Three Typical Noise Assessment Methods in EU

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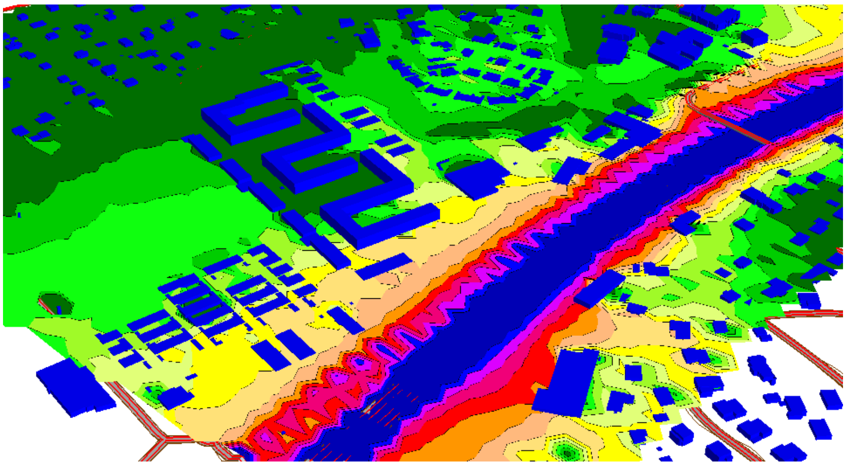

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Abstract

This project aims at working out a reliable and accurate assessment method for high-speed railway noise, with the focus on Swedish applications. However, the method should be generally applicable if proper input data become available. The project is divided into two parts. In part 1 (Etapp A) three typical noise assessment methods in EU will be reviewed; this review will provide a solid basis for Trafikverket (the Swedish Transport Administration) to choose the most suitable parts of these noise assessment methods for building up a new Swedish noise assessment method. In part 2 (Etapp B) the following issues will be addressed, properly and smartly: To build up a noise source model, to prepare the noise source data, to integrate these parts with an advanced propagation model and to formulate a calculation approach for noise assessments of high-speed lines as well as for necessary noise measures. Moreover, the model should be possible to implement in an IT application (for high-speed lines), while not within the frame of this project.

In this report three typical noise assessment methods in EU, Nord2000/2006, CNOSSOS-EU, and NMPB 2008, have been reviewed and compared. A proposal has been made for building up a new Swedish noise assessment method for high-speed railway applications.

Key words: Noise assessment method, high-speed railway noise, sound propagation model, source model for railway noise, Nord2000 method, CNOSSOS-EU method, NMPB 2008 method

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Contents

Preface

This project is founded by the Swedish Transport Administration (Trafikverket), with the framework contract number (ramavtal kontraktsnummer) TRV 2011/51717A and the order number (avropsavtal beställningsnummer) 2541.

Dr. Hans Jonasson provides his opinions on the sound propagation models.

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Summary

In this report three typical noise assessment methods in EU, Nord2000, CNOSSOS-EU and NMPB 2008, have been reviewed, with the focus on railway noise. Based on the review, a proposal has been made for building up a new Swedish noise assessment method for railway noise.

It has been concluded that the Nord2000 propagation model is so far the most advanced engineering model; it is fully based on physics and has been thoroughly inspected at European level. The Nord2000 has been validated by measurements and/or reference calculations. Its calculation speed is high, although not the fastest because it did not employ any empirical methods or rough simplifications.

NMPB 2008 propagation model employed several empirical methods. Its most advantage part is the huge database based on readings from 41 meteorological stations across Metropolitan France, over a period between 17 and 20 years (1987-2007)! The other feature is the good trade-off between accuracy and CPU time. The meteorological parameters are only used to retrieve the pre-defined two propagating conditions (homogeneous and downward-diffraction). This method is more suitable for strategic noise mappings than for detailed case studies.

CNOSSOS-EU propagation model is based on the NMPB 2008 propagation model.

For railway noise, the Harmonoise source model is in general the most advanced one, typically the parts for rolling noise and for traction noise. The part for aerodynamic noise is still quite rough and some other details (bridges, tunnels, viaducts) are missing. Moreover, its proposal for track and vehicle classifications requires huge effort in data collection.

Thus, it is proposed that a new Swedish noise assessment method shall employ the Nord2000 propagation model as its propagation module, without any revision or simplification. Its source module will be based on the Harmonoise source model for railway noise, while introducing some flexibility: three sub-source modules are considered, a high-speed module, a conventional-speed module and a low-speed module. For each sub-module it is possible to have different track and vehicle/train classifications, depending on national requirements.

The third part of the noise assessment method is for calculating expected quantities based on national requirements, such as L_{den}, L_{Aeq24}, L_{AFmax}, and indoor sound levels, etc. Most of these calculations are straightforward, while some may be not simple such as calculating indoor sound levels.

1 Introduction

EU Member States are now acting to fight noise pollution: to determine the exposure to environment noise through strategic noise mapping and to elaborate action plans to reduce noise pollution, required by the Environment Noise Directive (2002/49/EC). Since June 2007, it is mandatory to produce strategic noise maps for all major roads, railways, airports and agglomerations, on a five-year basis. These noise maps are used by national competent authorities to identify priorities for action planning and by the European Commission to globally assess noise exposure across the EU.

The Swedish Transport Administration (Trafikverket) is now investigating new high-speed lines, up to 320 km/h. Noise impact from such a high-speed line as well as necessary noise measures should be evaluated/estimated in the planning phase before starting the construction. However, the current noise assessment method used in Sweden is not applicable for high-speed railways [1]. Therefore, the Swedish Transport Administration decided to replace the current method by a reliable and accurate noise assessment method for high-speed railway applications.

This project aims at working out a reliable and accurate noise assessment method for high-speed railways, with the focus on Swedish applications while the method should be generally applicable if proper input data become available. The project is divided into two parts. In part 1 (Etapp A) three typical noise assessment methods in EU will be reviewed; this review will provide a solid basis for the Swedish Transport Administration to choose the most suitable parts of these noise assessment methods for building up a new Swedish noise assessment method. In part 2 (Etapp B) the following issues will be addressed, properly and smartly: To build up a noise source model, to prepare the noise source data, to integrate these parts with an advanced propagation model and to formulate a calculation approach for noise assessments of high-speed lines as well as for necessary noise measures. Moreover, the model should be possible to implement in an IT application (for high-speed lines), while not within the frame of this short project (from May 16 to August 10, 2014).

In the following three sections the propagation and source parts of three typical noise assessment methods in EU, NORD2000/2006, CNOSSOS-Harmonoise and NMPB 2008, will be reviewed, respectively. The review is limited to railway noise applications and has a focus on the main characteristics of and the important simplifications made in the three methods. Discussions and comments on each of these methods will be given in the respective section. The three noise assessment methods will also be compared with further in details in Section 5, while excluding unnecessary details such as how to determine a propagation path, or how to calculate the sound attenuation or other quantities, etc. And, finally, a proposal on choosing a propagation model as well as on building up a source model will be provided.

2 NORD2000/2006 Method

The NORD2000 project was initiated in 1996 and completed in 2001, and aimed at working out a new generation of prediction methods for environmental noise utilising scientific development having taken place since the first Nordic methods published in the 1970s and 1980s [2-6]. The idea is, by completely separating source emission and sound propagation, to develop a general sound propagation model and to establish source-specific prediction methods for road and rail traffic and other types of environment noise; all prediction methods should apply the same general propagation model.

The project was financed by the Nordic Council of Ministers and by Nordic authorities and research councils. The project work was carried out by SP Swedish National Testing & Research Institute (Sweden; today it is renamed as SP Technical Research Institute of Sweden), SINTEF Telecom and Telecom and Informatics (Norway) and DELTA Acoustics and Vibration (Denmark), with VTT Building Technology-Acoustics (Finland) supplemented.

To enable engineering computations of road traffic noise according to the Nord2000 model, the national Nordic road authorities decided to develop guidelines and tools for predicting road traffic noise using the new Nordic prediction method Nord2000 and asked DELTA, SINTEF, SP and VTT to cooperate in a project to develop such guidelines and tools. The project, Nord2000 Road, was then initiated in February 2005 and completed in March 2006 [7]. Within this project, not only the guidelines and tools have been produced for road traffic noise [8], but also the original work on Nord2000 propagation model as well as the source model (road) has been adjusted in a few places [5, 9].

2.1 Propagation model

2.1.1 The Harmonoise Reference Model

During the European project Harmonoise (2001-2004) [10], Work Package 2 (Reference Model) made a series of investigations: Task 2.1 defined the physical problems; Task 2.2 described the state of the art of various computational models for sound propagation; Task 2.3 performed benchmark calculations with those models and tested various modelling approximations [11]; the results of Task 2.3 were used in Task 2.4 in developing the Reference Model. This Reference Model has been used to assess the accuracy of the Harmonoise engineering model, and can be used to assess the accuracy of any engineering model such as the Nord2000; it can also be used for other purposes such as parameter studies of complex atmospheric effects.

The Reference Model [12] yields predictions of long-term average sound levels in situations that are geometrically relatively simple but physically complex. The Reference Model employs various numerical propagation models to calculate effects of the atmosphere, the ground surface, and obstacles on sound waves. Three types of propagation models are used:

- Parabolic Equation models (PE): CNPE, GFPE, and GTPE
(CNPE is for Crank-Nicholson PE, GFPE is for Green's Function PE, and GTPE is for Generalized-Terrain PE)
- Ray model (RAY)
- Boundary Element Method (BEM).

PE models are used to account for effects of atmospheric refraction; A BEM model is used to model sound propagation over complex obstacles. In the source region, PE, RAY, or BEM is used. In the region outside the source region, a PE model is used.

Atmospheric refraction is taken into account by PE but not by RAY and BEM. Therefore, PE is used in the source region if possible. PE cannot be used for complex situations (for example, situations with tilted barriers or barriers with a complex shape) and for situations with sound waves propagating at large elevation angles. PE can handle screening and reflection by simple rectangular noise barriers through the Kirchhoff approximation. The discontinuous change of effective sound speed upon reflection may be taken into account.

If PE cannot be applied and if refraction may be neglected, RAY or BEM is used. BEM can handle arbitrary complex geometries, but is restricted to two-dimensional modeling due to computational limitations. RAY is a three-dimensional model but is restricted to relatively simple geometries.

The choice between PE and RAY or BEM corresponds to a choice between accurate modeling of atmospheric refraction and accurate modeling of a complex geometry. Both options imply an approximation: either the atmosphere in the source region is approximated by a non-refracting atmosphere, or the complex geometry is approximated by a simpler geometry. Which option is best depends on the situation.

In the region outside the source region, a PE model is used. For a flat ground surface, the CNPE model or the GFPE model is used. For a ground surface with smooth hills, the GTPE is used.

If RAY or BEM is used in the source region, the model is coupled to a PE model at the boundary of the source region. RAY or BEM produces a set of complex sound pressures that is used as a starting field for PE.

The PE model is a two-dimensional model, based on (along the line of travel of a sound source) the axisymmetric approximation. The CNPE gives accurate results for sound waves travelling at elevation angles up to about 30^o.

The GFPE model is in many ways similar to the CNPE model. A major difference is that with GFPE larger range steps are possible than with CNPE: the horizontal grid spacing with GFPE can be as large as 5 to 50 wavelengths, rather than one tenth of a wavelength with CNPE.

Another advantage of GFPE is that accurate results can be obtained up to higher elevation angles than with CNPE, provided an appropriate higher-order starting field is used. With a fourth-order starting field accurate results up to 60^o are obtained.

The GTPE model is a generalization of the CNPE model for sound propagation over a ground surface with smooth hills. Terrain-following coordinates are used rather than the rectangular grid. GTPE gives accurate results for smooth hills with local slopes that do not exceed about 30°.

The RAY model used for the Reference Model is based on the theory of geometrical acoustics. Sound propagation from a (monopole) point source to a receiver is calculated by summation of contributions from sound rays. A ray consists of straight segments between reflection points and diffraction points. Reflection occurs at plane surfaces and diffraction occurs at wedges.

The (complex) sound pressure contribution of a sound ray is of the form

$$QD\exp(ikR)/R \ , \tag{2.1}$$

where k is the wave number, R is the ray path length, Q is a product of spherical-wave reflection coefficients, and D is a product of spherical-wave diffraction coefficients. The spherical-wave diffraction coefficient includes the option to model diffraction by an absorbing wedge, i.e. a wedge that consists of two finite-impedance surfaces. This approach works for diffraction by a single absorbing wedge, but gives inaccurate results for double diffraction by the top of a wide barrier. In the latter case, BEM (or PE) should be used rather than RAY. In cases with complex barrier shapes, BEM should be used.

In principle, the ray model is based on a high-frequency approximation. This means that all dimensions should be large compared to the wavelength. In many situations, however, the ray model works well down to frequencies where this condition is not fulfilled.

A general problem with BEM is the so-called non-uniqueness problem: at certain frequencies, corresponding to internal resonances of the scattering volume, inaccurate results are obtained. This problem is solved by including a number of points inside the scattering volume where the field is forced to be zero.

The spectrum of a point-source sound power covers the frequency range from 25 Hz to 5 kHz. In practice, it may be necessary to neglect contributions from the highest frequency bands, due to limitations of the propagation models.

2.1.2 Nord2000 propagation model

Numerical calculation methods such as PE methods or FFP (Fast Field Program) method are extremely time consuming so they are not suitable to be used as a basis of an engineering method [4].

The new Nordic comprehensive model for sound propagating outdoors in an atmosphere *without significant refraction* is based on geometrical ray theory and theory of diffraction; sound rays are assumed to follow *straight lines*. And, calculations are carried out in one-third octave bands from 25 Hz to 10 kHz. The model is applicable for any non-flat terrain approximated by a segmented terrain shape (a number of straight line segments) with or without screens. In the model ground surface properties are characterised by its impedance (in total 8 impedance categories, from A to H for acoustically very soft to very hard respectively) and its roughness (unevenness) and may vary along the propagation path. The model may also include the effect of reflection from obstacles.

In an atmosphere *with refraction*, the above mentioned straight line model can be modified to include the effect of moderate atmospheric refraction by introducing *curved sound rays* in the propagation model. The modification is based on simple equations assuming that the sound speed varies linearly with the height above the ground in which case the rays will follow circular arcs.

The aim of the Nord2000 project has been to develop a propagation model with sufficient accuracy for "uncomplicated" weather conditions. These are weather conditions where sound speed is either decreasing or increasing monotonically with the altitude without significant jumps in the sound speed gradient. Most often such "uncomplicated" weather conditions can approximately be represented by sound speed profiles with a logarithmic and a linear part called log-lin profiles. The crux when using the linear sound speed profile concept has been how to approximate a non-linear sound profile by an equivalent linear profile. A principle has been elaborated for determination of the equivalent linear sound speed profile.

In case of strong downwind refraction the model based on simple geometrical modification of rays has been extended to include the effect of additional rays from multiple reflections. In case of strong upward refraction where no ray will reach the receiver in a shadow zone the model has been extended to include effects of shadow zones.

The Nord2000/2006 Propagation Model has been validated with a large number of case studies (544) based on measurements and reference calculation results, and 9 cases with calculation of the yearly average L_{den} from a road [13]. The standard uncertainty of individual results has been found to be in the order of 1 dB for propagation distances up to 400 m. Above 400 m reference results have only been available for flat ground (range of distances 600-1000 m) where the standard uncertainty has been estimated to be in the order of 2 dB. And, the 9 cases with calculation of the yearly average L_{den} from a road covering propagation distances up to 300 m show an average difference less than 0.5 dB and a standard uncertainty less than 1 dB.

Under homogeneous conditions, the Nord2000 propagation model has been proved the best for engineering applications.

2.2 Source model for railway noise

The Nord2000 source model for road traffic noise has been modified by referring to the Harmonoise source model [9]. However, such a update has not been made for railway sources. In this sub-section the Nord2000 source model for railway noise [14] will be summarised.

Three main noise types were considered, i.e. power unit noise, wheel/rail interaction noise and aerodynamic noise. As high-speed trains in the Nordic countries (at the current time) do not travel faster than about 200 km/h the aerodynamic noise was neglected in the source modelling.

2.2.1 Source positions

Each train is divided into the following sources, situated above the nearest rail as described in Table 2.1 or using the default positions given in Table 2.2.

