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IMAGINE

Improved Methods for the Assessment of the Generic Impact of Noise in the Environment

D12/D13

Rail noise database and manual for implementation

WP6: Rail noise sources

WP-leader: DeltaRail UK

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Amendments

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EXECUTIVE SUMMARY

The mechanism of noise generation from a railway vehicle is complex, resulting from a variety of sources at various locations on the vehicle. The spectral, temporal and level characteristics of each of these sources may be dependent on a number of factors, such as speed and load, and can vary significantly from type to type of vehicle. Therefore, in order to model railway noise with confidence, it is necessary to understand all these sources and the factors that control them. In IMAGINE the approach to railway noise modelling for wide-scale noise mapping is to characterise each railway vehicle as a set of separate sound sources, at various heights relative to the head of the rail, and then to amalgamate these sources into lines of acoustic energy at those different heights, resulting from the flow of a number of vehicles over a defined time period. These source lines of acoustic energy interface with the IMAGINE propagation method allowing noise prediction at defined receiver locations.

The main objective of IMAGINE Work Package 6, Rail Noise Sources, was to provide a database system to enable controlled acquisition, storage and extraction of disaggregated rail noise source information. This was to be supplemented with guidance on the measurement of appropriate data, on the assembly of the traffic model source lines, and on modelling non-standard situations. Importantly, the database was to be delivered with an initial measured dataset representative of the range of railway vehicles operating across Europe. In addition, default data, based on a combination of measurement and theory, was to be provided to assist the modeller in situations where appropriate measured data was not available.

During the IMAGINE project all these objectives have been met, with the creation of a robust rail noise source database populated with 233 example spectra and 76 default spectra. These spectra provide information (measured and/or default) on rolling noise, separated into vehicle and track contribution, traction noise, aerodynamic noise, braking noise and curve squeal. A methodology for combining the acoustic energy of these sources has been developed, and a structured method for acquiring the source data in the field is described. The data acquisition process is further controlled by the provision of a data input sheet that guides the technician through the process and enables data to be transferred automatically to the database.

Via this structured process, the accuracy of rail noise modelling for wide-scale noise mapping has been increased considerably. The separation of railway noise into a number of discrete sources increases the accuracy of the modelling of sound propagation away from the source, and enables cost-effective Action Planning to be carried out.

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1 Introduction

1.1 The IMAGINE Project

In June 2002, the European Directive on the Assessment and Management of Environmental Noise, 2002/49/EC, (the “END) was accepted and came into force. Under this Directive, member states are obliged to produce strategic noise maps of major roads, railways, airports and large agglomerations by 30th June 2007. These noise maps shall express the environmental noise levels caused by the above sources, in terms of the harmonised noise indicators L_{den} and L_{night}. From these, other statistics such as the total number of residents exposed to certain noise levels shall be derived. This information shall then be submitted to the European Commission and made public. The next step will be to draft Noise Action Plans, the first of which will have to be produced by July 2008.

It has always been the intention of the Commission to establish common assessment methods for the production of these noise maps but until such methods are made available, the END has defined interim methods. These interim methods or a Member State’s national method, if it can be shown to be equivalent to the interim method, will be used in the first round of mapping in 2007. As a first step to developing a common method, the project HARMONOISE was initiated in August 2001. This project was partly funded by the European Commission (DG Information Society and Technology) under the 5th framework programme. Its main objective was to develop harmonised, accurate and reliable methods for the assessment of environmental noise from roads and railways. This was completed in August 2004.

This was taken further in the present project, IMAGINE, which commenced in November 2003, and is a Strategic Targeted Research Project which addresses Task 3 of the *Scientific Support to Policies* (SSP) Call under the 6th Framework Programme. The IMAGINE project aims to extend the HARMONOISE source databases for road and rail and to use the HARMONOISE methodology to develop prediction methods for aircraft and industrial noise sources.

The overall objective of both projects is therefore to provide a model which will meet the requirements of the common assessment method.

The main stated objective of WP 6 in IMAGINE is to provide default databases for the source description of rail noise, i.e. vehicle category and track type, for an example sample of the European rail traffic fleet, and to provide guidelines on how to deal with situations deviating from those that are typical.

The essential requirement of IMAGINE Work Package 6 “Rail Noise Sources” is to provide a means by which railway noise source data for single rail vehicles or trains can be acquired, stored, retrieved and amalgamated into lines of acoustic energy (traffic model) to interface with the IMAGINE sound propagation method. This report (D12/D13) together with the database itself comprises the full set of deliverables from Work Package 6. It includes: an overview of the technical background to the Work Package; an indication of its objectives and outline methodology; a description of the source model; a description of the database; default data that is included within the delivered database; the recommended measurement protocol and practical guidelines on data acquisition; instructions on the process by which data is input to and extracted from the database.

The deliverables fit into the IMAGINE scheme as highlighted in Figure 1.1.

The global structure of the HARMONOISE and IMAGINE methods can be seen in this Figure. A clear separation is made in the methods between the source properties and propagation.

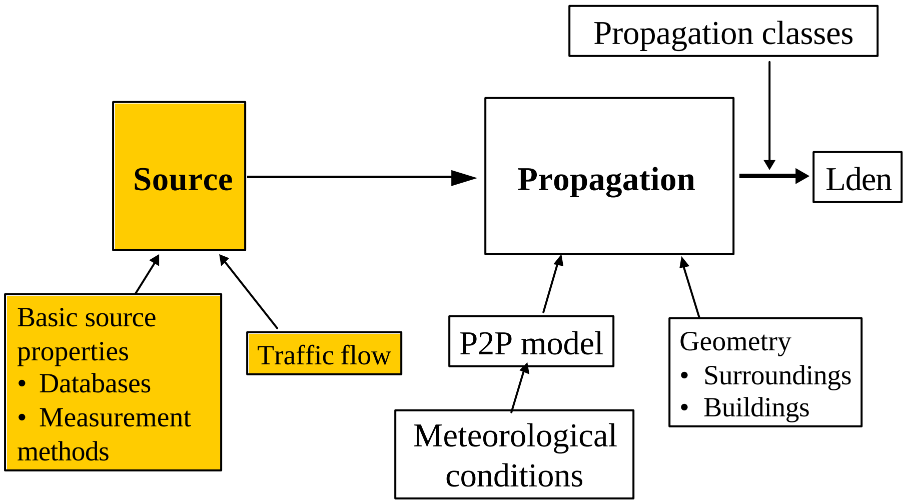


Figure 1.1 The location of Work Package 6 deliverables in the IMAGINE scheme

The result of the source methods is a sound power level per sub source type per source height, with certain directivity.

The propagation method describes the transmission of sound along a set of propagation paths, linking the source positions to the receiver point. The number and type of the propagation paths depend on the complexity of the site. The Point-to-Point module estimates the effects of ground and obstacles on the propagation of the sound along these paths, under various meteorological conditions.

The result of the propagation model is an Leq at a certain receiver point for each meteorological class. The long term Lden value is calculated from the available Leq values by determining the occurrence of the different propagation classes, and summing up over the occurrence.

2 General technical background

Environmental noise from railways can be subdivided broadly into dominant contributions from traction (engines, fans, gears etc) up to around 50 km/h, rolling (wheel/rail interaction) from around 50 km/h to around 270 km/h, and aerodynamic effects (especially at the current-collecting “pantograph”, and from general body-generated turbulence) from around 270 km/h. Figure 2.1 shows these three regimes. The contributor over the widest speed range is rolling noise. This is a function of the excitation of the wheel and track system by the combined roughness at the wheel/rail interface as the wheel rolls on the rails, the vibration response of the various coupled components, and the resultant radiation of sound from these components. It is this source that is of greatest interest in railway noise mapping, although traction noise and aerodynamic noise can still be important contributors.

In order to quantify a railway vehicle as an acoustic source for modelling, overall sound power levels and positions of the rolling, traction and aerodynamic contributions (see Figure 2.2) are required as a minimum (although aerodynamic noise is not normally an issue for non- High Speed railways). For more precise modelling, the subdivision of rolling noise into vehicle and track contributions is preferable, as is the directivity and spectral content of the sources. This subdivision allows improved modelling accuracy of the propagation of rolling noise, as the vehicle and track contributions are at different heights. It also enables the responsibility for noise generation and to be correctly attributed to vehicle or track or apportioned between them. Identification and quantification of the various sub-sources allows cost-effective mitigation to be carried out, which will be of benefit during Action Planning under Directive 2002/49/EC.

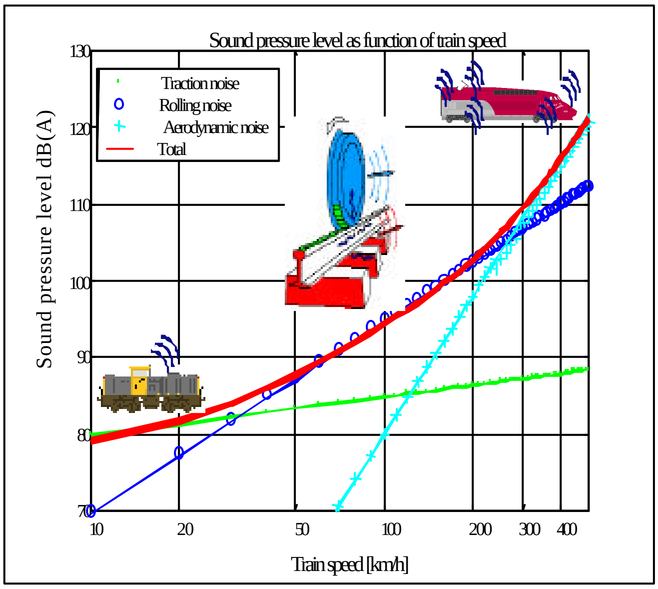


Figure 2.1. The three regimes of railway environmental noise

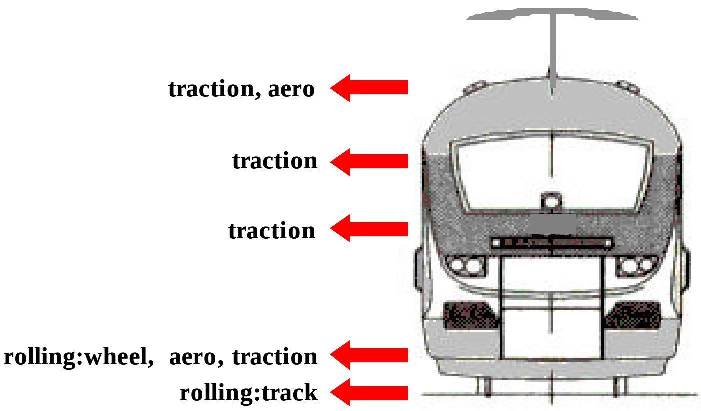


Figure 2.2. Typical vertical distribution of railway noise sources

Rolling noise is a function of the system as a whole. Wheel roughness, rail roughness, vehicle parameters, track parameters and track support structures such as sleepers, viaducts and slab tracks all have an influence on this. Wheel and rail roughness are critical factors. On “smooth” track a wheel with cast iron brakes that bear on its running surface emits rolling noise that is 8-10 dB(A) greater than that from a disc-braked wheel, where the brakes have no contact with the running surface. Composite blocks (resin-based) that bear on the wheel running surface can be as quiet in rolling as disc-braked wheels as they do not roughen the surface in the same manner as cast-iron brakes. Similarly, a rough track, especially one that has a corrugated wear pattern, can lead to rolling noise for a “smooth” wheel that is as much as 20 dB(A) greater than on a track of low roughness.

A complete railway noise source database should therefore hold data on the acoustic characteristics of all sub-sources and also, in order to generate the traffic model for application to specific track sections, it should be able to take into account speed, mode of operation, and the wheel and rail roughness. The process of defining and setting up such a database was commenced within the HARMONOISE project, while the overall responsibility of Work Package 6 in IMAGINE was to take this forward to a practical implementation.

3 Objectives and Outline Methodology of Work Package 6, “Rail Noise Sources”

The stated objectives of Work Package 6 are:

- To provide default databases for the source description of rail noise, i.e. vehicle category and possibly track type related, for an exemplary sample of the European rail traffic fleet, and provide guidelines on how to deal with situations deviating from the typical samples.

This has been achieved by the following approach:

The current situation on measurement methods used internationally for rolling noise, traction noise and aerodynamic noise and available data for rolling noise and traction noise in the public domain and via IMAGINE partners were all reviewed.

Practical measurement techniques for rolling noise source assessment were determined. The measurement methods explored in STAIRRS were developed for application to various track and rolling stock types. Guidelines for application of the methods were formulated as a measurement protocol.

The traction noise models proposed in the HARMONOISE project were assessed using pre-existing measurement data and data acquired during the project, and improved where necessary. Measurements of noise from in-service trains were carried out using the recommended measurement protocol.

A database structure was created allowing source terms to be stored and efficiently accessed for general purposes and, specifically, to feed into the HARMONOISE/IMAGINE prediction procedures for noise mapping.

The database was populated with all data acquired during the project, either by measurement or by access to existing databases, and is amenable to routine update as more data becomes available in the future. The resulting data is also suitable as input to calculation procedures for action plans, and as example data for demonstration purposes and standardisation work.

Although the elements of a section of railway that are responsible for the local noise environment are often very similar across Europe, there are some situations where the local track characteristics and the nature of the traffic are non-standard and not easy to model simply. Guidance is provided on how to approach such situations.

The Team that was assembled to carry out the tasks of Work Package 6 comprised:

BUTE (Hungary)
Labein (Spain)
Kilde (Norway)
SP (Sweden)
TNO (Netherlands)
DeltaRail BV (Netherlands)
DeltaRail (UK)

4 The railway noise source method

The railway source “traffic noise model” that interfaces with the IMAGINE Propagation Method comprises a set of sound energy “source lines” at different heights that are each acoustically homogeneous. In order to calculate the sound energy and characteristics of each of those lines, it is necessary to construct them from individual elements, namely the various acoustic sub-sources on each railway vehicle that runs over that line during the time period of interest.

4.1 Traffic noise model

The railway traffic noise model calculates an average sound pressure level at a reception point due to contributions from multiple track source lines, source heights, vehicle types and speeds, operating conditions and physical sources. The model works with one-third octave band data.

Within the overall HARMONOISE-IMAGINE method, the A-weighted sound pressure level at the receiver position $L_{pAeq,rec}$ due to the traffic flow is determined from energy summation over frequency bands, track source lines and source heights:

$$L_{pAeq,rec} = \sum_{i=1}^{B}\sum_{j=1}^{J}\sum_{h=1}^{N} \oplus L_{peq,ijh} + L_{FA,i} \tag{4.1}$$

With

$\Sigma\oplus$	energy sum: $\Sigma\oplus x_i = 10 \lg (10^{x1/10} + 10^{x2/10} + \ldots)$
$L_{peq,ijh}$	sound pressure level in frequency band i due to the contribution from source line j and source height h [dB] (energy averaged over an observation period);
$L_{FA,i}$	A-weighting filter for each frequency band i [dB];
B	number of frequency bands; i = frequency band number;
J	number of source lines; j=source line number;
N	number of source points (heights); h = source height index.

The sound pressure level $L_{peq,ijh}$ is determined from the level of sound power per unit length in each source line $L_{W,ijh}'$ due to the traffic flow (see Figure 4.1) with

$$L_{peq,ijh} = L_{W,ijh}' + 10 \lg l_{sl} - A_{total,i} \tag{4.2}$$

where

$L_{W,ijh}'$	level of sound power per unit length in frequency band i on source line j and at source height h [dB];
l_{sl}	source line length [m];
$A_{total,i}$	total attenuation due to geometrical spreading, atmospheric absorption, ground reflections, diffraction effects, reflection and scattering [dB].

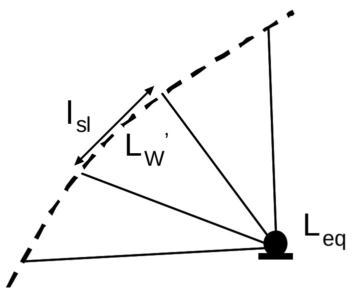


Figure 4.1. Sound pressure reception Leq from one track source line with a sound power per unit length L_W'.

Expressions for all the attenuation parameters are given in [1].

It was agreed by the Work Package that the five source heights above rail head level (h) identified originally within HARMONOISE were suitable for carrying forward as the IMAGINE recommendations. These are shown in Figure 4.2.

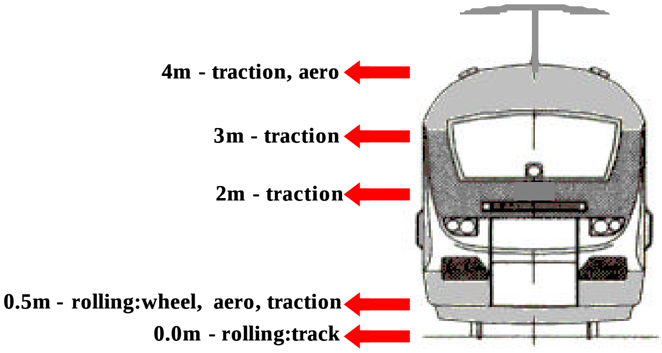


Figure 4.2. Source heights (h) above rail head level, chosen for the IMAGINE method

The level of sound power per unit length $L_{W,ijh}'$ for the traffic flow depends on the vehicle emission $L_{W'kmpijh}$ consisting of contributions from all vehicle types and speeds (m) under all relevant conditions (k) such as constant speed, braking, accelerating and curving, and each physical source type (p). It also takes into account the number of vehicle units (wagons) per hour $N_{u,mk}$ and their length $l_{u,m}$, resulting in an adjustment in the sound power for the proportion of time that vehicles are passing:

$$L'_{W,ijh} = \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{p=1}^{P} \oplus \left(L_W{}'_{kmpijh} + 10lg\left(\frac{N_{u,mk} l_{u,m}}{1000 v_{mk}} \right) + C_{dir,pih} \right) \quad (4.3)$$

with

K number of operating conditions relevant at the source line:
k 1=constant speed, 2 = braking, 3 = accelerating, 4= curving;
M total number of vehicle types and speeds;
m index for vehicle type and speed;
P number of physical source types;
p 1=rolling noise and impact, 2=traction noise, 3= aerodynamic noise, 4 = braking noise, 5 = curve squeal;
$N_{u,mk}$ number of units of type and speed m and condition k, per hour;
$l_{u,m}$ length of units of type m in metres;
v_{mk} train speed in km/h, for type m and condition k;
$C_{dir,pih}$ directivity function for each source type p, source height h and frequency band i.

Directivity C_{dir} is 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 [2], given by:

$$C_{dir,pih} = 10\ \lg(0.01 + 0.99\cos^2(\pi/2 - \varphi)) \qquad (4.4)$$

where φ is the angle in the horizontal plane between the propagation path and the source line.

For diesel engines the noise from the body of the engine and from the exhaust is recommended to be treated as a monopole (ie $C_{dir,\ pih} = 0.0$) although, in view of the fact that in most instances the directivity is not particularly important when acoustic energy is integrated over a track section, the general assumption of dipole directivity will suffice.

Equation 4.3 is not applicable for the case when the train is stationary ($k = 5$). This is most likely to occur when the train is stopped at a station. In this situation, it is recommended that a train is assumed to be travelling at a constant speed of 40 km/h over the source line.

The source strength is expressed in terms of sound power per unit length as this is independent of train length, and for a given type of train the number of units may vary. Equivalent point source strength can be derived for the traffic flow using $L_{W'ijh} + 10\ \lg\ l_{sl}$, and for an individual train or vehicle using $L_{W'kmpijh} + 10\ \lg\ l_{veh}$.

It should be noted that each operating condition can potentially include several physical sources, as shown in Table 4.1. In practice, only one or a few physical sources will be dominant for a given operating condition, but it should be taken into account that there will often be a mix of sources present. Some sources may dominate a particular frequency range. For example, during curving or passing a set of points, rolling noise, impact noise, traction noise and curve squeal can occur together; curve squeal will often dominate the high frequency range above 1 kHz; traction, rolling and impact noise could dominate the low and medium frequency range. Braking noise can potentially also occur at constant speed on gradients, or in curves.

Condition	Rolling and impact noise	Traction noise	Braking noise	Curve squeal	Aerodynamic noise
Constant speed	x	x	x (gradients)	x	x
Braking	x	x	x	x	x
Accelerating	x	x		x	x
Curving	x	x	x	x	x
Stationary/idling		x			

Table 4.1. Potential occurrence of noise sources under various modes of operation

4.2 Sound power from pass-by sound pressure

The source method includes all those physical sources that may potentially dominate the average noise level for particular locations or operating conditions. Discrete source heights used in the method are 0m, 0.5m, 2m, 3m and 4m above the rail surface, as illustrated in Figure 4.2. Each physical source has one or more common source heights. As many of the basic source data are obtained from measurements of a single train pass-by, it is easier to define the source calculations from sound pressures at a fixed distance (7.5m), which has been adopted as the standard during the formulation of the database.

