fluctuations within the segment. The ground roughness should be represented by one of the four classes shown in Table 12 based on an estimate of the range of height fluctuations.

The method for including ground roughness in Nord2000 Road has not yet been validated, and it is recommended to use class *N* unless accuracy is known to be improved by using class *S*, *M*, or *L*.

¹⁾ The square root of the sum of the squared terrain height deviations from the linear segment.

Table 12
Classification of ground roughness.

Roughness class	Description	Ground roughness [m]	Range of heights [m]
<i>N</i>	Nil	0	±0.25
<i>S</i>	Small	0.25	±0.5
<i>M</i>	Medium	0.5	±1
<i>L</i>	Large	1	±2

Reflections and Screens of Finite Length

In order to take into account reflections from vertical surfaces, propagation paths additional to the direct path from source to receiver may be included. The reflected path is from the source via the reflection point to the receiver. The terrain cross section is defined along the broken propagation path in the same way as for the direct path, but a correction for the efficiency of the reflector shall be included in the computation.

Similarly, for transmission around the edges of a screen of finite length, two additional propagation paths from the source via the vertical screen edge (left or right) to the receiver include the contribution from sound propagating around the vertical edges. The terrain cross section is defined along the broken propagation path, and the screening effect of the vertical edges shall be included.

Single receiver software normally can neither include contributions from reflecting surfaces nor sound propagating around the vertical edges of a finite screen. In case it can do so, the characteristics of the reflecting surface shall be taken into account as described below.

Mapping software automatically should detect vertical surfaces which may contribute to the sound pressure level at the receiver. For each reflecting surface the characteristics of the reflecting surface shall be defined by the energy reflection coefficient given in Table 13 unless more accurate data are available.



Table 13
Examples of energy reflection coefficients ρ_E

Characteristics of reflecting surface	ρ_E -
Plane and acoustically hard surface (concrete, stone, brick wall, metal sheets)	1.0
Non-absorbent building facades with windows and small irregularities, dense wooden panels	0.8
Factory walls with 50% of the surface consisting of openings, installations or pipes	0.4

In mapping software the number of reflections most likely is a parameter controlled by the user. The number of reflections is defined as the maximum order of reflections (the number of times the sound field is reflected). This maximum order is a balance between accuracy and computation time. Fifth order reflections are considered the “ideal” choice in strongly reflecting environment, but for mapping purposes to include fifth order reflections would require too much computation time. It is recommended to include up to third order reflections. Less than third order should only be used in rough estimation.

Mapping software should automatically include contributions from additional propagation paths around the vertical edges of a finite screen.

Scattering Zones

With Nord2000 Road it is possible to predict the propagation effect of “scattering zones” which are urban areas or vegetation. In urban areas the sound propagation is influenced by multiple reflections, diffuse scattering by irregularities of building facades, diffraction at house corners, and absorption by buildings and ground surfaces. In vegetation the sound propagation is influenced by reflections, scattering, and absorption due to trunks, branches, and foliage. In such areas, sound propagation is too complicated for a detailed calculation, and it is necessary to use a statistical scattering model.

The effect of a scattering zone depends on the length of the ray path through the scattering zone as shown in Figure 8 and on the density and size of the scattering objects and their reflection coefficients [10].

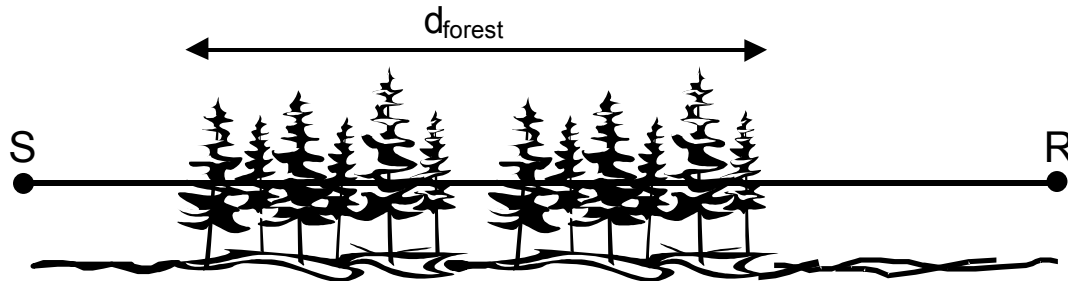


Figure 8
Ray path through a forest.

To determine the effect of scattering in a housing area the following input data are needed: the fraction of the plan area of all buildings to the total area of the scattering zone, the surface area (the sum of walls and roof surfaces) of an average building, the height of the highest building, and the average building plan area.

To determine the effect of scattering in a forest, data are needed on the density of trees, the mean trunk diameter and the height of the forest above the ground.

Recommended parameter values for different kinds of scattering zones are not yet available, but such data should become available in the future.

3.2.3 Weather Conditions

Nord2000 Road can be used for calculating:

- 1) The yearly average noise level
- 2) The noise level under specific weather conditions
- 3) The noise level corresponding to actual weather conditions

Specific weather conditions are administratively fixed weather conditions such as moderate downwind in the old road traffic noise prediction method.

Actual weather conditions are short-term weather conditions. The purpose of calculations for actual weather conditions, cf. Appendix 4, is not to compare with noise limits, but with measured noise levels.

Calculation of Yearly Average Noise Levels

Nord2000 Road is a point-to-point method taking weather conditions into account. The yearly average noise level (or any other long-term average noise level) cannot be calculated directly. It is necessary to group the weather during the time period under considera-



tion into a number of meteorological classes and to calculate the noise level for each class [11]. Subsequently the calculated noise levels are combined taking into account the probability of occurrence of each meteorological class.

To calculate the yearly average of L_{den} or L_{night} , statistics shall be available on the probability of occurrence of each meteo-class during the day, evening, and night. Also the average air temperature and relative humidity within each meteo-class shall be available together with values of other input parameters for Nord2000 Road. The road authorities in each Nordic country provide such data.

In mapping software the statistics should be built in so that the user just has to choose the set of statistics to use (country or region). With less automatic software the user may have to input the statistics.

The procedures are described in Appendix 4.

