MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

A New Standard for the Measurement of Source Terms for Railway Noise Prediction Models

Michael Dittrich [1]
TNO Technical Sciences
Oude Waalsdorperweg 63, 2597 AK, The Hague, The Netherlands

Fabien Letourneaux [2]
SNCF Innovation et Research, 1- 3 avenue François Mitterrand, 93212 St Denis, France

Chris Jones
RSSB, The Helicon, 1 South Place, London, United Kingdom

Henning Brammer
Eisenbahn-Bundesamt, Heinemannstraße 6, 53175 Bonn, Germany

Christian Gerbig
DB Systemtechnik, Völckerstraße 5, 80939 Munich, Germany

Günter Dinhobl
ÖBB-Infrastruktur Aktiengesellschaft Nordbahnstrasse 50, A-1020 Wien, Austria

Edwin Verheijen
dBvision, Groenmarktstraat 39, 3521AV, Utrecht, The Netherlands

Ard Kuijpers
M+P, Wolfskamerweg 47, 5262 ES Vught, The Netherlands

Fabrice Aubin
SNCF Centre d'ingenierie du materiel, 4 Allée des Gémeaux – 72100 Le Mans
France

Christian Czolbe
PROSE AG, Zürcherstrasse 41, 8400 Winterthur, Switzerland

ABSTRACT

A number of models for predicting railway noise have been, or are being developed that are all based on the approach devised in the EU Imagine project that finished in 2007. The CNOSSOS model for strategic noise mapping in the EU is amongst them. There is therefore a need to determine train- and track-specific source terms for these calculations. A new CEN standard is therefore being developed to guide these measurements. Most current railway noise measurement standards were developed for type testing purposes, such as EN ISO 3095, referred

to by the European TSI legislation. Measurement of source terms for prediction models differs from type test measurements, particularly in their applicability to a vehicle fleet, to operational track conditions, and the requirement to determine sound power terms rather than sound pressure levels. The new standard sets out methods to characterise individual physical noise sources including rolling noise, traction noise, aerodynamic noise, impact, curving and braking noise. The standard must give guidance on how to derive each of the source sound power terms from sound pressure measurements. The rolling noise sound power is calculated from wheel/rail roughness spectra and transfer functions from roughness to vehicle and track sound powers. This paper gives an overview of the scope, key elements and considerations of the current draft standard.

---

[1] michael.dittrich@tno.nl [2] fabien.letourneaux@sncf.fr

Keywords: Railway Noise, Source terms measurement, Standards
I-INCE Classification of Subject Number: 81,72,13

1. INTRODUCTION

The strategic noise mapping undertaken in the European Union is to be carried out using a method common to all countries [1]. In working towards that goal, the 'Harmonoise' and then 'Imagine' research projects [2] were commissioned more than ten years ago. These projects devised a calculation scheme based more on the physical noise generation mechanisms of the separate sources of railway noise than previous schemes. These Imagine-type methods include terms for rolling noise, traction noise, aerodynamic noise, rail joint impact noise, curving, braking noise and other sources. For rolling noise, the source is divided into a term for radiation from the track and one for radiation from the vehicle. These two terms are calculated from the acoustic rail and wheel roughness spectra specific to the prediction conditions via transfer functions to yield sound powers.

This approach to railway noise prediction improves the ability to examine noise mitigation solutions such as roughness control, wheel and rail dampers, rail shielding, optimised rail pads and tracks and wheel design. It also allows, for example, for one vehicle type to be modelled on different track types and allows for different speed dependencies or directivities for different sources.

The method for the common strategic noise mapping is simplified a little from the methods devised in the research projects and packaged with default source terms as CNOSSOS [1]. The idea is that countries can either use the default source parameters or, better, use source term parameters derived for the specific track types and vehicles on their own networks. The CNOSSOS model was designed to be suitable for the Environmental Noise Directive mapping but not beyond that.