Table 2.1 *Trains. Principle source locations.*

	Height above top of rail (m)	**Horizontal location**
Source 1 Wheel/rail	0.01	Evenly distributed along the train
Source 2 Wheel/rail	0.35*wheel diameter	Evenly distributed along the train
Source 3 Wheel/rail	0.70*wheel diameter	Evenly distributed along the train
Source 4 Engine	Actual height	Centre of engine openings
Source 5 Exhaust	Actual height of exhaust	Exhaust outlet
Source 6 Aerodynamic	To be determined in each case	To be determined in each case

Cars and locomotives should, if possible, be dealt with separately. In case no details are known the default parameter values given in Table 2.2 are recommended:

Table 2.2 *Default values for source locations.*

	Height above top of rail (m)	**Frequency range[1)] (Hz)**	**Horizontal location**
Source 1 Wheel/rail	0,01	50-10000 Hz	Evenly distributed along the train
Source 2 Wheel/rail	0,35	50-10000 Hz	Evenly distributed along the train
Source 3 Wheel/rail	0,70	50-10000 Hz	Evenly distributed along the train
Source 4 Engine/Exhaust	2.5	To be determined in each case	Centre of engine.

[1)] Often frequencies below 50 Hz and above 5000 Hz can be neglected.

2.2.2 Directivity

The vertical directivity of railway noise was neglected; the horizontal directivity, although considered not of major importance to determine SEL or L_{eq} values, was assumed

$$\Delta L(\varphi) = 10 * \lg[0.15 + 0.85 * \cos(\varphi)] + 2 \ , \qquad (2.2)$$

where φ is the angle to the normal of the train and lg is for $\log_{10}$.

2.2.3 Classifications

Classifications of trains, tracks and driving conditions are given in Tables 2.3-2.5, respectively.

Table 2.3a *Swedish train categories.*

Main category	Sub category	Category name
1		**High speed trains (≥ 180 km/h)**
	1a	X2000
	1b	Arlanda train
	1c	Öresund train (Sweden and Denmark)
2		**Normal speed Inter-City trains**
	2a	With RC engine
	2b	
3		**Local and regional trains**
	3a	X10, X12 (el)
	3b	Y1 (diesel)
	3c	Y2 (diesel)
4		**Freight trains**
	4a	Normal, RC engine (el)
	4b	Normal, T44 engine (diesel + el)
	4c	Iron ore train (Sweden and Norway)
5		**Others**

Table 2.3b *Danish train categories*

Main category	Sub categor y	Category name
1		**Passenger train sets**
	1a	Diesel trains (IC3)
	1b	Electric trains (IR4)
	1c	Electric trainsets (ET) Øresund
	1d	Electric trainsets X2000
2		**Locomotive driven trains**

	2a	Diesel passenger trains with MZ or ME locomotive(MZ/P, ME/P)
	2b	Diesel goods trains with MZ or ME locomotive(MZ/G and ME/G)
	2c	Electric passenger trains with EA locomotive (EA/P)
	2d	Electric goods trains with EA locomotive (EA/G)
	2e	Electric goods train (EG)
3		**Regional trains**
4		**Local trains**
	4a	S-trains 2nd and 3rd generation
	4b	S-trains 4th generation
	4c	Diesel train sets (MR)
	4d	Y-trains, IC2 trains, RegioSprinter, RegioSprinter, Desiro
5		**Others**

Table 2.3c *Norwegian train categories (bold sub.cat. with data)*

Main category	Sub category	Category name
1		**High speed trains ($\geq$ 180 km/h)**
	1a	Gardermoen train, type BM 71
2		**Normal speed Inter-City/Express trains**
	2a	Type BM 70
	2b	Passenger train, El (locomotive driven)
	2c	Passenger train, Di (locomotive driven)
	2d	Type BM 73
	2e	Type BM 93
3		**Passenger train sets**
	3a	Type BM 69
	3b	Type BM 92
	3c	Type BM 72
4		**Freight trains, locomotive driven**
	4a	Ordinary goods, El
	4b	Container Express Goods, EL
	4c	Goods, Di
5		**Others**

Table 2.4 *Track categories*

Main category	Sub category	Name
1		**Modern** (ballasted, concrete sleeper, welded joints with UIC 60 rail, soft pads)
	1a	Well maintained (roughness < X)
	1b	Average (X $\leq$ roughness $\leq$ Y)
	1c	Worse than average (roughness > Y)
2		**Semi-modern** (ballasted, concrete sleeper, welded joints

		with UIC= , soft pads)
	2a	Well maintained (roughness < X)
	2b	Average (X ≤ roughness ≤ Y)
	2c	Worse than average (roughness > Y)
3		**Old** (ballasted, wood sleepers, unwelded joints with UIC= , soft pads)
	3a	Well maintained (roughness < X)
	3b	Average (X ≤ roughness ≤ Y)
	3c	Worse than average (roughness > Y)
4		**Track on steel bridge**
	4a	Well maintained (roughness < X)
	4b	Average (X ≤ roughness ≤ Y)
	4c	Worse than average (roughness > Y)

Table 2.5 *Driving conditions*

Category	**Name**	**Objective description**
1	Cruising	Constant speed
2	Acceleration	Continuous acceleration[1)]
3	Deceleration	Continuous deceleration[2)]
4	Curves	Squeals

[1)] E.g. after stations or speed limit signs
[2)] E.g. before stations or speed limit signs

2.2.4 Sound power level

Because of no enough data for each sub-source, the source model is based on pass-by measurements which contain the contribution from all important sub-sources. The sound power level is determined from the pass-by sound exposure level. The total sound power is then distributed to the sub-sources according to the source model.

Sound power level is normalised to 1 m train length (dB/m) and is given in the following form:

$$L_{W,1m} = a * \lg\left(\frac{v}{100}\right) + b \ , \qquad (2.3)$$

where *v* is the speed in *km/h* and the coefficients *a* and *b* are given in the following tables. Thus, if the total train length is *l* m

$$L_W = L_{W,1m} + 10\lg(l) \qquad (2.4)$$

The measurements have in general taken place at normal cruising speeds of the trains. This means that the data given should not be extrapolated to very low speeds.

Table 2.6 *Input data for Swedish trains (dB). N.B. the corrections in Table 2.6A.*

Cat	**1a X2**		**2a Pass**		**Pass/wood**		**3a X10**		**4b Freight-Di**		**4a Freight-El**	
Freq. Hz	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
25	32,0	88,0	18,0	90,0	20,0	89,0	20,0	92,0	-2,0	95,0	10,0	91,0
31,5	32,0	88,0	18,0	90,0	20,0	89,0	20,0	92,0	-2,0	95,0	10,0	91,0
40	32,0	88,0	18,0	90,0	20,0	89,0	20,0	92,0	-2,0	95,0	10,0	91,0
50	31,6	88,1	19,0	89,9	21,3	88,9	20,5	92,0	-2,0	94,7	10,0	90,8
63	31,6	88,1	19,0	89,9	21,3	88,9	20,5	92,0	-2,0	94,7	10,0	90,8
80	32,6	87,8	16,3	90,2	17,9	89,2	19,1	92,0	-2,0	95,7	10,0	91,5
100	35,0	86,6	12,0	90,2	12,6	88,5	17,7	91,8	-2,0	97,1	10,0	91,8
125	36,0	86,3	9,3	90,5	9,3	88,9	16,4	91,8	-2,0	98,1	10,0	92,4
160	34,3	88,0	9,3	92,2	9,3	91,9	14,4	92,5	-2,0	98,8	10,0	94,4
200	32,5	90,6	11,5	94,4	10,8	96,1	11,5	93,3	-4,9	99,1	9,3	97,0
250	30,8	92,3	11,5	96,1	10,8	99,1	9,5	94,0	-4,9	99,7	9,3	99,0
315	28,1	92,9	8,2	97,1	9,2	100,7	9,5	94,7	3,1	101,1	10,9	100,4
400	23,4	93,5	0,6	98,1	4,0	103,2	8,0	95,6	16,9	103,6	13,8	102,3
500	20,8	94,1	-2,7	99,1	2,3	104,9	8,0	96,2	24,9	105,0	15,5	103,7
630	22,1	94,5	2,3	99,8	10,6	103,9	14,7	96,2	24,9	103,3	15,5	103,0
800	24,0	95,1	10,9	100,8	25,0	102,0	25,6	96,2	21,3	100,2	15,0	101,7
1000	25,4	95,5	15,9	101,5	33,3	101,0	32,3	96,2	21,3	98,5	15,0	101,0
1250	29,7	94,5	19,3	100,8	38,3	99,7	34,0	95,6	24,0	98,2	15,0	100,3
1600	36,7	93,2	23,9	99,9	42,5	98,4	34,4	95,1	28,6	98,8	15,0	100,0
2000	41,0	92,2	27,2	99,3	47,5	97,0	36,1	94,4	31,3	98,5	15,0	99,3
2500	41,3	90,2	23,9	97,6	47,5	95,0	34,4	92,1	30,6	96,5	15,0	97,3
3150	39,8	88,0	16,8	95,8	45,0	93,0	30,8	89,1	28,3	94,0	15,0	95,0
4000	40,2	86,0	13,4	94,1	45,0	91,0	29,1	86,8	27,7	92,0	15,0	93,0
5000	40,2	82,6	13,4	90,8	45,0	87,6	29,1	83,4	27,7	88,6	15,0	89,6
6300	40,0	77,9	15,0	85,9	45,0	82,9	30,0	78,9	28,0	83,9	15,0	84,9
8000	40,0	74,6	15,0	82,6	45,0	79,6	30,0	75,6	28,0	80,6	15,0	81,6
10000	40,0	74,6	15,0	82,6	45,0	79,6	30,0	75,6	28,0	80,6	15,0	81,6

As the sound power levels given in Table 2.6 has been obtained using different propagation and source models compared to Nord2000 they have to be corrected. The correction to apply are given in Table 2.6A.

Table 2.6A *Correction to apply to Table 2.6.*

Frequency (Hz)	(dB)
25-160	-3
200-315	-3

The source locations to be used for the most common Swedish trains are given in Tables 2.6B and 2.6C.

Table 2.6B *Source locations for X2, X10, X11 and X12.*

	Height above top of rail (m)	Frequency range (Hz)	Horizontal location
Source 1 Wheel/rail	0,01 (0,21 above rail bed)	200 - 10000	Evenly distributed along the train
Source 2 Wheel/rail	0,35 (0,55 above rail bed)	200 - 10000	Evenly distributed along the train
Source 3 Wheel/rail	0,70 (0,90 above rail bed)	200 - 10000	Evenly distributed along the train
Source 4 Engine	1,8 (2,0 above rail bed)	25-160	Centre of locomotive

Table 2.6C *Source locations for trains with RC locomotives.*

	Height above top of rail (m)	Frequency range (Hz)	Horizontal location
Source 1 Wheel/rail	0,01 (0,21 above rail bed)	400 - 10000	Evenly distributed along the train
Source 2 Wheel/rail	0,35 (0,55 above rail bed)	400 - 10000	Evenly distributed along the train
Source 3 Wheel/rail	0,70 (0,90 above rail bed)	400 - 10000	Evenly distributed along the train
Source 4 Engine	2,8 (3,0 above rail bed)	25-315	Centre of locomotive

Below are the source data for Norwegian trains. Categories with mark * are the data of 1/3 octave bands obtained from interpolation between the octave bands and then normalised to the correct octave band sound power level.

Table 2.7 *Input data for Norwegian trains (dB).*

Cat.	***1a-2d-3c**		**2a**		**2b**		***2c-3b**		***2e**	
Freq. Hz	a	b	a	b	a	b	a	b	a	b
25	20,0	92,0	20,0	89,0	20,0	92,0	10,0	99,0	20,0	92,0
31,5	20,0	92,0	20,0	89,0	20,0	92,0	10,0	99,0	20,0	92,0
40	20,0	92,0	20,0	89,0	20,0	92,0	10,0	99,0	20,0	92,0
50	20,0	92,2	19,6	89,1	19,6	92,2	10,0	98,8	20,0	92,2
63	20,0	92,2	19,6	89,1	19,6	92,2	10,0	98,8	20,0	92,2
80	20,0	91,6	20,9	88,8	20,8	91,6	10,0	99,5	20,0	91,6
100	19,4	90,0	23,8	87,8	23,8	90,0	10,0	100,6	19,3	89,7
125	19,4	89,3	25,1	87,4	25,1	89,3	10,0	101,2	19,3	89,1
160	21,0	90,7	23,4	88,8	23,4	90,7	10,0	101,2	21,0	91,1
200	23,0	92,7	19,5	89,7	19,5	91,7	8,5	100,8	22,9	94,2
250	24,6	94,0	17,8	91,1	17,8	93,1	8,5	100,8	24,6	96,2
315	26,6	95,0	19,5	94,1	19,5	96,1	13,1	101,5	26,6	97,2
400	29,5	96,5	21,1	98,9	21,0	100,8	19,6	102,6	29,5	98,5
500	31,5	97,5	22,8	101,9	22,7	103,8	24,3	103,2	31,5	99,5

630	31,8	97,1	27,5	101,6	27,4	103,8	28,9	103,2	31,8	99,1
800	31,7	96,5	35,6	100,7	35,4	103,3	35,4	103,3	31,7	98,5
1000	32,0	96,2	40,2	100,4	40,1	103,3	40,1	103,3	32,0	98,2
1250	32,4	95,2	39,2	98,7	39,1	102,3	39,1	102,3	32,4	97,2
1600	32,7	94,0	35,6	96,5	35,7	101,0	35,7	101,0	32,7	96,0
2000	33,1	93,0	34,6	94,8	34,7	100,0	34,7	100,0	33,1	95,0
2500	33,4	92,0	34,3	93,2	34,3	98,7	34,3	98,7	33,4	94,0
3150	33,8	91,4	34,2	91,8	34,2	97,6	34,2	97,6	33,8	93,4
4000	34,2	90,4	33,8	90,1	33,8	96,3	33,8	96,3	34,2	92,4
5000	34,2	87,1	33,8	86,8	33,8	93,0	33,8	93,0	34,2	89,1
6300	34,0	81,9	34,0	81,9	34,0	87,9	34,0	87,9	34,0	83,9
8000	34,0	78,6	34,0	78,6	34,0	84,6	34,0	84,6	34,0	80,6
10000	34,0	78,6	34,0	78,6	34,0	84,6	34,0	84,6	34,0	80,6

Table 2.7 *Input data for Norwegian trains (dB) (Cont.)*

Cat.	**3a**		**4a**		***4b**		***4c**	
Freq. Hz	a	b	a	b	a	b	a	b
25	10,0	93,0	20,0	95,0	20,0	92,0	10,0	99,0
31,5	10,0	93,0	20,0	95,0	20,0	92,0	10,0	99,0
40	10,0	93,0	20,0	95,0	20,0	92,0	10,0	99,0
50	10,0	93,1	19,6	95,2	20,0	92,2	10,0	98,8
63	10,0	93,1	19,6	95,2	20,0	92,2	10,0	98,8
80	10,0	92,8	20,9	94,6	20,0	91,6	10,0	99,5
100	10,8	91,9	23,8	93,0	19,2	89,3	10,0	100,6
125	10,8	91,6	25,1	92,3	19,2	88,6	10,0	101,2
160	8,8	92,6	23,4	93,7	20,9	91,6	10,0	101,2
200	2,6	93,4	19,5	95,1	22,8	96,5	8,4	100,7
250	0,6	94,4	17,8	96,4	24,5	99,5	8,4	100,7
315	7,3	96,7	19,5	98,8	26,5	100,2	13,0	101,7
400	18,1	100,7	21,4	102,7	29,5	100,7	19,8	103,7
500	24,7	103,0	23,1	105,0	31,5	101,4	24,5	104,7
630	29,4	102,0	27,7	104,0	31,9	101,0	29,1	103,7
800	35,7	100,2	35,7	102,0	31,7	100,5	35,7	102,0
1000	40,4	99,2	40,4	101,0	32,0	100,2	40,4	101,0
1250	39,4	97,2	39,4	99,7	32,4	99,2	39,4	99,7
1600	35,6	94,7	35,7	98,1	32,7	98,0	35,7	98,1
2000	34,6	92,7	34,7	96,7	33,1	97,0	34,7	96,7
2500	34,3	91,0	34,3	96,1	33,4	96,0	34,3	96,1
3150	34,2	89,8	34,2	96,3	33,8	95,4	34,2	96,3
4000	33,8	88,1	33,9	95,6	34,2	94,4	33,9	95,6
5000	33,8	84,8	33,9	92,3	34,2	91,1	33,9	92,3
6300	34,0	79,9	34,0	86,9	34,0	85,9	34,0	86,9
8000	34,0	76,6	34,0	83,6	34,0	82,6	34,0	83,6
10000	34,0	76,6	34,0	83,6	34,0	82,6	34,0	83,6

As the sound power levels given in Table 2.7 has been obtained using different propagation and source models compared to Nord2000 they have to be corrected. The correction to apply are given in Table 2.7A.