Calculation for Specific Weather

The most interesting specific weather is the reference weather conditions of the old Nordic prediction method for road traffic noise. These reference conditions are not particularly well-defined, but the Nord2000 Road parameters presumed to give the best estimate are given in Appendix 4.

Another kind of specific weather represents “moderate” worst case propagation. Recommendations can also be found in Appendix 4.

In well-designed mapping software and other software the specific weather conditions can probably be defined by choosing from categories such as “Weather as in the old Nordic method” or “Moderate worst case” implying that the user does not have to key in the Nord2000 Road parameters.

4. Special Procedures

4.1 Special Maximum Noise Levels

4.1.1 Energy Mean and Arithmetic Mean Value

When the maximum sound pressure level is calculated from the sound power levels defined in [4], the result is an energy mean value. This mean value shall be converted to the arithmetic mean value. For a normal distribution with standard deviation σ the relation between energy mean value L_{em} and arithmetic mean value \bar{L} is shown in Eq. (3) and Figure 9.

$$L_{em} - \bar{L} = 0.05 \cdot \ln(10) \cdot \sigma^2 \quad (3)$$

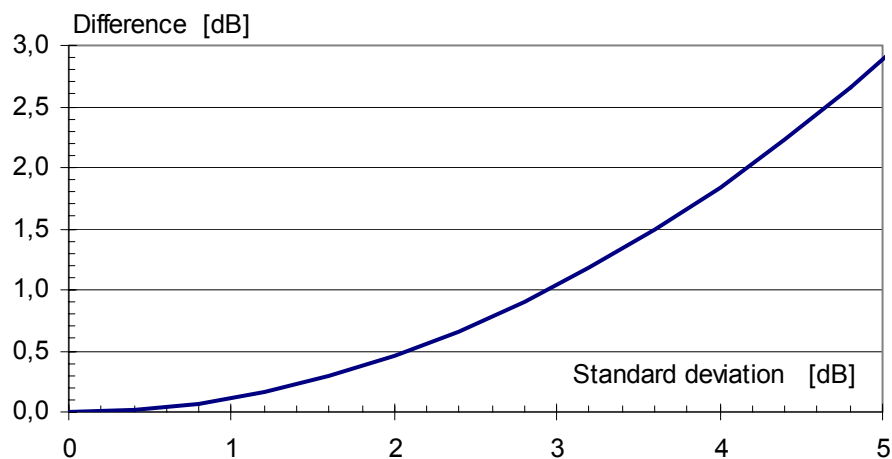


Figure 9

Difference between energy mean value and arithmetic mean value for a normal distribution of maximum noise levels.

If the standard deviation is unknown, the values from [12] shown in Figure 10 may be used.

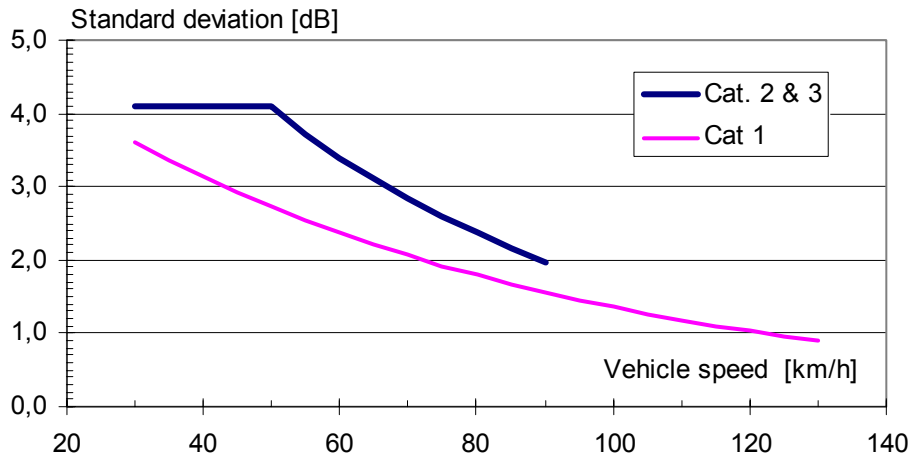


Figure 10
Standard deviation of maximum noise levels from heavy and light vehicles [12].

4.1.2 Maximum Level Exceeded by 5% of the Vehicles

The maximum noise level exceeded by 5% of the vehicles of a category can be determined by adding 1.65 times the standard deviation s to the arithmetic mean value $\overline{L_{AF\max}}$ presupposing a Gaussian distribution.

$$L_{\max,5\%} = \overline{L_{AF\max}} + 1.65 \cdot s \quad (4)$$

If the standard deviation is unknown, the values from [12] shown in Figure 10 may be used.

4.1.3 Maximum Level Exceeded more than a Certain Number of Times

The n^{th} highest maximum noise level $L_{AF\max,n}$ from N vehicles passing during a specified time period is given by

$$L_{AF\max,n} = \overline{L_{AF\max}} + P\left(\frac{100 \cdot n}{N}\right) \cdot s \quad (5)$$

where $\overline{L_{AF\max}}$ is the arithmetic mean value, $P(x)$ is the function shown in Figure 11, and s is the standard deviation.

If the standard deviation is unknown, the values from [12] shown in Figure 10 may be used.