For purposes that require more detail, such as planning or reconstruction, some countries are therefore implementing the principles of the Imagine model in their own schemes, for instance sonRail [3]. Other national models such as the Dutch SRM II [4], the German Schall03 [5], the French NMPB [6] and the Scandinavian Nord2000 [7] models do work similarly in frequency bands, but without the detail in the derivation of the rolling noise terms. All these models, are built on the principles developed in the research projects although they differ in aspects such as source terms and heights.

To ensure that predictions are made on a comparable basis in different countries as well as for the different purposes, there is a clear need for standardisation of the measurement methods used to derive the source terms for the calculation schemes. This paper outlines the work that is now being undertaken by CEN to provide such a standard [8].

Standard measurement methods for railway noise already exist, for example in ISO 3095 [9]. These methods address the need for rolling stock type acceptance under the Technical Specifications for Interoperability (TSI) [10]. The same methods are to be followed as far as possible in the new standard. However, measurements yield sound *pressure* levels at standstill and for a moving train as the sum from all sources. Prediction source terms must, rather, be rendered in terms of (effective or directional) sound *power,* and for the separate physical sources.

Methods to derive the required terms were researched in the European Commission's projects. For the Dutch model, a procedure was documented in 2006 by which source terms can be derived from measurements [11]. The Imagine project already provided the background at a stage ready for standardisation in many of the areas required. Since then, though, other developments in technology have occurred that can be put to use. These include improved theoretical models of the sources and improved measurement technology, particularly in sound level monitoring systems and information systems.

2. SCOPE AND CONTENT OF THE STANDARD

The standard addresses the measurement of source terms for environmental noise calculation for rail traffic, including light rail, such as trams and metros. It is applicable to the measurement of in-service trains on operational tracks. It is not applicable to type acceptance testing of rolling stock or tracks, or to derive source terms for time domain models.

The railway noise sources within the scope are rolling noise, traction noise, aerodynamic noise, impact noise (such as rail joints, switches, crossings), bridge noise and curve squeal. Noise from rail vehicles at standstill is included, such as engine idling and auxiliary equipment. The calculation of sound propagation is part of generally standardised propagation models and is not addressed in this standard. Noise from fixed installations such as stations, depots and electricity sub-stations are also not within the scope of the new standard.

Each source is individually characterized in terms of its frequency spectrum (octave or one-third octave band), source height and directivity. Rolling noise is characterised in terms of its generating wheel and rail roughness along with vehicle and track transfer functions.

The methods of a prediction scheme are defined within the scheme itself and the new standard does not cover topics such as the L_{eq} arithmetic for the vehicle traffic flow and the calculation methods for sound propagation from source to receiver.

Source terms are generally to be given as a sound power spectrum level L_W' per unit length of vehicle at particular source heights and frequency bands. Although often referred to as sound power they are actually an effective or ‘apparent’ sound power relevant for the sound pressure at one side of the train and including a directivity function assumed differently for different source types. Such source levels are normally derived as a function of train speed from multiple sound pressure measurements at several sites.

Where possible, the new standard relies on established standards for measurements, e.g. of standstill and pass-by microphone measurements and of rail and wheel roughness measurement. Where sources can be measured independently, methods are described; otherwise possible separation techniques are set out.

To ensure the quality of results, sampling requirements are defined. This involves the selection of suitable vehicles and track, the numbers of measurements, speeds and locations.

Where development of measurement methods is progressing or complex procedures are most practical to perform with software tools, it is not appropriate to define every detail in a normative manner. Non-normative annexes therefore cover: methods for combined roughness, source separation, and the propagation calculations used to estimate sound power from trackside sound pressure measurements. These areas are described in Section 4 of this paper. Topics which still require future R&D and refinement at a later stage include amongst others:

- characterization of braking noise, squeal noise, aerodynamic noise at a reasonable cost, with straightforward measurement set-up and advanced processing;
- separation methods for traction, aerodynamic and rolling noise;
- measurement processing of site characteristics for noise propagation close to the track.

3. MEASUREMENT PROCEDURES FOR EACH PHYSICAL SOURCE

3.1 General

It is the policy of the standard's authors to specify only methods that are within the resources of a wide range of laboratories. No sound intensity or microphone array methods are therefore specified although these may be options.