Table 2.7A *Corrections to apply to Table 2.7.*

Frequency (Hz)	(dB)
25	-3
31.5	-3
40	-3
50	-2
63	-1
80	0
100	0
125	0
160	-1
200	-2
250	-2
315	-2
400	-2
500	-2
630	-2
800	0
1000	1
1250	1
1600	1
2000	1
>= 2500	0

The source locations to be used for Norwegian trains are given in Table 2.7B (valid default values to be used until specific information is available).

Table 2.7B *Source locations for Norwegian trains.*

	Height above top of rail (m)	**Frequency range (Hz)**	**Horizontal location**
Source 1 Wheel/rail	0,01 (0,21 above rail bed)	200 - 10000	Evenly distributed along the train
Source 2 Wheel/rail	0,35 (0,55 above rail bed)	200 - 10000	Evenly distributed along the train
Source 3 Wheel/rail	0,70 (0,90 above rail bed)	200 - 10000	Evenly distributed along the train
Source 4 Engine	2,5 (2,7 above rail bed)	25-160	Centre of locomotive

In Table 2.8 are the source data for Danish trains.

Table 2.8 *Input data for Danish trains (dB).*

Train type	A&D		B, C, H & I		E		F2 & F3		F4	
	a	b	a	b	a	b	a	b	a	b
25	18,0	84,6	10,0	92,6	10,0	90,6	20,0	89,6	18,0	79,6
31,5	18,0	84,6	10,0	92,6	10,0	90,6	20,0	89,6	18,0	79,6
40	18,0	87,9	10,0	95,9	10,0	93,9	20,0	92,9	18,0	82,9
50	19,0	93,9	10,0	102,4	8,6	100,2	16,8	98,7	16,4	88,7
63	19,0	97,3	10,0	105,7	8,6	103,5	16,8	102,0	16,4	92,0
80	16,3	96,3	10,0	103,4	13,6	101,8	27,1	101,7	21,0	91,7
100	11,7	93,6	10,0	98,1	23,7	98,2	47,9	100,2	30,0	90,0
125	9,1	92,6	10,0	95,8	28,7	96,5	58,2	99,9	34,6	89,7
160	9,1	92,9	10,0	96,8	23,7	96,2	49,2	99,9	32,0	90,4
200	10,0	93,3	8,5	98,5	12,5	96,2	24,9	98,8	24,3	90,9
250	10,0	93,6	8,5	99,5	7,5	95,9	15,9	98,8	21,6	91,6
315	10,0	95,0	11,9	101,5	10,2	95,9	30,2	101,8	25,6	93,2
400	7,7	97,4	16,1	104,8	15,0	95,9	57,9	107,3	30,8	96,0
500	7,7	98,8	19,4	106,8	17,6	95,9	72,2	110,3	34,8	97,6
630	17,0	97,8	24,7	106,2	22,0	96,2	69,9	109,0	43,8	97,3
800	33,0	96,0	32,6	104,8	28,6	96,7	62,1	106,3	60,0	96,9
1000	42,3	95,0	37,9	104,1	32,9	97,0	59,8	105,0	69,0	96,6
1250	44,0	94,0	39,9	103,1	31,6	97,4	56,8	103,3	60,7	93,9
1600	42,9	93,2	41,6	102,3	28,6	98,4	52,1	101,4	43,0	89,9
2000	44,6	92,2	43,6	101,3	27,3	98,7	49,1	99,7	34,7	87,3
2500	40,9	90,2	40,3	98,9	24,6	96,7	51,7	98,4	33,3	85,9
3150	34,3	87,9	33,9	96,1	20,9	93,9	58,1	97,8	34,5	85,3
4000	30,6	85,9	30,6	93,7	18,3	91,9	60,7	96,4	33,1	84,0
5000	28,6	82,9	29,2	90,7	15,3	88,9	58,1	92,1	34,5	82,3
6300	27,0	78,8	28,7	86,8	11,6	84,8	52,2	85,4	37,2	80,1
8000	25,0	75,8	27,3	83,8	8,6	81,8	49,5	81,1	38,6	78,4
10000	25,0	75,8	27,3	83,8	8,6	81,8	49,5	81,1	38,6	78,4

For different track conditions suitable input data are currently not available. Therefore, provisionally, default corrections are proposed, as given in Table 2.9.

Table 2.9 *Corrections for track conditions*

Condition	**Effective distance**	**Correction (dB)**
Rails with joints	Continuously	+3
Switches and crosses	10 m/switch or crossing	+6
Bridge without ballast	Length of bridge	+6
Bridge with ballast	Length of bridge	+3

In future new source data should be collected in 1/3 octave bands, for each sub-sources following the proposed classifications.

2.2.5 Comments on the Nord2000 source model

- In general, this source model is less advanced than the source model made in the Harmonoise project, which was adopted by the CNOSSOS-EU while with some simplifications employed such as reducing the number of source heights.
- The lateral source position, the nearest rail, is good for special cases such as in calculating the shielding effect of near-track low barriers. For distant receivers and strategic noise mappings, the lateral source position can be put at the centre of the track, as proposed in the CNOSSOS-EU.
- For rolling noise the three default source heights, 0, 0.35 m and 0.7 m above the railhead, can be reduced to two source heights, 0 and 0.5 m as proposed in the Harmonoise project. In the CNOSSOS-EU method the number of source heights for rolling noise has been reduced to one, i.e. 0.5 m only. However, this extreme simplification is questionable. In case a railway track has a height similar to the surrounding's one source height model would lead to bigger errors in noise prediction. It is always a trade-off issue between accuracy and calculation time/cost.
- For power unit noise, the bogie height (0.5 m) is sometimes an applicable source height.
- The proposed horizontal directivity function, Eq. (2.2), has in fact been used in several national models [15]. As indicated in [16], if modelling the directivity of wheel radiation as $\Delta L_{wheel}(\varphi) = 10 * \lg[0.4 + 0.6 * \cos(\varphi)]$, and taking the rail radiation (which is horizontally a dipole source) 3 dB stronger than the wheel radiation, the horizontal directivity of the total rolling noise will be the one given by Eq (2.2).
- Comparing with the classifications made in the Harmonoise or made in the CNOSSOS-EU, one must realise that a balance between the necessary accuracy and the required work load/cost is extremely important, because collecting reliable source data for all categories is very costly. For Nordic applications it may be practical to use train categories instead of vehicle categories which were proposed in the Harmonoise project as well as in the CNOSSOS-EU project.
- For the first three driving conditions the traction noise is concerned (except while braking); the traction noise depends more on the load than on the train speed. At a speed when rolling noise dominates, it is not necessary to distinguish between these three driving conditions.
- The formulation of sound power level, Eq. (2.3) together with Tables 2.6 - 2.8, is less advanced than the roughness-transfer function description which was proposed in the Harmonoise project. Specially, in a narrow speed range Eq. (2.3) can be worked out based on the measurements in order to provide approximate results; however, when a wider speed range is to be handled the error by using this source description will become larger.
- Table 2.8, Input data for Danish trains, the train categories do not match the one presented in Table 2.3b.
- In Table 2.9, correction for joints should depend on the number of joints per 100 m, not a constant correction for all situations.
- In Table 2.4, BV50 (similar to UIC54) rails are also popular in Sweden.

3 CNOSSOS-HARMONOISE Method

In 2009, the European Commission decided to develop the CNOSSOS-EU (**C**ommon **NO**ise a**SS**essment Meth**O**d**S** in EU) method for noise mapping of road traffic, railway traffic, aircraft and industrial noise. In the development phase (phase A, methodological framework, 2010-2012) of the CNOSSOS-EU process a harmonized methodological framework for noise assessment was developed. It was based on state-of-art scientific, technical and practical knowledge about environment noise assessment in Europe, while considering the cost burden incurred by EU countries when undertaking the periodic strategic noise mapping.

The core of the CNOSSOS-EU methodological framework consists of [17]:

- a quality framework that describes the objectives and requirements of CNOSSOS-EU;
- parts describing road traffic, railway traffic, industrial noise source emission and sound propagation;
- a part describing the methodology chosen for the aircraft noise prediction and its associated performance database;
- a methodology to assign receiver points to the facades of buildings and to assign population data to the receiver points at the facades of buildings;
- the scope and the concept of the "Guidance for the competent use of CNOSSOS-EU", which should be fully developed in the implementation phase (phase B, tools and validation, 2012-2015) of the CNOSSOS-EU process.

Moreover, the revision of the Electronic Noise Data Reporting Mechanism (ENDRM) represents the key interface between the throughout Europe and the sharing of the results by means of one common noise methodological framework.

The CNOSSOS-EU was developed by the European Commission in a cooperative process involving the European Environment Agency, the World Health Organization Europe, the European Aviation Safety Agency and experts nominated by EU countries.

The European Commission will amend Annex II of Directive 2002/49/EC, in connection with the implementation phase of CNOSSOS-EU in 2012-2015. The ultimate goal is to have the common noise assessment methodology operational for the next round of strategic noise mapping in the European Union, in 2017.

In this section, the parts describing railway traffic and sound propagation will be studied.

3.1 From Harmonoise to CNOSSOS-EU

Briefly, the European Harmonoise project (2001-2004) aimed at developing proper noise assessment methods for road and railway traffic noise; the European Imagine project (2004-2007) aimed at developing noise assessment methods for industrial noise and aircraft noise; and the European CNOSSOS-EU project (phase A, 2009-2012; phase B, 2012-2015) aimed at developing a harmonized methodological framework for noise assessment, based on state-of-art scientific, technical and practical knowledge about environment noise assessment in Europe, while considering the cost burden incurred by EU countries when undertaking the periodic strategic noise mapping. In other words, noise assessment methods developed in the CNOSSOS-EU project are simplified compared with those methods developed in the Harmonoise/Imagine project.

The full title of the European Harmonoise project is: **H**armonised **A**ccurate and **R**eliable **M**ethods for the EU Directive on the Assessment and Management **O**f Environmental **NOISE**.

The goals of the Harmonoise project were [10],

- The HARMONOISE project intends to develop new, intelligent, commonly accepted, harmonised computation methods for future use as the main tool for environmental noise management throughout all Member States of the EC.
- By describing the source term in more general, physical terms the HARMONOISE project intends to provide a better link between two main political goals of the EC: on the one hand to monitor the extend of environmental noise annoyance throughout the EC and to stimulate (or to enforce) that counteractive measures be developed and carried out by local authorities, and on the other hand to control an reduce the noise creation of a wide variety of noise sources by stating noise creation limits.
- Thirdly, by de-coupling the description of the source from the description of noise propagation, the HARMONOISE project intends to provide the basis for a general noise propagation model, that will be validated within the project for road and railway noise, but which can be used without change for any other noise sources, e.g. aircraft noise, ship noise, recreational noise and industrial noise.

The full title of the European Imagine project is: **I**mproved **M**ethods for the **A**ssessment of the **G**eneric **I**mpact of **N**oise in the **E**nvironment.

The objectives of the Imagine project were [18],

1. To provide practical guidelines for data management and information technology aspects of noise mapping (Work Package 1),
2. To provide guidelines and examples for an efficient link between traffic flow management on the one hand and noise action planning on the other (Work Package 2),
3. To provide guidelines and examples of how and when noise measurements can add to the credibility and reliability of assessed noise levels (Work Package 3),
4. To provide a harmonised, accepted and reliable method for the assessment of environmental noise levels from airports, which links well within the methods for noise propagation description developed in HARMONOISE and – at the same time – have large acceptance in the field of future users and other stakeholders (Work Package 4),
5. To provide default databases for the source description of road noise, i.e. vehicle category and possibly road surface type related, for a typical fleet of European

road traffic, and provide guidelines on how to deal with situations deviating from the default value (Work Package 5),

6. To provide default databases for the source description of rail noise, i.e. vehicle category and possibly track type related, for a exemplary sample of the European rail traffic fleet, and provide guidelines on how to deal with situations deviating from the typical samples (Work Package 6),
7. To provide a harmonised, accepted and reliable method for the assessment of environmental noise levels from industrial sites and plants, which links well within the methods for noise propagation description developed in HARMONOISE, in combination with methods for source description by measurements based on the existing set of standards and guidelines, together with a default database for typical sound production for a limited but representative number of industrial activities (Work Package 7),
8. To provide for acceptance and easy and quick implementation of the above deliverables and those from the HARMONOISE projects, in order to allow a smooth and harmonised process of noise mapping and noise action planning in all member states (Work Package 8).

3.2 Some general concepts

Point source

A point source is an elementary dimensionless representation of an ideal source of noise located in a specific place in space. Point source strength is expressed exclusively by the directional sound power level $L_{w,0,dir}$ per frequency band and towards a specific direction in space. All relevant parameters that define source strength will be incorporated, including horizontal and vertical directivity if applicable.

Source line/source line segment

A source line is an approximate trajectory of a moving equivalent point source or a series of incoherent point sources along the line in the case of fixed sources. For practical reasons, a source line can be approximated by a set of straight-line segments (polyline). However, ideally, it would be represented by a curve in space.

A source line is characterised by a continuous distribution of point sources. The strength of a source line is expressed as directional sound power level per metre per frequency band, towards a specific direction in 3D space. All relevant parameters that define source strength will be incorporated, including horizontal and vertical directivity if applicable. In practice, the continuous distribution of point sources will be replaced by a discrete distribution, i.e. equivalent point sources placed at representative positions along the source line. Point sources are situated at the intersections of each propagation path with each source line.

Equivalent vehicle

An equivalent vehicle is an ideal vehicle for which the acoustically relevant properties correspond to the average of a specific set of real vehicles moving along a specific road or railway.

Vehicle model

The vehicle model is the acoustical description of a single moving equivalent vehicle at specific speed and acceleration. A single vehicle might be composed of one or several mutually incoherent sub-sources at different positions, the strength of which is defined in terms of their directional source sound power level.

Traffic model

The traffic model is the acoustical description of a traffic flow, based on the directional source sound power levels of single moving equivalent vehicles. In the traffic model, the specific sound power output is combined with statistical data, yielding an equivalent noise emission for each sub-source in order to produce the source strength of the relevant source line segments.

NB: As a single vehicle can be represented by one or a set of point sources at different heights, the resulting traffic model will consist of one or a set of superimposed source lines that share a single footprint on the ground.

Receiver

A receiver is a single point at which the incident time-averaged sound intensity level will be calculated. A distinction should be made between free-field receivers that have propagation paths in all directions (360°) and receivers that represent the incoming acoustical energy on a façade. The latter will have a total viewing angle of 180° and a bisector perpendicular to the façade.

Sound power

In the CNOSSOS-EU model, the acoustical emission of all sources is defined as directional sound power level emitted per frequency band. Real sources are commonly close to reflecting surfaces that are included in the source definition as defined in ISO 9614. The sound power of the source as defined in this method includes possible effects of reflections by the surface immediately next to the real source and in a specific direction in space. For road and railway these nearby surfaces are the surfaces (e.g. asphalt, ballast) under the source; for industrial noise it can be the ground under a source and/or any nearby vertical surface opposite to the direction of the source-receiver. This sound power is commonly defined as ‘semi-free field’ or ‘in situ’ sound power. Any surface that has been included and counted to determine the directional source sound power level should not be used in the propagation calculation.

3.3 Source model and source data for railway noise

(The source model presented in this section is for general applications, not only for high-speed railway noise.)

According to [17], the relevant sound sources of railway noise consist of various components of the track-train system, namely: the rails and the sleeper or slab, the wheels, the fans, the compressors and the engines, the electrical equipment and the exhaust in the case of diesel-powered locomotives and the superstructure of freight trains. At high speeds, aerodynamics of the bogies and of the pantograph and the train body become relevant as well. Depending on the speed, contributions from these sources change their relative importance. Therefore, it is not possible to exclude a priori any of these sources.

The sources mentioned are mostly dependent on the specific features of single sub-units within a train, rather than being of a constant type along the whole train. For this reason, it is appropriate to classify each single subunit of a train and add up the number of single sub-units travelling on a specific track section, rather than using classifications by the whole train type.

3.3.1 Classification of vehicles

A ***vehicle*** is defined as any single subunit of a train (typically a locomotive, a self-propelled coach, a hauled coach or a freight wagon) that can be moved independently and can be detached from the rest of the train. Some specific circumstances may occur for sub-units of a train that are a part of a non-detachable set, e.g. share one bogie between them. For the purpose of this calculation method, all these sub-units are grouped into a single vehicle.