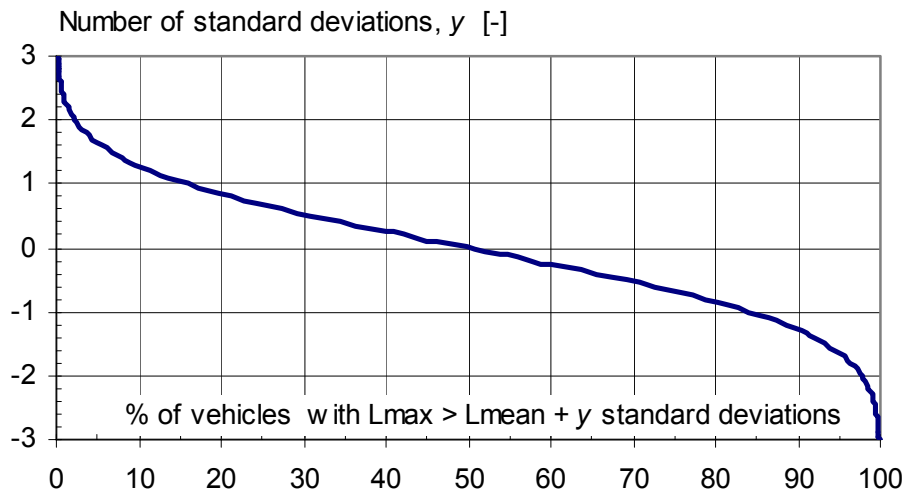


Figure 11
Percentage of single events with a maximum sound pressure level exceeding, by a certain number y of standard deviations, the (arithmetic) mean of a normal distribution of maximum sound pressure levels

4.2 Sound Radiated from Tunnel Openings

The method to calculate the level of traffic noise originating from vehicles inside a tunnel is documented in [13]. Special noise sources are positioned in the tunnel openings, for example as illustrated in Figure 12.

The sound power levels of these sources are functions of vehicle flow, traffic composition, and speed as well as the sound propagation conditions inside the tunnel. Input parameters are the absorption coefficient of the tunnel walls and ceiling and the tunnel dimensions. Guidance on the sound absorption coefficient is given in Table 14. The directivity of the sources representing the traffic noise radiated from a tunnel opening is given in [13].

Table 14
Default sound absorption coefficients [-] for use in cases when no information is available on the tunnel interior surface properties.

Frequency range [Hz]	≤ 125	160-400	500-1250	≥ 1600
1. Smooth concrete	0.08	0.08	0.08	0.08
2. Rough concrete	0.08	0.11	0.14	0.14
3. Sound-absorbing treatment	0.15	0.5	0.8	0.65

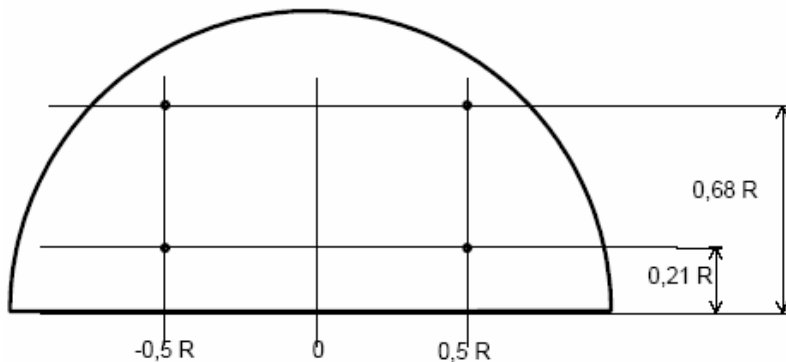


Figure 12
Illustration of the position of four noise sources representing the sound radiated from a tunnel with a semi-circular cross section with radius R [13].

4.3 Sound Transmitted through Facades

According to ISO 140-5 [14] the sound pressure level, L_{in} , indoors is given by

$$L_{in} = L_{ff} - R + 10 \lg \left(\frac{S}{A} \right) - 3 \quad (6)$$

where L_{ff} is the calculated free field level outdoors, R is the sound reduction index of the facade, S is the wall area of the facade, and A is the equivalent sound absorption area of the room. A can either be estimated in octave bands using tables in EN ISO 10052 [15], measured or, for common dwelling, estimated using the equation

$$A = 0.32 \cdot V \quad (7)$$

where V is the volume of the room (in m^3).

The one-third or octave band sound pressure levels obtained are then to be A-weighted and added to yield the overall A-weighted sound pressure level indoors.



5. Accuracy

Nord2000 Road has not yet been applied to computations by numerous users, and its accuracy must be judged based on results of experiments made during the method development.

5.1 General

The accuracy of Nord2000 Road is not directly comparable with that of the old model. The new model has more input parameters, and it is possible to calculate the noise level for more sets of conditions (i.e. weather/road surface/air temperature/traffic flow with 3 categories/acceleration/number of axles/ground impedance) while the old model predicted the noise level averaged over several of these sets of conditions. It is easier to make an accurate estimate of a mean value than of an individual value. For example, the standard uncertainty of a mean value based on N independent measurements is \sqrt{N} times smaller than that of one individual measurement.

5.2 Estimates of Accuracy

The source data for free-flowing traffic have been calibrated against measured energy averaged sound exposure levels, and the standard uncertainty under these conditions has been found to be smaller than 1 dB.

The propagation model has been validated by comparing calculated attenuation values with “true” results of measurements or reference results obtained by accurate calculation methods.

Point-to-point validation (for stationary sources) showed small average differences in total A-weighted levels between Nord2000 Road predictions and “true” results. The largest differences were behind screens where Nord2000 Road predicts in the order of 1 dB higher noise levels than the reference results. The standard uncertainty of individual differences was in the order of 1 dB for distances up to 400 m. Above 400 m reference results have been available for flat ground up to 1000 m where the standard uncertainty was in the order of 2 dB. The accuracy of predictions for a road for fixed weather conditions is presupposed to be better than for the point-to-point prediction.

The ability of the propagation model to predict the yearly average of L_{den} from a road has been validated by comparing Nord2000 Road predictions with reference results obtained by accurate calculation methods. For distances up to 300 m the average differences were smaller than 0.5 dB and the standard deviation of differences smaller than 1 dB.



In Appendix 5 guidelines in accordance with [16] are given for determining the uncertainty. The standard uncertainty $u(L_{Aeq})$ of a predicted equivalent noise level L_{Aeq} is

$$u(L_{Aeq}) = \sqrt{(c_W u_W)^2 + (c_{tf} u_{tf})^2 + (c_v u_v)^2 + (c_N u_N)^2} \quad (8)$$

The factors c are sensitivity coefficients, and the uncertainty contributions u are contributions from:

- index W : the source noise emission
- index tf : the sound attenuation during propagation (transfer function)
- index v : the vehicle speed
- index N : the traffic intensity, composition, and diurnal distribution

Guideline values of c and u are given in Table 15.

Table 15
Guideline values of sensitivity coefficients and uncertainty contributions.