Since the measurement effort can easily become large, it is important to allow elimination of measurements if it can be shown that certain sources are not relevant or typical. This should therefore be studied carefully in planning. It is therefore suggested that sources not exceeding the others by more than 3 dB in one or more one-third octave frequency band may be omitted. This may for example occur in tonal traction noise, braking or curve squeal noise. In practice, the choice of measurement locations is also constrained by availability of track and rolling stock type, line speed and many other factors.

Due to the potential for uncertainty in the measurement, it is recommended to validate the source terms obtained by feeding them into the relevant prediction model and comparing the results with measurements at other sites whenever possible.

The procedures outlined below are still subject to review in the working group.

3.2 Rolling noise

Rolling noise is radiated by structural vibration in rails, sleepers, wheels and in rare cases (mainly freight wagons) also by the vehicle superstructure. It is generated by the combined wheel and rail roughness. For CNOSSOS [1], the source term quantities are listed in section 2.3 of the Directive and some default values are given in Appendix G. Default values for Harmonoise/Imagine can be found in [3].

The rolling noise sound power spectra from vehicle and track may be calculated from combined effective roughness and vehicle and track transfer functions. These are obtained from measurements carried out in the following steps:

1. Select the vehicle speeds and operating conditions such that rolling noise is ensured to be the dominant source, i.e. without significant traction noise or aerodynamic noise. The measurements are to be taken at constant speed of at least 60 km/h for conventional and high speed rail, at least 40 km/h for light rail (trams and metros) and no higher than 250 km/h. At least three different speeds are to be measured, as available at one or more sites.
2. Determine the combined effective roughness $L_{Rtot,i}$, at the measurement site and

for the vehicles, as a function of frequency, in one-third octaves i for each pass-by at each speed v;

3. Measure the sound pressure $L_{peq,tp,i}$ in one-third octave bands for each pass-by at each speed v, at 7.5 m from the track centreline and 1.2 m above rail surface;
4. Determine the total transfer function $L_{HpR,tot,nl,i}$ in one-third octaves from the combined roughness and the sound pressure (see eq. (1)).
5. Repeat steps 2 to 4 for all required speeds and determine the average of the total transfer function from roughness to sound pressure. If individual results for the transfer function differ from others by more than 5 dB in single one-third octave bands, a larger sample of measurements should be taken, or individual measurements rejected.
6. Calculate the total sound power transfer function $L_{HWR,tot,nl,i}$ from $L_{HpR,tot,nl,i}$ using a propagation calculation in line with the principles set out in the informative annex of the standard (see 4.2 in this paper for a preliminary outline).
7. Separate the total transfer function $L_{WR,tot,nl,i}$ into a vehicle transfer function $L_{WR,VEH,nl,i}$ and a track transfer function $L_{WR,TR,nl,i}$ function following the methods set out in the informative annex of the standard.

The total transfer function $L_{HpR,nl,i}$ from combined roughness to sound pressure normalised to the axle density is determined from

$$L_{HpR,tot,nl,i} = L_{peq,tp,i} - L_{Rtot,i} - 10 \lg (N_{ax}/ \ell_{veh}) \tag{1}$$

in accordance with CEN TR16891 [12], with N_{ax} = number of axles and ℓ_{veh} = vehicle length in meters, $L_{Rtot,i}$=combined effective roughness at speed v in third octave band i, $L_{peq,tp,i}$=sound pressure level at speed v over pass-by time t_p.

This can be converted to the transfer function of combined roughness to sound power per axle $L_{HWR,n,i}$ for a given vehicle length ℓ or normalised to axle density N_{ax}/ℓ, $L_{HWR,nl,i}$. The sound power level of the rolling noise of a of a track $L_{WTR,i}$ and of a vehicle $L_{WVEH,i}$ in one-third octave bands is obtained by adding the 10 lg of the axle number or axle density, as appropriate, and the combined roughness $L_{R,tot,i}$ to the transfer function at the specified train speed:

$$L_{WTR,i} = L_{R,tot,i} + L_{HWR,TR,i} + 10 \times \lg(N_{ax}) \tag{2}$$

$$L_{WVEH,i} = L_{R,tot,i} + L_{HWR,VEH,i} + 10 \times \lg(N_{ax}) \tag{3}$$

Step 7 requires a separation function obtained from measurement or calculation (see 4.3). Most calculation schemes already apply a simple separation function implicitly.