For the purpose of this calculation method, a ***train*** consists of a series of coupled vehicles.

Table 3.1 defines a common language to describe the vehicle types included in the source database. It presents the relevant descriptors to be used to classify the vehicles in full. These descriptors correspond to properties of the vehicle, which affect the acoustic directional sound power per metre length of the equivalent source line modelled.

Table 3.1: *Classification and descriptors for railway vehicles*

Digit	**1**	**2**	**3**	**4**
Descriptor	**Vehicle type**	**Number of axles per vehicle**	**Brake type**	**Wheel measure**
Explanation of descriptor	A letter that describes the type	The actual number of axles	A letter that describes the brake type	A letter that describes the noise reduction measure type
Possible descriptors	**h** high speed vehicle (>200 km/h)	**1**	**c** cast-iron block	**n** no measure
	m self-propelled passenger coaches	**2**	**k** composite or sinter metal block	**d** dampers
	p hauled passenger coaches	**3**	**n** non-tread braked, like disc, drum, magnetic	**s** screens
	c city tram or light	**4**		**o** other

	metro self-propelled and non-self-propelled coach			
	d diesel loco	**etc.**		
	e electric loco			
	a any generic freight vehicle			
	o other (i.e. maintenance vehicles etc.)			

The number of vehicles for each type should be determined on each of the track sections for each of the time periods to be used in the noise calculation. It should be expressed as an average number of vehicles per hour, which is obtained by dividing the total number of vehicles travelling in a given time period by the duration in hours of this time period (e.g. 24 vehicles in 4 hours means 6 vehicles per hour). All vehicle types travelling on each track section (defined in Section 3.2.2) will be used.

3.3.2 Classification of tracks and support structure

The existing tracks may differ because there are several elements contributing to and characterising their acoustic properties. The track types used in this method are listed in Table 3.2. Some of the elements have a large influence on acoustic properties, while others have only secondary effects. In general, the most relevant elements influencing the railway noise emission are: railhead roughness, rail pad stiffness, track base, rail joints and radius of curvature of the track. Alternatively, the overall track properties can be defined and, in such a case, the railhead roughness and the track decay rate according to ISO 3095 are the two acoustically essential parameters, plus the radius of curvature of the track.

Table 3.2: *Classification of the track types*

Digit	**1**	**2**	**3**	**4**	**5**	**6**
Descriptor	**Track base**	**Railhead roughness**	**Rail pad type**	**Additional measures**	**Rail joints**	**Curvature**
Explanation of descriptor	Type of track base	Indicator for roughness	Represents an indication of the 'acoustic' stiffness	A letter describing acoustic device	Presence of joints and spacing	Indicate the radius of curvature in m
	B	**E** Well	**S** Soft	**N**	**N**	**N**

Code allowed	Ballast	maintained and very smooth	(150-250 MN/m)	None	None	Straight
	S Slab track	**M** Normally maintained	**M** Medium (250 to 800 MN/m)	**D** Rail damper	**S** Single joint or switch	**L** Low (1000-500 m)
	L Ballasted bridge	**N** Not well maintained	**H** Stiff (800-1000 MN/m)	**B** Low barrier	**D** Two joints or switches per 100 m	**M** Medium (Less than 500 m and more than 300 m)
	N Non ballasted bridge	**B** Not maintained and bad condition		**A** Absorber plate on slab track	**M** More than two joints or switches per 100 m	**H** High (Less than 300 m)
	T Embedded track			**E** Embedded rail		
	O Other			**O** Other		

A track section is defined as a part of a single track, on a railway line or station or depot, on which the track's physical properties and basic components do not change.

Table 3.2 defines a common language to describe the track types included in the source database.

The parameters associated with the different track section types will be found in the CNOSSOS-EU database, which will be developed during phase B of the CNOSSOS-EU process.

3.3.3 Positions of the equivalent sound sources

All source lines are placed at the centre of the track, at a height referred to the plane tangent to the two upper surfaces of the two rails. As simplified, only two source heights are relevant: (1) for rolling noise (including the superstructure noise of freight trains) only one representative source height of 0.5 m will be used; this source height is also used for impact noise, squeal noise and bridge noise; (2) for aerodynamic noise the around-bogie components have a representative source height of 0.5 m and the over-roof components as well as pantograph noise have a representative source height of 4 m; (3) for traction noise gear transmissions and electric motors have a representative source height of 0.5 m while engine exhausts of diesel locomotives are often located at 4 m high; other traction noise sources such as fans or engine blocks may be located at a height of 0.5 m while louvers and cooling outlets can be located at various height.

3.3.4 Sound power emission

From each specific noise (rolling, impact, squeal, braking, traction, aerodynamic, other effects) of a single vehicle in the directions ψ, φ defined with respect to the vehicle's direction of movement (see Figure 3.1), directional sound power level is obtained as

$$L_{W,0,dir}(\psi,\varphi) = L_{W,0} + \Delta L_{W,dir,vert}(\psi) + \Delta L_{W,dir,hor}(\varphi) \qquad (3.1)$$

where

- $\Delta L_{W,dir,vert}(\psi)$ is the vertical directivity correction function
- $\Delta L_{W,dir,hor}(\varphi)$ is the horizontal directivity correction function

And $L_{W,0,dir}(\psi,\varphi)$ should, after being derived in 1/3 octave bands, be expressed in octave bands.

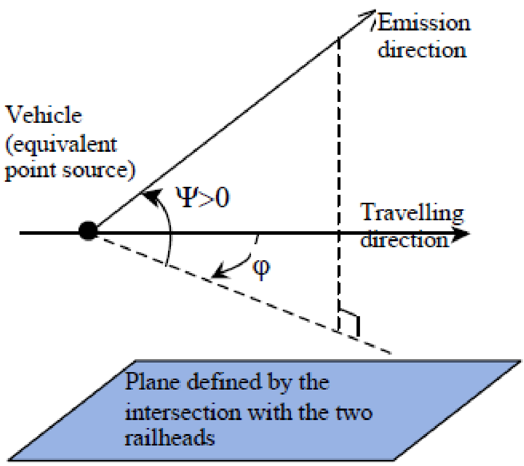

Figure 3.1: *Geometrical definition*

3.3.4.1 Rolling noise

The vehicle contribution and the track contribution to rolling noise are separated into four essential elements: wheel roughness, rail roughness, vehicle transfer functions to the wheels and to the superstructure (vessels) and track transfer function. Wheel and rail roughness represent the cause of the excitation of the vibration at the contact point between the rail and the wheel, and the transfer functions are two empirical or modelled functions that represent the entire complex phenomena of the mechanical vibration and sound generation on the surfaces of the wheel, the rail, the sleeper and the track substructure. This separation reflects the physical evidence that roughness present on a rail may excite the rail vibration, but it will also excite the vibration of the wheel and vice versa. Excluding any one of these four parameters would prevent the decoupling of the classification of tracks and trains.

The total and effective roughness level is defined as the energy sum of the roughness levels of the rail and of the wheel plus the A3 contact filter which takes into account the filtering effect of the contact patch between the rail and the wheel, and is given in dB:

$$L_{r,TOT} = 10 * \lg\left(10^{L_{r,TR}/10} + 10^{L_{r,VEH}/10}\right) + A_3 \qquad (3.2)$$

where $\lg$ denotes for $\log_{10}$.The contact filter depends on the rail and the wheel type and the load, and is presented for some specific common cases in Table 3.3.

Table 3.3: *The contact filter depends on the rail and wheel type and the load; and it is presented here for some specific common cases.*

Wavelength (cm)	**360 mm / 50 kN**	**680 mm / 50 kN**	**920 mm / 25 kN**	**920 mm / 50 kN**	**920 mm / 100 kN**
1	-8.4	-12	-12	-12	-12
0.8	-12	-12.5	-12.6	-13.5	-14
0.63	-11.5	-13.5	-13.5	-14.5	-15
0.5	-12.5	-16	-14.5	-16	-17
0.4	-13.9	-16	-16	-16.5	-18.4
0.315	-14.7	-16.5	-16.5	-17.7	-19.5
0.25	-15.6	-17	-17.7	-18.6	-20.5
0.2	-16.6	-18	-18.6	-19.6	-21.5
0.16	-17.6	-19	-19.6	-20.6	-22.4
0.125	-18.6	-20.2	-20.6	-21.6	-23.5
0.1	-19.6	-21.2	-21.6	-22.6	-24.5
0.08	-20.6	-22.2	-22.6	-23.6	-25.4
0.063	-21.6	-23.2	-23.6	-24	
0.05	-22.6	-24.2	-24.6	-25.6	-27.5
0.04	-23.6	-25.2	-25.6	-26.6	-28.4

Vehicle and track transfer function

Three speed-independent transfer functions, $L_{H,tr}$, $L_{H,veh}$ and $L_{H,veh,\sup}$ are defined for each track section and vehicle type. They relate the total effective roughness level to the sound power of the track and of the wheels, respectively. These functions can be obtained from specific measurements but are also tabulated for some common cases in Tables 3.4 to 3.6.

For rolling noise, therefore, the contributions from the track and from the vehicle are fully described by these transfer functions and by the total effective roughness level.

Following the scheme shown in figure 3.2, the sound power per vehicle is calculated at axle height, and as input parameters it uses the total equivalent roughness level as a function of the vehicle speed v through $\lambda = v/f$, the track-, vehicle- and vehicle-superstructure (for freight trains only) transfer functions, and the total number of axles N_a:

$$L_{W,0,tr} = L_{r,TOT} + L_{H,tr} + 10\lg(N_a) \quad (3.3)$$

$$L_{W,0,veh} = L_{r,TOT} + L_{H,veh} + 10\lg(N_a) \quad (3.4)$$

$$L_{W,0,veh,\sup} = L_{r,TOT} + L_{H,veh,\sup} + 10\lg(N_a) \quad (3.5)$$

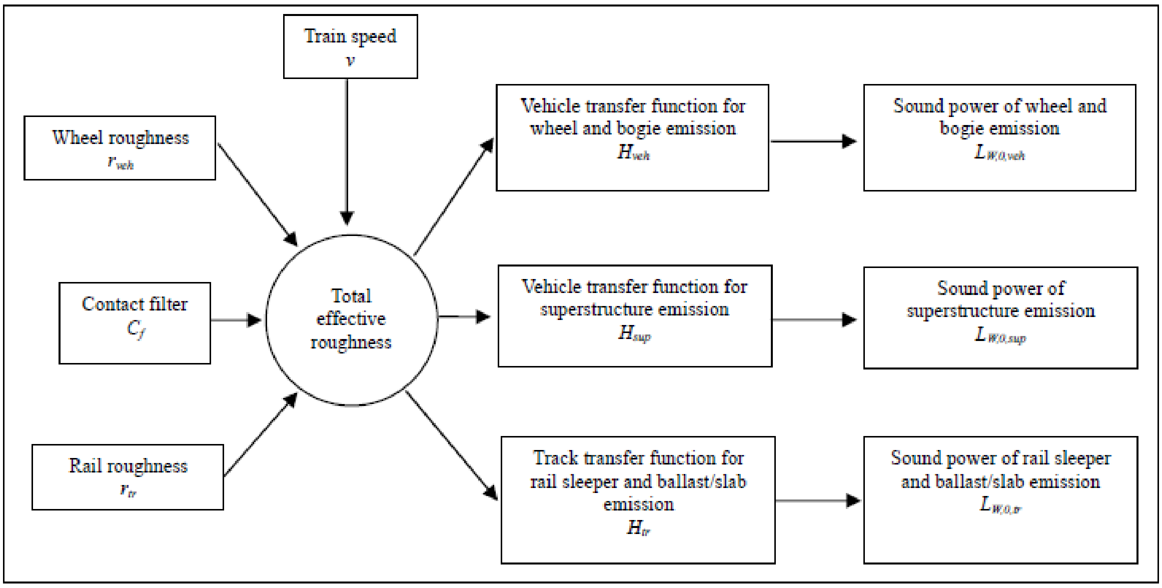

Figure 3.2: *Scheme of the use of the roughness and transfer function definitions.*

Table 3.4: *Speed independent track transfer functions for some common cases.*

Frequency (Hz)	Mono-block on soft rail pad	Mono-block on medium stiffness rail pad	Mono-block on hard rail pad	Bi-block on soft rail pad	Bi-block on medium stiffness rail pad	Bi-block on hard rail pad	Wooden sleepers
25	35.1	32.1	31.1	32.1	31.1	31.1	26.1
32	41.6	38.6	37.6	38.6	37.6	37.6	32.6
40	49.4	46.4	45.4	46.4	45.4	45.4	40.4
50	56.2	53.8	53.0	53.8	52.9	52.7	46.9
63	61.9	60.4	59.8	59.2	58.7	58.5	53.6
80	63.6	62.9	62.7	60.7	60.5	60.4	56.3
100	71.0	71.9	72.3	67.4	67.6	67.6	65.9
125	78.3	80.0	80.7	74.5	74.9	75.0	74.2
160	82.4	83.9	84.6	79.1	79.7	80.0	77.7
200	85.6	87.2	87.9	83.2	85.0	85.8	78.6
250	83.3	84.7	85.4	81.3	83.4	84.4	75.6
315	86.7	87.3	87.8	84.8	85.3	85.9	81.0
400	92.0	91.4	91.8	89.4	87.2	87.7	90.0
500	96.7	95.3	95.5	94.2	90.3	90.5	96.7
630	101.1	99.3	98.9	99.4	95.7	95.0	100.6
800	98.7	96.4	95.0	98.7	95.3	92.6	97.5
1000	103.0	100.3	98.4	103.8	100.6	97.0	101.3
1250	107.7	105.4	103.6	108.3	105.7	102.8	105.9
1600	110.7	109.0	107.6	111.0	109.3	107.6	108.6
2000	112.3	110.9	109.7	112.4	111.4	110.3	110.1
2500	105.8	104.7	103.7	106.0	105.1	104.3	103.9
3150	106.9	106.0	105.1	107.0	106.3	105.6	105.3
4000	110.2	109.6	108.9	110.3	109.9	109.3	108.9
5000	110.2	109.8	109.3	110.2	109.9	109.5	109.0
6300	109.0	108.9	108.7	108.9	108.8	108.6	108.1
8000	104.7	104.9	105.0	104.6	104.6	104.5	104.1
10000	105.6	106.0	106.4	105.4	105.5	105.6	105.2

Table 3.5: *Speed independent vehicle transfer functions for some common wheel diameters.*

Frequency (Hz)	Wheel with diameter 920 mm	Wheel with diameter 840 mm	Wheel with diameter 680 mm	Wheel with diameter 1200 mm
25	78.1	78.1	78.1	78.1
32	77.8	77.8	77.8	77.8
40	77.9	77.9	77.9	77.9
50	77.2	77.2	77.2	77.2
63	79.5	79.5	79.5	79.5
80	82.1	82.1	82.1	82.1
100	82.0	82.0	82.0	82.0
125	83.0	82.5	82.5	82.5
160	82.1	81.1	81.1	81.1
200	85.5	83.6	83.4	84.0
250	88.8	85.6	85.0	89.1
315	89.0	87.1	87.2	89.6
400	87.4	88.3	90.6	88.3
500	84.8	86.9	89.9	86.1
630	90.1	91.2	92.2	91.0
800	91.1	90.2	89.6	90.2
1000	92.3	90.4	87.8	91.0
1250	97.3	95.6	90.1	97.4
1600	103.0	100.0	91.9	103.0
2000	110.6	108.6	100.6	116.6
2500	113.6	110.6	103.6	114.6
3150	113.2	112.7	106.2	114.2
4000	113.7	113.2	109.7	114.7
5000	113.2	112.7	109.2	114.2
6300	115.7	115.2	111.7	116.7
8000	113.4	112.9	109.4	114.4
10000	113.0	112.5	109.0	114.0