For a given train type m, operating condition k and source height h, the relation between level of sound power per unit length and sound pressure level $L_{peq,Tp,kmih}$ at 7.5 metres during pass-by transit time $T_p = l_{veh}/v$ and for test vehicle length l_{veh} is given by:

$$L_{W}'_{kmih} = L_{peq,Tp,kmih} - \overline{A^{h}_{line,propagation(T_p)}} \tag{4.5}$$

where

$$\overline{A^{h}_{line,propagation(T_p)}} = 10\lg\left\{\frac{1}{4\pi r N}\sum_{n=1}^{N}\int_{\varphi_{n,\min}}^{\varphi_{n,\max}} 10^{\left[\Delta L(\varphi_n) - A^{h}_{excess}(\varphi_n)\right]/10} d\varphi_n\right\} \tag{4.6}$$

r	is the measurements distance (7.5 metres)
n, N	are the n^{th} sub-source element of the N sub-sources of length = 1m which form the source line
φ_n	is the angle to the normal to the track of the n^{th} sub-source
A^{h}_{excess}	is the total attenuation along the path φ_n, excluding geometrical spreading

Pre-calculated values for $\overline{A_{line,\ propagation(T_p)}}$ are proposed in Table 4.2. for trains of at least 70m in length, with excess attenuation calculated using the Nord2000 propagation model with neutral weather conditions, at 15^{o}C and 50% relative humidity, and ground impedance between 200 and 200000 kPas/m^2.

Frequency (Hz)	Source height above railhead (m)				
	0.0	0.5	2.0	3.0	4.0
25	-8.8	-9.1	-9.7	-10.2	-10.6
31.5	-8.7	*-9.0*	-9.9	-10.5	-11.2
40	-8.7	-9.1	-10.3	-11.2	-12.2
50	-8.9	-9.4	-11.1	-12.4	-13.7
63	-9.5	-10.3	-12.8	-14.5	-15.5
80	-11.1	-13.1	-15.3	-15.9	-16
100	-13.2	-15.1	-15.2	-15.6	-14.5
125	-12.4	-13.3	-15.0	-15.3	-13.8
160	-11.2	-13.3	-15.5	-14.2	-14.1
200	-11.0	-13.5	-15.5	-13.9	-13.4
250	-11.2	-15.3	-14.6	-13.9	-13.2
315	-13.6	-15.1	-14.1	-13.7	-12.9
400	-12.2	-16.2	-14.0	-13.5	-13.3
500	-13.3	-16.1	-14.1	-13.8	-13.3
630	-13.7	-15.1	-13.5	-13.6	-13.3
800	-15.2	-15.7	-14.4	-13.7	-13.2
1000	-15.2	-15.6	-13.7	-13.7	-13.5
1250	-15.6	-15.6	-14.2	-13.8	-13.4
1600	-15.9	-14.6	-14.0	-13.9	-13.6
2000	-15.7	-14.6	-14.1	-14.0	-13.7
2500	-15.9	-14.9	-14.1	-14.1	-13.8
3150	-15.3	-15.0	-14.3	-14.2	-14
4000	-15.9	-15.0	-14.5	-14.4	-14.2
5000	-16.2	-15.5	-14.7	-14.7	-14.5
6300	-15.9	-15.6	-15.1	-15.1	-14.9
8000	-16.6	-16.0	-15.6	-15.6	-15.4
10000	-16.5	-16.7	-16.3	-16.3	-16.2

Table 4.2: Pre-calculated $\overline{A_{line,\ propagation(T_p)}}$ values

For each source type the expressions are given as sound pressure levels at 7.5m. The sound power terms required for formula (4.3) can now be obtained for each physical source and source height, converting with formula (4.6). Where available, proposed default values are given for each source type based on calculation and measurement data.

The sound power or the sound power per unit vehicle length is a useful quantity for input to the further calculation process. It can be written in this way for both individual sources and source heights.

This expression is already useful for whole train or vehicle measurements if partial sources and individual parametric effects such as roughness or operating conditions are not included.

In the following sections, the models for partial sources are written in terms of sound pressure, as this is most practical to measure.

4.3 Source method

Calculation methods for each source type are given in the following. An overview is given in Table 4.3. The source heights for traction noise and aerodynamic noise may not all be required, depending on the vehicle in question.

Source type	**Typical source heights**	**Formula** (Refer to indicated section for further details)
Rolling noise See 4.3.1	0m 0.5m	$L_{peqi,roll}$ (h=0m)=$L_{rtot,net,i}$ (v) + $L_{Hpr,nl,tr,i}$ + 10 lg (N_{ax}/l_{veh}) $L_{peqi,roll}(h=0,5m)=L_{rtot,net,I}$ (v) + $L_{Hpr,nl,veh,i}$ + 10 lg (N_{ax}/l_{veh})
Impact noise See 4.3.1	0m, 0.5m	*Enhancement of total rolling noise roughness* $L_{rtot,net,I}$ *for use in rolling noise calculation* $L_{rtot}(l) = L_{rveh}(l) \oplus L_{rtr}(l) \oplus L_{rimpact}(l)$
Traction noise, total, see 4.3.2	0.5m, 2m, 3m, 4m	$L_{peq,i,traction,idle}$, $L_{peq,i,traction,acc}$, $L_{peq,i,\ traction,cs}$, *and* $L_{peq,i,\ traction,dec}$ *or:* $L_{ptraction,i}(n_{drive}, n_{fan}) = L_{pdrive,i}(n_{drive}) \oplus L_{pfan,i}(n_{fan}) \oplus L_{pdj,i}$
Traction noise, drive, see 4.3.2	0.5m, 2m, 3m, 4m	$L_{pdrive,i}(n_{drive}) =$ $L_{pdrive,nmax,i}(f_i\ .(n_{drive,max}/n_{drive})) + C_{drive}$ lg $(n_{drive}/n_{drive,max})$
Traction noise, fan, see 4.3.2	0.5m, 2m, 3m, 4m	$L_{pfan,i}(n_{fan}) =$ $L_{pfan,nmax,i}(f_i\ .(n_{fan,max}/n_{fan})) + C_{fan}$ lg $(n_{fan}/n_{fan,max})$
Traction noise, other, see 4.3.2	0.5m, 2m, 3m, 4m	$L_{pdj,i} = L_{pi}(f)$+ 10 lg (d_j)
Deceleration noise, total See 4.3.3	0.5m	$L_{pdeceleration,i}(v) = L_{pbrake,i}(v) \oplus L_{pdsqueal,i}$
Deceleration noise, braking See 4.3.3	0.5m	$L_{pbrake,i}(v) = L_{pbrake,i}(v_0)$ + C_{brake} lg (v/v_0)
Deceleration noise, squeal	0.5m	$L_{pdsqueal,i} = L_{psqueal,i}$ + 10 lg (d_{squeal})

Source type	**Typical source heights**	**Formula** (Refer to indicated section for further details)
See 4.3.3		below squeal cut-in speed (when mechanical braking starts)
Curve squeal See 4.3.4	0.5m	$L_{psqueal}$ = constant (average value) in curve with d< 1000m
Aerodynamic noise, See 4.3.5	0.5m, 2m, 3m, 4m	$L_{paero,h}(f,v) = L_{paero,h}(f,v_0) + a_h(f) lg\ (v/v_0)$

Table 4.3. Calculation methods for physical railway noise sources

4.3.1 Rolling noise and impact noise

Rolling noise

As indicated in Section 2, it is desirable to separate the vehicle contribution and the track contribution to rolling noise for accuracy of propagation modelling, for apportionment of responsibility for environmental noise, and for cost-effective action-planning. Further to this, because of the sensitivity of rolling noise to the "combined effective roughness" at the wheel-rail interface (ie the combined roughness at the contact between wheel and rail, taking into account filter effects at their interface), this roughness should be included as a causal parameter for rolling noise. The approach taken within IMAGINE has been to apply techniques developed within the EC projects "METARAIL" and "STAIRRS", considering rolling noise to be generated via the mechanism shown in Figure 4.3.

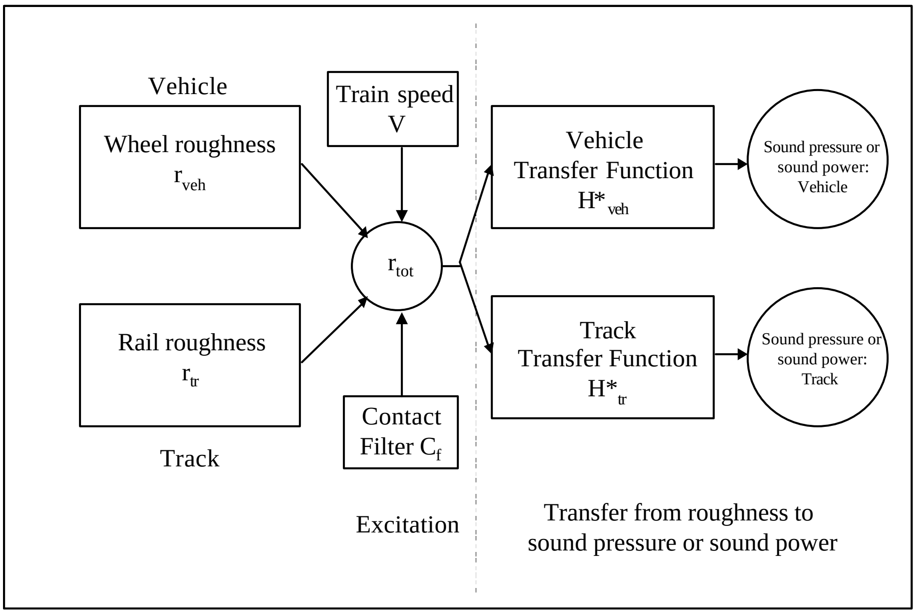


Figure 4.3. The mechanism of rolling noise generation applied within IMAGINE

This mechanism requires the contribution of the track and the vehicle to rolling noise to be quantified separately. From this, provided the combined effective roughness is known, transfer functions relating the vehicle contribution and the track contribution, separately, to this roughness, can be directly calculated for each 1/3 octave band of frequency. Techniques for carrying out this separation are outlined in Section 6.

For rolling noise, therefore, the contributions from the track and from the vehicle are fully described by these transfer functions, provided the combined effective roughness is known. This roughness can be acquired either as a single value via pass-by measurements of track vibration, or by the use of direct measurements of wheel and rail roughness and the inclusion of contact filter effects. These techniques are described in Section 6. It is these transfer functions that are the core data relating to rolling noise within the IMAGINE Rail Noise Sources Database.

Rolling noise is calculated at axle height (vehicle contribution at 0.5m above rail head) and rail head height (track contribution), and has as an input the total effective roughness $L_{r,tot,i,}(v)$ as a function of train speed v, the track and vehicle transfer functions $L_{Hpr,nl,tr,i}$ and $L_{Hpr,nl,veh,i}$ and the axle density N_{ax}/l_{veh}:

$$L_{peqi,roll}\,(h=0m)=L_{rtot,i}\,(v) + L_{Hpr,nl,tr,i} + 10\ \lg\,(N_{ax}/l_{veh}) \tag{4.7}$$

$$L_{peqi,roll}(h=0{,}5m)=L_{rtot,i}\,(v) + L_{Hpr,nl,veh,i} + 10\ \lg\,(N_{ax}/l_{veh}) \tag{4.8}$$

N_{ax} is the number of axles per vehicle and l_{veh} the vehicle length. If the roughness is obtained as a function of wavelength λ, it must be converted to the required speed using the relation $\lambda = v/f$, where f is frequency [Hz] and v is train speed in [m/s].

The transfer functions $L_{Hpr,nl,tr,i}$ and $L_{Hpr,nl,veh,i}$ are speed-independent. They have the reference unit of sound pressure squared per unit roughness squared, normalised to the axle density N_{ax}/l_{veh}. They are known from measurement or calculation for different track and vehicle types and are defined by

$$\begin{aligned} L_{Hpr,nl,tr,i} &= L_{peq,tr,i}(v) - L_{rtot,i}(v) - 10\lg\frac{N_{ax}}{l_{veh}} \\ L_{Hpr,nl,veh,i} &= L_{peq,veh,i}(v) - L_{rtot,i}(v) - 10\lg\frac{N_{ax}}{l_{veh}} \end{aligned} \tag{4.9}$$

where $L_{peq,veh,i}(v)$ and $L_{peq,tr,i}(v)$ are the vehicle and track noise contributions in the sound pressure level, i is the frequency band number, v is the speed, $L_{rtot,i}(v)$ is the combined effective roughness at speed v.

Rolling noise is speed dependent and is therefore relevant for the operating conditions constant speed, acceleration, deceleration and curving.

It is practical to work with effective roughness as it is related directly to the real excitation. Effective roughness is related to direct roughness via the contact filter $A_3(l)$:

$$L_{rtr}(l) = L_{rtr,dir}(l) + A_3(l) \tag{4.10}$$

Combined effective roughness can be obtained from a rail vibration measurement of the vehicle(s) in question (see Section 6), using the formula

$$L_{rtot,i}(v) = L_{veq,i}(v) + 10\lg\left(\frac{D_{s,i}}{8.68 N_{ax}/l_{veh}}\right) - A_{2,i} - 20\lg(2pf_i) \tag{4.11}$$

where $L_{veq,i}(v)$ is the equivalent vertical railhead vibration level during a pass-by, $D_{s,i}$ is the vertical track decay rate in one third octave bands and $A_{2,i}$ is the difference spectrum between the rail displacement in the contact point and the effective roughness. $A_{2,i}$ is tabulated (see Section 6) but can also be calculated using TWINS. Spatial decay $D_{s,i}$ can be determined from pass-by measurement or from hammer impact response measurements (see Section 7).

The track transfer function can also be used in the same way for noise from bridges or for non-standard track support structures (eg slab track). For steel bridges it will tend to be significantly higher than for normal tracks. Bridge noise is included in the rolling noise source by using a track transfer function at h = 0m including the track and the bridge.

<u>Impact noise</u>

Impact noise can be caused by rail joints, crossings and points. It can vary in magnitude and can dominate over rolling noise. As it is often localised, it has to be taken into account when choosing track segmentation.

If present, impact noise is included in the rolling noise term by (energy) adding a supplemental roughness to the effective combined roughness:

$$L_{rtot}(l) = L_{rveh}(l) \oplus L_{rtr}(l) \oplus L_{rimpact}(l) \tag{4.12}$$

This approach is partly based on [3].

Impact noise will depend on the severity and number of impacts per unit length or joint density n_l, so the impact roughness can be given as:

$$L_{rimpact}(l) = L_{rimpact,nl}(l) + 10\ lg(n_l/0.01) \tag{4.13}$$

where $L_{rimpact,nl}(l)$ is the normalised impact roughness level and n_l is the joint density. The default impact roughness is given for a joint density $n_l = 0.01$, which is 1 impact per 100m track.

Situations with different numbers of joints can be approximated by adjusting the joint density n_l.
A different joint severity can be obtained by increasing the impact roughness level by approximately 20 lg h, where h is the step height of the joint.

It should be noted that when modelling the track layout and segmentation, the rail joint density should be taken into account, i.e. it may be necessary to take a separate source segment for a stretch of track with points.

The track noise $L_{ptr,i}$ is allocated to h=0m, the vehicle noise $L_{pveh,i}$ to h=0.5m.

4.3.2 Traction noise

Traction noise is specified for each characteristic operating condition: idling, acceleration, constant speed and deceleration. The source strength at each operating condition is an average for ‘normal conditions’ and therefore takes an ‘average load’ into account. This results in the quantities $L_{peq,i,traction,idle}$,$L_{peq,i,traction,acc}$, $L_{peq,i,\ traction,cs}$, and $L_{peq,i,\ traction,dec}$.

These quantities can either be obtained from measurement 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.

As far as relevant, several traction noise sources have to be characterised which are not all directly train speed dependent:

- noise from the powertrain, such as diesel engine (including inlet, exhaust and engine block), gear transmission, electrical generators, mainly dependent on engine 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.

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 measurement 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 EMUs, DMUs and high speed trains have a more well defined load. More details on traction noise can be found in [4] and [5].

Traction noise is the energy sum of noise due to the powertrain L_{pdrive}, cooling fans L_{pfan} and other (intermittent) sources L_{pd}:

$$L_{peqi,traction} = L_{pdrive,i} \oplus L_{pfan,i} \oplus L_{pd,i} \qquad (4.14)$$

where
$\Sigma\oplus$ = energy sum: $\Sigma\oplus x_i = 10 \lg (10^{x1/10} + 10^{x2/10} + \ldots)$

Noise from the powertrain is often approximately proportional to the driveshaft speed n_{drive} of the diesel engine or electric motor with gear transmission. For electrically powered vehicles, the shaft speed of the electric motor(s) and gear transmission is often directly linked to the train speed. For diesel-powered vehicles however, the engine shaft speed is often independent of the train speed, and varies with required power. Some vehicles also have fixed speed diesel engines. Many modern electric locomotives, EMUs and high speed train units have electrical power control systems that emit varying tonal noise which increases with power output and are especially audible during high torque conditions. In these cases, where power output or torque is the main influencing parameter, noise levels for each characteristic operating condition are required. For locomotives, it is important to apply a sufficiently high load to obtain realistic noise emission levels. A hauled load of at least 5 times the locomotive weight is recommended.

For those vehicles for which the noise emission depends strongly on driveshaft speed, the following formula can be used to estimate noise emission at various operating conditions:

$$L_{pdrive,i}(n_{drive}) = L_{pdrive,nmax,i}(f_i.(n_{drive,max}/n_{drive})) + C_{drive} \lg (n_{drive}/n_{drive,max}) \qquad (4.15)$$

The sound pressure level at maximum shaft speed $L_{pdrive,i,nmax}$ is determined for a maximum drive speed $n_{drive,max}$ (or the nearest feasible speed) and the factor C_{drive} is determined from 2 or more operating points. A default value for C_{drive} is 30, if mechanical sources are predominant. The noise level for arbitrary speed is determined from a level shift (C_{drive} term) and a frequency shift ($n_{drive,max}/n_{drive}$). For fan noise with variable shaft speed n_{fan}, the fan noise L_{pfan} is given in a similar manner:

$$L_{pfan,i}(n_{fan}) = L_{pfan,nmax,i}(f_i.(n_{fan,max}/n_{fan})) + C_{fan} \lg (n_{fan}/n_{fan,max}) \qquad (4.16)$$

$L_{pfan,nmax}$ is determined for a maximum drive speed $n_{fan,max}$ (or the nearest feasible speed) and the factor C_{fan} is determined from 2 or more operating points. A default value for C_{fan} is 50, if flow noise sources are predominant. If the fan has fixed settings such as high and low speed, or is automatically controlled, the noise level that is characteristic of each operating condition is required. If cooling fans are attached to the driveshaft linked to the axles, then it is possible that fan noise may dominate drive noise at higher speeds. In this case formula (4.16) may coincide with formula (4.4), with C_{drive}=C_{fan}.

For any other traction or auxiliary sources *q,* with non-continuous or intermittent operation, the level L_{pqdi} corrected for the duty factor d_q (proportion of operating time to total time) is determined with:

$$L_{pdqi} = L_{pq,i} + 10 \lg (d_q) \qquad (4.17)$$

The operational level $L_{pq,i}$ is obtained from measurement of source q; the duty factor is determined from the percentage of time the source is active. If the corrected level is significantly lower than other traction noise from the powertrain or cooling system, it can be omitted. Such sources may also only be significant during idling or at low speeds, and for a short duration.

For diesel engine noise and for fan noise, defaults for shaft speeds can be given for each operating condition, as shown in Table 4.4.

Drive speed (diesel engine) n_{drive}	Fan speed n_{fan}
Constant speed	
$n_{driveidle} + 0.5(n_{drivemax} - n_{driveidle})$	$n_{fanmin} + 0.25(n_{fanmax} – n_{nfanmin})$ or n_{fanLOW}
Acceleration	
$n_{driveidle} + 0.75(n_{drivemax} - n_{driveidle})$	$n_{fanmin} + 0.75(n_{fanmax} – n_{nfanmin})$ or $n_{fanHIGH}$
Deceleration	
$n_{driveidle}$	$n_{fanmin} + 0.75(n_{fanmax} – n_{nfanmin})$ or $n_{fanHIGH}$
Idling	
$n_{driveidle}$	n_{fanmin} or n_{fanLOW}

Table 4.4: Default drive shaft speeds for diesel engines and fan shaft speeds for different operating conditions

If it is possible to measure traction noise for all required conditions with all relevant sources in operation, then formulas (4.14)-(4.16) can be omitted. In that case, source spectra are determined for idling $L_{peq,idle}$, acceleration $L_{peq,acc}$, constant speed, $L_{peq,cs}$, and deceleration $L_{peq,dec}$. Measurements on locomotives should be performed with a load of at least 5 times the vehicle weight to ensure sufficient power output.

The source heights for traction noise sources are determined either by the physical position of the component concerned, or by measurement using special techniques such as microphone array measurements. Sources such as gear transmissions and electric motors will often be at an axle height of 0.5m. Louvres and cooling outlets can be at various heights; engine exhausts are often at roof height of 4m. Other traction sources such as fans or diesel engine blocks may be at 2 or 3m height. If the exact source height is in between the model heights, the sound energy is distributed proportionately over the nearest adjacent source heights.