Rolling noise is typically attributed a source height of the axle for the wheel contribution and to the rail height for the track contribution, but these heights may be specified by the calculation scheme.

For calculation schemes that do not compose the sound power from roughness and transfer functions, the sound powers would be determined directly only from the pass-by sound pressures $L_{peq,tp}$.

Speeds of 70, 100 and 160 km/h will be recommended for conventional rail, or 40, 60, and 80 km/h for light rail. As the speed range may be limited at one site, measurements from different sites may be combined, as long as the track type and other site properties are the same. Rail roughness, track dynamic behaviour and site acoustic properties may differ between sites. The rail fasteners and pads, sleeper type, site geometry and type of ground cover should be kept constant between sites. The track dynamic behaviour can be characterised by means of the track decay rate. Differences between sites may be corrected for by specific calculation methods if necessary.

3.3 Traction and equipment noise

Traction and equipment noise includes all powertrain and auxiliary sources at all conditions such as standstill, constant speed, acceleration and braking. The list includes diesel engines, cooling fans, HVAC, electrical motors and inverters, transformers and transmissions. These sources are typically most predominant at lower speeds, but can sometimes also contribute at high speeds. The source terms for traction and equipment noise may be obtained either according to EN ISO 3095 for standstill and acceleration conditions or following relaxed site and operating conditions at start and stopping points such as stations or signal locations.

Source level for traction/equipment noise following EN ISO 3095

The sound power level for standstill is obtained from the average of multiple sound pressure levels around the vehicle as set out in EN ISO 3095, and applying a suitable method to convert them to sound power. The sound pressure data may be available from type test data. Alternatively, measurements may be made with single microphones on either side of the train from a very slow pass-by. The measurement cycle may differ from EN ISO 3095 if necessary, to include a whole work cycle for individual components of specific duration (e.g. compressors, fans, blow-off valves).

The sound power level for acceleration is obtained from the energy-average sound pressure level over several positions along the track as in EN ISO 3095. The sound power level for constant speed is derived either from the idling level, a low speed measurement or the acceleration level. It may be extrapolated for higher speeds as far as this can reasonably be done based on measurements including all sources.

Source level for traction/equipment noise using statistical data collection

Measurements are taken with one or more microphones positioned at the expected point(s) of maximum sound level. Suitable locations are along an upward slope, at acceleration points at stations or other stop/start locations with relatively low speeds below 30 km/h and varying operating conditions. Measured sound levels are either averaged to obtain a single characteristic value for traction noise or interpolated logarithmically as a function of speed to obtain a speed dependent spectrum.

Background noise (e.g. from rolling or rail joints) needs to be minimised. Traction sources which only occur at higher speeds can be assessed by comparison with the rolling noise if they cause an increase of more than 3 dB compared to the rolling noise itself within particular one-third octave frequency bands.

Traction and equipment noise is typically attributed to source heights of the axle, the middle and the top of the vehicle.

3.4 Impact noise

Impact noise sources include rail joints, switches and crossings. The source level can be characterised by applying an increased combined roughness level to the rolling noise transfer function. If the prediction model does not incorporate roughness, then a correction ΔL_W can be determined from the sound pressure level difference with and without joints on the same track. Measurements are to be taken at two positions: at a cross-section with joints and at a cross-section without joints, for at least 10 pass-bys of different trains at different speeds.