Table 3.6: *The total roughness for some common cases.*

Wavelength (cm)	Cast iron braked wheel on Dutch typical rail roughness	Disk braked wheel on Dutch typical rail roughness	Disk braked wheel on smooth roughness rail	ISO spectrum	TSI	Very smooth wheel on Dutch typical rail roughness	Composite block on smooth roughness rail	Maximum roughness combined	Minimum roughness combined	Roughness of standard disk braked wheel
63	20	11	20.5	23.5	17.1	11	18.5	25	5	11
50	17	11	18.7	21.7	17.1	11	16.7	20	0	11
40	14	11	16.8	19.8	17.1	11	14.8	20	-5	11
31.5	12	10	15	18	15	10	13	20	-6	10
25	10	9	13.1	16.1	13	9	11.1	20	-7	9
20	10	8	11.3	14.3	11	8	9.3	20	-8	8
16	11	7	9.4	12.4	9	7	7.4	20	-9	7
12	11	6	7.6	10.6	7	6	5.6	20	-10	6
10	11	5	5.8	8.8	4.9	5	3.8	20	-11	5
8	13	3.8	3.7	6.7	2.7	3.8	1.7	20	-12	3.8
6.3	14	2.5	1.6	4.6	0.4	2.5	-0.4	20	-13	2.5
5	14	1.1	-0.7	2.3	-2	1.1	-2.7	20	-14	1.1
4	13	-0.6	-3.2	-0.2	-4.8	-0.6	-5.2	20	-15	-0.6
3.2	10	-2.5	-6	-3	-7.5	-2.5	-8	19	-16	-2.5
2.5	7	-4.8	-9.1	-6.1	-9.4	-4.8	-11.1	17	-17	-4.8
2	3	-7.8	-12.9	-9.9	-12	-7.8	-14.9	15	-20	-7.8
1.6	-2	-11.5	-17.5	-14.5	-15.3	-11.5	-19.5	10	-23	-16
1.2	-7	-15.4	-22.2	-19.2	-18.8	-15.4	-24.2	5	-27	-19
1	-14	-17	-24.7	-21.7	-20	-17	-26.7	0	-30	-22
0.8	-19.5	-19.5	-26.2	-23.2	-22.1	-19.5	-28.2	-5	-31	-25
0.63	-21.5	-21.5	-27.2	-24.2	-23.7	-21.5	-29.2	-10	-32	-28
0.5	-24	-24	-28.7	-25.7	-25.8	-24	-30.7	-15	-33	-31
0.4	-25.5	-25.5	-29.2	-26.2	-26.9	-25.5	-31.2	-20	-34	-34
0.32	-27.7	-27.7	-30.4	-27.4	-28.7	-27.7	-32.4	-25	-35	-37
0.25	-29.6	-29.6	-31.3	-28.3	-30.2	-29.6	-33.3	-26	-36	-40
0.2	-31.6	-31.6	-32.3	-29.3	-31.8	-31.6	-34.3	-27	-37	-43
0.16	-33.6	-33.6	-33.3	-30.3	-33.4	-33.6	-35.3	-28	-38	-46
0.13	-35.6	-35.6	-34.3	-31.3	-35	-35.6	-36.3	-29	-39	-49
0.1	-37	-37.6	-35.3	-32.3	-36.6	-37.6	-37.3	-30	-40	-52

3.3.4.2 Impact noise (crossings, switches and junctions)

Impact noise can be caused by crossings, switches and rail joints or points. It can vary in magnitude and can dominate rolling noise. As it is often localised, it has to be taken into account when choosing track segmentation. If it is to be considered, impact noise is included in the rolling noise term by (energetically) adding a supplementary fictitious impact roughness level to the total effective roughness level. In this case a new roughness level $L_{r,TOT,\ IMPACT}$ should be used in place of $L_{r,TOT}$:

$$L_{r,TOT,IMPACT} = 10 * \lg\left(10^{L_{r,TOT}/10} + 10^{L_{r,IMPACT}/10}\right) \tag{3.6}$$

Impact noise depends on the severity and number of impacts per unit length or joint density. In the case of multiple impacts, the impact roughness level to be used in Eq. (3.6) is:

$$L_{r,IMPACT} = L_{r,IMPACT-SINGLE} + 10 * \lg\left(\frac{n_1}{0.01}\right) \quad \text{(dB)} \tag{3.7}$$

where $L_{r,IMPACT-SINGLE}$ is the impact roughness level of a single impact in Table 3.7 and n_l is the joint density (number of joints per 100 m of track).

Table 3.7: *A default single-impact roughness as a function of wavelength*

Wavelength (cm)	$L_{R,IMPACT-SINGLE,i(\lambda)}$
63	22.4
50	23.8
40	24.7
31.5	24.7
25	23.4
20	21.7
16	20.2
12	20.4
10	20.8
8	20.9
6.3	19.8
5	18
4	16
3.2	13
2.5	10
2	6
1.6	1
1.2	-4
1	-11
0.8	-16.5
0.63	-18.5
0.5	-21
0.4	-22.5
0.32	-24.7
0.25	-26.6
0.2	-28.6
0.16	-30.6
0.13	-32.6

3.3.4.3 Curve squeal noise

Curve squeal is a special source that is only relevant for curves and is therefore localised. As it can be significant, an appropriate description is required. Curve squeal is generally dependent on curvature, friction conditions, train speed and track-wheel geometry and dynamics. The emission level to be used is determined for curves with radius below or equal to 700 m and for sharper curves and branch-outs of points with radii below 300 m. The noise emission should be specific to each type of rolling stock, as certain wheel and bogie types may be significantly less prone to squeal than others.

Taking a simple approach, squeal noise should be considered by adding 8 dB for R<300 m and 5 dB for 300 m<R<500 m to the rolling noise sound power spectra for all frequencies. Squeal contribution should be applied on railway track sections where the radius is within the ranges mentioned above for at least a 50 m length of track.

The applicability of these sound power spectra should normally be verified on-site, especially for trams.

3.3.4.4 Traction noise

Traction noise is generally specific to each characteristic operating condition: constant speed (including deceleration, when it is assumed to be the same noisy as for constant speed), acceleration and idling. The appropriate source strength is to be used according to the operating condition of the train in each track segment. The source strength modelled here only corresponds to maximum load conditions; resulting in the equal quantities $L_{W,0,const} = L_{W,0,dec} = L_{W,0,acc} = L_{W,0,idling}$ where the subscripts denote constant speed, deceleration, acceleration and idling respectively.

The term $L_{W,0,idling}$ is expressed as a static noise source in the idling position, for the duration of the idling condition, and to be modelled as a fixed point source. It is to be considered only if trains are idling for more than 30 minutes.

These quantities can either be obtained from measurements of all sources at each operating condition, or the partial sources can be characterised individually, determining their parameter dependency and relative strength. This may be done by means of measurements on a stationary vehicle, by varying shaft speeds of the traction equipment, following ISO 3095. As far as is relevant, several traction noise sources have to be characterised, which might not be all directly depending on the train speed:

- Noise from the power train, such as diesel engines (including inlet, exhaust and engine block), gear transmission, electrical generators, mainly dependent on engine round per minute speed (rpm), and electrical sources such as converters, which may be mostly load dependent;
- Noise from fans and cooling systems, depending on fan rpm; in some cases fans can be directly coupled to the driveline;
- Intermittent sources such as compressors, valves and others with a characteristic duration of operation and corresponding duty cycle correction for the noise emission.

Table 3.8: *The standard proportion of traction noise to be attributed to the two source heights,* $L_{W,0,acc,0.5m} = L_{W,0,acc,4m} = L_{W,0,acc} - 3$.

Frequency	$L_{W,0,acc,i}$ *(traction)*	
	Traction 1: Electric locomotive	Traction 2: Electrically Motored Unit with gears
25	68	58
31.5	67	60
40	68	57.3
50	69	60
63	75	60
80	69	56.3
100	70	56
125	72	70
160	74	55.3
200	85	55
250	76	70
315	75	54.3
400	80	54
500	73	53.6
630	71	53.33
800	70	53
1000	75	60
1250	67	55
1600	65	57
2000	63	55
2500	61	52
3150	59	49
4000	57	46
5000	55	43
6300	53	40
8000	51	37
10000	49	34

As each of these sources can behave differently at each operating condition, the traction noise must be specified accordingly. The source strength is obtained from measurements under controlled conditions. In general, locomotives will tend to show more variation in loading as the number of vehicles hauled and thereby the power output can vary significantly, whereas fixed train formations such as electric motored units (EMUs), diesel motored units (DMUs) and high-speed trains have a better defined load.

There is no a priori attribution of the source sound power to the source heights, and this choice will depend on the specific noise and vehicle assessed. Here it is modelled to be at 0.5 m height and at 4.0 m height. In Table 3.8, the standard proportion of traction noise to be attributed to the two sources heights is given.

3.3.4.5 Aerodynamic noise

Aerodynamic noise is only relevant at high speeds above 200 km/h and therefore it should first be verified whether it is actually necessary for application purposes. If the rolling noise roughness and transfer functions are known, it can be extrapolated to higher speeds and a comparison can be made with existing high-speed data to check whether higher levels are produced by aerodynamic noise. If train speeds on a network are above 200 km/h but limited to 250 km/h, in some cases it may not be necessary to include aerodynamic noise, depending on the vehicle design.

The aerodynamic noise contribution is given as a function of speed and source height, for source heights 0.5 m and 4.0 m:

$$L_{W,0,0.5m}(v) = L_{W,0,0.5m}(v_0) + \alpha_1 * \lg\left(\frac{v}{v_0}\right) \quad \text{(dB)} \qquad (3.8)$$

$$L_{W,0,4m}(v) = L_{W,0,4m}(v_0) + \alpha_2 * \lg\left(\frac{v}{v_0}\right) \text{(dB)} \qquad (3.9)$$

where v_0 was taken as 250 km/h, while α_1 and α_2 are the coefficients representing the speed dependences of respective components of the aerodynamic noise. The default values are $\alpha_1 = \alpha_2 = 50$.

3.3.4.6 Source directivity

The horizontal directivity $\Delta L_{W,dir,hor}(\varphi)$ in dB is given in the horizontal plane and by default can be assumed to be a dipole for rolling, impact (rail joints etc.), squeal, braking, fans and aerodynamic effects, given for each frequency band by:

$$\Delta L_{W,dir,hor}(\varphi) = 10 * \lg\left(0.01 + 0.99 \sin^2 \varphi\right) \qquad (3.10)$$

The vertical directivity $\Delta L_{W,dir,vert}(\psi)$ in dB is given in the vertical plane for the source height 0.5 m, as a function of centre band frequency *f* by

$$\Delta L_{W,dir,vert}(\psi) = \frac{40}{3} * \left[\frac{2}{3}\sin(2\psi) - \sin\psi\right] * \lg\left(\frac{f + 600}{200}\right) \qquad (3.11)$$

The vertical directivity function given in Eq. (3.11) was shown in Figure 3.3.

For source height 4 m the vertical directivity is considered only for aerodynamic noise:

$$\Delta L_{W,dir,vert}(\psi) = 10 * \lg(\cos^2 \psi), \quad for\, \psi < 0$$

$$\Delta L_{W,dir,vert}(\psi) = 0, \qquad elsewhere \tag{3.12}$$

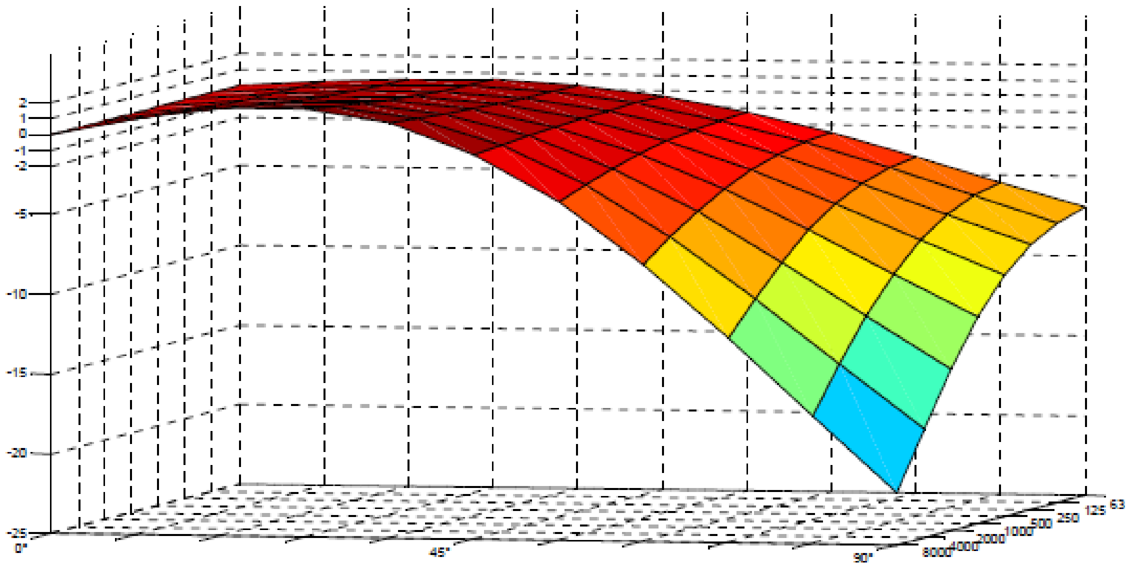

Figure 3.3: *The vertical directivity correction as a function of angle and frequency given by Eq. (3.11).*

3.3.4.7 Additional effects

Correction for structural radiation (bridges and viaducts)

In the case where the track section is on a bridge, it is necessary to consider the additional noise generated by the vibration of the bridge as a result of the excitation caused by the presence of the train. Because it is not simple to model the bridge emission as an additional source, given the complex shapes of bridges, an increase in the rolling noise is used to account for the bridge noise. The increase is modelled exclusively for the A-weighted overall level and corresponds to a fixed increase in the noise sound power. The sound power of only the rolling noise is modified when considering the correction and the new $L_{W,0,rolling-and-bridge}$ is to be used instead of $L_{W,0,rolling-only}$:

$$L_{W,0,rolling-and-bridge} = L_{W,0,rolling-only} + C_{bridge} \text{ (dB)} \tag{3.13}$$

where C_{bridge} is a constant that depends on the bridge type (which can be determined by special measurements), and $L_{W,0,rolling\text{-}only}$ is the rolling noise sound power on the given bridge that depends only on the vehicle and track properties.

Correction for other railway-related noise sources

Various sources like depots, loading/unloading areas, stations, bells, station loudspeakers, etc. can be present and are associated with the railway noise. These sources are to be treated as industrial noise sources (fixed noise sources) and should be modelled, if relevant, according to Chapter V in [17].

Source types; directional noise sound power and position; source data: roughness and transfer functions for rolling noise and sound power levels and speed dependence for aerodynamic noise; traction noise; others

3.3.5 Comments on the CNOSSOS-EU source model

- The roughness-transfer function description is an advanced method in producing source data for rolling noise. In principle, this method can be extrapolated to higher speeds, provided that the roughness data as well as the transfer function data have been prepared accurately.
- For producing source data for the lower end of 1/3 octave bands between 25 Hz and 10 kHz, it would at a high speed about 400 km/h require roughness data at a wavelength about 4.5 m! However, due to the limitation of the measurement instrument it is difficult to obtain reliable roughness data at a wavelength longer than 1 m. Moreover, for high frequency components, the contact filter has a strong effect in the equivalent roughness level that lowers the requirement on the accuracy of roughness data at short wavelengths. However, uncertainty in high-frequency components of the transfer functions is usually higher because of the low noise levels. Therefore, for covering a speed range between 30 km/h and 400 km/h, a frequency range from 125 Hz to 4 kHz is a reasonable choice. (In detail, for a speed less than 90 km/h, it is possible to go down to 25 Hz; while, for a speed around 400 km/h, 125 Hz will the lowest.)
- In fact, according the calculations made in [19], for a speed above 100 km/h, aerodynamic noise dominates in railway noise below 125 Hz. Therefore, accuracy requirement on roughness data can be relaxed for those wavelength components longer than 63 cm. A wide frequency range 1/3 octave bands from 25 Hz to 5~10 kHz seems possible to be managed, provided the aerodynamic noise has been properly modelled.
- For obtaining reliable roughness data and the transfer functions data for each of the vehicle-track combinations given in Tables 3.1 and 3.2, huge of measurements and validation work are required! As understood, at Europe level such a detailed classification is advanced and it makes the comparison of railway noise emission possible between different countries. However, it is not always necessary to prepare such a big database for national applications. For example, at a national level, it may be enough to collect total roughness data and transfer functions data for each of representative

train-track combinations, although a train contains more than one type of vehicles.

