RailNoise: future-Proofing Norwegian noise calculations with new source data for Nord2000 and CNOSSOS-EU

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Abstract

The primary objective of the RailNoise project is to enable reliable railway noise calculations using the calculation methods Nord2000 and CNOSSOS-EU. This requires gathering source emission data for both methods representing all operational train classes currently in regular use, and addressing limitations within standard CNOSSOS-EU. The noise measurements are based on ISO 3095/NS 8177 but adapted for measuring in-service trains on operational railway lines. Computational back-propagation techniques are applied to account for locally varying ground impedance and to derive absolute sound power levels. This paper presents the measurement methodology, the back-propagation process, and the process of converting the measured emission data into source data.

Keywords: *railway noise, acoustic source model, cnossos-eu, nord2000*

1. Introduction

Transportation noise is one of the most widespread environmental challenges in Europe, associated with stress and sleep disturbance, and cardiovascular diseases [1]. Railway noise is an important contributor, and is expected to increase due to European transport policies actively promoting the transfer of road and air traffic to rail, which raises traffic volumes. In addition, urban planning is increasingly based on transport-oriented development policies that promote establishment of residences near transport corridors and hubs, further increasing the population exposed to transport noise [2].

Reliable prediction of railway noise is essential to both strategic noise mapping [3] and planning of new infrastructure, as well as urban development near existing infrastructure.

Railway noise methods rely on representative source emission data. For the Norwegian railway network, the available source database has several shortcomings. Much of the existing data is based on older measurements and does not fully represent the current train fleet or present wheel and rail conditions.

The RailNoise project was initiated and is an ongoing project aiming to establish updated source emission data for railway noise calculations in Norway for both CNOSSOS-EU and Nord2000. The main objective of this work is the development of a practical methodology for deriving CNOSSOS-EU source parameters from measurements performed on operational railway lines. The methodology is specifically designed for Norwegian conditions, where measurements are often performed at locations that do not fully satisfy standard reference-track requirements.

This paper presents the measurement methodology, the back-propagation procedure, and the process used to convert measured railway noise into source data for both Nord2000 and CNOSSOS-EU.

2. Background

The Environmental Noise Directive (END) [3] obliges all EU and EEA member states, including Norway, to produce strategic noise mapping for major railways and agglomerations. To ensure comparability between countries, the CNOSSOS-EU method was made mandatory for all strategic noise mapping from 1st January 2019 [4]. It is therefore necessary to establish source data for Norwegian trains to be able to do calculations with the CNOSSOS-EU method.

In Norway, the national guideline and regulation for transport noise is defined in T-1442 [5]. Although the Nordic prediction method, Nord96, is currently the

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most commonly used method for railway noise assessment, there is an ongoing transition towards more modern calculation methods. Both CNOSSOS-EU and Nord2000 are candidates for future railway noise assessments in Norway.

The RailNoise project was initiated to address limitations in the existing source database for Norwegian trains. The available source data are partly outdated and do not fully represent the current train fleet or operating conditions. The project aims to establish updated source emission data that can be used consistently in both CNOSSOS-EU and Nord2000 calculations, and to develop methodologies for deriving reliable source data for future train types and operating conditions. The overall objective is to reduce uncertainty and improve the accuracy of noise predictions.

3. Source model

3.1 CNOSSOS-EU and Nord2000

Noise from railways is typically modelled as a series of point sources or line sources. The source model describes the emitted sound power level (Lw), while the propagation model describes how sound propagates from source to receiver.

CNOSSOS-EU and Nord2000 are two established noise calculation methods in Europe. CNOSSOS-EU (Common Noise Assessment Methods in Europe) was developed by the European Commission as a harmonized framework for environmental noise assessment across Europe (END) [4]. Nord2000 was developed jointly by research institutions from the Nordic countries and provides a detailed physical description of sound propagation [6]. Both methods treat source emission and sound propagation separately and include effects such as geometrical spreading, atmospheric absorption, ground effects, reflections, and screening by terrain and buildings. The methods differ in propagation modelling; Nord2000 is a more complex method that treats meteorological conditions, diffraction, and ground interaction in more detail, and is widely regarded as a state-of-the-art engineering method for environmental noise prediction.

CNOSSOS-EU uses a simpler and more empirical propagation model designed primarily for large-scale strategic noise mapping and the calculation of long-term noise indicators such as Lden. This makes the method easier to apply, but generally less detailed than Nord2000.

