A simplified approach for evaluating noise impact from high-speed lines

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ABSTRACT

Sweden is now considering new railway lines typically adapted to high speeds up to 320 km/h. Noise impact from high-speed lines and noise mitigation measures where required becomes urgent to be investigated. As the current calculation model for railway noise used in Sweden is not applicable for the purpose, the Swedish Transport Administration decides to prepare a new noise assessment method for high-speed lines. This new noise assessment method is not necessary to be comprehensive because noise evaluation along high-speed lines is mainly oriented.

In this paper a simplified source module is described. The simplification has three folds of meanings: (1) only dominant noise sources, rolling noise and aerodynamic noise, are considered; (2) a classification of train types is made based on noise emission strength, not on the physical parameters; (3) the effect of noise measures (such as rail/wheel dampers, sleeper pads or mats, wheel skirts, etc.) is integrated into a single parameter, additional noise reduction (given either in total level or in spectrum). Moreover, the effect of noise barriers along a high-speed line is left to be handled by the sound propagation module.

Keywords: High-Speed Railway Noise, Source Model, Classification of Train Types I-INCE Classification of Subjects Number(s): 13.4, 52.4, 76.1.2

1. INTRODUCTION

Sweden is now considering new railway lines typically adapted to high speeds up to 320 km/h. It is necessary in the planning phase before starting the construction to evaluate noise impact from the high-speed lines and to estimate noise mitigation measures where required. Thus, the Swedish Transport Administration (Trafikverket) decides to prepare a new noise assessment method for the purpose, because the current one used in Sweden is not applicable for high-speed lines. SP Acoustics was consulted and a three-month long project was launched for preparing the new method.

The project is divided into two parts. In the first part three typical noise assessment methods in EU (Nord2000, CNOSSOS-Harmonoise, NMPB2008) have been reviewed (1); this review provides a solid basis for the Swedish Transport Administration to choose the most suitable parts of these methods for building up a new Swedish noise assessment method. In the second part the focus is put on preparing a new source module for high-speed railway noise, as the Nord2000 model has already been chosen as the propagation module of the new method. Desired calculation quantities have also been considered because they have some impact on building up a source module. For example, in order to calculate train pass-by maximum level, a classification based on train types instead of on vehicle types will be favoured.

In general, a noise assessment method consists of three parts: a propagation module which is for handling sound propagation under different conditions, a source module which is for specifying the noise sources and the source positions and determining the directional sound powers, and a calculation module which is for calculating desired acoustic quantities as well as estimating noise mitigation measures where required. In this paper the focus will be on describing the source module which was prepared typically for high-speed railway applications.

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2. THE SOURCE MODEL FOR HIGH-SPEED RAILWAY NOISE

2.1 General Description

Railway noise has multiple sub-sources, either localized ones such as locomotive traction noise or pantograph noise, or the ones distributed along the whole train such as rolling noise or aerodynamic noise around the bogies. Thus, railway noise will be described by source lines and/or point sources, with directional sound power levels specified. A source line consists of a line of *incoherent* point sources, differing from a line source which consists of a line of *coherent* point sources. And, source positions are specified by representative lateral positions and heights, referring to the physical origins.

The three main noise types are traction noise (emitted from traction motors, cooling fans, gears and auxiliary equipment), rolling noise (through wheel-rail contact interaction) and aerodynamic noise (due to vortex shedding from wheels and pantographs, flow separations at train nose and tail, flow disturbances at edges and cavities). Other noise types are impact noise (at joints, points and switches, or due to out-of-round wheels), bridge noise, viaduct vibration noise, curve squeal noise, braking noise and braking squeal noise, noise from auxiliary equipment, etc. These noise sources are distributed over the height and length of the train, with directional sound powers of different strengths. For high-speed lines, rolling noise and aerodynamic noise are the two dominant noise sources, provided some contribution from the cooling fan noise (2).

A source module for railway noise should specify the important noise types, the representative source positions, the directional sound power levels, and make classifications of vehicle/train types, track types and driving conditions as well as define the related calculation procedures.

2.2 Source Positions

At high speed traction noise is negligible (while cooling fan noise which is usually categorised as a component of traction noise may have some effect on the total noise level (2)). And, on a high-speed line, other noise types such as curve squeal noise or impact noise are as believed irrelevant. For some high-speed lines noise emission from viaduct vibration may be relevant; while the most important noise types are always rolling noise and aerodynamic noise.

For strategic noise mapping, it is acceptable to put all source lines at the centre of the track. However, for detailed case studies exact source locations may be required, e.g. to study the shielding effect of near-track low noise barriers. Thus, the nearest rail was chosen as the lateral position for all the source lines/point sources, although for pantograph noise this position may be slightly worse than the centre of the track.