- By using one source height (0.5 m) for rolling noise, it may cause a big error in noise prediction when near-track low barriers presented. In the case, the barrier effect can differ much for a sound source located at the railhead height compared with that located 0.5 m above. Therefore, one should be careful in using this simplified source model; for some special applications a detailed source description is to be applied.
- At the conventional speed range (< 200 km/h), noise emission from the track is more important than from the wheels. The choice of one source height of 0.5 m will produce extra error in noise prediction by using a "wrong" source height, especially when the track has a height similar to the surrounding's. The error due to this simplification should be evaluated for typical terrains and for representative receiver positions before this simplification in describing source height could be safely applied.
- By using one source height for rolling noise, it is not necessary, for strategic noise mappings, to separate the rolling noise into its two components, i.e. track and vehicle contributions. And, the total transfer function is usually more reliable to use.
- However, for choosing proper measures on rolling noise, one may need to separate track contribution from wheels'. It should be careful in making such separations. According to the TWINS calculations [20], sleeper contribution will dominate in rolling noise below about 400 Hz, or below about 250 Hz if soft pads are used. Thus, it can be seen that the CNOSSOS-EU proposal for default vehicle transfer functions seems questionable.
- Sound power should be defined per unit length. However, as those given in Eqs. (3.3) to (3.5), they were defined per vehicle then not self-consistent.
- Curve squeal noise has tonal features; the proposed model does not take this into account.
- For railway aerodynamic noise, the theory indicates a speed dependence of 60; however, the proposed model takes $\alpha_1 = \alpha_2 = 50$.
- The horizontal directivity for wheel radiation may differ much from the dipole directivity [21]. Although this will not affect much on pass-by noise exposure, it would have significant effect on the maximum level. More seriously, the Doppler Effect has a strong directional effect on the noise emission while it has not been mentioned in the model.
- Correction data for viaducts are missing.

Some remarks given by the CNOSSOS-EU source model should be respected:

- The choice of source height 4.0 m for pantograph noise is known to result in a simple model, and will be considered carefully if the objective is to choose an appropriate noise barrier height.
- For impact noise, applicability of the source data produced by the model was required to be verified on-site.
- The directional sound power data should, after derived in the 1/3 octave bands, be expressed in the octave bands.
- The CNOSSOS-EU propagation model works in the octave bands, for road and railway noise between 125 Hz and 4 kHz. However, the propagation

model also works at 63 Hz octave band because industry noise is to be handled in octave bands between 63 Hz and 4 kHz.

3.4 Propagation model

The Harmonoise Reference Model has been briefly summarised in sub-sub-section 2.1.1. The Reference Model provides the calculation results for different benchmark situations; these results can be used to assess the accuracy of an engineering model.

3.4.1 The Harmonoise engineering propagation model

The Harmonoise engineering propagation model [22] took the Nord2000 propagation model as the starting point; it was also built based on the RAY model. The frequency range is 1/3 octave bands from 25 Hz to 10 kHz. The accuracy of the method are

- 1 dB standard deviation for distances up to 100 m;
- 2 dB standard deviation for distances up to 2000 m in flat surroundings / behind 1st row of buildings;
- 5 dB standard deviation for distances up to 2000 m in hilly surroundings / behind 2nd row of buildings.

These accuracy levels correspond with a 95% confidence interval of $\pm$ 2 dB, $\pm$ 4 dB and $\pm$ 10 dB respectively. The distance mentioned above is for the shortest distance to a road or a railway.

Wind speed has been classified into 5 classes from W1 to W5 for 0-1 m/s, 1-3 m/s, 3-6 m/s, 6-10 m/s and > 10 m/s, respectively. Atmospheric stability has also been classified into 5 classes from S1 to S5 for cloud cover 0/8-2/8 (day), 3/8-5/8 (day), 6/8-8/8 (day), 5/8-8/8 (night) and 0/8-4/8 (night). In total of these combinations there are 25 weather classes.

According to [23], in two aspects the Harmonoise engineering model was made in a better manner: in handling the curvatures of sound rays (although still needs some improvement [22]) and in speeding up the calculation time mostly by introducing a simpler approach in handling barrier situations.

How to model sound propagation in upward-refraction conditions should be while has not been mentioned in [22].

3.4.2 The CNOSSOS-EU propagation model

Aiming at strategic noise mapping, it is necessary to consider a balance between the accuracy and the calculation time; many simplifications were then employed in the CNOSSOS-EU propagation model, which is based on the French propagation model NMPB 2008 (see next section).

Two types of atmospheric conditions will be relevant:

- downward-refraction propagation conditions (positive vertical gradient of effective sound celerity) from the source to the receiver;

- homogeneous atmospheric conditions (null vertical gradient of effective sound celerity) over the entire area of propagation.

Sound levels in upward-refraction conditions are not provided. It seems that each EU MS is free to choose how to handle these upward-refraction conditions.

Calculations will be made in octave bands with the centre frequencies from 63 Hz to 4 kHz, up to 800 m for a normal distance to the road/railway. A receiver height should not be less than 2 m above the ground.

Calculations of ground attenuations are simplified by introducing the concept "mean ground plane". As commented in next section, this approach has not been proved scientifically. This approach seems acceptable for calculating long-term sound levels, e.g. when making strategic noise mappings; while it is a question if this approach can be used for detailed case studies. In the French method NMPB, from its first version NMPB 96 to the revised one NMPB 2008, this approach was employed. However, the Nord2000 and the Harmonoise engineering propagation models did not consider such empirical methods; these two advanced engineering propagation models handle all situations based on proper physics.

Other simplifications may also be made in different calculation procedures, which are not necessary to be pinpointed - it is in fact not easy, if not impossible, to pinpoint such details only based on the descriptions made in [17, 22].

4 NMPB 2008 Method

The French noise prediction method, NMPB (Nouvelle Méthode de Prevision du Bruit – new method for predicting noise) deals with sound propagation outdoors. Its first version, NMPB 96, was published in 1996 or in 1997 [25-26]. Predictions made by the French road noise assessment method NMPB-Road-96 have been validated on a large experimental campaign featuring acoustical and meteorological data on real sites with complex topography, although overestimate noise levels under downwind conditions were recognised [26]. The revision of NMPB 96 was started in 2000 under the request of Sétra*; the output of the revised version, NMPB 2008, was published in 2009 [25]. (And, in [27-28] NMPB 2009 was mentioned, which was declared by the French national authorities to be under the process of being extended also to railway and industrial noise. However, unfortunately, it is not yet available.)

* Sétra - Service d'Études sur les Transports, les Routes et leurs Aménagements - Technical Department of the Ministry of Ecology, Energy Sustainable Development and the Sea, which is an engineering and expertise reference in the fields of transport, road infrastructure and engineering structures.

4.1 Overview of the NMPB 2008

4.1.1 Atmospheric conditions

The NMPB method is based on the concept of propagation path; explicitly, it is based on the RAY model. Several paths between a source and a receiver can exist, depending on topography and obstacles. Associated to each path *i*, a long-term sound level $L_{Ai,LT}$ is derived from two computations on each path, one for homogeneous atmospheric conditions (in cases sound rays are straight) and the other for downward (e.g. downwind) conditions (in cases sound rays are curved). The two types of meteorological conditions shall be weighted by the probability of occurrence of downward-refraction conditions on the site in question and its counterpart.

No simple operational model currently exists to calculate sound levels in ‘upward’ refraction conditions. To assess long-term sound levels, taking into account all the meteorological conditions encountered on the site, the current method replaces the sound levels in ‘upward-refraction conditions’ by an upper bound represented by sound levels in ‘homogeneous conditions’. This assumption overestimates the actual sound levels obtained in these propagation conditions, but such calculations tend to protect local residents better.

Together with the introduced simplified approach, mean ground plane (see 4.1.3), in calculating ground attenuations, the NMPB 2008 method can be considered more suitable for strategic noise mappings than for detailed case studies.

The NMPB 2008 propagation model was made as a 2.5 D (dimension) model, because a 3 D model can be very costly. Side reflections from vertical surfaces, or from surfaces with an off-vertical slope of less than 15^{o}, will be processed in 2 D in a vertical plane. Reflections from significantly sloping obstacles should be processed in 3 dimensions.

4.1.2 Attenuations and sound level calculations

For a point sound source of directional sound power level $L_{W,0,dir}$, the sound level at a receiver through a path in homogeneous atmosphere conditions is calculated as

$$L_H = L_{W,0,dir} - A_H \tag{4.1}$$

The term A_H is for the total attenuation along the propagation path in homogeneous conditions

$$A_H = A_{div} + A_{atm} + A_{boundary,H} \tag{4.2}$$

where

- A_{div} is the attenuation due to geometric divergence;
- A_{atm} is the attenuation due to atmospheric absorption;
- $A_{boundary,H}$ is the attenuation due to the boundary of the propagation medium in homogeneous conditions. It may contain the following terms:
  - $A_{ground,H}$, which is the attenuation due to the ground in homogeneous conditions;
  - $A_{dif,H}$, which is the attenuation due to diffraction in homogeneous conditions.

In favourable conditions, the calculation procedure is exactly identical to that in homogeneous conditions

$$L_F = L_{W,0,dir} - A_F \tag{4.3}$$

The term A_F is for the total attenuation along the propagation path in favourable conditions

$$A_F = A_{div} + A_{atm} + A_{boundary,F} \tag{4.4}$$

where

- A_{div} is the attenuation due to geometric divergence;
- A_{atm} is the attenuation due to atmospheric absorption;
- $A_{boundary,F}$ is the attenuation due to the boundary of the propagation medium in favourable conditions. It may contain the following terms:

- $A_{ground,F}$, which is the attenuation due to the ground in favourable conditions;
- $A_{dif,F}$, which is the attenuation due to diffraction in favourable conditions.

The sound level in homogeneous atmosphere L_H is also a safe estimation of the sound level in upward conditions, because homogeneous atmospheric conditions are only a transient state of the atmosphere at the scale of the day-night cycle. The downward level L_F is obtained assuming a standard atmosphere with an invariant sound speed gradient. With a proper site- and orientation-dependent probability p_i of occurrence of downward conditions it allows to compute

$$L_{LT} = 10 \lg\left[p_i 10^{0.1L_F} + (1 - p_i) 10^{0.1L_H} \right] \tag{4.5}$$

Based on the analysis of the readings from 41 meteorological stations across Metropolitan France, the probabilities of occurrence (percentages) of downward-refraction conditions by 20° sectors of receiver-source direction and for different periods day-night (06.00-22.00, 22.00-06.00) and day-evening-night (06.00-18.00, 18.00-22.00 and 22.00-06.00) have been defined in two series of tables, for each of the 41 stations. Reading these tables shows that overall, for a given station, the value of occurrence does not vary tremendously between two separate directions of 20°, except for sites where a prevailing wind is extremely marked. The variations based on the direction are smoothed out especially given the isotropic effect of thermal factors.

In practice, for a random elementary source-receiver path, the value of occurrence of the closest angular direction will be used, whether selected from the maps or the tables.

By summing contributions from all paths, all types included, the total long-term sound level at the receiver is obtained

$$L_{tot,LT} = 10 \lg\left(\sum_n 10^{0.1L_{n,LT}} \right) \tag{4.6}$$

where n is the index of the paths between a sound source and the receiver.

The total level in dBA is obtained by summing levels in each frequency band

$$L_{Aeq,LT} = 10 \lg\left(\sum_i 10^{0.1\left(L_{tot,LT,i} + AWC_i\right)} \right) \tag{4.7}$$

where i is the index of the frequency band; AWC is the A-weighting correction according to the international standard IEC 61672:2003.

This sound level $L_{Aeq,LT}$ is the final result of the long-term A-weighted SPL at the receiver over a specific reference time interval (e.g. day, evening or night; or, a short of time period when constant source conditions are found).

4.1.3 The mean ground plane and ground attenuation

The boundary is composed of the ground and, occasionally, the obstacles such as barriers and buildings. In $A_{boundary}$, the ground attenuation part, A_{ground}, is not derived from reflected paths on the ground but by a term of ground effect based on the concept of "mean ground plane" between the source and the receiver as shown in Figure 4.1.

Real heights measured vertically in relation to the ground are noted by letter *h*; equivalent heights measured orthogonally in relation to the mean ground plane is noted by letter *z*. By introducing the concept of mean ground plane, the ground effect is calculated under this simplified geometric frame, also in handling diffractions.

The mean ground plane can be obtained by regression using the least squares method applied to the ground profile included between the source and the receiver.

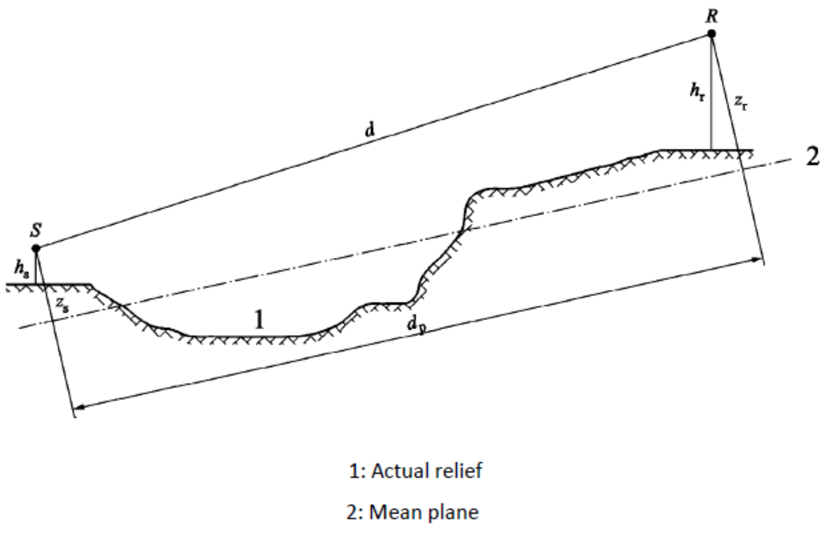

Figure 4.1. *The mean ground plane and the equivalent heights in relation to the ground [17].*

4.2 Calculation method flow chart

In the noise assessment method NMPB 2008 the concept of source lines is applied. A source line is a line of incoherent point sources simulating the modeled moving vehicles. (When handling industrial noise, by setting 0 length to these source lines, it becomes a group of point sources.) Noise calculations are to be made in 1/3 octave bands from 100 Hz to 5 kHz, up to 800 m distance normal to the road or the railway, for receiver heights not less than 2 m above the local ground. The calculation quantities are long-term sound levels such as yearly averaged L_{den}, L_{day}, $L_{evening}$, L_{night} and L_{dn}. It is also possible to handle short-term sound levels $L_{eq,T}$ provided constant sound sources and relevant atmospheric conditions well defined in the time period T.

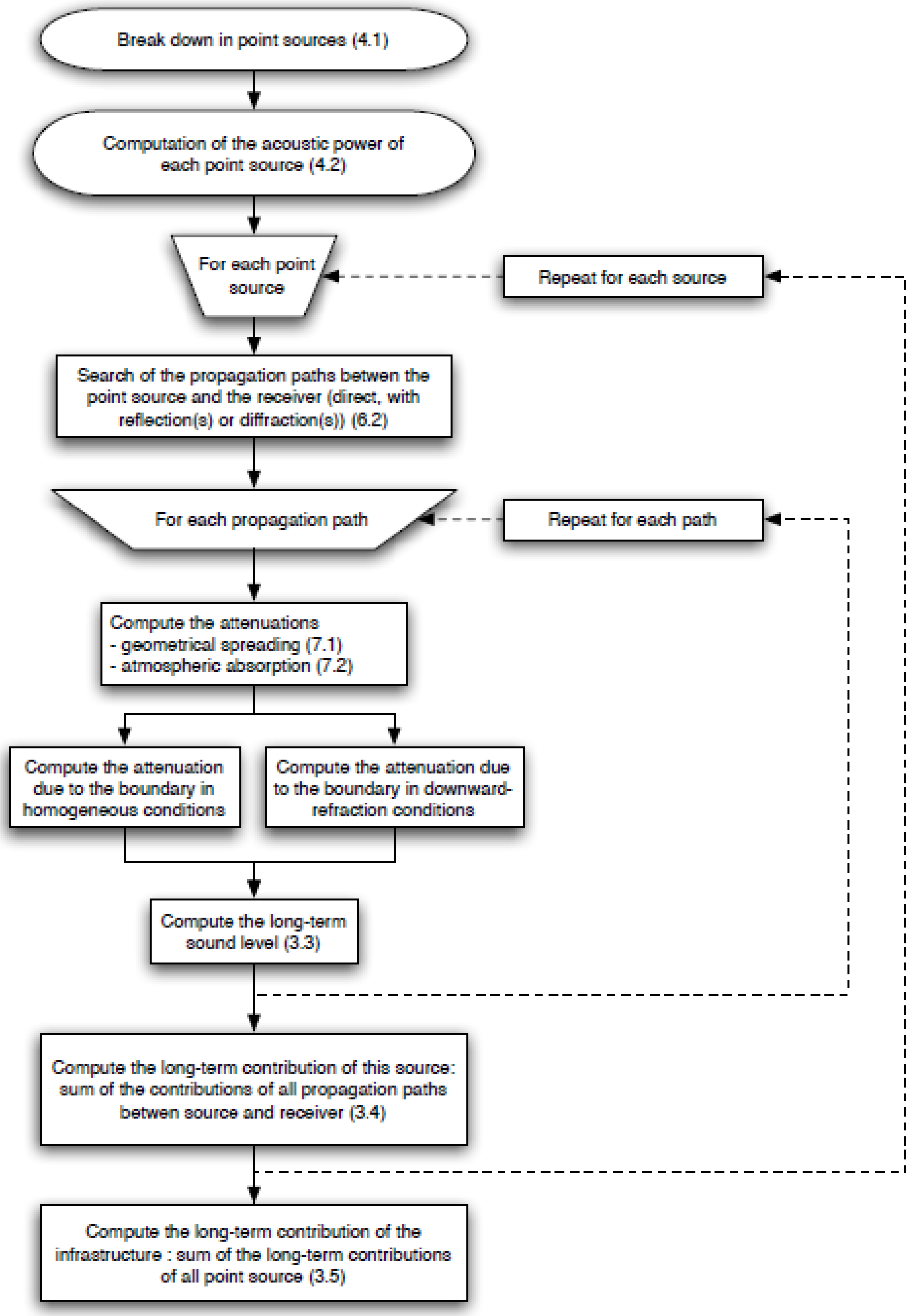

Figure 4.2. *General flow chart of the NMPB-Roads-2008 for a set of road and a receiver [25].*

The general flow chart for the calculation method presented in NMPB 2008 for a set of roads and a receiver is shown in Figure 4.2. The step in this flow chart to calculate the attenuation from the boundary formed by the ground and the obstacles is broken down in Figure 4.3. The section numbers showed in the flow charts are the ones in the original document [25].