Index	c	u
W	1	1 dB
tf	1	1 dB $d < 400$ m 1/3 + d/600 dB $d \geq 400$ m
v	10.9/v	3 km/h
N	4.3/N	0.1 · N vehicles (10%)

With the default values in Table 15 Eq. (8) yields at a distance of 100 m for a speed of 70 km/h, the standard uncertainty

$$u(L_{eq}) = \sqrt{(1.0)^2 + (1.0)^2 + \left(\frac{10.9}{70} \cdot 3\right)^2 + (0.43)^2} = 1.6 \text{ dB} \quad (9)$$

The expanded uncertainty (confidence interval) is determined by multiplying the standard uncertainty by a coverage factor depending on the required coverage probability. A coverage factor of 2 yields 95%, a factor of 1.65 yields 90%, and a factor of 1.3 yields 80% coverage probability.

5.3 Required Accuracy of Input Data

The following is a guidance on the required accuracy of input data.

A variation in traffic flow and composition of $\pm 10\%$ yields a 0.5 dB change and $\pm 5\%$ yields a 0.2 dB change of L_{Aeq} .

A standard uncertainty of vehicle speed of 3 km/h yields a standard uncertainty in L_{Aeq} as shown in Figure 13.

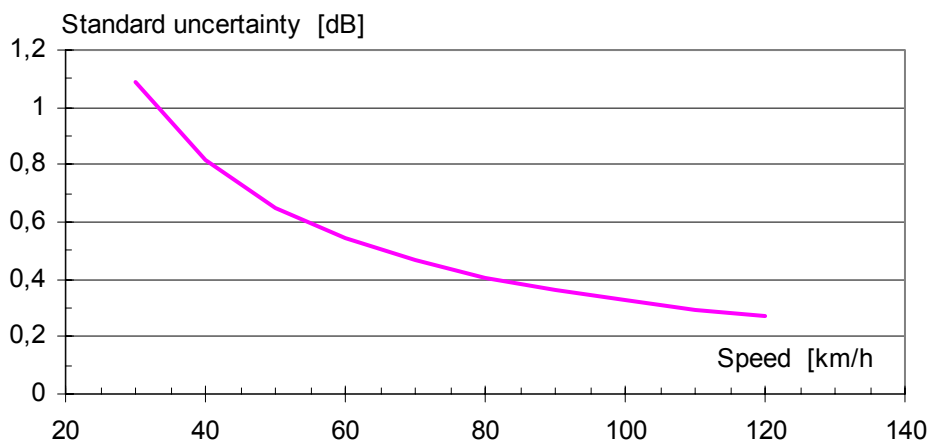


Figure 13

Standard uncertainty of L_{Aeq} resulting from a 3 km/h standard uncertainty of vehicle speed.

A change of the distance from road of $\pm 10\%$ yields 0.5 dB and $\pm 5\%$ yields 0.2 dB change of L_{Aeq} .

A change of small road or receiver heights of ± 0.2 m yields 0.5 dB, ± 0.1 m yields 0.2 dB of L_{Aeq} . Results of computations for receiver heights smaller than 1.5 m should be used with care.



Appendix 1

Source Emission Compared with the Old Model

The change of vehicle noise emission introduced with Nord2000 Road is illustrated in Figure 14 and Figure 15 comparing the noise emission from Danish vehicles with that of the old model. Figure 14 shows L_{AE} at 10 m distance, Figure 15 L_{AFmax} at 7.5 m distance, both at 1.2 m above the ground.

The levels are higher in the new model, particularly L_{AFmax} at high speed. In the old model heavy vehicles were a mix of Category 2 and 3 with Category 2 dominating at low speed and Category 3 dominating at high speed. Nord2000 Road emission data are based on measurements made since 1999. It is unknown if the higher emission values are due to changes of vehicle fleet or tyres.

The emission values for Finnish, Norwegian, and Swedish vehicles in the new method are 1-2 dB higher than for Danish vehicles because of the extensive use of harder road surfaces and larger aggregate in these countries.

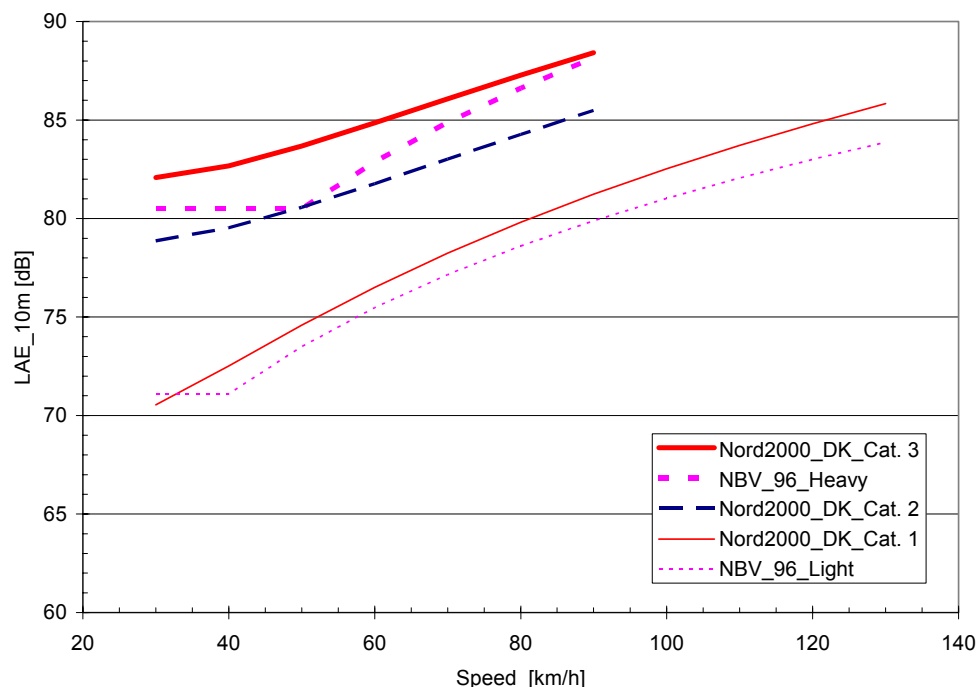


Figure 14

L_{AE} at 10 m distance from a Danish vehicle as a function of vehicle speed according to the old method NBV_96 [12] and the new Nord2000 Road.