Two source heights (above the railhead) are specified for rolling noise: 0.01 m for rail/track vibration noise and 0.5 m for wheels' vibration noise. Here 0.01 m corresponds to 0 because in the calculation software of the Nord2000 model any source or receiver height less than 0.01 m will be treated as 0.01 m to avoid possible numerical difficulty. For aerodynamic noise, there are also two source heights specified: 0.5 m for the component around bogie areas and 5 m for the pantograph noise. By taking the source height 5 m instead of 4 m, pantograph noise is thought more important than other roof components of aerodynamic noise. In ref. (2) it was shown that other roof components of aerodynamic noise are comparable to pantograph noise; however, recent noise measurements made in Sweden (3) showed that pantograph noise predominates in the roof components of railway noise at high speed.

A source height of 0.5 m is specified for cooling fan noise because for high-speed trains these cooling fans are mounted on bogies. Thus, in total, three source heights (above the railhead), 0.01m, 0.5 m and 5 m, have been specified for calculating high-speed railway noise. There could be an extra source height for viaduct vibration noise when it contributes; the source height for it could be the center of the noise emission area.

2.3 Classifications

A classification of trains/vehicles in a noise source model is usually based on those important parameters which have significant effects on noise emission. Some parameters are related to roughness level (e.g. brake type or normally maintained rail) while the others will affect the response of a vehicle or track to a roughness-induced excitation (which is described by respective transfer function). For aerodynamic noise, there are currently no any parameters specified. (Note: By "high speed vehicle" it indicates that aerodynamic noise needs to be considered; however, not all types of high-speed trains have the same aerodynamic and acoustic characteristics.) Within this project, it was considered that a classification should help with noise calculation while not increase the burden in source data collection. Accordingly, a classification of noise calculation oriented is expected.

For high-speed trains the design of train nose and train tail, as well as the design of inter-coach spacing is important for good streamline behaviour of the train. Moreover, aerodynamic noise around a bogie depends not directly on the train speed but the mean flow velocity at the bogie which in turn depends on the train speed and the distance between the bogie and the train head. A measurement of flow velocity made in Japan showed that at the middle of fifth car (118.9 m from the train head) the mean flow velocity decreases to 42% of the train speed (4). Thus, it is understood as that aerodynamic noise around pantograph, train nose and train tail can be considered as local noise sources while aerodynamic noise around bogies depends also on the train length and the bogies' positions relative to the train nose. Therefore, for high-speed trains, a classification based on train types is favoured because if a train has been disassembled into individual vehicles the aerodynamic noise could not be properly defined.

A classification based on vehicle types can distinguish a locomotive from coaches, concerned with traction noise and possible difference in rolling noise. However, for specifying traction noise it has no problem to merge locomotive types into train types, such as a train with "diesel loco" or "electric loco" or "self-propelled". What left in a vehicle classification is to distinguish a locomotive from a coach based on their rolling noise emission. In general, a locomotive may have larger wheels and traction wheels may be rougher than trailer wheels. In other words, a locomotive may emit rolling noise a few dB more than a coach vehicle does. However, this is not always true even for passenger trains: some coach vehicles can emit rolling noise more than the locomotive does. Considering a noise mapping, it is usually the mean roughness level of a train that will be specified. Accordingly, if difference in roughness levels between coach wheels is not specified, then it does not always make a sense to distinguish locomotive rolling noise from the coaches'. Moreover, when necessary (e.g. for some case studies) one can specify a roughness distribution along a train. Thus, it has no problem, for a classification based on train types, to distinguish locomotive rolling noise from the coaches'.

In Sweden, maximum value of AF-weighted sound pressure level of train pass-by noise, L_{AFmax}, is an important noise indicator. Obviously, for calculating L_{AFmax}, a classification based on train types is favored. It seems that a classification based on vehicle types is noise mitigation oriented, which is neither convenient for noise calculation nor proper for high-speed applications.

Thus, put all these discussions together, we like to conclude that a classification based on train types is better than based on vehicle types, not only for handling high-speed railway noise but also for detailed case studies.

Moreover, passenger trains can have different wheel types (with a straight or curved web) and different wheel sizes. These two parameters should be considered in classification because they are important in determining the vehicle transfer function. These two parameters may be merged into some other parameter. And, if considering noise emission strength, not all high-speed train types are necessary to be distinguished; those train types which behave acoustically the same or comparable shall be put into the same category. For example, some TGV train types and some ICE train types may be put into one category if they behave acoustically the same. This is to say, a train classification may not intend to point out the differences between train types but focus on their acoustic characteristics, or simply, their noise emission strengths. Of course the relevant noise source data shall be obtained from validated field measurements, or based on manufacturer's product specification (the acoustical part) if the relevant information is provided.

Being noise calculation oriented, for high-speed trains, a classification based on noise emission strength becomes very simple, as shown in Table 1.

A classification of high-speed railway tracks was made by referring to the classification proposed in (5) while simplified as much as possible. As high-speed railways are constructed based on modern technology, also considering that there are no problem of joints or small curvatures for a high-speed line, a much simpler classification can be made for high-speed railways, as presented in Table 2. (Note: Some French experience (2) may suggest that for high-speed lines a very smooth rail running surface shall not be expected.)