The impact roughness $L_{R,impact}$ (λ) can be determined by measuring the pass-by noise level $L_{peq,tp}$ from a vehicle with and without a rail joint. The total effective roughness for the pass-by without joint $L_{R,roll}$ must also be determined. The normalised impact roughness level $L_{R,impact,nl,i}$ for one joint per 100 m is then obtained in one-third octave frequency bands as

$$L_{R,impact,nl,i} = L_{R,roll,i} + L_{peq,tp,impact,i} - L_{peq,tp,roll,i} - 10 \lg (N_{ax}/ \ell) - 20 \qquad (4)$$

where N_{ax} is the total number of axles measured in the pass-by and ℓ is the total length of the train. The impact roughness as function of wavelength λ, $L_{R,impact}(\lambda)$, is obtained by frequency to wavelength transformation as described in CEN TR16891. It is averaged arithmetically over all the pass-bys. Different impact roughnesses may be found for track joints, points and crossings, as the geometry and impact amplitude may vary. Impact noise is typically at track and axle heights.

3.5 Curve squeal

If squeal is audible, or present in a spectrum as tones, but is not detectable in one-third octave band analysis, it need not be considered. If squeal is to be included, for example due to observed occurrence or particular critical situations, then the source level is determined from at least five pass-by measurements at two to three characteristic speeds with audible, occurring squeal. The average level obtained may be reduced by a probability of occurrence, for example by -3 dB for 50%. The specification of site requirements and differences in calculation models is under review.

3.6 Bridge noise

Bridge noise is defined as the rolling noise radiated by any track support structure in excess of the noise radiated at the track at either end of the bridge. The source level due to a bridge depends on the wheel/rail roughness, the rail type and its fastening on the bridge deck, the deck and bearing structure, shielding elements and the acoustic characteristics of the space underneath the bridge, which may further amplify the bridge noise. The track on the bridge may have different support and fastener systems and different rail roughness to the adjacent track.

The sound pressure level from the bridge will be recommended to be measured at 7.5 m from the track centreline at right angle to the bridge, if possible at its middle. If this is impractical, measurements may be taken at greater distance, taking propagation characteristics and background noise into account and correcting for these. If the transfer function of the whole bridge including the track is to be determined, at least five pass-bys of different trains at different speeds are to be taken without measurements along the adjacent track. If roughness is not taken into account, then three to five pass-bys of each train category relevant to the traffic composition, and speed shall be taken, both on the bridge and along the adjacent plain track.

3.7 Braking noise

Braking noise includes screech and other equipment noise that may occur during braking to standstill. It may also include extra noise occurring during deceleration at higher speeds, for example from some brake systems such as block brakes or energy recovery systems. If braking noise is audible or present in a spectrum as tones but is not detectable in one-third octave band analysis, it need not be considered.

Braking noise is typically attributed to axle source height.

Source level for braking noise following EN ISO 3095

The sound pressure level, $L_{eq,tp}$, determined according to EN ISO 3095 may be used to estimate the sound power level for noise of braking to standstill. This result is only applicable to braking down to standstill from 30 km/h. If braking noise is measured at other sites for practical reasons, the conditions in EN ISO 3095 should be followed where possible. The microphone positions should be at or near the position where the train actually brakes, and where the highest sound levels may be expected.

Source level for braking noise at speed

If source levels for braking noise from higher speeds are required, then measurements should be taken following the EN ISO 3095 constant speed test but with the train braking during the pass-by. The speeds as the front and back of the train pass the microphone and the deceleration should be reported. At least three braking pass-bys should be measured for speed ranges 60 to 100 km/h and for 100 to 160 km/h (depending on train type). If the difference with constant speed noise level is less than 3 dB(A), the braking noise at speed may be disregarded.

3.8 Aerodynamic noise

Aerodynamic noise is most relevant for high speeds, typically above 250 km/h, and is due to multiple sources at the head and rear of the train, under the train, at inter-coach spaces, pantographs and their recesses. As aerodynamic noise is often mixed with rolling noise and traction noise, separation techniques are required to distinguish them. An example is given in [13], using the total rolling noise transfer function.

Sound pressure is measured as in EN ISO 3095 at constant speeds. Type test spectra at maximum and other speeds may be used. The spectrum of the total sound pressure level is compared with that calculated from the combined roughness and total rolling noise transfer function for the particular train-track combination. The total noise of all aerodynamic sources is then constructed from the parts of the spectrum which exceed the calculated rolling noise spectrum by more than 2 dB. In the frequency bands where this limit is not exceeded, aerodynamic noise is assumed to be 7 dB or more below the rolling noise level.