3.2 Rolling noise

For speeds typical of the Norwegian railway network, up to 200 km/h, rolling noise is the dominant source. Apart from sounds typical of each train class, it arises from the roughness of the contact band of the rails and wheels, which sets the wheels, rails and sleepers into vibration [7]. The emitted sound is modified by the

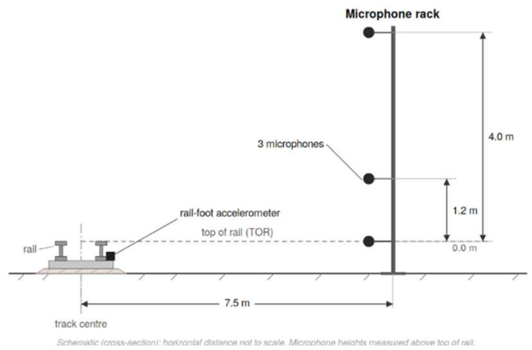

Figure 1. *Schematic cross-section of the measurement rig*

contact filter, which attenuates wavelengths shorter than the length of the contact patch.

Because radiated sound power depends on both the vehicle and the track properties – the same vehicle sounds differently on a smooth track than on a rougher one – rolling noise source data are only meaningful when the associated roughness is known. Roughness varies greatly across a railway network, from well-maintained to degraded rails, and from newly reprofiled wheels to wheels with rougher surface, from regular wear or from the use of cast-iron brake blocks.

3.3 From measurements to source data

The commonly used standards for measuring railway noise in Norway are NS 8177 [8] for immission, and ISO 3095 [9] for emission measurements. The measurement setup builds on both standards, but with adaptations to increase flexibility and efficiency. Rather than a defined reference track, measurements are carried out on an operational line with uncontrolled conditions; the traffic is mixed, the roughness and dynamics are variable, and the ground profile and hardness varies from site to site. As a result, the measured sound levels are influenced by local propagation effects and rail roughness it cannot be directly compared between locations. To obtain representative source data, the measured sound levels are converted to source sound power levels using back-propagation with the Nord2000 method.

4. Measurement setup

Initial measurement campaigns were performed to gather experience and to collect source data. The measurements were conducted at Leirsund, on the Gardermoen line (210 km/h, passenger trains only) and Huseby on the Oslo-Drammen line (130 km/h, mixed traffic) in Norway in 2024 and 2025. In this paper the results from Huseby are presented. These measurements mainly included passenger trains of 100-200 m lengths, travelling at speeds between 100 and 130 km/h. Equivalent sound pressure levels (Leq) were recorded for each pass-by event. Along with the sound recording, all pass-bys were recorded on video, for identification of the train set and calculation of the pass-by speed. Train lengths were gathered from Norske tog's train database [10], and meteorological conditions were taken from the Norwegian Meteorological Institute's free service.

The measurement setup, based on NS 8177 [10] and ISO 3095 [11] with adaptations to improve flexibility and efficiency, is shown in figure 1. Three microphones at 7.5 m from the track center were used: A lower microphone at 1.2 m and an upper microphone at 4 m above the rail top. A third microphone at rail top level was included as reference to improve the robustness of the analysis. In addition to the sound measurements, the rail roughness of the sites was measured using a CAT trolley.

5. Analysis and results

5.1 Measurements

Figure 2 presents measured pass-by levels for 25 BM75 train pass-bys at Huseby for microphone position 1.2 m over railtrack. Figure 3 shows the level differences between the measured results for the microphones located at 1.2 m and 4 m above rail level. The measurements show relatively small variation between individual pass-bys despite differences in train speed and operating conditions, indicating consistent acoustic behavior.