4.3.3 Deceleration noise

Deceleration noise consists of braking noise at normal speeds (often broadband) and brake squeal, which usually sets in at lower speeds. The corresponding sound pressure expressions have to be determined, if applicable:

For braking noise with speed dependency, especially broadband braking noise at speed:

$$L_{pbrake,i}(v) = L_{pbrake,i}(v_0) + C_{brake} \lg (v/v_0) \qquad (4.18)$$

Here, at least two measurements at different speed are required whilst braking; one at reference speed v_0 to determine $L_{pbrake,i}(v_0)$ *and* another to determine the speed dependency factor C_{brake}.

For brake squeal:

$$L_{pdsquea,il} = L_{psqueal,i} + 10 \lg (d_{squeal}) \qquad (4.19)$$

Here the squeal noise level $L_{psqueal,i}$ and its duration correction d_{squeal} need to be measured, and the speeds at which brake squeal occurs.

The energy sum is taken for braking and brake squeal (if relevant) to give the overall deceleration noise sound pressure spectrum as a function of speed.

$$L_{pdeceleration,i}(v) = L_{pbrake,i}(v) \oplus L_{pdsqueal,I} \qquad (4.20)$$

Deceleration noise is normally allocated to the source height 0,5m. If it is well below the rolling noise level at all speeds, it can be neglected.

4.3.4 Curve squeal

Curve squeal is a special source that is only relevant for curves and points 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. As all these parameters are rather complex to include in a traffic noise prediction method, it is proposed to use noise levels measured during the transit time of a vehicle squealing in a curve. This should then be corrected for the percentage of pass-bys it is expected to occur, as a default 50%, which reduces the level by 3 dB. This takes all statistical effects into account such as variation in geometry, friction and humidity. The statistical variations over the length of the vehicle are accounted for by using the equivalent noise level measured over the pass-by length. The emission level to be used should be determined for curves with radius below 1000m and for sharper curves and branch-outs of points with radii below 100m. The noise emission should be specific to each type of rolling stock, as certain wheel types may be significantly less prone to squeal than others. The emission level $L_{p,i,squeal}$ is given as a function of speed and curve radius, depending on the track (curve or points) and the vehicle type. The source height is at axle height (0.5m).

Squeal noise levels for different speeds or curve radii can be approximated by the following relationship, based on [6]:

$$L_{p,squeal,i} = L_{p,squeal,i}(v_0,R_0) + 20 \lg (v/v_0) - 20 \lg (R/R_0) \qquad (4.21)$$

This formula may be used for deriving squeal noise levels at other speeds or radii, but preferably by no more than a factor 10 in speed or radius.

4.3.5 Aerodynamic noise

Aerodynamic noise is only relevant at high speeds 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 limited to 250 km/h, in some cases aerodynamic noise may not be necessary to include, depending on vehicle design.

The aerodynamic noise contribution is given as a function of speed and source height:

$$L_{paero,i}(h,v) = L_{paero,i}(h,v_0) + a_i(h) \lg (v/v_0) \qquad (4.22)$$

where v_0 is a speed at which aerodynamic noise is dominant and $a_i(h)$ is a coefficient determined from 2 or more measurement points, for sources at known source heights, for example, the first bogie (0.5m) and the pantograph recess heights (4m).

4.4 Step-by-step rail traffic noise method

The above elements are needed in order to create the source line of acoustic energy that interfaces with the propagation method. The step-by-step process is as follows:

- Define railway source lines with end points (these are at each source height where sound is being created and must be acoustically homogeneous)
- Identify railways
- Identify rail vehicle type, track types, traction noise, rolling noise, aerodynamic noise
- Define operating conditions per unit of time (eg day, evening, night), No. per hour, track roughness, speed, acceleration
- Define locations of source lines with end points
- Correction factors for directivity, curves, joints, bridges etc
- Calculate Sound Power Level (1/3 octave bands, for each source height, per m of source line, per hour, per D/E/N)
- Sum SWLs per source height

5 Database description and structure

5.1 Database concept and philosophy

The IMAGINE database builds on a concept developed within HARMONOISE. As delivered, it holds both “Example” and “Default” Data. The Example Data has been acquired by measurements in the field. The Default Data has been developed by reviewing all relevant theoretical and experimental datasets in the ownership of the WP6 partner TNO, and deriving from these a set of indicative spectra for typical European railway scenarios.

The Example Data can be used by noise modellers to represent either the exact vehicle or track type whose characteristics were measured, or a vehicle or track type that the modeller judges is sufficiently acoustically similar to the example data to justify its use. The Default Data provides generic information that may be used in the absence of appropriate Example Data, but with an associated reduction in accuracy. Therefore, in the absence of appropriate Example Data, the modeller has two options; either to acquire new field data or to use the supplied Default Data.

All spectral data is identified by one or more descriptors, in accordance with vehicle and track descriptors developed in HARMONOISE. In the case of spectra derived from measurement, it is always possible to access the original measurement dataset, including specific metadata such as member state, location, measurement team etc. While the IMAGINE data input sheet contains data grouped by pass-by events, the data is reordered within the database itself. This reordering makes it possible to use the deconstructed elements (the spectral data tables) separately for defining the characteristics of new classes of vehicles, tracks or vehicle/track combinations.

Because of the complexity of this (relational) railsource database, manual input of the data is very time consuming and is not recommended. Therefore an Access software tool was built to automate the importation of measurement data and default data.

Automation of data import is possible only when a uniform input format is available. Uniform input formats for measurement and default data were created in an Excel spreadsheet. Guidelines for acquiring data via the standardised input sheet are given in Section 8. The separate Excel data sheet for inputting default data is also described.

The user can access the database via 3 levels described as: basic, advanced and expert. Only the expert level contains the data import option described above. A discussion of the three user levels can be found in Section 5.2.

The database design goals can be summarized as the following:

- state of the art rail source database including all currently known physical rail source parameters
- transparent structure
- option for input of newly acquired measurement data via a standardised input sheet
- applicable in a GIS environment
- prepared for central European administration
- user entry levels from basic to expert

5.2 Global description

A simplified structure of the IMAGINE Rail Source Database is given in Figure 5.1.

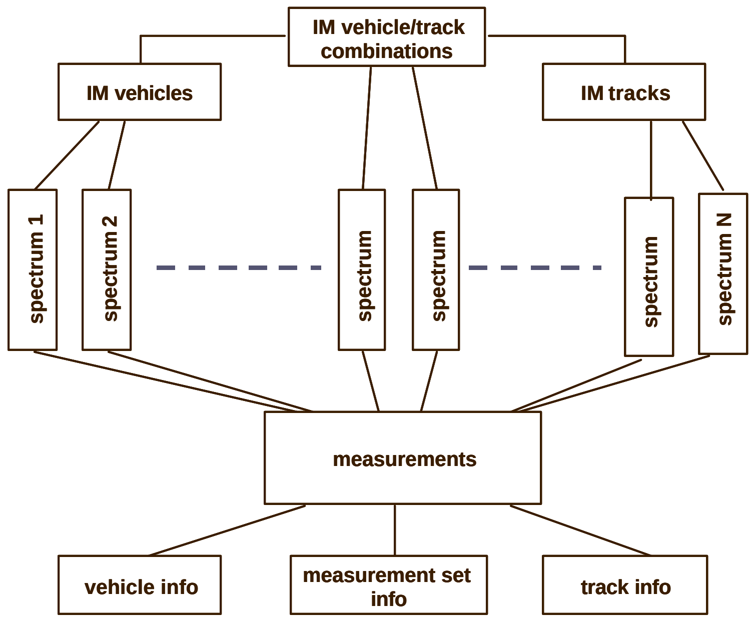


Figure 5.1 Simplified structure of the IMAGINE Rail Source Database

The full database scheme is in accordance with the UML 2.0 standard.

The heart of the database is a set of spectra. Two types of spectral data are possible:

1. data directly related to a measurement. These spectra have a relation with the table <*measurements*>

2. default data from theoretical research or field measurements or a combination of both.

In Figure 5.1, the table *measurements* is the central table that links the spectral data tables and all other measurement data. The table *measurements* only contains pointers to the spectral datatables and to the other measurement data. It does not contain any measurement data itself. The tables *vehicle info, measurement info* and *track info* contain all non-spectral background information (metadata), as can be entered onto the data import Excel sheets.

Above the spectral data tables are the tables *IM vehicles*, *IM Tracks* and *IM vehicle/Track combinations*. These tables can contain predefined sets of vehicles, tracks or vehicle-track combinations. These sets can be defined by the IMAGINE project, the EC or a local user. In this way typical categories for vehicles and tracks can be predefined by each Member State.

At user-level 0 (basic), the user chooses predefined vehicles, tracks or vehicle-track combinations. At user-level 1 (advanced), the user sets up information for vehicles, tracks or vehicle-track combinations from existing spectra available within the database, and stores them in the tables prefixed "*IM*". At user-lever 2 (expert), the user does the same, but with newly imported measurement data for vehicles or tracks.

5.3 Description of spectral data tables

All tables with spectral data have the same structure. The first field, a unique ID, is followed by the fields *default* and *default reference*, describing whether the data is default data or not, and describing the origin of the default data (IMAGINE project, European Commission etc), and the field description. These four fields are standard in all spectral data tables. This set is followed by one or more fields, related to the vehicle and track descriptors. Every table contains the relevant descriptor for that particular data. For example, for wheel roughness only the brake type is relevant. Finally, the tables contain a frequency or wavelength spectrum.

Table Name	ID	Default	Default Reference	Description	Speed dependent?	Speed	Load	Wheel diameter	Brake type	Wheel measure	Track base	Sleeper type	Roughness condition	Rail joints	Railpad type	Curvature	Mic height	Source type
Traction noise - acceleration	x	x	x	x													x	x
Traction noise - deceleration	x	x	x	x													x	x
Traction noise - constant speed	x	x	x	x													x	x
Traction noise - idling	x	x	x	x													x	x
Aerodynamic noise - bogie	x	x	x	x	x	x												
Aerodynamic noise - pantograph	x	x	x	x	x	x												
Aerodynamic noise - total	x	x	x	x	x	x												
Braking noise	x	x	x	x	x	x			x									
Brake Squeal Noise	x	x	x	x					x									
Roughness - Wheel	x	x	x	x					x									
Transfer function - vehicle	x	x	x	x				x		x								
Transfer function - total	x	x	x	x				x		x		x			x			
Roughness - Total Effective	x	x	x	x					x				x					
Contact filter	x	x	x	x			x	x										
Transfer function - track	x	x	x	x								x			x			
Roughness - Rail	x	x	x	x									x					
Impact noise	x	x	x	x										x				
Curve Squeal Noise	x	x	x	x	x											x		

Table 5.1. Spectral tables and related information included in the IMAGINE database.

6 Default data included within the delivered database

6.1 Overview of default parameters

Default values for the key physical sources are described in this section. These have been developed by reviewing all relevant theoretical and experimental datasets in the ownership of the WP6 partner TNO, and deriving from these a set of indicative spectra for typical European railway scenarios [7]. They must only be used in modelling exercises when the database does not hold either example data for the railway scenario to be modelled, or example data for situations that are similar to that scenario. When default data is used, the accuracy of modelling cannot be guaranteed, but it has been provided to enable indicative noise levels always to be calculated, even when no directly applicable data is available.

All of the default noise values are given in terms of sound pressure level in one-third octave bands at 7.5m during transit time T_p, as this is straightforward to compare with measurement. Default transfer functions also relate sound pressure level at 7.5m to combined effective roughness.

Table 6.1 provides a summary of the default quantities that have been considered in IMAGINE. **76** default spectra are supplied within the delivered database. (See section 4 for definition of quantities).

Source type	Default quantities	Vehicle	Track
Rolling noise	N_{ax}/l_{veh} =0.15 (passenger coach) $L_{Hpr\ nl,i}$ for track $L_{Hpr\ nl,i}$ for vehicle $L_{r,total,i}(v)$ for vehicle/track combinations	Cast-iron tread braked K-block tread braked Disc-braked	Concrete monoblock Concrete biblock Wooden sleeper Soft/medium/stiff railpad Rail roughness: ISO, TSI, Network average
Impact noise	$L_{rimpact}(l)$ n_{nl} = 1/100 m		Average joints, points and crossings
Traction noise, drive	$L_{p,drive,i}(n_{drive})$ *Diesel:* $n_{drive} = n_{25\%}, n_{50\%}, n_{75\%}$ *Electric: 1 or 2 speeds accelerating at normal load* $C_{drive} = 30$	DMU, Dloco EMU, Eloco	
Traction noise, fan	$L_{p,fan,i}(n_{fan})$	EMU, Eloco	

Source type	**Default quantities**	**Vehicle**	**Track**
	$n_{fan} = n_{50\%}$ or n_{low}, n_{max} or n_{high} $d_{fan} = 80\%$ for n_{low}, $d_{fan} = 20\%$ for n_{high} $C_{fan} = 50$		
Traction noise, other	L_{pi}, d	Compressor and relief valves	
Deceleration noise, braking	$L_{p,brake,i}(v) = 88 + 30\ lg\ (v/80)$ @800-8000 Hz *Only for CI braked vehicles*	Cast-iron braked vehicles	
Deceleration noise, squeal	$L_{pbrakesqueal,i} = 100$ dB @ 1kHz *Below 50 km/h*	Freight HST, EMU	
Curve squeal	$L_{p,curve\ squeal,\ points,i} = 100$ dB @ 1kHz, 2kHz $L_{p,curve\ squeal,\ curve,i} = 95$ dB @ 2kHz , 4kHz	All, unless demonstrated squeal free	Points (when curving) Curve
Aerodynamic noise	$L_{peq,i,aero}(v,h=0,5m) =$ $85–3\ lg\ (f_i)+60*log10(v/200)$ for $20<=f_i<=500$ Hz $L_{peq,i,aero}(v,h=0,5m) =$ $76.5+60*lg(v/200)$ for 500 Hz$<f_i<=$3.15 kHz $L_{peq,i,aero}(v,h=0,5m) =$ $130–15*lg(f_i)+60*log10(v/200)$ for, $f_i>$3.15 kHz $L_{peq,i,aero}(v,h=4m) =$ $68+60*log10(v/200)$ for f_i = 1.6 kHz , f_i = 3.15kHz $L_{peq,i,aero}(v,h=4m) =$ $73+60*log10(v/200)$ for f_i = 2 kHz , f_i = 2.5 kHz	Unshielded bogies and pantograph recesses	

Table 6.1. Overview of default input quantities for the railway noise source model

6.2 Defaults for rolling noise

Default data is given for total effective roughness and track and vehicle transfer functions as follows:

- Total effective roughness (ie combined wheel and rail roughness, with the addition of a contact filter for different wheel and rail combinations): for cast-iron block-braked vehicles (“CI”), disc-braked vehicles (“Disc”) and K-block braked vehicles (“KB”) in various typical combinations with rails with Dutch average network roughness (“netrail”) or with smooth rails (“smoothrail”). (Table 6.2)

- ISO roughness, TSI roughness and Dutch average network roughness, without contact filter effects, are tabulated separately in Table 6.3.

(The ISO roughness is that which is incorporated within pr-EN ISO 3095 2001 and ISO 3095 2005 as the upper limit for a test section for pass-by noise. The TSI roughness is that which is defined within the EC Technical Specification for Interoperability “relating to the subsystem ‘rolling stock — noise’ of the trans-European conventional rail system”, Dec 2005.) (Table 6.3)

- Vehicle transfer functions: for vehicles with wheels of several diameters (Table 6.4).

- Track transfer functions: for ballasted tracks with concrete monoblock or biblock sleepers, soft, medium-stiff or stiff railpads, and for wooden sleepers. (Table 6.5).

Wave-length [cm]	CI-netrail	Disc-netrail	Disc-smoothrail	KB-smoothrail	ISO	TSI	Netrail
63	20	11	20.5	18.5	23.5	17.1	11
50	17	11	18.7	16.7	21.7	17.1	11
40	14	11	16.8	14.8	19.8	17.1	11
31.5	12	10	15	13	18	15	10
25	10	9	13.1	11.1	16.1	13	9
20	10	8	11.3	9.3	14.3	11	8
16	11	7	9.4	7.4	12.4	9	7
12	11	6	7.6	5.6	10.6	7	6
10	11	5	5.8	3.8	8.8	4.9	5
8	13	3.8	3.7	1.7	6.7	2.7	3.8
6.3	14	2.5	1.6	-0.4	4.6	0.4	2.5
5	14	1.1	-0.7	-2.7	2.3	-2	1.1
4	13	-0.6	-3.2	-5.2	-0.2	-4.8	-0.6
3.2	10	-2.5	-6	-8	-3	-7.5	-2.5
2.5	7	-4.8	-9.1	-11.1	-6.1	-9.4	-4.8
2	3	-7.8	-12.9	-14.9	-9.9	-12	-7.8
1.6	-2	-11.5	-17.5	-19.5	-14.5	-15.3	-11.5
1.2	-7	-15.4	-22.2	-24.2	-19.2	-18.8	-15.4
1	-14	-17	-24.7	-26.7	-21.7	-20	-17
0.8	-19.5	-19.5	-26.2	-28.2	-23.2	-22.1	-19.5
0.63	-21.5	-21.5	-27.2	-29.2	-24.2	-23.7	-21.5
0.5	-24	-24	-28.7	-30.7	-25.7	-25.8	-24
0.4	-25.5	-25.5	-29.2	-31.2	-26.2	-26.9	-25.5
0.32	-27.7	-27.7	-30.4	-32.4	-27.4	-28.7	-27.7
0.25	-29.6	-29.6	-31.3	-33.3	-28.3	-30.2	-29.6
0.2	-31.6	-31.6	-32.3	-34.3	-29.3	-31.8	-31.6
0.16	-33.6	-33.6	-33.3	-35.3	-30.3	-33.4	-33.6
0.13	-35.6	-35.6	-34.3	-36.3	-31.3	-35	-35.6
0.1	-37	-37.6	-35.3	-37.3	-32.3	-36.6	-37.6

Table 6.2. Effective roughness in dB re 10^{-6}m for a selection of wheel-rail roughness conditions.

Wavelength [cm]	ISO	TSI	Netrail
63	23.5		
50	21.7		
40	19.8	17.1	11
31.5	18.0	15	10
25	16.1	13	9
20	14.3	11	8
16	12.4	9.0	7.0
12	10.6	7.0	6.0
10	8.8	4.9	5.0
8	6.9	2.9	4.0
6.3	5.1	0.9	3.0
5	3.2	-1.1	2.0
4	1.4	-3.2	1.0
3.2	-0.5	-5.0	0.0
2.5	-2.3	-5.6	-1.0
2	-4.1	-6.2	-2.0
1.6	-6.0	-6.8	-3.0
1.2	-7.8	-7.4	-4.0
1	-9.7	-8.0	-5.0
0.8	-9.7	-8.6	-6.0
0.63	-9.7	-9.2	-7.0
0.5	-9.7	-9.8	-8.0
0.4	-9.7	-10.4	-9.0
0.32	-9.7	-11.0	-10.0
0.25	-9.7	-11.6	-11.0
0.2	-9.7	-12.2	-12.0
0.16	-9.7	-12.8	-13.0
0.13	-9.7	-13.4	-14.0
0.1	-9.7	-14.0	-15.0

Table 6.3. Rail roughness in dB re 10^{-6}m for ISO 3095, HS-TSI 2002, CR-TSI 2005 and the Dutch average network.

freq Hz	Vehicle transfer functions			
	920mm	840mm	680mm	1200mm
20	62	62	62	62
25	63	63	63	63
32	64	64	64	64
40	65	65	65	65
50	66	66	66	66
63	67	67	67	67
80	68	68	68	68
100	69	69	69	69
125	70	69.5	69.5	69.5
160	71	70	70	70
200	72.5	70.6	70.4	71
250	74.8	71.6	71	75.1
315	74.7	72.8	72.9	75.3
400	72.8	73.7	76	73.7
500	72.7	74.8	77.8	74
630	75.3	76.4	77.4	76.2
800	76.7	75.8	75.2	75.8
1000	79.3	77.4	74.8	78
1250	84.8	83.1	77.6	84.9
1600	90	87	78.9	90
2000	95	93	85	101
2500	100	97	90	101
3150	100	99.5	93	101
4000	100	99.5	96	101
5000	100	99.5	96	101
6300	100	99.5	96	101
8000	100	99.5	96	101
10000	100	99.5	96	101

Table 6.4. Vehicle transfer functions, in dB re 20 Pa/m$^{1/2}$, based on measurements and TWINS calculations for different wheel diameters. A moderate contribution from the bogie or vehicle structure is assumed below 125 Hz.