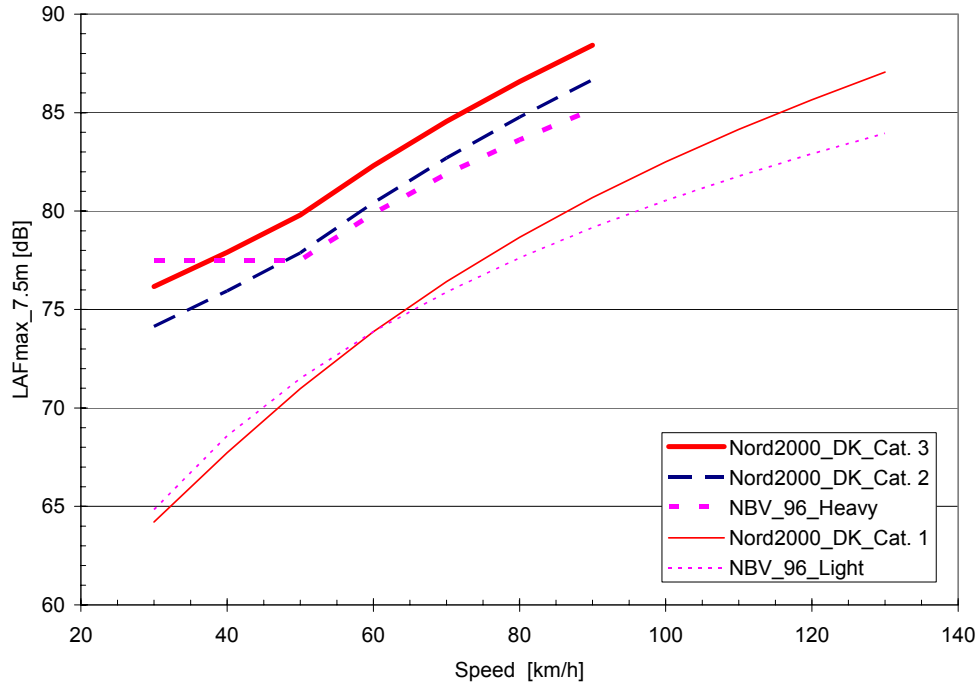


Figure 15

L_{AFmax} at 7.5 m distance from a Danish vehicle as a function of vehicle speed according to the old method NBV_96 [12] and the new Nord2000 Road.



Appendix 2

User-Defined Road Surface Correction

In the Nord2000 Road model only the most common road surfaces are taken into account. For other road surfaces it is difficult to make general corrections. Nominally the same road surface may have different properties depending on where and when it was constructed. Thus, each user, preferably each national road administration, is recommended to determine the correction in each individual case. This is most simply done by carrying out pass-by tests and then comparing with measurement results or calculation results for a reference surface. Preferably the tests shall be carried out according to methods proposed within the European SILVIA project. The difference can then be stated as

$$\Delta L_{\text{surface}} = 2 \text{ dB rel. Nord2000 Road reference surface} \\ \text{(average between DAC 11 and SMA 11)}$$

$\Delta L_{\text{surface}}$ is often different for light and heavy vehicles. $\Delta L_{\text{surface}}$ can either be given for each one-third octave band or for the total A-weighted value. If only the A-weighted correction is used, it has to be applied equally for each frequency band. The temperature coefficient (the change in pass-by noise level caused by a change in temperature) of the surface has to be determined and stated as well.

Appendix 3

Main Categories and Subcategories of Vehicles

Table 16

Vehicle categories applied when collecting data. Normally only the three main categories are used in predictions.

Main category	No.	Subcategories: Example of vehicle types	Notes	Vehicle length [m]
Light vehicles	1a	Cars (incl. MPV's up to 7 seats)	2 axles, max. 4 wheels	0-5.5 m (car with trailer or caravan not included)
	1b	Vans, SUV, pickup trucks, RV, car+trailer or car+caravan ¹⁾ , MPV's with 8-9 seats	2-4 axles ¹⁾ , max 2 wheels per axle	
	1c	Electric vehicles, hybrid vehicles driven in electric mode ²⁾	Driven in combustion engine mode ²⁾	
Medium heavy vehicles	2a	Buses	2 axles (6 wheels)	7.7-12.5
	2b	Light trucks and heavy vans	2 axles (6 wheels) ³⁾	5.6-7.6
	2c	Medium heavy trucks	2 axles (6 wheels) ³⁾	7.7-12.5
	2d	Trolley buses	2 axles	
	2e	Vehicles designed for extra low noise driving	2 axles ⁵⁾	
Heavy vehicles	3a	Buses	3-4 axles	12.5-15.9
	3b	Heavy trucks ⁴⁾	3 axles	>16
	3c	Heavy trucks ⁴⁾	4-5 axles	
	3d	Heavy trucks ⁴⁾	≥6 axles	
	3e	Trolley buses	3-4 axles	12.5-15.9
	3f	Vehicles designed for extra low noise driving	3-4 axles ⁵⁾	
Other heavy vehicles	4a	Construction trucks (partly off-road use) ⁴⁾		
	4b	Agr. tractors, machines, dumper trucks, tanks		Mostly 7.7-12.5
Two-wheelers	5a	Mopeds, scooters	Includes also 3-wheel motorcycles	
	5b	Motorcycles		

¹⁾ 3-4 axles on car & trailer or car & caravan

²⁾ Hybrid vehicles driven in combustion engine mode: Classify as either 1a or 1b.

³⁾ Also 4-wheel trucks, if it is evident that they are >3.5 tons.

⁴⁾ If high exhaust: identify this in the test report. Categorize as 3b', 3c', 3d', or 4a'.

⁵⁾ For example, some delivery trucks are designed for extra low noise (meeting more stringent standards than the current EU limiting levels) combined with a driving mode called "Whisper mode" making it possible to drive in a residential area with much lower noise emission than for a conventional delivery truck. Trucks and buses especially designed in accordance with these ideas are counted in this category.