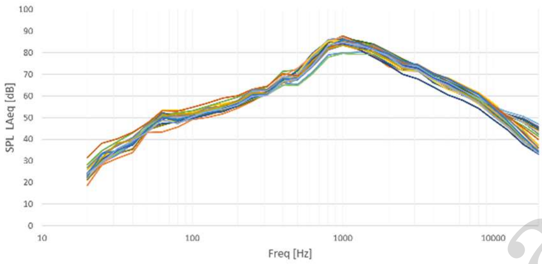

Figure 2. *Sound measurement, LAeq, at Huseby for passenger trains.*

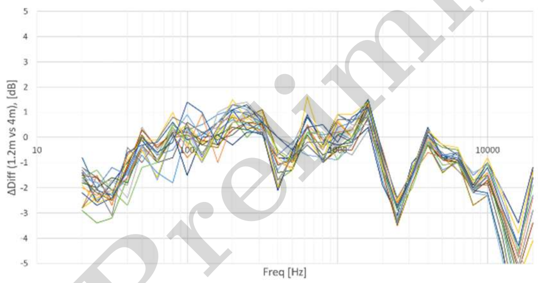

Figure 3. *Delta difference between the measured microphone positions 1 and 2 (1.2 m and 4 m over rail level).*

5.2 Ground impedance

Ground impedance between the source and receiver is a key parameter to understand when determining the sound power level with back propagation. In this study, sound propagation calculations were performed using the Nord2000 method, including the latest updates implemented in 2019. To determine the ground impedance parameters were performed by matching the measured delta sound levels between microphone 1 and 2 with the delta, Δ, calculated level for the same microphone position:

$$\Delta L_{calc}(Mic1_{calc} - Mic2_{calc}) \approx \Delta L_{meas}(Mic1_{meas} - Mic2_{meas})$$

In the calculation representative source heights were selected for the dominant noise-generating components of the train. Rolling noise is the dominant source from the train and was represented by two sub-sources: one located at 0.2 m above the rail, representing rail radiation, and one at 0.5 m, representing wheel radiation.

The ground impedance parameters (flow resistivity, porosity, structure factor, and layer thickness), for the different terrain surfaces were then adjusted iteratively until the calculated level difference agreed as closely as possible with the measured level difference.

The surface closest to the track is typically the most influential and is usually represented by the railway ballast. To obtain reliable results, it is essential that the terrain geometry and microphone locations accurately represent the actual measurement conditions. It should also be noted that the ground impedance parameters vary from site to site, since the properties of the ballast and embankment slopes differ between railway sections. Consequently, the calibration of ground impedance can be a relatively time-consuming iterative process.

5.3 Back propagation

Back-propagation is well known method to estimate sound-power level from a source. The method is described in Nordtest [11] [12] and can be used when the ground impedance and other acoustic properties that influence sound propagation between the source and the receiver are known.

The procedure involves different steps. The first step is to solve the equation of the sound propagation for two unknown positions. The sound propagation equation for a line source in a free field is described as.

$$L_p = L_w - 10\log(r) + A$$

Where Lw is the sound power level, r is the distance from the source to the receiver, and A is the attenuation term representing ground impedance, air absorption, and other propagation losses.

When the distance r is known and the sound pressure level has been measured, the equation can be used to estimate the sound power level Lw. When two receivers are available, this yields two equations with two unknown source sound power levels, Lw1 and Lw2.

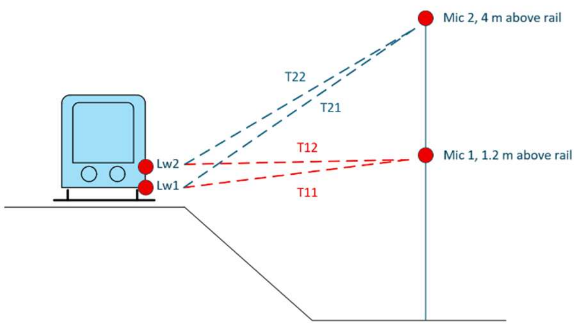

Figure 4. *Illustration of the transfer function paths used in the system of equations relating the sound sources Lw1 and Lw2, to the two microphone positions Lp1 and Lp2*

The figure illustrates the sound paths between the sources and the receivers, where T11 and T12 are the transfer functions between sources 1 and 2 and receiver 1, while T21 and T22 are the transfer functions between sources 1 and 2 and receiver 2. Expressed the first equation in terms of squared sound pressure we get:

$$P = W/T$$

By expanding the system of equations:

$$I: P1 = W1/T11 + W2/T12$$
$$II: P2 = W1/T21 + W2/T22$$

In matrix-format:

$$\begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{T_{11}} & \frac{1}{T_{12}} \\ \frac{1}{T_{21}} & \frac{1}{T_{22}} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \end{bmatrix}$$

Where the solution is

$$P = A \, x \, W$$

$$W = A^{-1} \, x \, P$$

Result from this exercise, W = W1 + W2, give us sound power level per meter train, L'w.