Track transfer functions

freq	mosoft	momed	mostiff	bisoft	bimed	bistiff	wood
20	20	17	16	17	16	16	11
25	26	23	22	23	22	22	17
32	32	29	28	29	28	28	23
40	38	35	34	35	34	34	29
50	43.9	41.5	40.7	41.5	40.6	40.4	34.6
63	49	47.5	46.9	46.3	45.8	45.6	40.7
80	54.1	53.4	53.2	51.2	51	50.9	46.8
100	60.8	61.7	62.1	57.2	57.4	57.4	55.7
125	65.9	67.6	68.3	62.1	62.5	62.6	61.8
160	68.5	70	70.7	65.2	65.8	66.1	63.8
200	70.7	72.3	73	68.3	70.1	70.9	63.7
250	73.3	74.7	75.4	71.3	73.4	74.4	65.6
315	75.9	76.5	77	74	74.5	75.1	70.2
400	78.3	77.7	78.1	75.7	73.5	74	76.3
500	80.9	79.5	79.7	78.4	74.5	74.7	80.9
630	84.1	82.3	81.9	82.4	78.7	78	83.6
800	88.3	86	84.6	88.3	84.9	82.2	87.1
1000	91.5	88.8	86.9	92.3	89.1	85.5	89.8
1250	92.7	90.4	88.6	93.3	90.7	87.8	90.9
1600	93.9	92.2	90.8	94.2	92.5	90.8	91.8
2000	95.1	93.7	92.5	95.2	94.2	93.1	92.9
2500	95.1	94	93	95.3	94.4	93.6	93.2
3150	95	94.1	93.2	95.1	94.4	93.7	93.4
4000	95	94.4	93.7	95.1	94.7	94.1	93.7
5000	94.8	94.4	93.9	94.8	94.5	94.1	93.6
6300	94.4	94.3	94.1	94.3	94.2	94	93.5
8000	94.1	94.3	94.4	94	94	93.9	93.5
10000	93.9	94.3	94.7	93.7	93.8	93.9	93.5

Table 6.5. Tabulated track transfer functions, in dB re 20 Pa/m$^{1/2}$, ballasted track with UIC60 rails, for different sleeper/railpad combinations: mo=concrete monoblock sleepers, bi=biblock concrete sleepers, soft/med/stiff refers to the railpad, wood=wooden sleepers.

6.3 Defaults for impact noise

As described in 4.3.1, impact noise can be accounted for in terms of an “impact roughness”. The default normalised impact roughness $L_{r,impact,nl}(l)$ is given for a single average joint impact level, for an impact density $n_l=0.01$ (1 impact per 100 metres track). Other values for the impact roughness may be obtained by measurement, although as a default the values can be increased by 10 lg (nl/0.01) to account for a change in density.

Wavelength [cm]	63.0	50.0	40.0	31.5	25.0	20.0	16.0	12.0	10.0	8.0
$L_{rimpact,nl}(\lambda)$	22.4	23.8	24.7	24.7	23.4	21.7	20.2	20.4	20.8	20.9

Wavelength [cm]	6.3	5.0	4.0	3.2	2.5	2.0	1.6	1.2	1.0	0.80
$L_{rimpact,nl}(\lambda)$	19.8	18.0	16.0	13.0	10.0	6.0	1.0	-4.0	-11.0	-16.5

Wavelength [cm]	0.63	0.50	0.40	0.32	0.25	0.20	0.16	0.13	0.10
$L_{rimpact,nl}(\lambda)$	-18.5	-21.0	-22.5	-24.7	-26.6	-28.6	-30.6	-32.6	-34.0

Table 6.6. Impact roughness in dB re 10^{-6}m for a joint density of 1 joint/100m, ie n_l=0.01

It should be noted that points and multiple points should be modelled by taking an adequate joint density over a relevant length of track. The approximate joint density to be taken for different situations is given in Table 6.7.

Joint situation	Joint density n_l
Single joint in normal track	0.01
Jointed track, joint density n_l	n_l
1 set of points	0.03
2 sets of points per 100m	0.06
Multiple sets of points, railway junction	0.08

Table 6.7. Joint density defaults for different situations

The data used here is in part derived from the Dutch SRM II calculation method, although modified with the joint density and approach for impact roughness.

6.4 Defaults for traction noise

Traction source default data is given in Table 6.8 for relevant operating conditions of diesel locomotives, electric locomotives, diesel multiple units (DMUs) and electric multiple units (EMUs). The source data given does not include rolling noise, which can exceed the traction noise above certain speeds or roughness conditions. Care should be taken when using this data as a default for traction noise, as it may differ significantly from type to type. For example, the traction noise from a diesel locomotive with known mechanical power may differ significantly from one design to another.

The default data is derived from measured data, which has been smoothed and transformed to different operating conditions where necessary.

6.4.1 Diesel locomotives

Several spectra are given for different diesel electric locomotives, with various mechanical power, number of axles, length and weight. The frequency peaks below around 100 Hz are generally associated with ignition frequencies and the exhaust. The medium frequency range tends to be dominated by a combination of cooling fan noise and radiated engine noise. Peaks above 1 kHz are often related to turbochargers, which set in during loaded conditions.

6.4.2 Electric locomotives

Electric locomotives can have strong fan noise, gear noise and electrical converter noise. An example is given here for a general-purpose electric locomotive with high fan noise and converter noise. The locomotive has 4560 KW mechanical power, a length of 17.6m and has 4 axles and a total weight of 86 tons.

6.4.3 Diesel Multiple Units (DMUs)

Source data is given for a diesel electric DMU with two coaches, each powered with a diesel engine mounted underneath the chassis (therefore not well shielded). The total mechanical power is 640 KW, total length 52.3m and a total weight of 94 tons. The diesel engine noise often dominates the overall noise.

6.4.4 Electrical Multiple Units (EMUs)

Source data is given for an electrical multiple unit with two coaches, each powered with an electric motor and a gear transmission mounted on the axle. The total mechanical power is 508 KW, total length 52.1m, total weight 88 tons. Gear noise is predominant at speed, while generator fans dominate noise at standstill, with a small contribution from compressors.

	Diesel loco Pmech 830KW vmax=120km/h M =64 ton L=14 m			Diesel loco Pmech2250KW vmax=160km/h M=114 ton L=20m			Diesel loco Pmech1155KW vmax=125km/h L=19.5m			Diesel loco Pmech1180KW vmax=125km/h W= 82 ton L=14.4m		
Freq [Hz]	Idling	Cst. Speed	Accel.	Idling	Cst. Speed	Accel.	Idling	Cst. Speed	Accel.	Idling	Cst. Speed	Accel.
20	75.0	71.0	74.0	70.0	70.0	70.0	68.0	69.0	70.0	67.0	68.0	71.0
25	65.0	81.0	74.0	70.0	72.0	72.0	71.0	71.5	72.0	72.0	68.0	71.0
32	70.0	71.0	84.0	70.0	74.5	74.5	74.0	74.0	74.5	77.0	73.0	71.0
40	75.0	76.0	74.0	80.0	77.0	77.0	77.0	77.0	77.0	65.0	78.0	76.0
50	70.0	81.0	79.0	70.0	80.0	80.0	80.0	80.0	80.0	65.0	83.0	81.0
63	65.0	76.0	84.0	70.0	87.0	82.0	83.0	83.0	83.0	75.0	71.0	86.0
80	65.0	71.0	79.0	80.0	80.0	90.0	80.0	86.0	86.0	67.0	71.0	74.0
100	65.0	71.0	74.0	70.0	77.0	82.0	77.0	89.0	89.0	60.0	81.0	74.0
125	65.0	71.0	74.0	70.0	76.0	80.0	74.0	86.0	92.0	55.0	73.0	84.0
160	65.0	71.0	74.0	70.0	76.0	79.0	74.0	83.0	89.0	55.0	66.0	76.0
200	65.0	71.0	74.0	70.0	76.0	79.0	74.0	80.0	86.0	55.0	61.0	69.0
250	65.0	71.0	74.0	70.0	76.0	79.0	74.0	80.0	83.0	55.0	61.0	64.0
315	65.0	71.0	74.0	70.0	76.0	79.0	74.0	80.0	83.0	55.0	61.0	64.0
400	65.0	71.0	74.0	70.0	76.0	79.0	74.0	80.0	83.0	55.0	61.0	64.0
500	65.0	71.0	74.0	70.0	76.0	79.0	74.0	80.0	83.0	55.0	61.0	64.0
630	70.0	75.0	79.0	70.0	76.0	79.0	73.0	80.0	83.0	55.0	61.0	64.0
800	65.0	71.0	74.0	70.0	76.0	79.0	71.4	80.0	83.0	55.0	61.0	64.0
1000	65.0	71.0	74.0	70.0	76.0	79.0	68.9	79.0	83.0	55.0	61.0	64.0
1250	65.0	71.0	74.0	67.7	73.7	76.7	66.3	77.4	82.0	55.0	61.0	64.0
1600	65.0	71.0	74.0	72.0	71.4	74.4	63.8	74.9	80.4	55.0	61.0	64.0
2000	65.0	71.0	74.0	63.1	69.1	72.1	61.2	72.3	77.9	52.0	61.0	64.0
2500	63.0	76.0	74.0	60.8	77.0	69.8	58.7	69.8	75.3	49.0	61.0	64.0
3150	60.0	69.0	82.0	62.0	64.5	80.0	56.1	67.2	72.8	46.0	58.0	64.0
4000	57.0	66.0	74.0	56.1	62.1	65.1	53.6	64.7	70.2	43.0	55.0	61.0
5000	54.0	63.0	71.0	53.8	65.0	62.8	51.0	62.1	67.7	40.0	52.0	58.0
6300	51.0	60.0	68.0	51.5	5.8	68.0	48.5	59.6	65.1	37.0	49.0	55.0
8000	48.0	57.0	65.0	49.2	55.2	58.2	46.0	57.0	62.6	34.0	46.0	52.0
10000	45.0	54.0	62.0	46.9	52.9	55.9	43.5	54.5	60.0	31.0	43.0	49.0
12500	42.0	51.0	59.0	44.6	50.6	53.6	41.0	52.0	57.5	28.0	40.0	46.0
16000	39.0	48.0	56.0	42.3	48.3	51.3	38.5	49.5	55.0	25.0	37.0	43.0
20000	36.0	45.0	53.0	40.0	46.0	49.0	36.0	47.0	52.5	22.0	34.0	40.0

Table 6.8a. Traction noise sound pressure level for selected powered vehicles

	Diesel loco Pmech2200KW vmax=121km/h M =126 ton L=20.1 m			DMU Pmech 640KW vmax=140km/h M=94 ton L=52.3m			Elec loco Pmech4560KW vmax=140km/h M=86 ton L=17.6m			EMU Pmech508 KW vmax=140km/h M= 82 ton L=52.1m		
Freq [Hz]	Idling	Cst. Speed	Accel.	Idling	Cst. Speed	Accel.	Idling	Cst. Speed	Accel.	Idling	Cst. Speed	Accel.
20	63.0	68.0	71.0	58.0	56.0	60.0	60.0	69.0	69.0	58.3	58.3	58.3
25	63.0	78.0	71.0	58.0	54.0	59.0	59.0	68.0	68.0	58.0	58.0	58.0
32	70.0	69.0	81.0	58.0	55.0	57.0	58.0	67.0	67.0	60.0	60.0	60.0
40	78.0	69.0	72.0	67.0	57.0	58.0	59.0	68.0	68.0	57.3	57.3	57.3
50	73.0	76.0	72.0	58.0	62.0	60.0	60.0	69.0	69.0	60.0	60.0	60.0
63	68.0	84.0	79.0	58.0	61.0	65.0	65.0	71.0	75.0	60.0	60.0	60.0
80	64.0	79.0	87.0	64.0	65.0	64.0	60.0	69.0	69.0	56.3	56.3	56.3
100	67.0	74.0	82.0	58.0	64.0	68.0	61.0	70.0	70.0	56.0	56.0	56.0
125	67.0	70.0	77.0	58.0	69.0	67.0	63.0	72.0	72.0	55.6	55.6	70.0
160	67.0	73.0	73.0	58.0	75.0	72.0	65.0	74.0	74.0	55.3	55.3	55.3
200	67.0	73.0	76.0	64.0	74.0	78.0	75.0	81.0	85.0	55.0	55.0	55.0
250	67.0	73.0	76.0	58.0	69.0	77.0	67.0	76.0	76.0	54.6	70.0	70.0
315	67.0	73.0	76.0	58.0	64.0	72.0	66.0	75.0	75.0	54.3	54.3	54.3
400	67.0	73.0	76.0	58.0	64.0	67.0	70.0	76.0	80.0	54.0	54.0	54.0
500	67.0	73.0	76.0	58.0	64.0	67.0	64.0	73.0	73.0	53.6	70.0	53.6
630	65.0	73.0	76.0	58.0	64.0	67.0	62.0	71.0	71.0	53.3	53.3	53.3
800	63.0	73.0	76.0	64.0	64.0	67.0	61.0	70.0	70.0	53.0	53.0	53.0
1000	61.0	71.0	76.0	58.0	65.0	67.0	65.0	71.0	75.0	60.0	60.0	60.0
1250	59.0	69.0	74.0	58.0	66.0	68.0	58.0	67.0	67.0	55.0	55.0	55.0
1600	57.0	67.0	72.0	58.0	67.0	69.0	56.0	65.0	65.0	57.0	57.0	57.0
2000	55.0	65.0	70.0	58.0	65.0	70.0	54.0	63.0	63.0	55.0	55.0	55.0
2500	53.0	63.0	68.0	58.0	62.0	68.0	52.0	61.0	61.0	52.0	52.0	52.0
3150	51.0	61.0	66.0	56.0	59.0	65.0	50.0	59.0	59.0	49.0	49.0	49.0
4000	49.0	59.0	64.0	53.0	57.0	62.0	48.0	57.0	57.0	46.0	46.0	46.0
5000	47.0	57.0	62.0	49.0	55.0	60.0	46.0	55.0	55.0	43.0	43.0	43.0
6300	45.0	55.0	60.0	45.0	52.0	58.0	44.0	53.0	53.0	40.0	40.0	40.0
8000	43.0	53.0	58.0	41.0	49.0	55.0	42.0	51.0	51.0	37.0	37.0	37.0
10000	41.0	51.0	56.0	37.0	46.0	52.0	40.0	49.0	49.0	34.0	34.0	34.0
12500	39.0	49.0	54.0	33.0	43.0	49.0	38.0	47.0	47.0	31.0	31.0	31.0
16000	37.0	47.0	52.0	29.0	40.0	46.0	36.0	45.0	45.0	28.0	28.0	28.0
20000	35.0	45.0	50.0	25.0	40.0	43.0	34.0	43.0	43.0	25.0	25.0	25.0

Table 6.8b. Traction noise source sound pressure level for selected powered vehicles

6.5 Default for broadband braking noise

A default for broadband braking noise is given at 80 km/h, which is only relevant for cast-iron block-braked vehicles:

$$L_{p,brake,i}(v) = 88 + 30 \lg (v/80) \quad @800\text{-}8000\ Hz \tag{6.1}$$

for 7,5 m distance from the track centreline.

6.6 Default for brake squeal

A default for brake squeal is given for any vehicles known to have brake squeal below speeds where mechanical braking sets in. This value is a constant spectrum:

$$L_{pbrakesqueal,i} = 100\ dB\ @\ 1kHz \tag{6.2}$$

for 7,5 m distance from the track centreline.

6.7 Defaults for curve squeal

Two defaults are given for curve squeal, one for large radius curves and one for sharp curves such as in points. These defaults include an assumed statistical occurrence and average number of wheels squealing.

Currently proposed defaults for curve squeal are:

$$L_{peq,curve\ squeal,\ points,i} = 100\ dB\ @\ 1kHz,\ 2kHz,\ for\ v=40km/h\ and\ R=40m \tag{6.3}$$

$$L_{peq,curve\ squeal,curve,i} = 95\ dB\ @\ 2kHz,\ 4kHz,\ for\ v=80km/h\ and\ R=250m \tag{6.4}$$

both for 7.5 m distance from the track centreline.

6.8 Defaults for aerodynamic noise

Defaults for aerodynamic noise are given at two source heights, 0,5m and 4m, intended for trains with unshielded bogies and unshielded pantograph recesses:

$$
\begin{aligned}
L_{peq,i,aero}(v,h=0{,}5m) &= 85 - 3\lg(f_i) + 60 \cdot \log10(v/200)\ ,\ 20 \le f_i \le 500\ Hz \\
L_{peq,i,aero}(v,h=0{,}5m) &= 76.5 + 60 \cdot \lg(v/200),\ 500\ Hz < f_i \le 3.15\ kHz \\
L_{peq,i,aero}(v,h=0{,}5m) &= 130 - 15\lg(f_i) + 60 \cdot \log10(v/200)\ ,\ f_i > 3.15\ kHz
\end{aligned}
\tag{6.5}
$$

$$
\begin{aligned}
L_{peq,i,aero}(v,h=4m) &= 68 + 60 \cdot \log10(v/200),\ f_i = 1.6\ kHz\ ,\ f_i = 3.15 kHz \\
L_{peq,i,aero}(v,h=4m) &= 73 + 60 \cdot \log10(v/200),\ f_i = 2\ kHz\ ,\ f_i = 2.5\ kHz
\end{aligned}
\tag{6.6}
$$

for 7.5 m from the track centre line.

6.9 Contact filter

Table 6.9 presents a set of contact filter values for a range of wheel diameters and loads.

Wavelength [cm]	360mm / 50 kN	680mm / 50 kN	920mm / 25 kN	920 mm / 50 kN	920 mm / 100 kN
63	0	0	0	0	0
50	0	0	0	0	0
40	0	0	0	0	0
31.5	0	0	0	0	0
25	0	0	0	0	0
20	0	0	0	0	0
16	0	0	0	0	0
12.5	0	0	0	0	0
10	0	0	0	0	0
8	0	0	0	-0.2	-0.2
6.3	0	-0.2	-0.2	-0.5	-0.6
5	-0.2	-0.4	-0.5	-0.9	-1.3
4	-0.5	-0.7	-0.9	-1.6	-2.2
3.15	-1.2	-1.5	-1.6	-2.5	-3.7
2.5	-2	-2.8	-2.5	-3.8	-5.8
2	-3	-4.5	-3.8	-5.8	-9
1.6	-4.3	-7	-5.8	-8.5	-11.5
1.25	-6	-10.3	-8.5	-11.4	-12.5

Wavelength [cm]	360mm / 50 kN	680mm / 50 kN	920mm / 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	-24.6	-26.5
0.05	-22.6	-24.2	-24.6	-25.6	-27.5
0.04	-23.6	-25.2	-25.6	-26.6	-28.4

Table 6.9. Contact filter spectrum (dB) for a range of wheel diameters and loads

6.10 Relationship between rail vibration and effective roughness

The level difference $A_2(f_{to})$ between the vibration displacement at the contact point $L_{x,contact}(f_{to})$ on the rail head and the combined effective roughness $L_r\ (V/f_{to})$, which describes to what extent roughness induces rail vibration, is the result of the wheel rail interaction.

$$A_2 = 20\log_{10}\left(\frac{|a_R|}{|a_R + a_W + a_C|}\right) \quad \text{dB} \qquad (6.7)$$

where a_R : rail receptance, a_W : wheel receptance and a_C: receptance of the contact stiffness. ”Receptance” = the inverse of stiffness.

Frequencies where $|a_R| \gg |a_W + a_C|$ give $A_2 \approx 0$ dB. This often occurs in practice between 100 and 1000 Hz. TWINS shows that the spectrum A_2 in fact does depend slightly on the track properties. Pad stiffness is shown to be the most influential parameter.

Table 6.10 indicates the categorisation of rail pads for the purposes of calculating the vibration relationship and Table 6.11 presents values of A_2 that may be used in equation 4.11.

	Soft pad	Medium pad	Stiff pad
bibloc sleeper	≤ 400 MN/m	400 - 800 MN/m	≥ 800 MN/m
monobloc sleepers	≤ 800 MN/m	≥ 800 MN/m	–
wooden sleepers	all	–	–

Table 6.10. Ranges of pad stiffness applying to different categories of pads used in defining the standard spectra for A_2

Frequency [Hz]	Soft pad	Medium pad	Stiff pad
20			
25			
32			
40			
50	0,84	-5	-5
63	1	-3	-3
80	4,1	2,3	2,3
100	2,7	2,6	2,6
125	0,9	0,8	0,8
160	0,1	0	0
200	0	0	0
250	-0,6	0	0,2
315	-1,2	-2,6	-0,1
400	-1,3	-3,9	-2,8
500	-0,9	-4,8	-6,5
630	-0,9	-3,2	-8,1
800	-1,6	-2,6	-6,9
1000	-2,7	-4,3	-5
1250	-5,6	-6,2	-4,4
1600	-8	-7,5	-6,4
2000	-9,5	-8,8	-8,4
2500	-10	-9,8	-9,5
3150	-11,3	-11,2	-11,1
4000	-13,7	-13,6	-13,6
5000	-14,9	-14,8	-14,8
6300	-16,9	-16,8	-16,9
8000	-18,8	-18,7	-18,8
10000	-20,5	-20,4	-20,6

Table 6.11. Spectra $A_2(f_{to})$ dB for three categories of rail pad stiffness

7 Recommended measurement protocol, application notes and practical guidelines for data acquisition

7.1 Protocol

7.1.1 Introduction

As the measurement effort for source strength can easily become too large, it is important to allow elimination of sources if it can be shown that they are generally not relevant or, if no measurement is done, default values can be assumed.

The procedure consists of the following steps:

a) Determine which noise sources are relevant for the vehicle in question and which operating conditions are required.
b) Determine the partial source contributions, either by measurement or by default values. Measurements are performed in accordance to EN ISO 3095:2005 with exceptions and additions as described below.
c) Determine total emission source strength for partial contributions and in terms of sound power per metre.