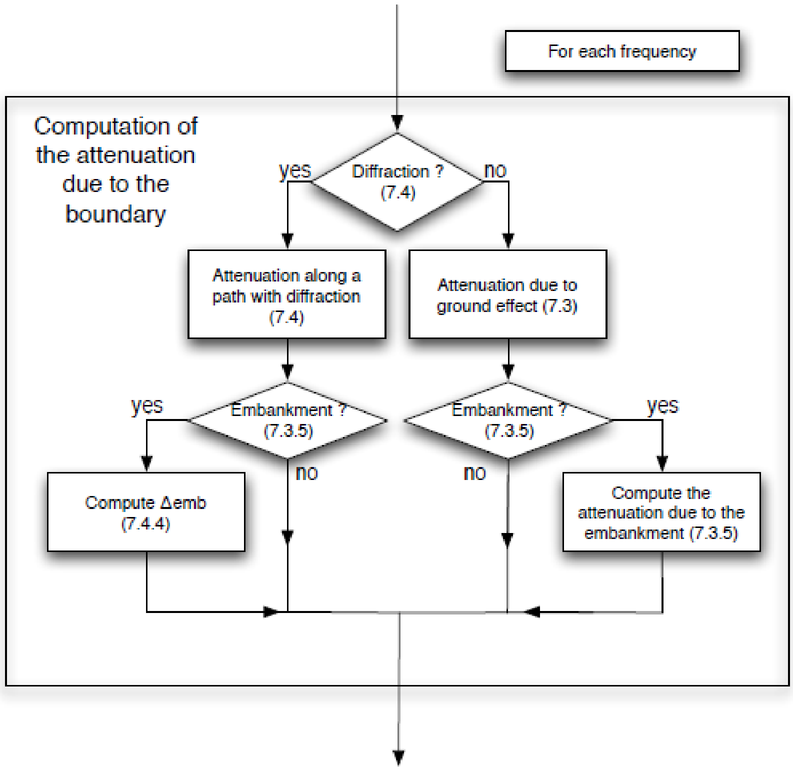

Figure 4.3. *Calculating the attenuation from the boundary of the fluid domain in the NMPB-Roads-2008. Valid in homogeneous and downward-refraction conditions.*

4.3 Validation

The NMPB-Roads-2008 has been validated in two stages [25-26]. Firstly, every change has been evaluated compared with a reference method. Depending on circumstances, the method using ray-tracing, boundary elements or the parabolic equation has served as a reference. Secondly, the entire method has been compared with measurements taken on six actual sites with cross-sections representative of common topographies:

- road in cut: sites at Molsheim (67) and Mulhouse (68);
- viaduct road: site at Saint Omer (62);
- road flanking a valley: site at Massiac (15);
- noise barrier: site at Couvron (02);
- hilly terrain: site at Mer (41).

A topographical survey was performed at each site. The sound levels at at least nine points were recorded in short *Leq* in the 1/3 octave bands for at least two weeks, at the same time the meteorological measurements were made. The meteorological readings were used to calculate the rose* of occurrences of downward refraction conditions. The extracted noise measurements give attenuation values with respect to a reference microphone for several legal Day (06.00-22.00) or Night (22.00-06.00) periods in *LAeq*. (* The curve showed in 360^o looks like a rose.)

It has been concluded that the NMPB-Roads-2008 is more accurate than the NMPB-Roads-96. However, as shown in [26], the accuracy is limited and the advantage of the NMPB-Roads-2008 is a good trade-off between accuracy and the CPU time.

4.4 Comments

- One advantage of this French method is the huge database of meteorological effects based on readings from 41 meteorological stations across Metropolitan France, over a period between 17 and 20 years (1987-2007)! Without these meteorological data, long-term sound levels could not be produced properly, see Eq. (4.5). In other words, both a proper noise assessment method and reliable and accurate input data are important for the quality of strategic noise mappings.
- Assimilation of upward-refraction conditions with homogeneous conditions is obviously not acceptable in detailed case studies; while it seems acceptable for strategic noise mappings. In the Nord2000 propagation model this part was handled physically: shadow-zone effect in upward-refraction conditions is calculated.
- The concept of mean ground plane is a simplified approach to calculate ground attenuations in this French method. This simplified approach can also be found in ISO 9613-2:1996(E) [29]. As understood, such empirical methods were popular at the time when computers' calculation speed was low. Today engineering models, e.g. the Nord2000 and the Harmonoise engineering propagation models, can be made advanced based on accurate physics. As the NMPB 2008 method employed several empirical approaches and aimed at calculating long-term sound levels, it may not be suitable for making detailed case studies. Moreover, this approach of mean ground plane has not been proved scientifically [23]. (In [27], Annex A – A.3 – Terrain profile, for the approach of mean ground plane, under "Origin" the answer is "Arbitrary choice"; and, under "Testing" the answer is "No unit test, difficult to test in itself. Overall testing of the method with respect to experiment (6 campaigns) or reference methods (BEM or PE)".)
- As mentioned in the former section, this French propagation model has been adopted as the propagation model in CNOSSOS-EU method which aims at making strategic noise mappings through EU Member States.
- For the time being a French engineering source model for railway noise is still not available.

5 Comparison of the three noise assessment methods

Based on the reviews presented in Sections 2–4, it can be concluded that, in a general sense, (1) the Nord2000 and the Harmonoise engineering propagation models are advanced because they are fully based on physics; (2) the French NMPB 2008 is a simplified engineering method because it employed several empirical approaches; (3) the propagation model adopted in CNOSSOS-EU is based on the French NMPB 2008 method and was considered good enough for strategic noise mappings through EU MS. (Note: In general, strategic (global) noise mapping differs from detailed (local) noise mapping for action planning.)

In this section, detailed comparison of the three methods will be made, with a focus on railway noise applications and the requirements set by Trafikverket (the Swedish Transport Administration).

5.1 Comparison of the noise assessment methods made in CNOSSOS-EU project

The first task of the CNOSSOS-EU project is to setup proper requirements and criteria for the selection of candidate noise assessment methods. The second task is to scrutinise possible candidate methods for further consideration in preparing the common European noise assessment methods to be used by the EU Member States for strategic noise mapping [27-28]. In Table 5.1 the requirements for the selection of the common noise assessment methods are summarized and ranked as 'essential' or 'recommendable', with "essential" meaning that the non-fulfilment of such requirement will result in considering such a method as inappropriate to meet END* requirements and basic environmental noise assessment standard. The rest of the requirements not being essential are indicated as '*recommendable*' to be part of the common methods. (* END is for Environmental Noise Directive.)

Note: In total there are 18 essential (E) and 17 recommendable (R) requirements. If numbering them by the order of appearance, then (1) under "General Requirements", there are E1-10 and R1; (2) under "Road Specific", there are E11-13 and R2-5; (3) under "Railway Specific", there are E14 and R6-9; (4) under "Industrial Specific", there are E15-16; (5) under "Aircraft Specific", there are E17 and R10-12; (6) under "Other Requirements", there are E18 and R13-17.

The noise assessment methods considered in the review of existing noise assessment methods in EU are listed in Table 5.2, wherein NMPB 2009 was declared by the French national authorities to be under the process of being extended also to railway and industrial noise while unfortunately not yet available. However, as believed, the propagation module in NMPB 2009 is the same as that in NMPB 2008.

Table 5.1. *Requirements for the selection of common noise assessment methods in EU*

Requirements for the selection of the common noise assessment methods	Essential	Recommendable
GENERAL REQUIREMENTS		
Possibility to modulate the method between a detailed (user defined specific input values) and an easy implementation with default values	X	
Fulfilment of requirements of END (Lden and Lnight, 4m/0.1m*, average meteorological year, neglecting corresponding façade reflection)	X	
Octave bands calculations		X
Geometrical divergence	X	
Atmospheric absorption	X	
Terrain profile	X	
Ground effect	X	
Reflections / diffractions	X	
Specific description of the segmentation technique to be used for decomposition of the large sources	X	
Propagation condition (are more propagation conditions allowed?)	X	
Meteorological influence (consider the effect of temperature, pressure, wind speed and direction on yearly average basis)	X	
ROAD SPECIFIC		
Road surface type correction	X	
Tyre type correction		X
Ability to split between tyre and engine noise		X
Acceleration/deceleration (Traffic flow)		X
At least 4 classes of vehicle types	X	
Gradients	X	
Specific cases (bridges, tunnels, viaducts)		X
RAILWAY SPECIFIC		
Wheel and rail roughness		X
Differentiation between track/support structure	X	
Differentiation between engine noise, rolling noise, aerodynamic noise		X
Differentiation between different types of vehicles/ locomotives		X
Specific cases (bridges, tunnels, viaducts)		X
INDUSTRIAL SPECIFIC		
Point, line, area source	X	
Lateral diffraction around obstacles	X	
AIRCRAFT SPECIFIC		
Aircraft performance as a function of air parameters, aircraft type, engine type, TOW	X	
Differentiation between different take off procedures and between different approach procedures		X
Terrain shielding / screening effects		X
Ground absorption (correction for hard ground at the receiver)		X
OTHER REQUIREMENTS		
Scientific evidence		X

Validation of the method/extent of validation		**X**
Royalties / IPR issues	**X**	
Easiness of implementation into software (complete and clear description)		**X**
Availability of parameters and input values databases		**X**
Frequency of update of database		**X**

* give results at **4 m** height **0.1 m** in front of the façade.

Table 5.2. *List of noise assessment methods considered in the review of existing noise assessment*

Road	Country		Industrial	Country
ASJ RTN 2009	JP		HARMONOISE/IMAGINE	EU
CRTN	UK		ISO 9613	EU
HARMONOISE/IMAGINE	EU		Aircraft	Country
NMPB 2009	FR		AzB 2008	DE
Nord 2000	DK- FI - IS- NO- SE		ECAC Doc. 29 3rd rev.-ICAO doc. 9911	EU
RLS90 / VBUS	DE		(FLULA)	CH
RMW	NL		(INM)	US
RVS	AT		(JCAB)	JP
Sonroad	CH		(NORTIM)	NO
Railway	Country		HARMONOISE/IMAGINE	EU
CRN	UK			
HARMONOISE/IMAGINE	EU			
Nord 2000	DK- FI - IS- NO- SE			
Onorm 305011	AT			
RMR	NL			
Schall 03 / VBUSch	DE			
Semibel	CH			

In Table 5.3 a list is given to show fulfilment of the requirements for the selection of common noise assessment methods in EU by existing noise assessment methods. It can be seen that only **Nord2000** method fulfil all the essential criteria.

However, the Nord2000 method does not explicitly contain a part for industrial noise assessment, nor it includes aircraft noise. Another method, the **HARMONOISE/ IMAGINE**, instead includes also industrial and aircraft noise, and fulfils the same criteria as the Nord2000 for road traffic and railway traffic noise, except that some IPR issues and possible associated royalties are still pending. The HARMONOISE/

IMAGINE methods, however, were still considered in the evaluation exercise given that as from recent communications most of the former HARMONOISE/IMAGINE project partners have expressed their willingness to remove any IPR issue on all parts published of the two projects. In the final report of CNOSSOS-EU project it stated that these issues had been resolved.

Table 5.3. *Fulfilment of the requirements for the selection of common noise assessment methods in EU by existing noise assessment methods*

Method	Essential		Recommendable		Total number of requirements considered
	Passed	Failed	Passed	Failed	
RLS 90	11	3	3	7	24
ASJ-RTN (2009)	12	2	6	4	24
CRTN (1998)	8	6	3	7	24
NMPB (2009)	12	2	7	3	24
NORD 2000	15	0	9	5	29
RMW	11	3	4	6	24
RVS (04.02.11)	12	2	3	7	24
Sonroad (2008)	11	3	4	6	24
HARMONOISE/IMAGINE	15	3	10	7	35
Onorm 305011 (2004)	9	3	4	6	22
Schall 03 (2006)	11	1	9	1	22
CRN (1995)	10	2	4	6	22
RMR	10	2	6	4	22
Semibel	9	3	5	5	22
ISO 9613	12	1	3	3	19
AzB (2008)	8	4	6	3	21
ECAC Doc. 29 Rev. 3 – ICAO 9911	6	6	2	7	21

For this report, only NMPB 2009 (its propagation module is believed the same as that of NMPB 2008), Nord2000 and HARMONOISE/IMAGINE are relevant. The fulfilment of the requirements by these three methods are chosen and presented in Tables 5.4-5.6.

Table 5.4. *Method: NMPB (2009)*

Requirements for the selection of the common methods	**Pass / Fail**	**Note**
GENERAL REQUIREMENTS		
Possibility to modulate the method between a detailed (user defined specific input values) and an easy implementation with default values	**p**	The method can allow for reductions
Fulfilment of requirements of END	**p**	The method allows calculating under

(Lden and Lnight, 4m/0.1m from the façade, average meteorological year, neglecting corresponding façade)		the essential requirements of the END
Octave bands calculations	**p**	Third octave bands are used
Geometrical divergence	**p**	It is considered
Atmospheric absorption	**p**	It is considered for fixed value
Terrain profile	**p**	Considered with a detailed description
Ground effect	**p**	It is considered
Reflections / diffractions	**p**	Some cases of cross sections are presented to explain how to get the reduction coefficient for homogeneous and downwind conditions
Specific description of the segmentation technique to be used for decomposition of the large sources	**p**	Well specified
Propagation condition (are more propagation conditions allowed?)	**p**	Two are given depending on occurrence of meteorological conditions.
Meteorological influence (consider the effect of temperature, pressure, wind speed and direction on yearly average basis)	**f**	Meteorological parameters are not considered in the propagation, but are only used to retrieve the pre-defined two propagating conditions
ROAD SPECIFIC		
Road surface type correction	**p**	A simple correction with discrete values for two cases is included
Tyre type correction	**f**	Not foreseen
Ability to split between tyre and engine noise	**p**	The method contains two separate formulations of sound power for tyre and engine noise
Acceleration/deceleration (Traffic flow)	**p**	Corrections are foreseen
At least 4 classes of vehicle types	**f**	Two vehicle classes are used
Gradients	**p**	Implemented by means of corrections
Specific cases (bridges, tunnels, viaducts)	**f**	Nothing foreseen
RAILWAY SPECIFIC		
Wheel and rail roughness		
Differentiation between track/support structure		
Differentiation between engine noise, rolling noise, aerodynamic noise		
Differentiation between different types of vehicles/ locomotives		
Specific cases (bridges, tunnels, viaducts)		
INDUSTRIAL SPECIFIC		
Point, line, area source		
Lateral diffraction around obstacles		
AIRCRAFT SPECIFIC		
Aircraft performance as a function of air parameters, aircraft type, engine type, TOW		
Differentiation between different take off procedures and between different approach procedures		
Terrain shielding / screening effects		