5.4 Adaptation and application

5.4.1 CNOSSOS-EU

One of the objectives of this study was to develop a practical method for deriving new emission data for use in CNOSSOS-EU.

CNOSSOS-EU states that the noise emitted by a train is represented by several components: train speed, rail roughness, wheel roughness, the transfer function for the rail, the transfer function for the wheel, the transfer function for the superstructure, and the contact filter. In the present analysis, only the conditions that were actually measured in the field are of relevance.
According to Cnossos-EU, aerodynamic noise becomes relevant for train speeds exceeding 200 km/h [7]. Since all trains analysed in this study run well below that, aerodynamic noise was disregarded. Furthermore, the measurements conducted did not involve superstructures such as bridges or viaducts, which were therefore disregarded as well.

As illustrated in Figure 5 (highlighted with a red dashed circle), the focus of the subsequent work is the sound power generated at the wheel–rail interface. The railway source level will therefore consist of a combination of rolling noise and train noise: Lw0tr (sound power from the rail) and Lw0veh (sound power from the vehicle). Cnossos-EU describes two source heights located at 0.5 m and 4.0 m above the railhead. The 0.5 m source height represents noise from the wheel and rail, while the 4.0 m source height is used to add sources at other heights, e.g. traction, exhaust or HVAC fans. In this work, the train noise source has been treated as a single component, assumed primarily to originate from the wheel–rail contact at 0.5 m above the rail. This is consistent with the assumptions underlying the back-propagation applied in earlier analyses, where the source level was estimated from

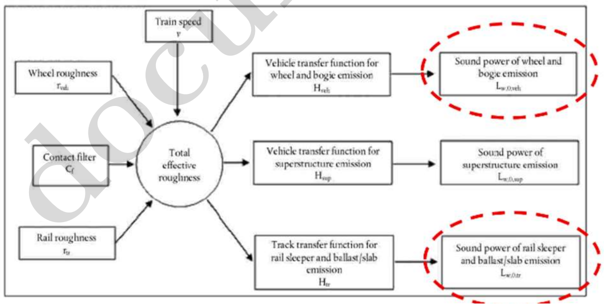

Figure 5. *Graphical representation of which parameters contribute to the sound effect level from railways. Red dotted circle shows the two parts that contribute to the sound effect level in the analysis. Figure taken from Cnossos-EU.*

measurements dominated by this noise component. The method consists of the following parameters and can be understood as follows:

Table 1. *Description of relevant symbols and terms.*

Symbol	Term	Interpretation
R	$(R_V + R_T) \cdot A$	Total effective vibration (after attenuation by the contact filter)
W_V	$R \cdot T_V \cdot n$	Radiated sound power from the vehicle/ wheel/bogie system (n = number of axles)
W_T	$R \cdot T_T \cdot n$	Radiated sound power from the track (n = number of axles)
W	$W_V + W_T$	Total radiated sound power from both the vehicle and the track

This leads to the following equation:

$$\boldsymbol{W = n \cdot A \cdot (R_V + R_T) \cdot (T_V + T_T)}$$

Where R represents the roughness, A the contact filter and T the transfer function. "$_V$" denotes the *Vehicle* component (coach, wheel, or bogie), while "$_T$" denotes the *Track/Rail*. The result gives the total sound power for the whole train. Sound power per meter train is then obtained using the following expression: $W' = W/\text{Trainlength}$

Selection of representative CNOSSOS-EU input parameters can be challenging. Appendix G in CNOSSOS-EU provides a set of standard values that may be used as a starting point. In this study, representative parameter values were selected in collaboration with Bane NOR based on current knowledge of the Norwegian train fleet. The transfer functions were subsequently adjusted to obtain the best agreement between CNOSSOS-EU source levels and source levels derived from Nord2000 back-propagation of the measurement data.

It is important to note that CNOSSOS-EU and Nord2000 results must be expressed in the same sound power unit before comparison. In this study, sound power levels per meter of train were used. Since CNOSSOS-EU calculates the sound power level of an entire train, a conversion was required prior to comparison. Table 2 summarizes the parameter values applied for passenger train.