Aerodynamic noise is typically attributed to axle source height, middle, roof and pantograph heights.

4. NON-NORMATIVE ANNEXES

4.1 Methods to determine combined effective roughness

Rolling noise is generated by the combined effective roughness. It consists of the energy sum of wheel and rail roughness filtered by the contact patch. A representative value for the combined effective roughness in calculation schemes can be determined from measurements. The roughness can be obtained directly, by means of measuring the rail and wheel surface profiles and calculating the combined effective roughness. This allows the roughness characteristic of different tracks or vehicle types to be combined in prediction from measurements that have not been made of them in combination. Alternatively, the combined effective roughness for a vehicle-track combination can be measured indirectly by measuring rolling noise and/or rail vibration and inferring the combined effective roughness using a model inversely. Whether to use the direct or indirect measurement method may be determined by practical considerations such as the availability of long-record rail roughness measurement equipment or access to track or vehicles. Indirect measurements may be made for many trains once a track site is instrumented but this obviously samples only one track.

Direct method requiring track and vehicle possession

Methods that measure the roughness directly on the rail surface must be used in combination with methods directly measuring the wheel roughness. The measurement method and requirements for the instrumentation are covered in EN 15610:2019 on rail and wheel roughness measurement. The method of combination including the effect of the length of the contact patch is described in annex C of EN15610:2019.

Indirect method using rail vibration – trackside method

A procedure for trackside indirect measurement method is described in CEN/TR 16891:2016 [12] based on [14]. This method is used to determine the combined wheel-rail roughness (and track decay rates) from rail vibration during the pass-by of a train.

Survey methods

Vehicle-based equipment for surveying long stretches of track is becoming available. This may measure the rail roughness directly or indirectly. These survey methods require a separate measurement of wheel roughness.

4.2 Calculation of sound power from sound pressure

Sound power source terms, or effective sound power, can be determined from pass-by sound pressure measurements. This involves the inverse use of a propagation calculation from the moving source to the line-side microphone. An assumed source directivity may be included in the calculation. The instantaneous sound pressure level $L_{p,i}$ in frequency band i due to each point source with (effective) directional sound power $L_{W0,dir}$ is obtained from

$$L_{p,i} = L_{W0,dir,i} – A_{div,i} – A_{ground,I} \qquad (5)$$

for each source type, height and frequency band. Integration over all positions of the pass-by is required to obtain a time-averaged sound pressure level.

$L_{W,0,dir}$ is the directional sound power level of the specific noise source of a single vehicle. A_{div} is called the free field term and represents the geometrical spreading. At the short distances to a trackside microphone, atmospheric effects are negligible.

The integration of the propagation term over the pass-by of the source with sound power W(t) (from t = 0 to t_p) with instantaneous distance r(t) is straightforward for the free-field term considered in isolation, for example, for a single omnidirectional source,

$$L_{peq,tp} = 10 \lg \{ (1/t_p) \int [W(t)/(4\pi r^2(t)W_0)] \, dt \} \qquad (6)$$

and for constant W, the sound power per unit length is:

$$L_W' = L_{peq,tp} + 10 \lg (2\pi r) - 10 \lg (\arctan(\ell_{veh}/2r)) \qquad (7)$$

A_{ground} is called the ‘excess attenuation’ and is more complicated to calculate. It accounts for the effect of the reflection from the ground compared to a free field. Generally, this will be + 6 dB at low frequency because of the addition of the reflected amplitude, then at a certain frequency a dip in the spectrum of A_{ground} occurs because of the path length difference between the direct and reflected paths. The frequency at which the dip and subsequent peaks and dips in A_{ground} occur depends on the site geometry and the absorption properties of the ballast and ground. At high frequency the excess attenuation should tend towards 0 dB.

Calculations of A_{ground} should take account of the effect of ballast and ground reflective properties at the patch of surface involved in the reflection (‘Fresnel zone’). In some geometric cases a path of diffraction over the ballast edge and subsequent reflection in the ground beyond may also have to be taken into account depending on the geometry of the site. Many texts cover this subject, for example reference [15].