Appendix 4

Weather Conditions

Nord2000 Road is basically a point-to-point method with weather conditions as described in Section A.4.1. The yearly average noise level (or any other long-term noise level) cannot be calculated directly by Nord2000 Road, but if the weather is grouped into a number of meteorological classes, the yearly average can be determined as described in Section A.4.2.

Nord2000 Road can also be used for calculating the noise level for specific weather conditions. Specific weather conditions are defined as administratively fixed weather conditions as for example in the old road traffic noise method where noise levels are determined for moderate downwind. The calculation for specific weather conditions is discussed in Section A.4.3.

Finally, Nord2000 Road can be used for calculating the noise level for actual weather conditions. Actual weather conditions are short-term weather conditions. The purpose of calculations for actual weather conditions is to compare with and analyze measured noise levels, cf. Section A.4.4.

A.4.1 Basic Weather Conditions of Nord2000 Road

Nord2000 Road is basically a short-term point-to-point method with fixed weather conditions.

The most important attribute of the atmosphere is how the sound speed varies with the height above ground. The sound speed is the effective sound speed which is the combination of the adiabatic sound speed and the wind speed in the direction of propagation. If the sound speed increases with height, the result is downward refraction leading to higher A-weighted noise levels compared to a non-refracting atmosphere, and if the sound speed decreases with height, the result will be upward refraction leading to lower A-weighted noise levels.

In Nord2000 Road the sound speed $c(z)$ is a function of the height above ground z with a logarithmic part and a linear part as shown in Eq. (10).

$$c(z) = A \ln \left(\frac{z}{z_0} + 1 \right) + Bz + C \quad (10)$$



where z_0 is the roughness length, A is the logarithmic weather coefficient, B is the linear weather coefficient, and C is the sound speed at the ground ($= c(0)$).

z_0 , A , B , and C depend on which type of noise level shall be calculated. A , B , and C must be determined on the basis of weather data from synoptic stations such as the

- wind speed (in m/s) measured at a specified height (normally 10 m above ground)
- wind direction (in degrees)
- stability of the atmosphere (normally determined indirectly on the basis of wind speed, cloud cover, time-of-day)
- air temperature t (in °C)

For a meteorologically neutral atmosphere the wind contributes to the logarithmic part of the vertical sound speed profile, and the temperature variation with the height contributes to the linear part of the profile. In this case A will be determined by the wind speed and direction while B corresponds to a decrease in temperature of 1° per 100 m (the adiabatic lapse rate). C is determined by the air temperature. If the atmosphere is not neutral, the determination of A and B is more complicated, see Section A.4.4.

Other meteorologically defined parameters in Nord2000 Road are the

- turbulence strength corresponding to wind C_v^2 (in $\text{m}^{4/3}\text{s}^{-2}$)
- turbulence strength corresponding to temperature C_T^2 (in Ks^{-2})
- standard deviation of the wind speed in the direction of propagation σ_w (in m/s)
- standard deviation of fluctuations in the temperature gradient $\sigma_{dt/dz}$ (in °C/m)
- relative humidity RH (in %)

The turbulence strength corresponding to the wind C_v^2 accounts for the turbulent motion of the atmosphere. The parameter is not available in standard weather data. The maximum observed value of C_v^2 is approx. $0.3 \text{ m}^{4/3}\text{s}^{-2}$, and it is recommended to use a value of $0.12 \text{ m}^{4/3}\text{s}^{-2}$ unless other information is available.

The turbulence strength corresponding to the temperature C_T^2 accounts for the turbulent variation of the temperature in the atmosphere. The parameter is not available in standard weather data. The maximum observed value of C_T^2 is approx. 0.05 Ks^{-2} , and it is recommended to use a value of 0.008 Ks^{-2} unless other information is available.

The standard deviation of the wind speed in the direction of propagation σ_w accounts for the fluctuation in wind speed in excess of what is already included in the turbulence strength. Turbulent motion is fluctuations taking place within seconds or minutes. For calculation of instantaneous sound pressure levels σ_w shall be zero. For calculation of the equivalent sound pressure level with duration above a few minutes up to a few hours, the



effect of slow variations in wind speed can be taken into account by this parameter. The parameter should not be used for calculating long-term effects where the weather is basically changing during the time. Instead a procedure where the weather is divided into a number of meteorological classes should be used.

The standard deviation of fluctuations in the temperature gradient $\sigma_{dt/dz}$ accounts for fluctuation in temperature gradient in excess of what is already included in the turbulence strength. It is recommended to use a value of zero unless other information is available.

Together with the air temperature the relative humidity is used to predict the attenuation due to air absorption. The value is normally available in standard weather data.

A.4.2 Calculation of Yearly Average of Noise Levels

The procedure described in this section is used to calculate the yearly average of L_{den} and L_{night} defined in Section 2.2. L_{den} is based on L_{Aeq} for the day, evening, and night time while L_{night} is L_{Aeq} for the night time.

To calculate the yearly average a number of meteorological classes (meteo-classes) have been defined to represent all types of weather occurring through the year. A format has been defined with 25 meteo-classes where each class is defined by a representative value of A and B [11]. When determining the sound speed profile by Eq. (10) a value of $z_0 = 0.025$ m is used.

To calculate the yearly average of L_{den} and L_{night} statistics shall be available giving the probability of occurrence of each meteo-class. Also the average air temperature and relative humidity within each meteo-class shall be available, for use in noise emission as well as noise attenuation computation. The statistics vary with the direction of propagation and should be available in the range of propagation direction 0° - 360° with a spacing of 10° . The direction of propagation is the direction of the source seen from the receiver using the coordinate system of wind direction. The direction of propagation is 0° if the source is at a position north of the receiver and 90° if the source is at a position east of the receiver. Linear interpolation is used between the 10° values. An example of a table of such statistics is given in Table 17. Meteorological statistics are presumed to be available to the user. The principles for producing such data based on hourly observations (or every third hour) preferably for a time period of 10 years are described in [11]²⁾.