Ground absorption (correction for hard ground at the receiver)		
OTHER REQUIREMENTS		
Scientific evidence	**p**	Recent publications show the testing of the method
Validation of the method/extent of validation	**p**	The validation of the method was performed in 6 measurement campaigns up to 400 m
Royalties / IPR issues	**p**	Public
Easiness of implementation into software (complete and clear description)	**p**	The method is well and thoroughly described
Availability of parameters and input values databases	**p**	All input values are included
Frequency of update of database	**f**	It was not possible to get information on the update of the database

Table 5.5. *Method: Nord2000*

Requirements for the selection of the common methods	**Pass Fail**	**Note**
GENERAL REQUIREMENTS		
Possibility to modulate the method between a detailed (user defined specific input values) and an easy implementation with default values	**p**	The method can allow for reductions
Fulfilment of requirements of END (Lden and Lnight, 4m/0.1m from the façade, average meteorological year, neglecting corresponding façade)	**p**	The method allows calculating under the essential requirements of the END
Octave bands calculations	**p**	Third octave bands are used
Geometrical divergence	**p**	It is considered
Atmospheric absorption	**p**	It is considered as function of temperature and humidity
Terrain profile	**p**	Considered in many detailed sub-models
Ground effect	**p**	It is considered as a function of the ground flow resistivity and roughness
Reflections / diffractions	**p**	Some cases of cross sections are presented to explain how to calculate the effect
Specific description of the segmentation technique to be used for decomposition of the large sources	**p**	Well specified
Propagation condition (are more propagation conditions allowed?)	**p**	As many propagation condition as decided by end user
Meteorological influence (consider the effect of temperature, pressure, wind speed and direction on yearly average basis)	**p**	Meteorological influence is detailed with several parameters
ROAD SPECIFIC		
Road surface type correction	**p**	Some corrections with discrete values are included
Tyre type correction	**p**	Two classes foreseen

Ability to split between tyre and engine noise	**p**	Differentiation between the two type of sources is included in the method
Acceleration/deceleration (Traffic flow)	**p**	Included
At least 4 classes of vehicle types	**p**	Three vehicle classes are used
Gradients	**p**	Implemented by means of corrections
Specific cases (bridges, tunnels, viaducts)	**f**	Nothing foreseen
RAILWAY SPECIFIC		
Wheel and rail roughness	**f**	Not defined
Differentiation between track/support structure	**p**	Four track categories are used
Differentiation between engine noise, rolling noise, aerodynamic noise	**p**	Six different sources are used (3 rolling, 2 engine, 1 aerodynamic)
Differentiation between different types of vehicles/ locomotives	**f**	Only train categories are used
Specific cases (bridges, tunnels, viaducts)	**p**	Tunnels and bridges are considered
INDUSTRIAL SPECIFIC		
Point, line, area source		
Lateral diffraction around obstacles		
AIRCRAFT SPECIFIC		
Aircraft performance as a function of air parameters, aircraft type, engine type, TOW		
Differentiation between different take off procedures and between different approach procedures		
Terrain shielding / screening effects		
Ground absorption (correction for hard ground at the receiver)		
OTHER REQUIREMENTS		
Scientific evidence	**p**	Some scientific publications are available till recently
Validation of the method/extent of validation	**p**	The method is tested by means of specific measurement campaigns and HARMONOISE project measurement campaigns
Royalties / IPR issues	**p**	Public
Easiness of implementation into software (complete and clear description)	**f**	The method is described in too many details and in multiple reference documents, therefore, this does not allow an unique interpretation of the proper formulas to be used.
Availability of parameters and input values databases	**p**	All input values are included
Frequency of update of database	**f**	It was not possible to get information on the update of the database

Table 5.6. *Method: HARMONOISE/IMAGINE*

Requirements for the selection of the common methods	**Pass Fail**	**Note**
GENERAL REQUIREMENTS		
Possibility to modulate the method between a detailed (user defined specific input values)	**p**	The method can allow for reductions

and an easy implementation with default values		
Fulfilment of requirements of END (Lden and Lnight, 4m/0.1m from the façade, average meteorological year, neglecting corresponding façade)	**p**	The method allows calculating under the essential requirements of the END
Octave bands calculations	**p**	Third octave bands are used
Geometrical divergence	**p**	It is considered
Atmospheric absorption	**p**	It is considered as a function of meteorological parameters
Terrain profile	**p**	It is considered
Ground effect	**p**	It is considered with ground impedance
Reflections / diffractions	**p**	A general calculation procedure is described
Specific description of the segmentation technique to be used for decomposition of the large sources	**p**	Well specified
Propagation condition (are more propagation conditions allowed?)	**p**	5 meteo classes are suggested, but more allowed
Meteorological influence (consider the effect of temperature, pressure, wind speed and direction on yearly average basis)	**p**	Meteorological influence is considered to define the meteorological classes
ROAD SPECIFIC		
Road surface type correction	**p**	A simple correction with discrete values for a few cases is included
Tyre type correction	**p**	It is considered
Ability to split between tyre and engine noise	**p**	The method divides the two sources
Acceleration/deceleration (Traffic flow)	**p**	Acceleration and deceleration are modelled
At least 4 classes of vehicle types	**p**	Five vehicle classes are suggested
Gradients	**p**	Implemented by means of corrections
Specific cases (bridges, tunnels, viaducts)	**f**	Not foreseen
RAILWAY SPECIFIC		
Wheel and rail roughness	**p**	It is considered
Differentiation between track/support structure	**p**	It is considered
Differentiation between engine noise, rolling noise, aerodynamic noise	**p**	Engine noise, rolling noise and aerodynamic noise are all considered separately
Differentiation between different types of vehicles/ locomotives	**p**	The method describes each single vehicle/locomotive
Specific cases (bridges, tunnels, viaducts)	**f**	Bridge noise is discussed but correction is not given
INDUSTRIAL SPECIFIC		
Point, line, area source	**f**	Only point to point model is described and no reference is made to how to deal with line and area industrial sources
Lateral diffraction around obstacles	**p**	Included in the general description of the method
AIRCRAFT SPECIFIC		
Aircraft performance as a function of air parameters, aircraft type, engine type, TOW	**f**	Not proposed in the set of project reports
Differentiation between different take off	**f**	Not proposed in the set of project

procedures and between different approach procedures		reports
Terrain shielding / screening effects	**f**	Not discussed
Ground absorption (correction for hard ground at the receiver)	**f**	Though tests were performed, no unique description of how to account for the ground is given
OTHER REQUIREMENTS		
Scientific evidence	**p**	The method is the result of two large EU funded projects and many peer reviewed publications are available
Validation of the method/extent of validation	**p**	The method has been partially validated within the two research projects HARMONOISE and IMAGINE
Royalties / IPR issues	**f**	The rights on the use of the know how for commercial reason remain of the project partners
Easiness of implementation into software (complete and clear description)	**f**	The method is not defined in an unique way in a single document, but description of the single parts are clear
Availability of parameters and input values databases	**p/f***	All input values are included for road, railway and industrial noise but are missing for aircraft noise
Frequency of update of database	**f**	It was not possible to get information on the update of the database

* for road, railway and industrial this criteria is passed, not for aircraft noise

Focusing on road and railway traffic noise, Tables 5.4 – 5.6 tell us:

- The Nord2000 method fulfils all the essential requirements, while fails the recommendable requirements R5, R6 and R8.
- The HARMONOISE/IMAGINE method fulfils all the essential requirements except E18, while fails the recommendable requirements R5 and R9.
- The NMPB 2009 method is in fact not available; the evaluation was then based on NMPB 2008 which is used for road noise. The NMPB 2009 method fails the essential requirements E10 and E12, and fails the recommendable requirements R2 and R5. And, the NMPB 2009 has not been evaluated for the requirements E14 and R6-9.

Within the three methods only HARMONOISE/IMAGINE method contains a part for industrial noise and a part for aircraft noise; however, it does not fulfil the requirements E15 and E17, neither R10-12.

For “Other Requirements”, the NMPB 2009 fails R17; the Nord2000 fails R15 and R17; and the HARMONOISE/IMAGINE fails E18, R15 and R17.

It should be indicated that the CNOSSOS-EU methods has the propagation module based on the French NMPB 2008 model and has the source modules based on the HARMONOISE/IMAGINE method, while certain simplifications have been made in the source description.

5.2 Fulfilment of the Trafikverket requirements by the three noise assessment methods

In the project description [1], Trafikverket (the Swedish Transport Administration) has made a list of requirements/enquiries for judging the capabilities of the methods. Answers to these enquiries will serve as a basis for Trafikverket together with Naturvårdsverket (the Swedish Environmental Protection Agency) to make her choice how to develop a new Swedish noise assessment method (for high-speed railway applications).

In Table 5.7 a part of the answers to the requirements/enquiries are listed. The rest of the answers are given in Table 6.1 in next section.

Table 5.7. *Fulfilment of Trafikverket (the Swedish Transport Administration) requirements by the three noise assessment methods*

Requirement/question	**NMPB 2008**	**Nord2000**	**CNOSSOS-EU**
Beräkna bullernivåer i måtten L_{den} och L_{night} utomhus,	Yes, 1/3 octave bands 100-5000 Hz which covers octave bands 125-4000 Hz	Yes, 1/3 octave bands 25-10000 Hz which covers octave bands 31.5-8000 Hz*	Yes, octave bands 125-4000 Hz
Beräkna bullernivåer i måtten L_{pAeq24}	Yes	Yes	Yes
och L_{pAFmax} utom- och inomhus samt L_p per ters minst inom frekvensområdet 25 – 200 Hz inomhus.	No	Yes, but not for indoor noise	No
Ha en källmodell som tar god hänsyn till rullningsbuller med förekommande spårstandard för höghastighetsbanor	-	Yes NP** 7	Yes NP 9***
samt till aerodynamiskt buller upp till 320 km/t	-	No	Yes NP 5
med relevanta höjdlägen och riktningskaraktäristik för delkällor.		Yes NP 7	Yes NP 6
Beräkna bullernivåer utomhus med hänsyn till topografi, byggnationer, markimpedanser och atmosfäriska förhållanden som är representativa omkring höghastighetsbanorna och kritiska för ljudspridningen. Byggnationer omfattar bland annat bullerskärmar	Yes NP 8	Yes NP 9	Yes NP 8

och tunnelmynningar.	No	Yes NP 6	No
Bedömning i noggrannhet, precision	8	9	8
och beräkningssnabbhet	9	8	9
Beräkna bullernivåer inomhus med hänsyn till vanliga uppbyggnader av bostadshus, fönster, tilluftsdon, väggar och även tak.	No	No	No

* Accurate source data are usually limited up to 4~5 kHz.
** NP denotes for noggrannhet (accuracy) and precision (in scale 1-10).
*** The Harmonoise/Imagine source model for railway noise is currently the most advanced one. However, in CNOSSOS-EU, some simplifications have been made.

5.3 Indoor noise level

For indoor noise levels, as stated in User's Guide Nord2000 Road [8], "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.".

Sound insulation of building façade is not an issue that a propagation model or a source model will handle. Once the sound level near or on the building façade has been determined, the indoor sound level will be calculated based on the theory of building acoustics.

In [30], guideline values for limiting traffic noise impact on housing areas proposed by Swedish Government are

- 30 dBA L_{eq} indoors
- 45 dBA L_{AFmax} indoors and night time
- 55 dBA L_{eq} outdoors at the façade
- 70 dBA L_{AFmax} at the patio adjacent to the residential

These guideline values implicitly take 25 dB as the representative level difference between outdoor and indoor noise levels. However, what level differences should be in frequency range from 25 Hz to 200 Hz have not been specified.

Scientifically, if the noise sound power transmitted into a room through the façade is the only sound source, the indoor noise level will be determined based on (1) the noise level at/near the façade (outside); (2) the noise reduction of the façade; (3) the volume of the room; (4) the distance to the facade (inside the room); and (5) the absorption area of the room. The indoor sound pressure level can be determined, approximately, according to the theory of building acoustics [31, 35]

$$L_p = L_W + 10\lg\left[\frac{D(\theta)}{4\pi r^2} + \frac{4}{R}\right] \qquad (5.1)$$

where L_W is the sound power level transmitted into the room, r the distance to the façade, $D(\theta)$ the direction index, and $R \approx S\overline{\alpha}$ the absorption area of the room.

An interesting empirical formulae proposed by Schultz (ASHRAE Transactions 1983, 91(1), pp 124-153) suggests, out of the near field, –3 dB/doubling of distance and independent of room absorption

$$L_p(f) = L_W(f) - 10\lg(r) - 5\lg(V) - 3\lg(f) + 12 \qquad (5.2)$$

where V is the room volume and f the frequency.

As can be seen, indoor sound pressure level varies with position and frequency, and depends on room volume and room absorption area. To find a representative level difference (of a function of frequency) between outdoor and indoor noise levels one needs to know (1) representative façade transmission reduction and (2) main parameters in determining indoor noise levels. A reliable while simplified method for calculating indoor noise levels is still an issue to solve.

6 SP's proposal for building up a new Swedish noise assessment method for railway noise

In general, a noise assessment method consists of two basic parts: a sound propagation module, which handles different attenuation effects during sound propagation, and a noise source module, which prepares proper directional sound powers of the noise sources as well as the source positions. These two basic modules will together determine sound pressure levels at (outdoor) receiving positions. Moreover, there is usually also an extra module for handling optional issues such as calculating L_{den}, L_{night}, L_{AFmax} …, or indoor noise levels, etc.

Based on the reviews made in Sections 2-4, SP prepares a proposal for building up a new Swedish noise assessment method for railway noise, presented in the following.

Nord2000 propagation model will be employed as the propagation module, without any revision or simplification. The Nord2000 propagation model was made fully based on the physics. During the Harmonoise project, it was taken as the starting point for building up the Harmonoise engineering propagation model and has been thoroughly inspected. And, it has also been updated after the Harmonoise project [5]. The model has been validated by measurements and/or by comparing with reference calculations. The Nord2000 has been proved the best under homogeneous conditions; it also works well under moderate downward-diffraction conditions. The calculation speed is high, although not as fast as the NMPB 2008 because the latter employed several simplifications/empirical methods. One may conclude that the Nord2000 is so far the most advanced engineering propagation model. Moreover, the Nord2000 propagation model has been implemented in commercial noise mapping software(s) such as SoundPlan.

The source module should be in principle based on the Harmonoise source model for railway noise which is currently the most advanced one. However, as a good balance in model accuracy, CPU time and effort in collecting source data is in fact an important issue, one should be careful in taking the track and vehicle classifications made in the Harmonoise source model; such very detailed classifications require enormous effort in data collection. Therefore, some flexibility in source modeling should better be introduced.

With the considerations mentioned above, SP proposes three sub-modules for the source module: a high-speed module where aerodynamic noise must be considered, a conventional-speed module where aerodynamic noise and traction noise can be neglected, and a low-speed module where traction noise, curve squeal noise, effects of joints/points/switches, braking noise and bridge noise will be considered. (Joints and bridges, even curve squeals, may also be a concern for conventional speeds.) Classifications of tracks and trains/vehicles can be made differently in different sub-modules of the source model, depending on national requirements. And, naturally, each sub-module will be developed independently.

Within this model frame, the high-speed module will be worked out in the second part of this project, based on the work presented in [32] together with the consideration of the TSI requirements on rolling stocks of trans-European high-speed rail system [33]. The noise data of the Green Train [34] could be included in near-future while unfortunately not possible within this project because of short of time for working out the source data.

The calculation approach will also include the methods for calculating required/ expected quantities L_{den}, L_{night}, L_{pAeq24}, L_{AFmax} and L_p in 1/3 octave bands from 25 Hz to 10 kHz. And, for indoor noise levels a rough estimation will be made by 25 dB reduction from the calculated façade sound levels. This temporary rough approach will be improved in future. A practical method for calculating indoor noise levels still needs to develop, while not within the frame of this project.

In Table 6.1 the rest of the enquiries addressed by Trafikverket are answered.

Table 6.1. *Answers to the rest of the enquiries addressed by Trafikverket (the Swedish Transport Administration)*

Question	Answer
Vara snabb att anskaffa så att den finns senast 1 augusti	The report for the second part of this project will be made ready on August 10, 2014, the deadline for this project. Therefore, estimated, the noise assessment method for high-speed railway noise will be made ready around 1st of August.
Vara kostnadseffektiv att anskaffa	In principle yes (i skala 7); it depends on the definition of “kostnadseffektiv”. Usually, collecting source data is costly.
samt vara rationell att utveckla och underhålla för senare användning	Yes (i skala 9~10)
Kunna bli implementerad i minst en IT-tillämpning före 2015	Unfortunately this cannot be guaranteed because of the short time. However, SP has been contacting the SoundPlan company about the implementation of the new method. More information will become available, as more details of the new model will be established along with the model work progresses.

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