The Swiss sonRail project [3] conducted experiments using a calibrated omnidirectional sound source fixed to a wagon at a height of 0.5 m. This was rolled a distance of one vehicle length past a microphone at 7.5 m. This experiment was conducted at many sites of differing geometry and ground conditions and comparisons were made between the average excess attenuation during the pass-by and calculations. Reference [3] also provides measured values of the ballast and ground reflection properties in terms of flow resistivity. The exercise showed that it would be very difficult to obtain satisfactory excess attenuation terms by site measurement.

Modelling by the current authors has indicated some of the guidelines for calculations that need to be given in the new standard. For example, the often used ‘locally reacting ground’ approximation in the reflection calculation is inadequate for modelling the ballast. Because of the reflection dip, an excess attenuation term inaccurately calculated might amplify an erroneous one-third octave band leading to significant error in the overall sound power. The use of both the 1.2 m and 3.5 m microphone heights at 7.5 m is therefore suggested to make the estimate of sound power more robust.

In the propagation model, a particular issue arises with rail noise radiation which usually dominates the spectrum of rolling noise sound power (i.e. over that of the sleepers or the wheels). Environmental noise propagation models assume that sources are point sources with an associated directivity function. However, since the wavelengths of vibration in the rail are longer that the wavelength of sound in air, in the frequency range where the rail is the main noise radiator, the rail is not a point source radiator but a coherent line source radiating cylindrical, not spherical, wave fronts [16]. The near-dipole directivity suggested for rolling noise in the methods should therefore be treated with care. The directivity function is necessary to force a realistic slope of rise and fall of the time history of L_p as the train approaches and leaves the microphone location. In reality, because the sound radiates from the rail perpendicularly to its axis in the frequency range where the rail source dominates (see Figure 10 of [16]), not radially from a point, the rise and fall in the time history is actually due to the decay of vibration along the rail, not an angular dependence of radial radiation. The effects of this mismatch between the physics of rail noise radiation and the necessary assumption of point-to-point propagation models may be small as the models are used with continuous lines of L_{eq} source from traffic flows and predictions are made for L_{eq} as the vehicles move all along the route past the receivers. However, the effect in the calculation for the estimation for sound power is more of concern as propagation calculations are used inversely and at close range. Sound sources other than the rail, such as traction noise and aerodynamic sources are not affected by this problem.

It must be emphasized that, since there are many alternatives in the methods and approximations implemented in different propagation software there is no single precise answer to the estimation of the excess attenuation term. However, apart from the reflection dip, the magnitude of the excess attenuation term is not very large. In general however, the need to estimate sound power terms from sound pressure with a very limited number of microphone positions is a significant cause of uncertainty in the sound power results.

4.3 Separation methods for rolling noise of vehicle and track

The measured rolling noise sound power must be split into a part radiated by the track and a part radiated by the vehicle. For this, specific methods are required which can provide a distribution function for track D_{TR} and vehicle D_{VEH}. The energy sum of these should be 0 dB in each frequency band. They are applied to the total sound power transfer function as follows:

$$L_{HWR,n,TR,i} = L_{HWR,n,tot,i} + D_{TR,I} \quad (8)$$

$$L_{HWR,n,VEH,i} = L_{HWR,n,tot,i} + D_{VEH,I}\ , \quad \text{and } 10^{DTR,i/10} + 10^{DVEH,i/10} = 0 \quad (9)$$

Separation based on calculation

If calculations from TWINS or a similar rolling noise model are available, the distribution functions are readily obtained from the track (rail + sleeper) and vehicle (wheel + superstructure) contributions (see [17]).

Separation based on measurement

A distribution function may also be estimated from measurement. A ‘reference vehicle’ method determines the track contribution using a reference vehicle with low sound radiation from the wheels (small and/or well damped wheels). The vehicle contribution may be estimated from the difference between the total spectrum and the track contribution. Another method eliminates the vehicle by making stationary vibro-acoustic response measurements on the track using an impact hammer or a loudspeaker (reciprocally). For a review of methods see [17].