²⁾ The correct distribution of meteo-class occurrence should be connected to the occurrence of the noise source emission. The distribution should be estimated by counting the occurrence of each propagation class for each vehicle during a reference year. The required data are hourly data for both traffic and meteorology. Example calculation and further details can be found in [17].

Table 17
Excerpt of an example of statistical weights [probability in %] for the period “Day”.

			0	10	20	30	40	50	60	70	80	90	100	110	12
class	A (log)	B (lin)													
1	-1,00	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	-1,00	-0,04	0,2	0,2	0,2	0,2	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,0
3	-1,00	0	22,0	22,7	23,3	23,7	22,4	20,5	18,3	17,4	14,4	11,2	9,1	7,1	6,0
4	-1,00	0,04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	-1,00	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	-0,40	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	-0,40	-0,04	2,6	2,7	2,8	2,6	2,5	2,4	2,3	2,3	1,8	1,5	1,5	1,6	1,5
8	-0,40	0	29,8	28,7	27,2	25,5	25,1	25,4	27,3	27,0	28,4	30,0	28,8	25,5	21,0
9	-0,40	0,04	1,8	2,0	2,0	2,2	2,3	2,5	2,5	2,5	2,5	2,4	2,2	2,1	2,0
10	-0,40	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	0,00	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	0,00	-0,04	0,3	0,3	0,1	0,1	0,5	0,3	0,1	0,1	0,4	0,2	0,1	0,1	0,0
13	0,00	0	20,8	21,0	22,1	22,8	22,0	22,6	22,3	21,3	20,8	21,2	23,0	27,4	28,0
14	0,00	0,04	0,3	0,2	0,3	0,3	0,3	0,2	0,2	0,4	0,5	0,6	0,5	0,5	0,0
15	0,00	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	0,40	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	0,40	-0,04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	0,40	0	13,1	12,5	12,5	12,5	13,4	14,2	14,6	15,8	18,3	20,7	21,7	22,4	24,0
19	0,40	0,04	3,9	3,8	3,5	3,1	3,1	3,4	4,0	4,2	4,1	4,1	4,1	3,7	3,0
20	0,40	0,12	1,4	1,3	1,3	1,2	1,0	0,8	0,8	0,7	0,7	0,7	0,7	0,7	0,0
21	1,00	-0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	1,00	-0,04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	1,00	0	3,1	3,6	3,6	4,4	5,7	6,0	6,3	7,2	7,0	6,4	7,3	7,9	8,0
24	1,00	0,04	0,8	0,9	1,2	1,5	1,5	1,4	1,3	1,0	1,0	0,8	0,7	0,9	1,0
25	1,00	0,12	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

For the time of day period and for each source point the sound pressure level is the energy average of the calculation result L_m in each meteo-class weighted with the percentage p_m of the class as shown in Eq. (11). L_m is calculated using the weather parameters A_m and B_m and the temperature t_m and relative humidity RH_m of the meteo-class.

$$L_{average} = 10 \lg \sum_{m=1}^{25} \frac{p_m}{100} 10^{\frac{L_m(A_m, B_m, t_m, RH_m)}{10}} \quad (11)$$



For transmission paths not directly from the source to the receiver such as those of reflected sound or sound diffracted around the vertical edges of a finite screen, the percentage p_m must be determined taking the actual propagation directions into account.

In principle a calculation has to be carried out for each of 25 classes, but in practice only 13 classes seem to contain occurrences, and 3-5 of them seem to contain so few occurrences that the number of classes can be reduced to 8-10. In order to reduce the calculation time in rough calculations, the number may be reduced to 4 or 5 classes (or maybe even less) by combining some of the meteo-classes.

When calculating the yearly average, the remaining parameters should be

- $C_w^2 = 0.12 \text{ m}^{4/3} \text{ s}^{-2}$
- $C_t^2 = 0.008 \text{ K s}^{-2}$
- $\sigma_w = 0 \text{ m/s}$
- $\sigma_{dt/dz} = 0$

A.4.3 Calculation for Specific Weather

The most interesting specific weather is the reference weather of the old Nordic road traffic noise calculation method. The reference condition of this method is not particularly well-defined, but the following values are recommended for the best estimate:

- $z_0 = 0.025 \text{ m}$
- $A = 0.25$ (corresponding to a wind speed of 1.5 m/s at 10 m above ground)
- $B = 0$ (corresponding to a temperature gradient of 0 °C /m)
- $t = 15 \text{ °C}$ (giving $C = 340 \text{ m/s}$)
- $RH = 70\%$
- $C_w^2 = 0.12 \text{ m}^{4/3} \text{ s}^{-2}$
- $C_t^2 = 0.008 \text{ K s}^{-2}$
- $\sigma_w = 0.5 \text{ m/s}$
- $\sigma_{dt/dz} = 0$

Another kind of specific weather might be useful represents “moderate” worst case propagation. It is recommended to use $A = 1.0$ and $B = 0.04$ corresponding to a wind speed of 6 m/s at 10 m above ground and a temperature gradient of 0.07 °C /m while the rest of the Nord2000 Road parameters correspond to the above parameters of the old Nordic road traffic noise prediction method.



A.4.4 Calculation for Actual Weather

When using Nord2000 Road for calculating the sound pressure level for actual weather conditions, the vertical sound speed profile has to be fitted the log-lin profile of Eq. (10). In special cases with a layered atmosphere this may not be possible, and Nord2000 Road cannot be expected to work well in such cases. However, such cases seldom occur, and in most cases the vertical wind and temperature profile can be estimated by the so-called Businger-Dyer profiles leading to vertical sound speed profiles which can be approximated by the log-lin profile with good accuracy using least squares fit. For a meteorologically neutral and stable atmosphere the log-lin profile gives a perfect fit to the actual sound speed profile, and for an unstable atmosphere the fit has been found sufficiently accurate.



Appendix 5

Accuracy of Predicted Road Traffic Noise Levels

There is no simple answer as to what is the prediction accuracy of Nord2000 Road. There are many parameters, and the uncertainty must be determined in each individual case. How this can be done is outlined in the following.