Table 2. *Description of relevant symbols and terms.*

Symbol	Term	Value
A	Contact filter	N25 (25 kN axle load, 920 mm wheel diameter)
T_T	Track transfer function	Based on ID4 from Appendix G. Adjusted the values against the results from back-propagation.
T_V	Vehicle transfer function	Adjusted against the results from back-propagation.
R_V	Vehicle roughness	Passenger disc brake (Appendix G)
R_T	Rail roughness	Site-specific measurements or representative values

As an example, source data for the BM75 passenger train were derived using the N25 contact filter, representative of a typical Norwegian passenger train. Wheel roughness was set to the standard Passenger disc brake spectrum, while rail roughness was based on measurements from the test site. The transfer functions were then adjusted to obtain the best agreement with sound power levels derived through Nord2000 back-propagation.

Previous studies have shown that wheel radiation typically dominates above 2 kHz, rail radiation in the mid-frequency range, and sleepers at low frequencies [13]. Similar trends were observed in the back-propagation results obtained in this study.

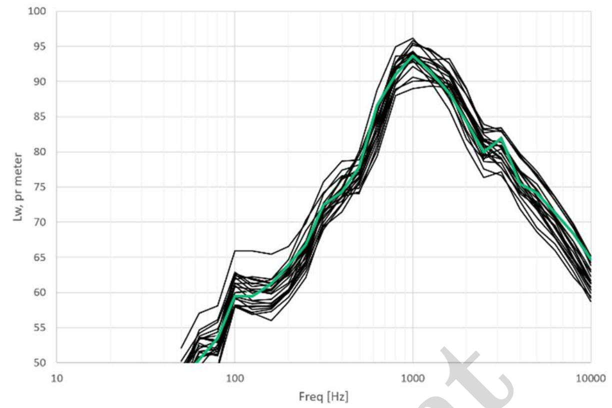

Figure 6. *Green line express the new emission data for CNOSSOS-EU, while the other black curves show the calculated Lw value for the different passby calculated with back propagation.*

Consequently, the vehicle transfer function was primarily adjusted at higher frequencies, while the track transfer functions were mainly adjusted at lower frequencies. The green curve in Figure 6 shows the resulting CNOSSOS-EU source emission data after adjustment for BM75 at Huseby.

5.4.2 Nord2000

To derive new source data for Nord2000 is relatively straightforward and follows the methodology described in [14]. Previously conducted source measurements can be combined with calculated transfer functions. The model parameters a and b are determined through regression analysis as described in the Nord2000 method. Transfer functions are calculated specifically for the relevant location and geometry. The ground impedance is determined using the same procedure as described in Section 5.2. The model parameter 'a' represents the slope (the coefficient multiplied by the logarithmic speed term lg(v/100), determining the speed dependence), while 'b' represents the characteristic sound power level per meter of train at the reference speed of 100 km/h.

As the model is derived directly from pass-by measurements, its validity is limited to the conditions under which the measurements were performed. In particular, the source data do not explicitly account for wheel and rail roughness.

6. Discussion and conclusion

A practical procedure for deriving CNOSSOS-EU and Nord2000 source parameters from railway noise measurements has been developed. The approach combines pass-by measurements on operational railway lines, Nord2000-based back-propagation, and an iterative adjustment of CNOSSOS-EU parameters to obtain source models representative of Norwegian conditions.

The procedure provides a framework for selecting roughness spectra, contact filters, and transfer functions and adapting them to match back-propagated sound power levels. This addresses a key challenge in establishing CNOSSOS-EU source data for train categories that are not represented by existing source databases.

The approach has been adapted to Norwegian measurement conditions, where suitable measurement locations are often limited. Our findings show that measurements from operational railway lines can be used to derive source data, provided that local propagation effects are adequately accounted for.

One challenge that was observed was the limited difference of ground impedance between the elevated microphone positions. Since both microphones are located above the ground surface, the difference in ground effect may be relatively small, which increases the sensitivity of the back-propagation procedure. Although the Nordtest methodology recommends placing one microphone close to the ground, this is often difficult for railway measurements due to shielding effects from the ballast and track structure.

Future measurement campaigns will be conducted to refine the methodology, assess variability between train types and locations, and expand the dataset to train classes representing all operational trains, compatible with both Nord2000 and CNOSSOS-EU. Roughness measurements using CAT and track decay rate measurements will also be included at measurement sites. Future work within the RailNoise project will also include the development of classifications for train types and track conditions. This will establish representative source categories and improve the railway noise prediction in Norway.

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