Separation based on external reference

If no calculation or measurements are available, a known distribution curve may be used, obtained from data of comparable wheel-track combinations.

4.4 Specific environments

This refers to measurements necessarily performed in conditions outside those specified in the normative text such as around stations, or using unsupervised or automated monitoring systems. Such monitoring requires stringent data selection to avoid invalid data.

4.5 Transposition between train and track types

Transposition between train and track types refers to the application of existing measurement data from a particular train and track type to another. This is already applied in practice as new train types may be attributed to an existing train category in a prediction model. It goes a step further to convert source data from one wheel or track type to another, based on calculation, as investigated in the Acoutrain project [18].

5. CONCLUSIONS

A new CEN standard is under preparation for the measurement of source terms for railway noise prediction models, especially CNOSSOS, IMAGINE and similar models using transfer functions for rolling noise, but also for other national models. It provides guidelines on how to acquire measured sound pressure data from in-service trains and how to convert these to source terms, also covering combined roughness and transfer functions, source separation and attribution to source height. The content presented here is preliminary and subject to revision.

6. ACKNOWLEDGEMENTS

This work has been supported by the Dutch National Institute for Public Health and the Environment (RIVM), which is gratefully acknowledged.

7. REFERENCES

1. *Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council.*

2. M.G. Dittrich: *'The IMAGINE Model for Railway Noise Prediction'*, Acta Acustica united with Acustica, Vol. 93 (2007) 185 – 200.

3. *Sonrail Lärmberechnung Eisenbahn, Projectdokumentation,* Swiss Confederation, 2010 (www.bafu.admin.ch).

4. *Reken- en meetvoorschrift geluid 2012 SRM II* – Bijlage IV (*Dutch calculation method for railway noise SRM II*). Regulation IENM/BSK-2012/37333, 12 June 2012.

5. *Schall03: Sechzehnte Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verkehrslärmschutzverordnung - 16.BImSchV),* 2014.

6. NMPB 2008, France (*French road and railway noise calculation model*)

7. Nord2000 (*Scandinavian road and railway noise Calculation Model*)

8. *CEN Draft standard Railway Applications - Acoustics -Measurement of source terms for environmental noise calculations,* CEN TC 256 Work Item 00256879, version January 2019.

9. *EN ISO 3095: 2013 Acoustics - Railway applications - Measurement of noise emitted by railbound vehicles.*

10. *Commission Regulation (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock — noise'.*

11. *Technische Regeling Emissiemeetmethoden, (Technical Regulation for Emission Measurement Methods),* CROW, The Netherlands, 2004/2006.

12. *CEN/TR 16891:2016 Railway applications. Acoustics. Measurement method for combined roughness, track decay rates and transfer functions*.

13. H.W. Jansen, M.G. Dittrich, *Separation of rolling noise and aerodynamic noise by in-service measurement of combined roughness and transfer functions on a high speed slab track*, Proceedings 10th IWRN, Nagahama, Japan, 2010.

14. M. H. A. Janssens, M. G. Dittrich, F. G. de Beer, C. J. C. Jones: *Railway noise measurement method for pass-by noise, total effective roughness, transfer functions and track spatial decay*. Journal of Sound and Vibration 293 (2006) 1007–1028.

15. K. Attenborough et al. *Sound propagation outdoors,* Spon, London 2006.

16. D.J. Thompson, C.J.C. Jones and N. Turner, *Investigation into the validity of two-dimensional models for sound radiation from waves in rails,* J. Acoustic Soc Am,113 (2003) 1965–1974.

17. D.J. Thompson et.al *Assessment of measurement-based methods for separating wheel and track contributions to railway rolling noise,* Applied Acoustics 140 (2018) 48–62.

18. H.W. Jansen, M.G. Dittrich, G. Squicciarini, D.J. Thompson, B. Betgen, *Transposition of Noise Type Test Data for Tracks and Vehicles,* Proceedings IWRN 11, Uddevalla, Sweden, 2013.