If the quantity to be calculated is L_{calc} , which is a function of the quantities x_j , the principal equation becomes

$$L_{calc} = f(x_j) \quad (12)$$

If each quantity has the standard uncertainty u_j , the combined standard uncertainty is given by

$$u(L_{calc}) = \sqrt{\sum_1^n (c_j u_j)^2} \quad (13)$$

where the sensitivity coefficient c_j is given by

$$c_j = \frac{\partial f}{\partial x_j} \quad (14)$$

Assume that $L_{eq,T}$ is determined for one vehicle category according to

$$L_{eq} = L_E - 10\lg(T) + 10\lg(N) = L_W + \Delta L_{tf} - 10\lg(v) + 10\lg\left(\frac{N}{T}\right) \quad (15)$$

where L_W is the total sound power level, ΔL_{tf} is the transfer function between L_W and sound exposure level L_E , v is the speed, T is the time, and N is the number of vehicles during the time T .

As shown in [4], the speed dependence of L_W , if we focus on tyre/road noise, is approx. $35 \lg(v)$, and we get

$$L_{eq} = L_W(v = v_{ref}) + \Delta L_{tf} + 25\lg\left(\frac{v}{v_{ref}}\right) + 10\lg\left(\frac{N}{T}\right) - 10\lg(v_{ref}) \quad (16)$$

Thus, the sensitivity coefficient, c_v , for speed is

$$c_v = \frac{\partial L_{eq}}{\partial v} = 25 \frac{1}{v} \lg(e) = \frac{10.9}{v} \quad (17)$$



and for traffic flow

$$c_N = \frac{\partial L_{eq}}{\partial N} = \frac{10}{N} \lg(e) = \frac{4.3}{N} \quad (18)$$

L_W and ΔL_{tf} are complicated quantities, and we cannot put up similar equations for these. Instead we shall assign them the sensitivity coefficient 1. The total standard uncertainty of Eq. (13) is

$$u(L_{eq}) = \sqrt{(c_W u_W)^2 + (c_{tf} u_{tf})^2 + (c_v u_v)^2 + (c_N u_N)^2} \quad (19)$$

As shown in [4] the source model reproduces measured A-weighted values with a standard uncertainty of 0.5-0.9 dB. However, all measurements have been carried out at roads in good condition. The comparisons are based on the average from many measurement sites. Some sites may give deviating results, and some sites may show better agreement than the average. Unless better information is available, it is recommended to use the default value $u_W = 1.0$ dB.

As to the transfer function the variations will be large. Complex weather conditions, complicated screening, or large distances yield a high standard uncertainty whereas small distances and favourable sound propagation conditions (e.g. during night time) yield lower uncertainty. It is also likely that averaging over many weather conditions will be more accurate than looking at one specific condition. Unless better information is available, it is recommended to use the default value $u_{tf} = 1.0$ dB for distances up to 400 m and $u_{tf} = 1/3 + d/600$ [dB] for distances d larger than 400 m.

The speed equations refer to an average speed which will show less variations than the speed of individual vehicles, and in many cases u_v may be quite small, e.g. 3 km/h. On the other hand a calculation for one specific rush hour may imply large uncertainty. Some days the traffic may flow well while it is more or less standstill on other days. Unless better information is available, it is recommended to use the default value $u_v = 3$ km/h.

The uncertainty due to traffic flow variation could vary. If it is a yearly measured average, the uncertainty will be small. On the other hand we may have to estimate the flow of heavy Category 3 vehicles based on traffic data several years old containing only the total number of Category 2 and Category 3 vehicles. Unless better information is available, it is recommended to use the default value $u_N = 0.1 \cdot N$ vehicles.

Eq. (17) is valid for one category of vehicles. We could assume that all categories have the same uncertainty. However, if the uncertainties are different between the categories, we have to add them up. We then get

$$L = 10 \lg(10^{L_1/10} + 10^{L_2/10} + 10^{L_3/10}) \quad (20)$$



where $L_1, L_2,$ and L_3 are the calculated L_{eq} for the three categories of vehicles.

The sensitivity coefficient c_{L_i} is then given by

$$c_{L_i} = \frac{\partial L}{\partial L_i} = 10 \lg(e) \frac{10^{L_i/10} \ln(10) \cdot 0.1}{10^{L_1/10} + 10^{L_2/10} + 10^{L_3/10}} = \frac{10^{L_i/10}}{\sum 10^{L_i/10}} \quad (21)$$

The standard uncertainties are given by Eq. (13) applied on all vehicle categories, and the total uncertainty is then given by

$$u(L_{eq,tot}) = \sqrt{(c_{L_1} u_{L_1})^2 + (c_{L_2} u_{L_2})^2 + (c_{L_3} u_{L_3})^2} \quad (22)$$

In case we want to add results from different weather conditions the following is useful:

L_{eq} for condition i , which lasts for p_i of the total time is denoted L_i . The total L_{eq} for the whole time interval is denoted L . We get

$$L = 10 \lg(p_1 10^{L_1/10} + p_2 10^{L_2/10} + \dots + p_n 10^{L_n/10}) \quad (23)$$

However, as $\sum p_i = 1$, these coefficients are not independent. Instead we write Eq. (23) in the form

$$L = 10 \lg \left(p_1 10^{L_1/10} + p_2 10^{L_2/10} + \dots + p_{n-1} 10^{L_{n-1}/10} + \left(1 - \sum_{i=1}^{n-1} p_i\right) 10^{L_n/10} \right) \quad (24)$$

For c_{p_i} we get

$$c_{p_i} = \frac{\partial L}{\partial p_i} = 10 \lg(e) \frac{10^{L_n/10} - 10^{L_i/10}}{\sum p_i 10^{L_i/10}} \quad (25)$$

L_i is determined with the standard uncertainty u_{L_i} and p_i with the standard uncertainty u_{p_i} . The standard uncertainty u of L is given by

$$u = \sqrt{\sum_{i=1}^n \left| \frac{\partial L}{\partial L_i} \right|^2 u_{L_i}^2 + \sum_{i=1}^{n-1} \left| \frac{\partial L}{\partial p_i} \right|^2 u_{p_i}^2} \quad (26)$$



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