Some sources that cannot be measured easily or are difficult to control may need to be measured with a stationary locomotive, especially intermittent sources, such as compressors and valves.

Source contributions are each allocated to one or more characteristic source heights.
The source height is determined either by physical position or by means of special measurements such as microphone arrays or others and then allocated to the nearest default source height in the source method.

Each source type requires a specific measurement as indicated in Table 7.1 and in the following sections. This table can also be used to check which source types are relevant for a particular vehicle.

Key to abbreviations: D=distance from track centreline; H= microphone measurement height relative to rail surface; L=position along track; L1,2=lateral vibration on rail; V1,2=vertical vibration on rail; v= train speed; L_v=vibration velocity level; N_{ax}=number of axles; lveh=vehicle length; D_s= track decay rate; $L_{peq,Tp}$=equivalent sound pressure level over transit time T_p; $L_{Hpr,nl}$=transfer function normalised to axle density; L_r=effective roughness; n=shaft speed; d=duty cycle.

Source type	**Measured quantities**	**Operating condition**	**Microphone position**	**Accelerometer position**	**Track requirement**
Rolling noise	v, L_{peqTp}, L_{veqTp}, D_s, N_{ax}/l_{veh} $L_{r,rail}$ $L_{Hpr\,nl}$ *for track* (using appropriate separation method)	Pass-by at several speeds One or more speeds between 50<v<250km/h Minimum of 3 recommended	D=7.5m, H=1.2m [D=1.75, H=0m]	L1,[L2], V1,[V2],[S1] dependent on method	ISO3095 or TSI compliant
Impact noise	v, N_{ax}/l_{veh} DL_{peqTp}, DL_r (impact/rolling)	Pass-by(s) with and without rail joint	D=7.5m, H=1.2m At joint	N/A	Joint, crossing or points
Traction noise total	$L_{peqTp,traction,idling}$ $L_{peqTp,traction,acceleration}$ $L_{peqTp,traction,const.\ speed}$ $L_{peqTp,traction,deceleration}$	Stationary Acceleration Constant speed Deceleration	D=7.5m, H=1.2m L=0m, 20 m (20m for acc./dec.)	N/A	ISO3095 compliant
Traction noise, drive (optional)	L_{peqTp}, n_{drive} , v	Pass-by, acceleration or stationary	D=7.5m, H=1.2m L=0+20 m	N/A	ISO3095 compliant
Traction noise, fan (optional)	L_{peqTp}, n_{fan}, d_{fan}	Stationary	D=7.5m, H=1.2m L=Box or L=0m	N/A	ISO3095 compliant
Traction noise, other (optional)	L_{peqTp}, d_i	Stationary	D=7.5m, H=1.2m L=Box or L=0m	N/A	ISO3095 compliant
Deceleration noise, braking	L_{peqTp}, v	Deceleration from maximum and service speeds	D=7.5m, H=1.2m L=0m	N/A	ISO3095 compliant
Deceleration noise, squeal	L_{peqTp}, v	Deceleration from 50 km/h 25 km/h	D=7.5m, H=1.2m L=0m	N/A	[ISO3095 compliant]
Curve squeal	L_{peqTp}, v	Curve pass-bys in points (10,20,40km/h) curve (80,120km/h)	D=7.5m, H=1.2m L=0m	N/A	In points and/or curve R<1000m
Aerodynamic noise	L_{peqTp}, v	Pass-by at high speeds	D=25m, H=3.5m Convert 7.5m	N/A	ISO3095 or TSI compliant

Table 7.1. Overview of measured quantities and conditions. EN ISO3095:2005 is applicable unless stated otherwise.

7.1.2 Rolling noise transfer functions

The **track transfer function** $L_{Hpr,nl,tr,i}$ and the **vehicle transfer function** $L_{Hpr,nl,veh,i}$ are determined from pass-by measurements containing only rolling noise. Other sources must not be present, and therefore must be switched off or minimised during the measurement.

Note that in the following all roughness L_r refers to effective (filtered) roughness unless otherwise indicated by index *dir* for direct roughness.

The **total** transfer function $L_{Hpr,nl,i}$ can be determined from the ratio between the pass-by sound pressure level $L_{peq,i}(v)$ at 7.5m distance from the track centreline, 1.2m above the rail surface, and the **total effective roughness** $L_{rtot}(f_i,v)$:

$$L_{Hpr,nl,i} = L_{peq,i}(v) - L_{rtot,i}(v) - 10\lg\frac{N_{ax}}{l_{veh}} \tag{7.1}$$

This can be measured from a single pass-by or averaged over a number of pass-bys, and will contain a contribution from the track and from the vehicle.

Sound pressure measurement is straightforward, total effective roughness is obtained from the equivalent vertical railhead vibration level.

$$L_{rtot,i}(v) = L_{veq,i}(v) + 10\lg\left(\frac{D_{si}}{8.68 N_{ax}/l_{veh}}\right) - A_{2,i} - 20\lg(2\pi f_i) \tag{7.2}$$

The **track** transfer function must be obtained by using the track contribution $L_{peq,tr}$ in formula (7.3). This can potentially be done in different ways:

- by using a low-response reference vehicle;
- by other separation techniques such as MISO and VTN;
- or by using a distribution function calculated for example with TWINS.

This will then result in:

$$L_{Hpr,nl,tr,i} = L_{peq,tr,i}(v) - L_{rtot,i}(v) - 10\lg\frac{N_{ax}}{l_{veh}} \tag{7.3}$$

$$L_{Hpr,nl,veh,i} = L_{peq,veh,i}(v) - L_{rtot,i}(v) - 10\lg\frac{N_{ax}}{l_{veh}} \tag{7.4}$$

For a given network or known test site, the track transfer function might only have to be measured once or occasionally, after which it is well known or even tabulated. It should be independent of the train speed.

If only the total transfer function and the track transfer function are known, the vehicle transfer function may be estimated by using an estimated vehicle contribition $L_{pveh}(f)$ (omitting subscript *eq)*:

$$L_{pveh,i} = 10\lg(10^{Lptoti/10} - 10^{Lptri/10}) \qquad (7.5)$$

$$\text{and if } L_{ptot,i} - L_{ptr,i} < 1: \quad L_{pveh,i} = L_{ptot,i} - 7 \text{ and } L_{ptr,i} = L_{ptot,i} - 1 \qquad (7.6)$$

Now the vehicle and track contributions $L_{peq,veh,i}(v)$ and $L_{peq,tr,i}(v)$ can be calculated for any roughness condition, speed, and axle density (N_{ax}/l_{veh} = axles/unit length):

$$\begin{aligned} L_{peq,tr,i}(v) &= L_{rtot,i}(v) + L_{Hpr,nl,tr,i} + 10\lg\frac{N_{ax}}{l_{veh}} \\ L_{peq,veh,i}(v) &= L_{rtot,i}(v) + L_{Hpr,nl,veh,i} + 10\lg\frac{N_{ax}}{l_{veh}} \end{aligned} \qquad (7.7)$$

If the total effective roughness includes the average network effective rail roughness $L_{rtr,net}$, then a prediction for the noise level under average network conditions is obtained.

7.1.3 Roughness

The total effective roughness for the average network situation $L_{rtot,net}(l)$ is determined as follows:

$$L_{rtot,net}(\lambda) = L_{rveh}(\lambda) \oplus L_{rtr,net}(\lambda) \qquad (7.8)$$

where $\oplus$ indicates energy summation and $L_{rtr,net}(\lambda)$ is the effective rail roughness for the network. The effective wheel roughness $L_{rveh}(\lambda)$ is estimated from:

$$L_{rveh}(\lambda) = 10\lg(10^{Lrtot(\lambda)/10} - 10^{Lrtr(\lambda)/10})$$

$$\text{and if } L_{rtot}(\lambda) - L_{rtr}(\lambda) < 1: \quad L_{rveh} = L_{rtot}(\lambda) - 7 \text{ and } L_{rtr}(\lambda) = L_{rtot}(\lambda) - 1 \qquad (7.9)$$

where $L_{rtr}(\lambda)$ is the rail roughness at the (smooth) measurement site. The effective wheel roughness can also be measured from a pass-by on a smooth track, where it can be demonstrated that the total roughness of the vehicle in question is above the lowest found total roughness from multiple pass-bys of various other vehicles.

The effective rail roughness for the network is chosen as a default spectrum, typical for the country in question. The Netherlands network roughness is provided as a default within the delivered database.

7.1.4 Impact noise

The impact roughness $L_{rimpact}(\lambda)$ can be determined by measuring the pass-by noise from a vehicle with ($L_{peq,Tp,impact}$) and without ($L_{peq,Tp,roll}$) a rail joint. Also the total effective roughness for the pass-by without joint $L_{r,roll}$ must be determined. The normalised impact roughness level $L_{rimpact,nl}$ for 1 joint per 100m can be then obtained from:

$$L_{rimpact,nl} = L_{r,roll} + L_{peq,Tp,impact} - L_{peq,Tp,roll} - 10 \lg (N_{ax}/l) - 20 \qquad (7.10)$$

where N_{ax} is the total number of axles measured in the pass-by and l is the total length of the train.

Different characteristic impact roughness may be found for track joints, points and crossings, as the geometry and impact amplitude may differ.

The track noise L_{ptr} is allocated to h=0m, the vehicle rolling L_{pveh} noise to h=0.5m.

7.1.5 Bridge noise

For bridges, the track transfer function must be determined by measurement in the same way as is done for a track.

7.1.6 Traction noise

Traction noise can be measured for each operating condition including idling, acceleration from standstill, constant speed and if relevant, deceleration. This will result in the spectral quantities

- L_{peqTp},traction, idling
- L_{peqTp},traction, acceleration
- L_{peqTp},traction, const. speed
- L_{peqTp},traction, deceleration.

The tests for all these conditions are performed according to EN ISO 3095:2005, with the following exceptions:

- For the acceleration test, $L_{peq,Tp}$ is determined for both microphones at 0m and 20m from the start position, and the energy average of both is taken as the result.
- The same is done for the deceleration test, which is only relevant for traction noise if the traction noise is significant (e.g. regenerative braking, diesel at lower rpm).
- For both acceleration and deceleration tests, locomotives are loaded with a load at least 5 times their own weight.

- For the stationary test, for vehicles with multiple microphone positions, positions with low noise levels can be left out, for example for fixed trainsets. This can be compensated in the calculated measurement results as follows:

$$L_{pAeq} = 10\ lg\ (\sum_i 10^{L_{pi}/10} . \ell_i / \ell_{total}) \qquad (7.11)$$

where L_{pi} is the measured sound pressure level for each measurement surface around the vehicle, l_i is the length of the i-th measurement surface along the train and l_{total} is the total length of the measurement surface around the train at 7.5m distance.

As an alternative to the stationary test it is also possible to perform a dead-slow measurement at 2-6 km/h with two microphones either side of the vehicle, with all equipment in normal operation. The energy average of the two positions is taken.

If it is difficult to perform running measurements or to derive or separate out the traction noise, it may be simpler to take only stationary measurements, for which the traction noise is dominant. However, in that case, the equipment operating conditions have to be simulated, for example by running a diesel engine or a fan at higher speeds during standstill. Procedures to do this are given in the following:

For noise from the powertrain, $\mathbf{L_{pdrive,nmax,i}}$ has to be determined for a maximum drive rpm $\mathbf{n_{drive,max}}$ (or the nearest feasible rpm) and the factor $\mathbf{C_{drive}}$ has to be determined from 2 or more operating points.

For fan noise $\mathbf{L_{pfan,nmax}}$ has to be determined for a maximum drive rpm $\mathbf{n_{fan,max}}$ (or the nearest feasible rpm) and the factor $\mathbf{C_{fan}}$ has to be determined from 2 or more operating points (similar to traction noise).

This data can be determined either from standstill, acceleration or pass-by tests.

For standstill testing, for example on diesel-powered vehicles, measurements are performed for drive rpms at idling, 25%, 50%, 75% and 100% of the rpm range, or as far as practicably allowable.

For acceleration tests, measurements are collected at several microphone positions along the track, at 0 and 20m from the front of the train. Optionally, 10m and 30m can be added if significant differences are expected. Fan and drive speeds are determined together with corresponding sound powers, if possible also at maximum driveshaft speed for diesels or maximum fan speed for electrically powered vehicles.

If a constant speed test is used, the driveshaft speed or fan speed needs to be determined, as appropriate. The vehicle should be operated with a characteristic load and for several speeds up to the speed range where traction noise no longer dominates.

For any other traction or auxiliary sources j with non-continuous or intermittent operation the characteristic duration $\mathbf{d_j}$ and fixed level $\mathbf{L_{pj,i}}$ need to be measured. This will often be possible with a stationary test during which such sources are active.

If specific characteristic operating points of the relevant sources are known, these may be used.

7.1.7 Deceleration noise

For braking noise with speed dependency, at least two measurements at different speeds are required whilst braking; one at reference speed v_0 to determine $L_{pbrake,i}(v_0)$ and another to determine the speed dependency factor $C_{brake.}$

For brake squeal, the squeal noise level $L_{psqueal,i}$ and its duration correction d_{squeal} for the relevant period need to be measured, as well as the speeds at which brake squeal occurs.

7.1.8 Curve squeal

As with aerodynamic noise, curve squeal only needs to be characterised if it actually occurs at all and is only required for certain situations.

Curve squeal noise is measured in a) a set of points and b) in a curve with a radius of between 500-1000m. A microphone is placed at 7.5m either side of the curve, at its sharpest point. The rail surface must be dry. There are no requirements for the rail roughness, although there should be no severe wear or rail corrugation.

The pass-by level $L_{peq,Tp,i}$ is measured. 5 pass-bys are taken for each speed. 2-3 characteristic speeds are taken: 10, 20, 40 km/h for points, 80, 120 km/h for a curve. Only pass-bys with audible squeal are included. If possible, the 5 pass-bys should be made going back and forth (3 in one direction, 2 in the other). The results for each speed are arithmetically averaged. The results from each microphone are energy averaged. As curve squeal will not occur all of the time, 50% probability is assumed, so the measured average value is reduced by 3 dB.

Measurements taken in points may contain a significant contribution of impact noise. The squeal noise should be separated out by taking the tonal components in the spectrum.

The measurements result in $L_{psqueal,i}$ for points and for a curve of given radius. The levels can be converted approximately for speed and curve radius using equation (4.21).

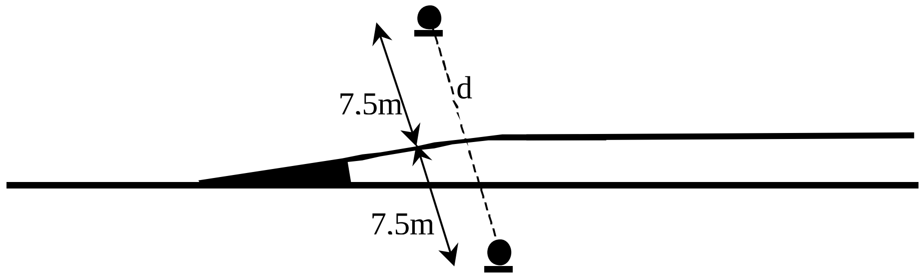


Figure 7.1. Microphone positions for measurement of curve squeal in points

7.1.9 Aerodynamic noise

Aerodynamic noise can only be measured at high speeds and therefore it should first be verified whether it is actually relevant for prediction purposes. Once the rolling noise is properly characterised, 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.

It is measured from 250 km/h in steps of 50 km/h upwards. For practical reasons the measurement position often has to be 25m, so the sound pressure is converted back to 7.5m. Special measurements are required to determine source height.

$L_{paero,i}(h)$ is determined from a curve fit in each third octave band for all measured speeds, resulting in:

$$L_{paero,i}(h,v) = L_{paero,i}(h,v_0) + \alpha_i(h)\lg (v/v_0) \qquad (7.12)$$

where v_0 is a speed at which aerodynamic noise is dominant and $\alpha_i(h)$ is a coefficient determined from 2 or more measurement points.

7.1.10 Examples

In the following tables, some examples are given of the source types and distribution which may typically be found on different types of rolling stock. If no measurement data is available, the default source data can be used. The sound power per unit length for each source height is determined by energy summation of each source type as in formula (4.2), at the relevant conditions.

At 0m there is always only the rolling noise contribution from the track. At 0.5m nearly all sources may occur. The source heights 2, 3, 4m are mainly relevant for traction and aerodynamic noise sources.

	0m	0,5m	2m	3m	4M	Remarks
Rolling / Joint noise	X	X				
Traction Noise		(X)	(X)	(X)	(X)	If auxiliary equipment is relevant
Curve Squeal		X				Only in curves or points
Braking Squeal		X				Only for deceleration
Braking Noise		X				Only for deceleration
Aerodynamic Noise		(X)				At speeds above 250 km/h

Table 7.2. Example unpowered passenger coaches

	0m	0,5m	2m	3m	4M	Remarks
Rolling / Joint noise	X	X				
Traction Noise		(X)	(X)	(X)	(X)	If auxiliary equipment is relevant
Curve Squeal		X				Only in curves or points
Braking Squeal		X				Only for deceleration
Braking Noise		X				Only for deceleration
Aerodynamic Noise						N/a for freight wagons

Table 7.3. Example freight wagons

	0m	0,5m	2m	3m	4M	Remarks
Rolling / Joint noise	X	X				
Traction Noise		X	X	X		
Curve Squeal		X				Only in curves or points
Braking Squeal		X				Only for deceleration
Braking Noise		X				Only for deceleration
Aerodynamic Noise		X	X	X	X	At speeds above 250 km/h

Table 7.4. Example high speed train

	0m	0,5m	2m	3m	4M	Remarks
Rolling / Joint noise	X	X				
Traction Noise		X	X	X	X	
Curve Squeal		X				Only in curves or points
Braking Squeal		X				Only for deceleration
Braking Noise		X				Only for deceleration
Aerodynamic Noise						

Table 7.5. Example electric locomotive

	0m	0,5m	2m	3m	4M	Remarks
Rolling / Joint noise	X	X				
Traction Noise		X	X	X	X	
Curve Squeal		X				Only in curves or points
Braking Squeal		X				Only for deceleration
Braking Noise		X				Only for deceleration
Aerodynamic Noise						

Table 7.6. Example EMU

	0m	0,5m	2m	3m	4M	Remarks
Rolling / Joint noise	X	X				
Traction Noise		X			X	
Curve Squeal		X				Only in curves or points
Braking Squeal		X				Only for deceleration
Braking Noise		X				Only for deceleration
Aerodynamic Noise						

Table 7.7. Example DMU

7.2 Application notes

7.2.1 Linking up to existing national calculation schemes

The calculation method should allow the setting up of source models for national rolling stock by setting the various model parameters in such a way so as to obtain the same emission levels.

This requires a matching of available information on national rolling stock to physical parameters in the IMAGINE method, for example, by setting the wheel roughness, average network roughness or transfer functions to a level that produces the corresponding noise level. The same can be done for the other sources.

In some cases, it may be required to construct a source model of an equivalent vehicle, which represents a train type consisting of a locomotive and passenger coaches together. A similar exercise could be done for mixed freight trains.

7.2.2 National average rail roughness of the network

One of the quantities required for calculating noise levels on an ‘average track’, is the national average rail roughness level for the network. This is applied in the Dutch prediction method and is required in any method that takes rail roughness into account. In the Dutch case, average rail roughness was determined by taking a series of rail roughness measurements at about 30 different sites, and simply averaging these. This method could still be applicable if a rail roughness measurement device is available. An alternative method is to use a monitoring vehicle with smooth wheels (disc braked, no flats), measuring sound pressure due to rolling noise in the vehicle and calibrating the on-board sound pressure level at a site with the known total effective roughness level at the same site. Then the network can be monitored over a number of representative routes at constant speed. The differences found in the sound pressure levels are directly related to the differences in total roughness. Once the ratio between total effective roughness and interior sound pressure level is established, an average total effective roughness can be determined from an averaged sound pressure level. This estimate is less accurate than direct measurements of rail roughness, but a much better average is obtained over the network. The estimate becomes better, the smoother the wheels are.

7.2.3 Characteristic or average operating conditions

When determining the source spectra for the various noise sources, traction noise requires special attention, as it needs to represent the average operating conditions. For example, the typical diesel rpm of a locomotive under acceleration conditions may be rather specific.

7.2.4 Intermittent sources

Intermittent or non-continuous sources need to be assessed in terms of duty cycle factor. Typically this requires information on the average operation time during acceleration, braking and constant speed. It should be noted that over a long enough period, intermittent sources may reduce significantly compared to other continuous sources.

7.2.5 Lack of measurement data

Sometimes rolling stock may not be available for source measurements as previously described. It may be possible to estimate source emission data with reduced effort. This does, however, require careful assessment of the individual physical sources, for example, by checking whether they are masked out by certain other sources or not.

7.2.6 Availability of a low response reference vehicle

A reference vehicle to determine the track transfer function may not always be available. There are other options to deal with this such as the use of calculations (e.g. TWINS) or special measurement tools (e.g. VTN). On the other hand, such a measurement is not often required, certainly not each time a measurement is performed on the same track.

7.2.7 Availability of rail roughness measurement

Another issue of availability may concern rail roughness measurement. This may be impossible due to lack of equipment, site access or cost. An alternative way of dealing with this is to measure the sound pressure level at 7.5m distance from the track centreline during a pass-by of unpowered passenger coaches at 80 km/h. If the level is below 77 dB(A), then the track may be assumed smooth enough. This is probably only possible with disc-braked coaches. Powered trainsets with low traction noise may also achieve such low levels.

7.2.8 Special track-vehicle combinations

Uncommon track designs and vehicles with bogie or wheel shrouds require special attention. If a track-vehicle combination is unique, it is advisable to measure a total transfer function to characterise the rolling noise. The combination of track and vehicle noise shielding may complicate the separation of vehicle and track noise contributions.

On normal tracks, vehicles with bogie or wheel shrouds may also reduce the radiation from the track.

This should be taken into account by comparing the total transfer function for unshrouded and for shrouded vehicles and using the difference as a correction in the emission calculation.

7.2.9 Use of 'microphone only' data

In some cases measured railway noise data may only be available in the form of sound pressure level spectra, without information on roughness or rail vibration. Although less accurate, it may sometimes be possible to derive the source data from such measurements.

The IMAGINE source method in its current state requires source information for operating conditions, physical sources, vehicle types and speeds, source heights and frequencies (spectrum).

The measured quantity is the $L_{peq,Tp}$. Each of the mentioned aspects can be dealt with as follows:

- Source height: This has to be estimated based on knowledge of the sources present and their physical location, i.e. rolling noise has sources at the wheels and the track, traction noise at axle height and fan height etc. If a source is between the fixed heights, the sound power can be distributed between them.
- Vehicle type: Source levels will be most accurate if noise sources are attributed to one vehicle type per measurement. If the sound pressure is measured for a whole train with different wagons or wagons/locomotive, it will be difficult to separate out physical sources afterwards.
- Operating conditions: This should generally be clear for vehicles and whole trains.
- Physical sources: For rolling noise, an estimate is needed for the roughness and the transfer functions. This is discussed in section 2. For other sources, such as traction noise, aerodynamic noise, curve squeal and braking noise, these must be measured under conditions in which they are dominant.

If a whole train consisting of different vehicle types is characterised within one measurement, then it may contain different sources on different vehicles, e.g. locomotive (traction and rolling noise) versus coaches (rolling noise). This may be acceptable if a train configuration is fixed, however, such configurations can be variable.

7.2.10 Estimating roughness and transfer functions from 'microphone only' data

In order to estimate roughness and transfer functions, it is important to have a track or vehicle for which the data is known. It is also easier to deal with total roughness and transfer functions than the partial ones of vehicle and track.

Firstly, rolling noise must be dominant, which for unpowered coaches and wagons on a straight continuously welded track, will often be the case. Any given vehicle-track combination has a constant total transfer function $L_{Hpr,nl,i}$, so differences in noise level at different locations at the same speed and on the same track type can only be due to a change in total effective wheel-rail roughness $L_{r,tot,i}(v)$:

$$L_{p,i} = L_{r,tot,i}(v) + L_{Hpr,nl,i} + 10 \lg (N_{ax}/l_{veh}) \qquad (7.13)$$

The total transfer function can be measured at a single location using a microphone and an accelerometer under the rail. Alternatively it can be calculated using programs such as TWINS or approximated from a set of default data.

Once the transfer function of a given track-vehicle combination (and hence the total effective roughness at that site) is known, it can be used to determine total effective roughness from any other pass-by measurement of the same vehicle at another location on the same track type:

$$L_{rtot,i}(v) = L_p - L_{Hpr,nl,i} - 10 \lg (N_{ax}/l_{veh}) \qquad (7.14)$$

With this approach it is now possible to compare total effective roughness levels from pass-bys at different locations. If significant differences are found, then an estimate of the effective wheel roughness $L_{r,wheel}$ can be made, as it will be no higher than the lowest found total roughness at several locations k:

$$L_{r,wheel} <= \min (L_{r,tot,k}) \qquad (7.15)$$

Once a total transfer function is known, it needs to be split into a track and vehicle transfer function. There are various ways of doing this. One is by using a default distribution function as presented in Table 7.8.

f_{centre} [Hz]	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
D_{wheel} [dB]	-1,0	-1,5	-2,0	-3,5	-5,0	-6,5	-7,0	-7,0	-7,0	-7,0	-6,5	-5,0	-3,5	-2,0	-1,5	-1,0
D_{track} [dB]	-6,9	-5,3	-4,3	-2,6	-1,7	-1,1	-1,0	-1,0	-1,0	-1,0	-1,1	-1,7	-2,6	-4,3	-5,3	-6,9

Table 7.8. Distribution functions to estimate track and vehicle transfer functions from total transfer function. For all frequencies below 63 Hz or above 2000 Hz the values at 63 Hz apply (Dwheel = -1, Dtrack =-6, 9).

With the above distribution functions, the track transfer function is:

$$L_{Hpr,nl,\,tr} = L_{Hpr,nl,tot} + D_{track} \qquad (7.16)$$

and the vehicle transfer function is:

$$L_{Hpr,nl,\,veh} = L_{Hpr,nl,tot} + D_{wheel} \qquad (7.17)$$

Another method is to measure the total transfer function at one location for vehicles with different wheels. Here, the track contribution stays constant, but differences are seen in the vehicle contribution.

7.3 Practical guidelines for data acquisition

7.3.1 Vehicle and track description

It is important that a full description of vehicle and track is recorded when carrying out measurements of data for inclusion in the database. The convention that must be applied is shown in Tables 7.9 and 7.10. Eight digit descriptors are required as a minimum, but it is also possible to append a further digit (eg P41pulnn_1) where it is necessary to discriminate between vehicle types within a group.

Digit:	1	2	3	4	5	6	7	8
descriptor	train type	number of axles per vehicle	length of vehicle	vehicle type	load	wheel diameter	brake type	Wheel measure
how it is encoded	type of the train	the actual number of axles	the class of length between the buffers	a letter that describes the type	freight vehicle load	the class of diameter	a letter that describes the brake type	a letter that describes the measure type
codes allowed	**O** Other (i.e. maintenance vehicles...)	**u** unknown	**u** unknown	**u** unknown	**u** unknown	**u** unknown	**u** unknown	n no measure
	H High speed passenger	1	**l** long, >20m	M Self-motored passenger coaches	**l** loaded freight	l large, >800 mm	**c** cast-iron	d dampers
	P conventional Passenger	2	**m** medium, 12 to 20 m	P pulled passenger coaches	**n** not loaded freight	m medium, 500 to 800 mm	**k** k-block	s screens
	F Freight	3	**s** short <12 m	**d** diesel loco		s small < 500 mm	n non tread braked, like disc, drum, magnetic	O other

Digit:	1	2	3	4	5	6	7	8
descriptor	train type	number of axles per vehicle	length of vehicle	vehicle type	load	wheel diameter	brake type	Wheel measure
	L Loco	4		**e** electric loco				
		et cetera		E, F, G, H, I, K, L, O, R, S, T, U, Z UIC-designation for freight vehicles				

Table 7.9 Vehicle description convention

digit:	1	2	3	4	5	6	7	8	9	10	11	12
descriptor	Track type	Track base	Sleeper type	Rail Fastener	Track dynamic characte-ristics	Rail type	Sleeper spacing	Additional measures	Rough-ness condition	Rail joints	Railpad type	Curvat-ure
how it is encoded	Applica tion speed related	Type of track base	Sleeper type indicator	Fastener abbreviati on	Decay rates	kg/m	Distance in cm	A letter describing acoustic device	Indicator for rough-ness	Presence of joints and spacing	Presents an indication of the stiffness	
codes allowed	H High speed (>200 km/h)	B Ballast	W Wood	S Springclip				D Rail damper	E Well maintain ed and very smooth	N None	S Soft	
	M Med-ium speeds	S Slab track	M Concrete mono-block	D Delta plate				B Low barrier	M Normally Maint-ained	S Single switch	M Medium	
	L Only low speeds	C Concrete bridge	B Concrete bi-block	B Bolted plate				**O** Other	N Not well maint-ained	D Two switches per 100m	H Hard	

digit:	1	2	3	4	5	6	7	8	9	10	11	12
descriptor	Track type	Track base	Sleeper type	Rail Fastener	Track dynamic characte-ristics	Rail type	Sleeper spacing	Additional measures	Rough-ness condition	Rail joints	Railpad type	Curvat-ure
	below 100 km/h											
		E Steel bridge	Z Steel zigzag	O Other					B Not maintain-ed and bad condition	M More than two switches per 100m		
		O Other	S Steel									

Table 7.10. Track description convention

7.3.2 Data acquisition

A full description of the recommended methodology for acquiring appropriate data is provided in IMAGINE report “IMAGINE – practical measurement guidelines & analysis” [8]. The essential elements of this process are presented in the following sections.

7.3.3 Track & vehicle transfer function for rolling noise

Several methods for separation of vehicle and track contribution have been developed in the STAIRRS project (VTN, MISO, PBA). The VTN and MISO tools separate L_p into $L_{p,veh}$ and $L_{p,tr}$ at a 7.5 m distance.

In order to provide input data to these processes, ideally, two **L**ateral and two **V**ertical accelerometers are needed (**L1, V1, L2, V2**): the two lateral ones are placed on one side of the railhead and the vertical ones under the rail foot, all at midspan (midway between two sleepers, see Figure 7.2). One more vertical accelerometer **S1** is placed on the sleeper close to the rail fastener.

Slab track: if there is not enough space to fit V1 and V2 under the rail foot, it is acceptable to fix these accelerometers on top of the rail foot, as close as possible to the centre. S1 should be placed between the fasteners, at about 1/3 of the slab length and 1/3 of the slab width.

Microphones positions (distance from centre of track / height above railhead):
M1: 7.5m/1.2m
M2: 1.75m/0.0m

One **T**rigger or treadle (**T1**): 2 sleeper spacings away from the cross section, upstream (the blue line in Figure 7.2).

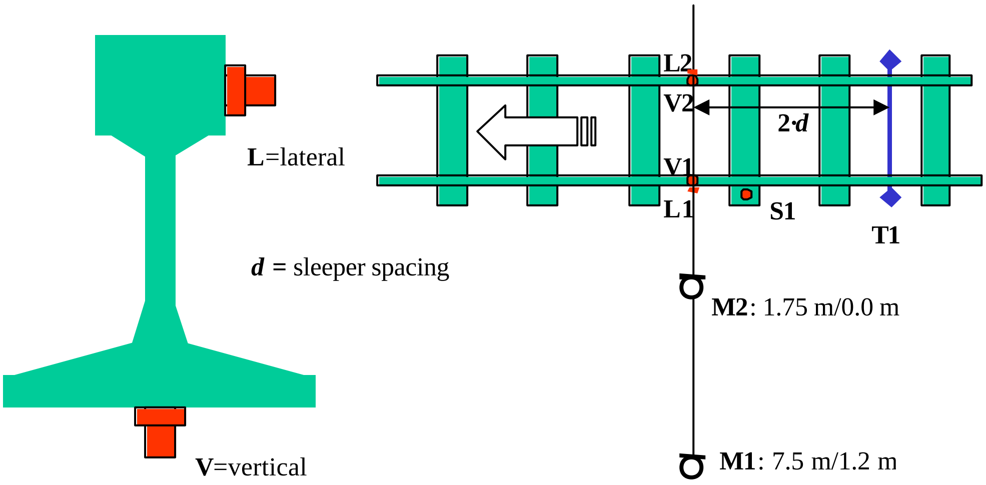


Figure 7.2. Instrumentation placement for complete pass-by data acquisition

7.3.4 Signal specifications

- Noise and vibration signal bandwidth: 10 Hz – at least 7.5 kHz, but preferably 10 kHz.
- Minimal Effective dynamic range: 40 dB
- Trigger signal: TTL-like pulse at each wheel passby at the same bandwidth as above.
- Noise, vibration and trigger signal must be of equal length, recorded simultaneously and synchronously on the same analyser. Signal length, however, may vary between pass-bys. Full train pass-by must be taken, leaving a few seconds of background noise before and after the pass-by.

7.3.5 Data file formats for rolling noise

- Raw signals are preferably stored as MATLAB files, or otherwise, ASCII-files.
- For each train pass-by, 8 files must be delivered to provide a complete data set:
  - 2 sound pressure signals with reference [1 Pa]
  - 5 acceleration signals with reference [1 m/s^2]
  - 1 trigger signal with its maximum aligned to unity.

If Matlab “mat” files are used they should be of the form:

Name	Size	Bytes	Class	
comment	1x102	204	char array	(optional) channel description; length may vary
Data	690000x1	5520000	double array	signal itself; length may vary; for units see above
Dt	1x1	8	double array	sample period [s]

If ASCII-files are used:

- The first line is a header, its first 7 digits are reserved for the sample period in seconds, ending with a tab.
- The rest of first line may be text (e.g., channel description).
- Data are written in one single column.

File names:
A file must be named using the following:

- file names are in 8 digits + extension;
- digit 1 and 2 are channel descriptor (M1, M2, T1, S1, L1, V1, L2 or V2);
- digit 3 is underscore;
- digit 4, 5, 6 is pass-by reference number (preceded by enough zeros as in example below);
- free digit 7 and 8 may contain additional information.

Example: `M1_008.mat` (or, if it’s an ASCII file, `M1_008.txt`)

7.3.6 Tools for separation of vehicle and track components of rolling noise

The STAIRRS project has yielded three tools that are used for characterisation and / or separation.

1. *TNO* developed the PassByAnalysis (PBA) tool that includes the InDirect Roughness (IDR) method and Transfer function calculation. These are characterisation tools (and in special cases these can perform separation).
2. *SNCF* developed the Multiple In Single Out (MISO) tool for separation.
3. *AEAT/DeltaRail* developed the Vibro-Acoustic Track noise (VTN) tool for separation.

In order to add data to the database, initial analysis with PBA is required, while either MISO or VTN are normally required for subsequent separation of the vehicle and track contributions to rolling noise. This means that the user is **free to choose** between VTN and MISO for separation. However, the STAIRRS measurement protocol suggests **all signals be measured**, **using a highpass filter** on M2, L1, V1, V2, L2, S1. For train speeds below 200 km/h, the cut-off frequency should be 80 Hz. For speeds above 200 km/h, this should be 150 Hz.

The following is a list of the signals that are required, per tool:

Tool	Developer	M1	M2	L1	L2	V1	V2	T1	S1	highpass filter (M2, L1, V1)
PBA	TNO	++	-	++	+	++	+	+	-	O
MISO	SNCF	++	++	++	+	++	+	++	+	++
VTN	AEAT	++	O	++	+	++	+	+	+	O

++ = required o = optional

+ = recommended - = not used

Reference can be made to the IMAGINE measurement guideline report [8] for details of how to apply PBA (including IDR), MISO or VTN. Alternatively, the organisations that developed them, namely TNO, SNCF and DeltaRail respectively, may be contacted directly for advice and assistance.

7.3.7 Measurement guidelines for traction noise

The measurement methods for traction noise should be performed either as loaded pass-by, acceleration, deceleration or stationary sound pressure measurements. The protocols of EN ISO 3095:2005 can be used for this but need to be supplemented with specific aspects. These are:

- better definition of duty cycles for acceleration, deceleration/braking and standstill
- sound power measurement of individual sources
- directivity measurement
- determining source heights and sound power allocation to multiple positions
- conversion from pass-by sound pressure levels to sound power levels

Individual sources are characterised by measuring them during operation only. Source heights are identified either by the physical position of the source and/or by additional measurements.

The following duty cycles and corresponding measurement procedures are proposed.

It may be possible to suffice with a stationary measurement to characterise traction noise, but only if the true operating conditions can be well simulated. This means that, at the very least, the engine rpm must be similar to real conditions; but even then, possible load effects and additional sources such as turbochargers may be missed. In general, the pass-by at constant speed may not always be the best method as the load condition is not necessarily stable: the rpm and instantaneous power level tend to vary during a normal pass-by, so this must be controlled.

The acceleration test is probably best for generating realistic operating conditions, but tend to display spread in results, which should be assessed.

For idling levels, the proposed duty cycle is at least 20 seconds and sufficiently long to include various relevant sources such as compressors, blow off valves and individual fans. The duty cycle should be representative for normal conditions of standstill at a station, shunting yard or anywhere along a track. The measurement commences directly after arrival to standstill (a locomotive must arrive with a hauled train). Standard 7.5 metre microphone positions are used, with the exception of positions in front and behind the vehicle. Microphones close to the sources are optional and measurements on only one side are permitted unless there is significant difference between source locations and strength either side of the vehicle. The following is determined:

- the duration of a characteristic standstill duty cycle
- the sound power, and if applicable rpm, of the drive at idling
- for diesel powered vehicles, if possible the sound power at rpm at 25%, 50%, 75% and 100% of the rpm range (to be used for constant speed and acceleration emission)
- the sound power, actual rpm (and if possible maximum rpm) and operation duration of the cooling fans
- the sound power and operation duration of all other relevant sources such as compressor and blow off valves
- heights of each source. Possible sources include air vents through which engine block noise is emitted, exhaust and intake positions, gear transmission and fan positions.

For acceleration, the duration of the acceleration duty cycle is from standstill up to 30 km/h, or the speed at which traction noise is dominated by rolling noise. This condition is relevant for areas near stations, shunting yards, tracks with a gradient and along tracks where trains frequently stop. Several microphone positions are required along the track, all at 7.5m from the track centre line and 1.2m above the rail surface. These are placed at the following positions either simultaneously or in successive measurements with displaced microphones:

- next to the front of the powered vehicle
- at 10 metres and 20 metres along the track, and additionally at more positions if required. This is the case if the rpm of the drive system or fans change significantly with increasing distance.

The $L_{peq,tp}$ is measured at each position to minimize frequency variation (tp is the transit time from buffer to buffer). For long vehicles and multiple units with distributed traction, $L_{peq,tp}$ is also registered for the duration of the audible passing of traction bogies or components.

The following is determined:

- the sound power and drive rpm at maximum rpm
- the sound power and fan rpm at maximum rpm, and fan duration, if it is not continuous
- heights of each source. Possible source heights include air vents through which engine block noise is emitted, exhaust and intake positions, gear transmission and fan positions.
- Maximum drive and fan rpms are determined and the corresponding sound powers, if possible.

The sound power spectra are derived as a function of drive rpm and fan rpm by interpolation of measured data for each frequency band.

Source heights may need to be set at air vents through which engine block noise is emitted, such as exhaust and intake positions, gear transmission and fan positions, if they are relevant sources.

If the above methods are not possible, it is allowable to base the sound power emission data on stationary measurements at different characteristic rpms.

The duty cycle for deceleration includes braking at any speed, and the deceleration from a given speed to standstill. Two measurements are required; one braking at speed, and one braking from 30 km/h down to standstill.

a) For braking at speed, two or more microphones are placed at sufficient distance along the track to measure braking noise at speed with at least 20% difference. The higher speed should be at least 80 km/h.
b) For braking to standstill, two or more microphones are placed, with one at the rear of the vehicle at standstill, and one at 10 and 20 metras.

In both cases the $L_{peq,tp}$ is measured at 7.5m from the track centre line and 1.2m above the rail surface. The sound power spectra are derived as a function of train speed. This results in L_{Wbrake}(f, v) , $L_{Wsqueal}$(f), d_{fan}, L_{Wi}(f,) and d_i for each other source. Deceleration noise is often dominated by braking noise, i.e. not noise from the drive or cooling systems.

Traction noise at constant speed is best derived from acceleration conditions for which a significant and defined load is present. Once the traction noise emission is known as a function of drive and fan rpms, a characteristic operating condition for the traction system can be defined based on several (loaded) pass bys at different constant speeds below 60 km/h. 2-3 pass bys at different speeds are required, from which the operating condition (fan and drive rpm) can be correlated to train speed.

An average load condition and/or engine rpm (for diesels) must be derived, characteristic of average operation at the mentioned speeds.

The sound pressure level is then derived as a function of load and/or engine rpm. The sound power can be derived from this.

The source heights can be identified by:

- specifying the physical location of the component or surface concerned
- comparing spectra from close measurements at each supposed source to the spectrum at larger distances, e.g. 7.5 m
- microphone array techniques
- simplified microphone array techniques.

Whatever technique is used, the total sound power for a given source from all source heights must be the energy sum of the individual source contributions.

Besides the basic set of measurements described above, additional measurements can be performed to reduce measurement uncertainty due to the number of samples, temperature, speed variation, timing or other effects. Averaging these additional measurements should reduce the measurement uncertainty.

7.3.8 Measurement guidelines for aerodynamic noise

The purpose of this section is to propose a practical measurement method to acquire aerodynamic noise data for the database. Two datasets are required. The first is for the source in the bogie area at a height of 0.5m above the railhead. The second is for the source in the pantograph + recess of the pantograph + roof equipment area at a height of 4m above the railhead.

The wheel roughness characteristics of the train being measured should be known, as should the track roughness (either measured or estimated).

Trains to be measured should pass the measurement location at the highest possible speeds and also be able to be controlled to run at lower speeds. A site with a noise barrier should also be chosen in the same area (with topography as close as possible to the open site without barrier).

The microphone position for all the following measurements is 25m from the track and 3.5m high.

The first step is to determine the change of the total noise with speed and then estimate:

- The transition speed between dominance of rolling noise and dominance of aerodynamic noise
- The speed exponent of the aerodynamic noise

The recommended speed range for this is 200km/h to 350 km/h with a minimum of seven different speeds (example: 200, 220, 250, 280, 300, 320, 350). Due to the difficulty in covering a sufficient range of speeds, the estimation of the speed exponent should be done cautiously and in a statistically valid manner.

The second step is to extract rolling noise. The estimation of the rolling noise part will be done from the previous measurements by analysing the results for the speeds range for which the rolling noise dominates.

The combined effective roughness (wheel and track) should be known (measured or estimated) and can be transformed into a frequency-dependent roughness for a given speed. This enables the transfer function between the roughness and rolling noise to be determined.

The rolling noise can then be extracted from the total noise measured at a high speed (V_{aero}) to determine the aerodynamic noise part. This element is the total aerodynamic noise (bogie source at 0.5m and higher sources at 4m) at V_{aero}.

The third step is to separate aerodynamic noise from the bogie area, from aerodynamic noise at the upper part of the vehicle. The same principle as described in the previous paragraphs is followed with measurements carried out behind a noise barrier for the same speed range. For this situation, the measurement $Lp_{Vaero,2\,mbarrier}$ contains mainly the higher aerodynamic sources (roof, pantograph). The bogie element can therefore be calculated by extracting the aerodynamic component for the pantograph, in energy terms, from the total aerodynamic element. The Measurement Guidelines report [8] provides more detail of this approach.

During the data acquisition campaign of IMAGINE, AEAT/DeltaRail UK used this protocol as the basis of aerodynamic noise measurements on Eurostar trains on the high speed UK Channel Tunnel Rail Link. Their findings and results are presented in Reference [9].

8 Database user instructions – data input and extraction

8.1 Introduction to the database

The database has been designed to accommodate a range of data types, stored in terms of levels in one-third octave bands of frequency or wavelength. Measured data is logged on a standard input form that also acts as a prompt for all the required data and metadata during a measurement exercise. A similar system is employed to log default data. Provided the data is tabulated using the standard input form, it can be automatically imported to the database using a dedicated software routine. Data is exported from the database, in order to create the rail traffic model that interfaces with the IMAGINE propagation method, using an export function that is incorporated within the supplied database management tool.

The database currently operates on an Access2000 (SR-1) platform, but it is amenable to upgrading to alternative database formats, such as SQL-server or Web-access formats.

The files and documents indicated in Table 8.1 comprise the full suite that is required in order to operate the system.

	File or document	Version	Filename
1	The IMAGINE rail source database, Access 2000 version	2.17	IMAGINEdB_rail_v2.xxx.mdb
2	Full definition of the database in Microsoft Visio and Adobe Acrobat (.pdf)	2.17	IMAGINEdB_rail_v2.xxx.vsd IMAGINEdB_rail_v2.xxx.pdf
3	IMAGINE input datasheet for measurements (Excel workbook)	3.5	IMAGINE_inputform_v3.5.xls
4	IMAGINE input datasheet guidance	3.1	IMA6TR-050905-AEATNL03_inputsheetGuidance.pdf
5	IMAGINE input datasheet for default values (Excel workbook)	1.11	IMAGINE_default_inputsheet_v1.11.xls
6	IMAGINE rail source database Administration tool, Access 2000 front end application*	2.31	IMAGINE_importData_v2_31.mde

Table 8.1. Overview of files and documents in the IMAGINE rail noise source database suite

8.2 The input sheet

8.2.1 General description

Data is input using the Excel routine “IMAGINE_inputform_v3.3.xls”.

Every Excel workbook of the IMAGINE input form v3.3.xls can hold data for one track location, with several train pass-bys or train data sets. If, however, measurements are carried out at the same location, but on a different track, then a new workbook must be started.

The purpose of the IMAGINE data input sheet is to collect data from measurement exercises in a uniform, understandable and consistent way for input to the database. Data formats other than this data input sheet are not readily amenable to inclusion within the database.

For some fields (e.g. vehicle descriptor table) a pop-up help text is available:

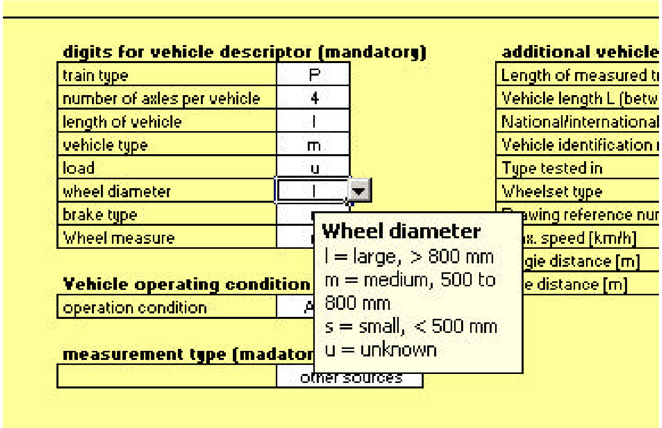


Figure 8.1 Example of pop-up help text for vehicle descriptor digits.

This sheet contains general information about the origin of the data and the organisation/person who acquired it. Please fill in this sheet as comprehensively as possible. The final Excel data workbook should comply with the following specification:

Excel File Name:
CC_<organisation shortname>_<campaign ID>_IMD_vN.xls,
where CC is the country code (see list in Annex I), campaign ID is a unique number for each measurement campaign per company/organisation and N is the number of the version sent out by the organisation. IMD means “IMAGINE Data”. The Excel version is Microsoft® Excel 2002.

All additional files and documents referred to in the Excel questionnaire need to be included in a compressed ZIP or SIT file, which should comply with the following specification:

File Name:
CC_<organisation shortname>_<campaign ID>_IMD_vN.zip or CC_<organisation shortname>_<campaign ID>_IMD_vN.sit
where CC is the country code (see list in the annex) and N is the number of the version sent out by the organisation. The version number is similar to the version number of the Excel file.

8.2.2 Track data and settings sheet

The header of this sheet contains all site and track info data (voluntary), and the mandatory track descriptor. The exact definition of the track descriptor can be found in 7.3.1.

The track descriptor is automatically calculated from the table *digits for track descriptor* (mandatory). The tables *site info* and *track info* contain additional information. Please fill in these tables as comprehensively as possible.

The measurement protocol for rail roughness measurements (direct and indirect) can be found in [8], § 3.

If direct roughness measurements are carried out, the data can be inserted into the field < Lr Rail roughness [re 1E-6 m]>. If track roughness is acquired by an indirect method, the data has to be marked with “calculated”. Additionally, the horizontal and vertical decay rate can be entered into this sheet.

The maximum frequency range of the spectra is 20Hz to 25kHz. In practice spectra for rail roughness have a shorter range. Leave the fields blank if no data is available for a certain frequency band. In further calculations a blank field will be interpreted as -∞.

Rail roughness is normally measured in the wavelength domain (λ). For conversion to the frequency domain (f) the reference speed v_{ref} is needed (f= v_{ref} /λ). This reference speed is recorded in the field *vref*.

This sheet contains a button for the conversion of the rail roughness from wavelength to frequency domain.

The settings section contains information about acoustical relevant hardware and software settings.

8.2.3 Train data

The header of this sheet contains a vehicle descriptor, a pass-by number and a button for creating a new sheet. The vehicle descriptor will be automatically calculated from the digits in the table *digits for vehicle descriptor (mandatory).* If data for a new train pass-by at the same location needs to be entered, a new sheet has to be created with the button *new page*. A new sheet is created, and the pass-by list in the sheet *pass-by list* is automatically updated with a new record.

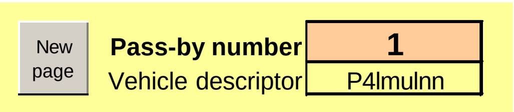


Figure 8.2 Header of pass by sheet

The header also contains five tables: pass-by data, vehicle descriptor, vehicle operating condition, measurement type, and additional vehicle info.

8.2.4 Rolling noise data

The measurement protocol is given in [8], § 3. For rolling noise data the following data needs to be measured:

Lp overall level (1.75 m, 0.0 m) (re2 E-5Pa)
Lp overall level (7.5 m, 1.2 m) (re 2 E-5 Pa)

Rail vertical vibration level (V1, re 1 E-6 m/s)
Rail lateral vibration level (L1, re 1 E-6 m/s)
Sleeper vertical vibration level (S1, re 1 E-6 m/s)
Lr,tot Total effective roughness (re 1E-6 m)

The Lr,tot (Total effective roughness) can be acquired using an indirect method, or by measuring the rail and wheel roughness directly and taking into account contact filter effects. See [8], § 3.1.

The next step is to calculate the transfer functions:

LHveh Vehicle transfer function (re 4 E 2 Pa^2/m)
LHtr Track transfer function (re 4 E 2 Pa^2/m)
LHtot Overall transfer function (re 4 E 2 Pa^2/m)

For available methods and software see [8], § 3.2.

Additionally data in the following field can be acquired for backup:

Lp overall level (25 m, 3.5 m) (re 2 E-5 Pa)

8.2.5 Aerodynamic noise data

A proposed measurement protocol is given in [8], § 6 and summarised in 7.3.8. The aerodynamic noise component can be obtained in 5 steps. Therefore it is recommended to use 1 sheet for each step. Only the data from the last sheet will be imported into the IMAGINE database.

The microphone position for all the following measurements is 25m from the track and 3.5m high spacing.

Step 1: rolling noise measurement at v_{ref}. Determine the rolling noise component as described in [8] (a speed v_{ref} lower than the transition speed between dominance of rolling noise and dominance of aerodynamic noise (recommended between 100 and 140km/h)). Insert all relevant data into pass-by sheet 1, and set the actual train speed in sheet 1 to v_{ref}. Mark the rolling noise data as “measured”.

The total effective roughness $L_{r,tot}$ and the total transfer function $L_{H,tot}^{RN}$ of the rolling noise at v_{ref} is the data required for step 2.

Step 2: determine rolling noise at v_{aero}. It is recommended to set v_{aero}>250km/h to be sure the aerodynamic component is dominant. The rolling noise at speed v_{aero} is:

$$L_p^{RN}(v_{aero},f) = L_{H,tot}^{RN} + L_{r,tot}(v_{aero},f) \quad (8.1)$$

Insert this data into sheet 2. Input v_{ref} into the field <settings> (in tracksheet), and set the actual train speed in sheet 2 to $v_{aero.}$ Mark the rolling noise data as “calculated”.

By means of energy subtraction $\ominus$, the aerodynamic noise at V_{aero} can be calculated:

Step 3a: measurement of aerodynamic noise at v_{aero}.
Carry out a high speed (v_{aero}) measurement at a mic. position of 25m from the track and a height of 3.5m. Insert the L_p data into the SPL overall level field in sheet 2. The total aerodynamic noise can be calculated from:

$$L_p^{AN,total}(v_{aero},f) = L_p \text{ overall level (25m, 3.5m)} \ominus L_p^{RN}(v_{aero},f) \quad (8.2)$$

The data for $L_p^{AN,total}(v_{aero},f)$ has to be inserted into field <Lp aero,v0 total> in the section aerodynamic noise. This result is the total aerodynamic noise (bogie source at 0.5m + higher sources at 4m) at the speed v_{aero}.

Step 3b: measurement of aerodynamic noise from pantograph part 1.
Carry out a rolling noise measurement as described in step 1, but with a 2m high barrier along the track. This measurement contains mainly the higher aerodynamic sources (roof, pantograph), the transmission of the rolling noise through the noise barrier and the diffraction effect of the barrier edge. The barrier should be long enough to be considered as acoustically infinite, which means at least 100m for a mic. position at 25m from the track.
Insert all relevant data into pass-by sheet 3, and set the actual train speed in sheet 3 to $v_{ref.}$ Mark the rolling noise data as “measured”.
Determine the rolling noise at v_{aero} as described in step 2, and add this rolling noise data to sheet 4. Mark the rolling noise data as “calculated”. Copy the data of <Lp aero,v0 total> from sheet 2 to sheet 4.

Step4: measurement of aerodynamic noise from pantograph part 2 and separation of aerodynamic noise from bogie and pantograph.
Carry out a high speed (v_{aero}) measurement at mic. position 25m from the track and at 3.5m high behind the same 2m high barrier. The data for $L_p^{AN,panto}(v_{aero},f)$ [$=L_p^{AN,2m\ barrier}(v_{aero},f)$] has to be inserted into field <Lp aero(v,f) 4m panto> in the section aerodynamic noise. Set the actual train speed in sheet 4 to $v_{aero.}$

The aerodynamic noise of the bogie area can be obtained by:

$$L_p^{AN,bogie}(v_{aero},f) = L_p^{AN,total}(v_{aero},f) \ominus L_p^{AN,panto}(v_{aero},f) \tag{8.3}$$

Insert the data of $L_p^{AN,bogie}(v_{aero},f)$ into field < Lp aero(v,f) 0,5m (bogie)> of sheet 4.

The data from sheet 4 can be imported into the IMAGINE database.

8.2.6 Traction noise data

The measurement protocol for traction noise can be found in [8], § 5, and is summarised in 7.16 above.

8.2.7 Other sources

The measurement protocol for other sources can be found in [8], § 4.

8.2.8 Acquiring multi pass-by data

For certain types of data it is only possible to acquire data, which is an average of more than one pass-by. A good example is curve squeal. In the case of averaged data the number of datasets used has to be inserted into the field:

pass-by data
multiple: number of pass bys

The field:

pass-by data
Actual train speed [km/h]

should contain the average train speed.

If the database user wishes to enter the results of multiple pass-by measurements into the database as a single entry, ISO 3095:2005 approach to multiple data acquisition may be applied in conjunction with normal statistical rules. However, in the absence of a detailed statistical analysis, the energy average figure is acceptable.

8.3 IMAGINE Rail Source database administration tool

The IMAGINE administration tool is specifically designed to manage the IMAGINE database. Because of the complexity of this (relational) rail source database, manual input of the data is not recommended and very time consuming. As a result, an Access software tool was built to automate the import of measurement data and default data. It contains a user interface for transferring data from the IMAGINE data input sheet into the IMAGINE database. This section contains a description of the functionality of the software. The software runs as a module in Access2000. It has been used for importing all data into the database (and tested extensively for this purpose).

The Access software module contains one menu, divided into tabs.

8.3.1 Main Menu

The *Main Menu* starts up automatically after opening the file *IMAGINE_importData_v2_xx.mde*.

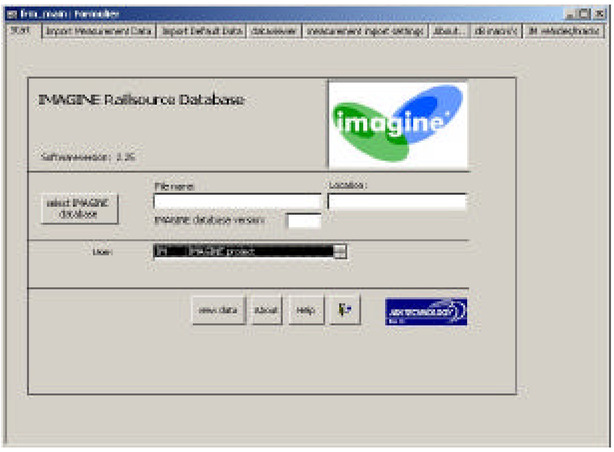


Figure 8.3 Main menu IMAGINE Database Administration Tool

Before proceeding to the other menus, the current IMAGINE Rail source Database file must be selected. After selecting the right database file, the file's location and version will appear in the menu.

The user identification contains the following options:
EC /European Commission

IM / IMAGINE project
MS/ Member State
LU / Local User

By giving identification to all imported datasets, it is always clear who has imported the dataset into the database, which is important in the case of central European administration and distribution.

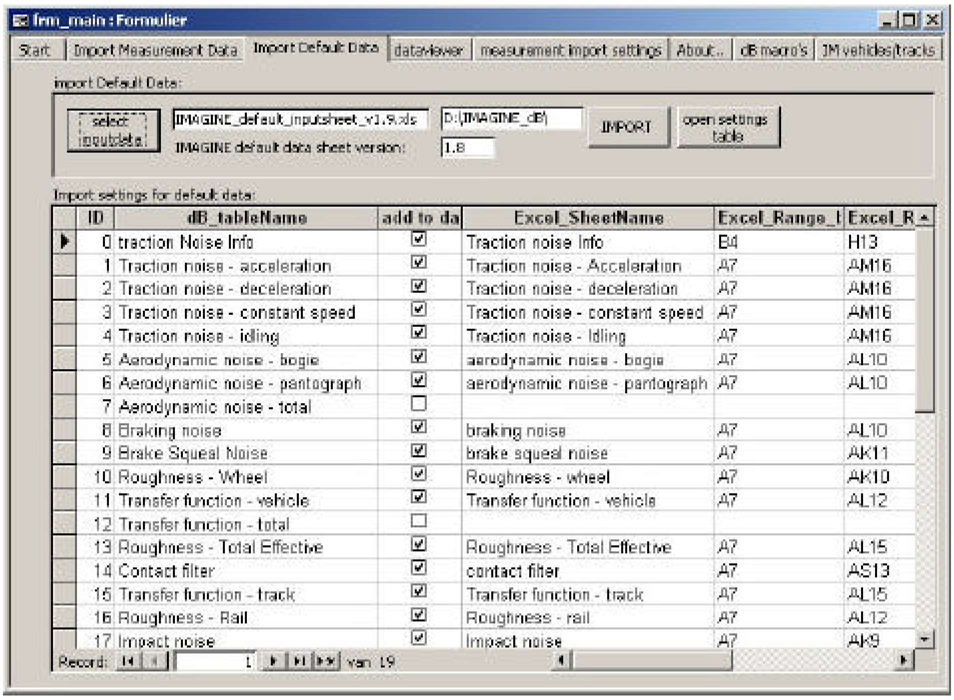
After fulfilling these initial steps, the user can start importing measurement data and default data.

8.3.2 Importing default data

Default IMAGINE data can be imported directly from the excel workbook *IMAGINE_default _inputsheet_v1.9.xls.* The data input sheet guidance in 8.2 contains all necessary information on how to provide data for this datasheet.

In the tab Import Default data, select the Excel workbook containing the default data. In the section Import settings for default data, the user can check the data to import for each data type separately. If sheet names and/or data ranges are changed in the Excel-workbook, these changes should be applied in the settings section too.

After choosing the right settings, the data can be imported with the Import button.



ID	dB_tableName	add to da	Excel_SheetName	Excel_Range_l	Excel_R
0	traction Noise Info	☑	Traction noise Info	B4	H13
1	Traction noise - acceleration	☑	Traction noise - Acceleration	A7	AM16
2	Traction noise - deceleration	☑	Traction noise - deceleration	A7	AM16
3	Traction noise - constant speed	☑	Traction noise - constant speed	A7	AM16
4	Traction noise - idling	☑	Traction noise - Idling	A7	AM16
5	Aerodynamic noise - bogie	☑	aerodynamic noise - bogie	A7	AL10
6	Aerodynamic noise - pantograph	☑	aerodynamic noise - pantograph	A7	AL10
7	Aerodynamic noise - total	☐			
8	Braking noise	☑	braking noise	A7	AL10
9	Brake Squeal Noise	☑	brake squeal noise	A7	AK11
10	Roughness - Wheel	☑	Roughness - wheel	A7	AK10
11	Transfer function - vehicle	☑	Transfer function - vehicle	A7	AL12
12	Transfer function - total	☐			
13	Roughness - Total Effective	☑	Roughness - Total Effective	A7	AL15
14	Contact filter	☑	contact filter	A7	AS13
15	Transfer function - track	☑	Transfer function - track	A7	AL15
16	Roughness - Rail	☑	Roughness - rail	A7	AL12
17	Impact noise	☑	Impact noise	A7	AK9

Figure 8.4 Menu import default data

8.3.3 Importing measurement data

Measurement data can be imported directly from the excel measurement data input sheet. The data input sheet guidance in 8.2 contains all necessary information on how to provide data for this datasheet.

In the tab Import Measurement Data, select the Excel workbook containing the measurement data. After selecting your datasheet, general information about your datasheet, which is stored in the selected Excel workbook, will be shown in the section Input sheet info. All measurement pass-bys are shown in the section select pass-bys to import. The user can select all or a subset of pass-by measurements to import.

Before importing the data, the menu import settings should be set. This menu, shown in Figure 8.4, contains for each main data type (track, rolling noise, traction noise etc), a checkbox to mark if this data should be imported. In the case of traction noise, the right source type also has to be selected.

For traction noise, the right table (Idling, constant speed, accelerating, decelerating) is selected automatically by using the field <Operating condition> in the pass-by sheets of the Excel book. The source type (all, fans, drive, other) has to be selected in the settings menu.

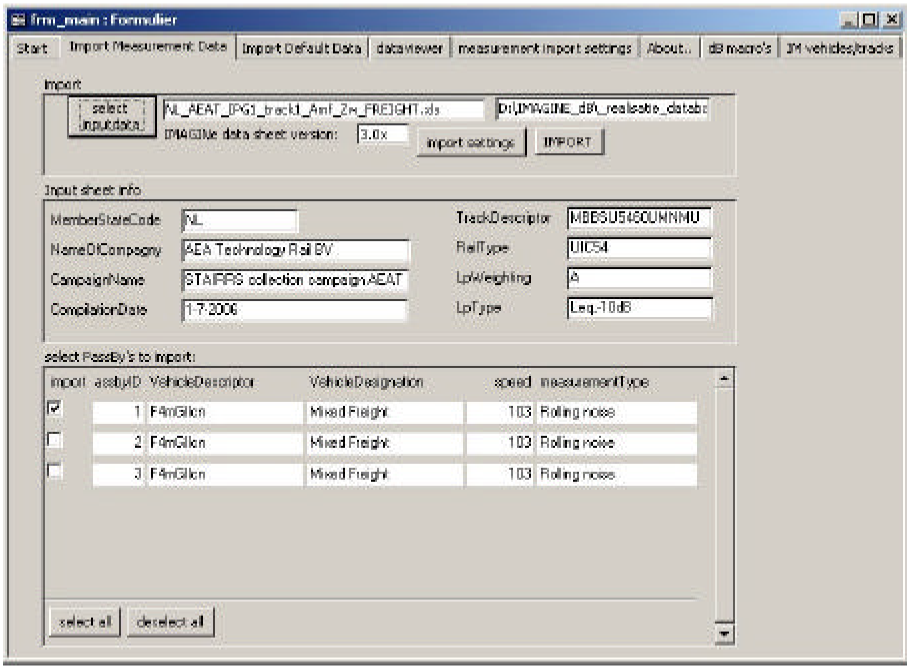


Figure 8.5 Menu import measurement data

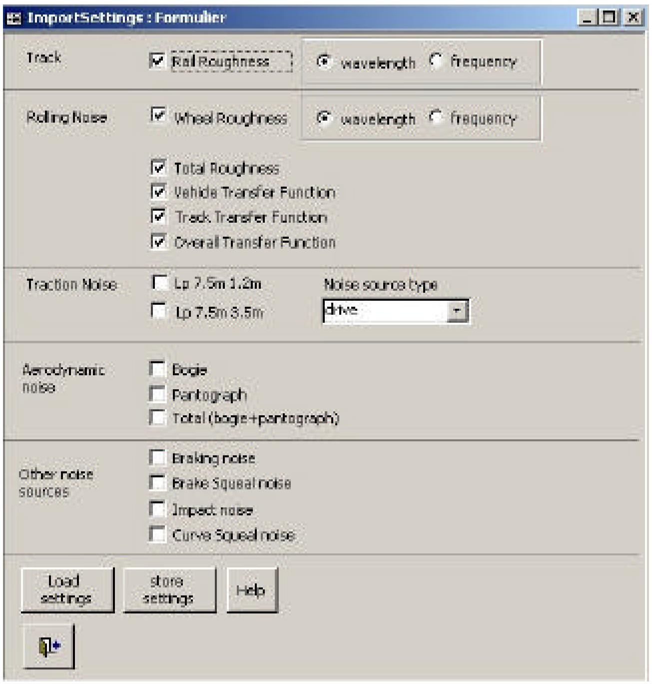


Figure 8.6 Import settings menu for measurement data

The menu import settings menu for measurement data contains the option to store and load settings.

8.3.4 The data viewer

To be able to evaluate the data in the IMAGINE database, and to make the data accessible, a data viewer is built into the tool; an example is given in Figure 8.7, for the first 6 records in the table Roughness – Rail.

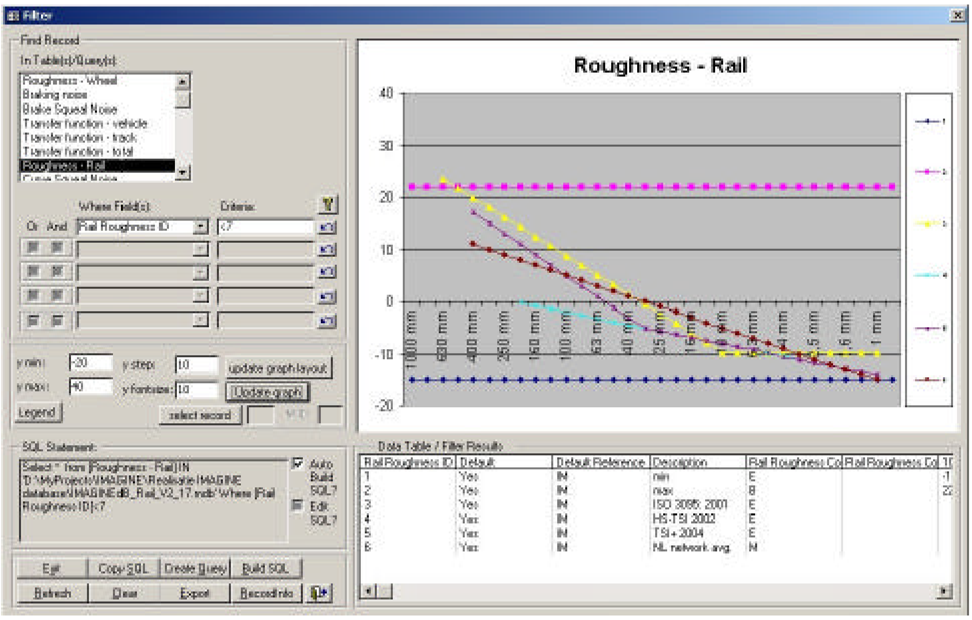
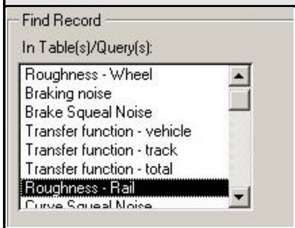
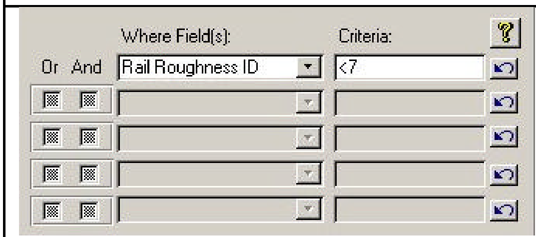
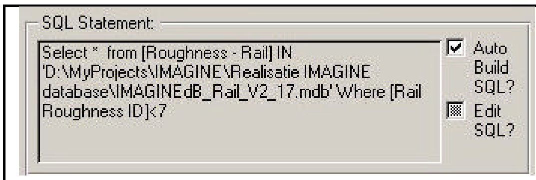
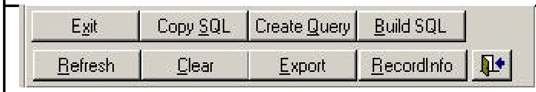
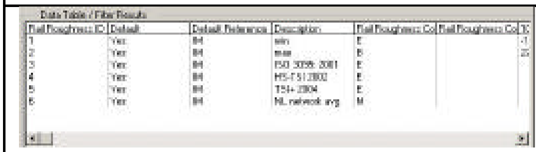
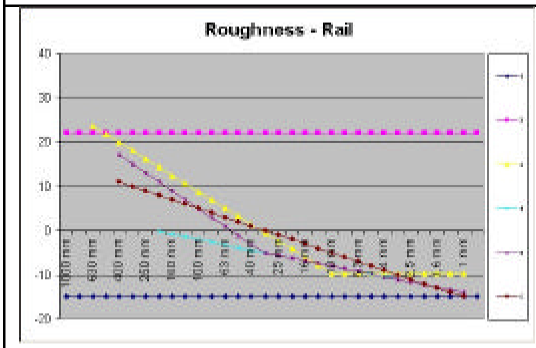
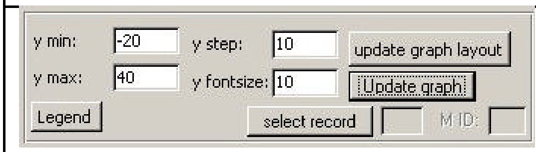


Figure 8.7 Example of the dataviewer in the IMAGINE administration tool.

The data viewer contains the following elements:

<table>
<tr><th>Data viewer menu element</th><th>Explanation</th></tr>
<tr><td>
</td><td>Selection list for choosing a data table of interest</td></tr>
<tr><td>
</td><td>Filter option, applicable to all fields in the chosen data table.
 The button [?] gives an explanation of advanced filtering options</td></tr>
</table>

	A textbox showing the SQL of the data filter. The SQL statement can be edited directly in this textbox.
	Several options to work with the filter/SQL-Query. With the button *Export* the filtered dataset can be exported to Excel. With the button RecordInfo Information will be shown about the selected record in the filter result table.
	Filter Results table to show the records after filtering the data.
	A Graph representing the filtered data. The first two lines always indicate the minimum/maximum range of the data, to help the user to judge if newly imported data fall into a theoretical correct range. Minimum/maximum ranges are delivered by the IMAGINE project.
	Options to manipulate the graph. The button <update graph layout> only updates the graph layout, with new values of Ymin/Ymax/Ystep and Yfontsize. The button Update Graph updates the graph after defining a new filter or SQL-query.

The initial number of records shown in the graph without filtering the data is set to 20; otherwise all records will be shown in the graph, causing long waiting and processing times. The initial number of records can be changed in <tab *dB Macro's* / Ini Table / GraphInitialRecords>.

8.3.5 Integration with GIS-software

Proposed integration of the IMAGINE Rail Source database into a GIS environment is shown in Figure 8.8.

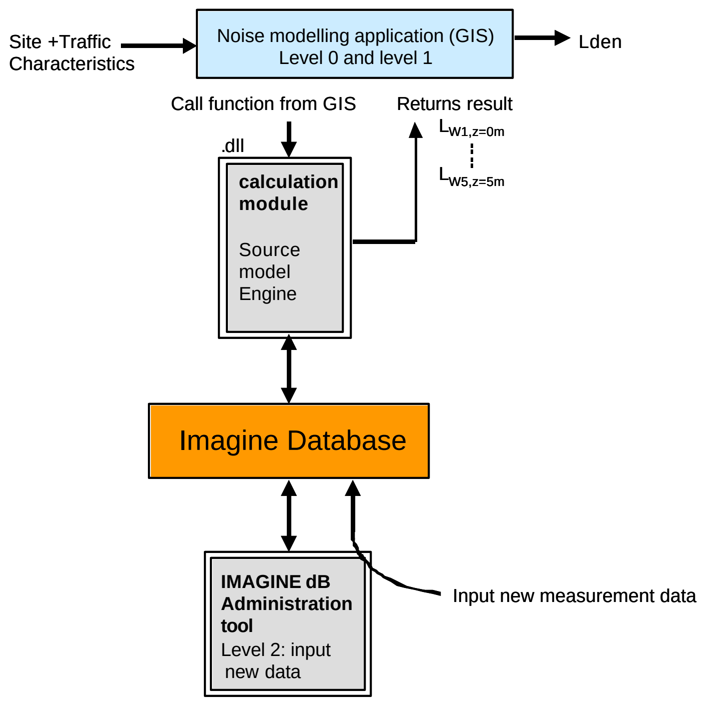


Figure 8.8 IMAGINE Database in a GIS environment.

The GIS software would contain the required acoustical model of the project, and all traffic flows. For every new vehicle/track combination, the GIS model "calls" the Railsource calculation module (which can be a windows dll (dynamic linked library)), which returns for that specific combination, the Sound power level L_w at the 5 source heights. To be able to calculate the Sound Power levels, the calculation module would use the data from the railsource database. In this proposed arrangement, the user can use predefined vehicles, tracks or vehicle/track combinations (basic level 0); or can define new vehicle and tracks with predefined spectral data (advanced level 1). With the use of the IMAGINE database administration tool, the user can also import newly acquired measurement data (expert level 2).

9 Example data supplied within the database

An essential part of the activity of Work Package 6 was to acquire example data representative of the range of stock that would be found across Europe. To cover this range, therefore, data from diesel and electric locomotives, diesel and electric multiple units, passenger coaches and freight wagons, both of an older generation and state-of-the-art, with 2, 4, or 6 axles per vehicle, was required. Traction noise, rolling noise (ideally separated into vehicle and track contributions and stored in the database as transfer functions between roughness and noise) and aerodynamic noise would all be needed to build a comprehensive picture of European railway sources. To this end a number of approaches were taken. Dedicated measurement exercises were carried out (eg in the UK and Hungary), data was donated from current national projects (eg the Netherlands, Sweden), and raw data was obtained from earlier measurement exercises and rigorously analysed using IMAGINE processes to make it compatible with the database (eg France, Netherlands, UK). By these means the complete required range of vehicle and sub-source types was covered, providing **233** spectra for the delivered database.

Table 9.1 presents a summary of the delivered example dataset, at February 2007. The database is, however, intended to be continuously updated, and therefore future readers of this report can expect an even greater set to be available over time.

Originator	Measurement country	Measurement type	Vehicle type	Axles per vehicle	Speed (km/h)	Number of source spectra
AEAT NL	NL	Rolling noise - separated	Freight, mixed	4	90-100	3
AEAT NL	NL	Rolling noise - separated	Freight, mixed	4	90-100	3
AEAT NL	NL	Rolling noise - separated	Freight, mixed	4	90-100	2
AEAT NL	NL	Rolling noise - separated	Freight, mixed	4	90-100	2
AEAT NL	FR	Rolling noise - separated	Passenger, high speed (Thalys)	2	300	13
AEAT NL	NL	Rolling noise - separated	Passenger, conventional (Benelux)	4	135	2
AEAT NL	NL	Rolling noise - separated	Freight, mixed	2	71-100	7
			Freight, mixed	4	71-100	5
			Freight, mixed	6	89	1
AEAT NL	NL	Rolling noise - separated	Passenger, conventional (ICR NL)	4	124-142	2
AEAT NL	NL	Rolling noise - separated	Passenger, conventional (IRM NL)	4	81-138	2
AEAT NL	NL	Rolling noise - separated	Passenger, conventional (Mat 64)	4	136	2
AEAT NL	NL	Rolling noise - separated	Passenger, high speed (Thalys)	2	133	2
AEAT NL	NL	Rolling noise -	Passenger, conventional	4	131	2

Originator	Measurement country	Measurement type	Vehicle type	Axles per vehicle	Speed (km/h)	Number of source spectra
		separated	(Benelux)			
AEAT NL	NL	Rolling noise - separated	Freight, mixed	2	89	2
			Freight, mixed	4	98	2
			Freight, mixed	6	70-84	3
			Locomotive	4	84	1
AEAT NL	NL	Rolling noise - separated	Passenger, conventional (ICR NL)	4	132	2
AEAT NL	NL	Rolling noise - separated	Passenger, conventional (IRM NL)	4	128-137	2
AEAT NL	NL	Rolling noise - separated	Passenger, conventional (Mat 64)	4	120	2
AEAT NL	NL	Rolling noise - separated	Passenger, high speed (Thalys)	2	136	2
AEAT UK	UK	Rolling noise - separated	Locomotive (Class 43)	4	160	4
			Locomotive (Class 87)	4	160	3
			Locomotive (Class 90)	4	160	4
			Passenger, conventional (Class 153 DMU)	4	107	1
			Passenger, conventional (Mark II coach)	4	150	4
			Passenger, conventional (Mark III coach)	4	160	10
AEAT UK	UK	Rolling noise - separated	Locomotive (Class 43)	4	169	2
			Locomotive (Class 66)	6	101	1
			Locomotive (Class 87)	4	170	5
			Locomotive (Class 90)	4	165	4
			Passenger, conventional (Class 153 DMU)	4	84-109	3
			Passenger, conventional (Class 220 DMU)	4	176	1
			Passenger, conventional (Mark II coach)	4	153	4
			Passenger, conventional (Mark III coach)	4	124-173	20
			Passenger, conventional	4	158-166	4

Originator	Measurement country	Measurement type	Vehicle type	Axles per vehicle	Speed (km/h)	Number of source spectra
			(Class 390)			
SP	SE	Rolling noise - separated	Freight	2	96	1
			Passenger, conventional (Intercity)	4	115-145	3
			Passenger, conventional (X2)	4	148-168	4
			Passenger, conventional (X11)	4	112-140	7
			Passenger, conventional (X53-Regina)	4	117-148	2
SP	SE	Rolling noise - separated	Freight	2	83-95	3
			Passenger, conventional (Intercity)	4	146	2
			Passenger, conventional (X2)	4	167	3
			Passenger, conventional (X11)	3	110-134	9
			Passenger, conventional (X53-Regina)	2	117	2
SP	SE	Rolling noise - separated	Freight	2	97	3
			Passenger, conventional (Intercity)	4	158	1
			Passenger, conventional (X2)	4	167-190	3
			Passenger, conventional (X53-Regina)	4	168	2
SP	SE	Rolling noise - separated	Freight	2	102	1
			Freight, post	4	160	1
			Passenger, conventional (Intercity)	4	145-164	2
			Passenger, conventional (X2)	4	170-205	5
			Passenger, conventional (X31K)	4	165-179	6

Originator	Measurement country	Measurement type	Vehicle type	Axles per vehicle	Speed (km/h)	Number of source spectra
AEAT UK	UK	Aerodynamic noise - separated	Passenger, high speed (Eurostar)	2	260	1
AEAT UK	UK	Squeal noise	Passenger, conventional (Mark II coach)	4	30	1
AEAT UK	UK	Traction noise	Locomotive (Class 67)	4	16	1
AEAT UK	UK	Traction noise	Locomotive (Class 66)	6	16	1
BUTE	HU	Rolling noise - separated	Passenger, conventional (Lover IC)	4	144	1
			Passenger, conventional (Polonia IC)	4	113	2
			Passenger, conventional (EC Bartók)	4	158	1
			Passenger, conventional	4	100	3
			Passenger, conventional (ÖBB EC25)	4	162	1
			Freight, mixed	2	86-94	3
			Freight, mixed	4	57-94	9
BUTE	HU	Rolling noise - separated	Passenger, conventional	4	98-139	4
			Freight, mixed	4	53-98	7
BUTE	HU	Traction noise	Locomotive	4	5	2
			Locomotive	6	5	2

Table 9.1. The example dataset delivered with the IMAGINE rail source database

10 Guidance on modelling non-standard situations

As has been indicated in Section 3, one objective of Work Package 6 was to provide guidance on how to approach situations where the local track characteristics and the nature of the traffic are non-standard and not easy to model. Fortunately, as the techniques for characterising source data and for generating the traffic model were developed during the course of IMAGINE, it emerged that the process was very flexible and would therefore accommodate the majority of situations.

Situations that might be considered difficult to acquire data for, or to model, include:

Light rail vehicles and trams, and embedded track: Such vehicles can be treated in exactly the same way as heavy rail vehicles when transfer functions between combined effective roughness and the vehicle contribution to rolling noise are being acquired, provided it can be arranged for the vehicle to run on conventional track. If, however, the vehicles can only run on tracks embedded in streets, this is more problematical as the techniques for separating vehicle and track contributions are designed around conventional tracks. It is suggested here that the transfer function between combined effective roughness and overall rolling noise be acquired, and that the apportionment between the vehicle and track contributions be approximated using the weightings presented in Table 7.8. A more analytical approach could be used to model the acoustic behaviour of embedded tracks. Should such an approach be developed and applied, the database is amenable to the storage of such data.

Elevated track support structures: Although there are many potential structural forms and materials that can be use to support railway tracks, they can all be treated simply as a specific track form when applying source separation techniques for rolling noise. Although the standard available source separation techniques PBA (provided a low response vehicle is available), VTN and MISO are designed around conventional at-grade track, the results obtained for other support structures will be adequate for wide-scale mapping purposes.

Vehicles fitted with wheel dampers: Here the wheel and damper combination is simply treated as a new wheel type.

Track fitted with tuned absorbers: As with wheel dampers, this combination is treated as a new track type.

Vehicles fitted with shields close to the wheels: Such treatments are strictly designed to affect sound propagation, but cannot be included within the IMAGINE propagation method. It is therefore appropriate to consider the shielded wheels as a new form of wheel, and to apply the standard source separation approach.

11 Conclusions

The Rail Noise Sources Work Package of IMAGINE has produced a flexible database for the storage and extraction of rail vehicle and track noise data. An additional methodology for assembling the individual noise sources into traffic noise source lines has been produced to interface with the IMAGINE propagation method. The noise sources are subdivided into track, vehicle, traction and aerodynamic elements, allowing improved modelling of propagation and also the design of cost-effective mitigation. Guidance on data acquisition is provided, as well as a data input sheet that allows automatic import of data into the database with a dedicated database administration tool. The database is designed for routine upgrade as new data is acquired. It is delivered with a comprehensive set of example measured data from across Europe (France, Netherlands, Sweden, Hungary, UK) as well as default data where example data is not considered appropriate. Because of the flexibility of the database, there are very few situations that cannot be catered for by its functions, and therefore the data acquisition routines and storage processes provide a robust system for handling rail source data for noise mapping in Europe.

12 References

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