By referring to Table 1, it can be understood that this classification of railway tracks is not oriented to specifying noise emission strength but to possible noise measures.

Driving conditions are used for specifying traction noise, and for specifying curve squeal noise where a sharp curve is relevant, or braking squeal noise when braking to (nearly) stop. Except cooling fan noise which may still have some influence on the total noise level at high speed (2), traction noise is only relevant at low speed including idling. And, for high-speed lines, a sharp curve is irrelevant. Thus, driving conditions are classified following these considerations, as shown in Table 3.

Table 1 – Classification of high-speed trains

Train category	Explanation
N	Normal. Trains in this category just fulfils the TSI requirement for noise: 92 dB(A) at the standard receiving position 25 m to the track center and 3.5 m above the railhead. With 1 dB tolerance.
Q	Quiet. Trains in this category shall be at least 3 dB quieter than those in category N.
O	Other. Trains neither in category N nor in category Q.

Table 2 – Classification of high-speed railway tracks

Digit	1	2
Descriptor	Types of track base	Indicator for railhead roughness
	B (ballast)	N (normally maintained)
	S (slab)	O (other situations)
	V (viaduct)	
	T (tunnel)	
	O (other, e.g. bridge …)	

Table 3 – Classification of driving conditions

Speed range	Category	Specification
High speed (> 200 km/h)	-	Irrelevant
Conventional speed	1	On a sharp curve
	2	Others
Low speed (< 50 km/h) including idling	1	On a sharp curve
	2	Braking to (nearly) stop
	3	Cruising or decelerating
	4	Accelerating
	5	Idling

2.4 Directional sound power level

Based on the work presented in (5), in general, directivity of railway noise has two components: the directional effect originated in source emission and the directional effect due to motion of the source (the Doppler Effect). In ref. (5) the former directional effect was described by “source term” in the formulation and the latter by “motion term”.

The angles are defined in Figure 1. As two source heights have been specified for each noise type (of rolling noise and aerodynamic noise), the respective horizontal and vertical directivity functions are given by equations (1) – (9).

The horizontal directivities for rolling noise are:

$$\Delta L_{\mathrm{wheel}}(\varphi) = 10\lg[0.4 + 0.6 * \cos(\varphi)] - 20\lg[1 - M * \sin(\varphi)] \tag{1}$$

$$\Delta_{\mathrm{rail}}(\varphi) = 10\lg[0.001 + 0.999 * \cos^2(\varphi)] - 20\lg[1 - M * \sin(\varphi)],\ f \geq 400\ \mathrm{Hz} \tag{2}$$

$$\Delta_{\text{track}}(\varphi) = -20\lg[1 - M * \sin(\varphi)],\ f < 400\ \text{Hz} \tag{3}$$

where $M = v/c$ is the Mach number, v is the train speed and lg denotes for $\log_{10}$.

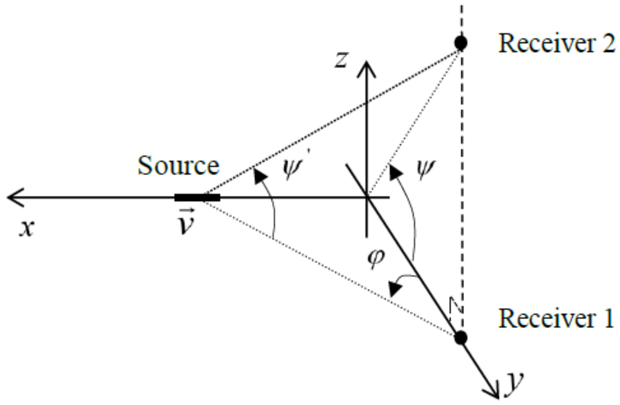

Figure 1 – *Definition of angles:* φ *is a horizontal angle in the x-y plane and relative to the y-z plane;* ψ *is a vertical angle in the y-z plane;* ψ' *is a vertical angle in a vertical plane containing the receiver and the source (or the centre of the source line); both* ψ *and* ψ' *are relative to the x-y plane.*

The horizontal directivities for aerodynamic noise are:

$$\Delta L^{A}_{\text{pantograph}} = 10 * \lg\left[0.006 + (1 - 0.006) * \cos^2(\varphi)\right] - 40 * \lg\left[1 - M * \sin(\varphi)\right] \tag{4}$$

$$\Delta L^{A}_{\text{bogie}}(\varphi) = 10 * \lg\left[0.03 + 0.97 * \cos^2(\pi/2 - \varphi)\right] - 40 * \lg\left[1 - M * \sin(\varphi)\right] \tag{5}$$

However, for low frequency components (estimated $f \le 250$ Hz), there is

$$\Delta L^{A}_{\text{bogie}}(\varphi, f \le 250 Hz) = -40 * \lg\left[1 - M * \sin(\varphi)\right] \tag{6}$$

The vertical directivities for aerodynamic noise are:

$$\Delta L^{pantograph}_{vertical}(\psi) = 10\lg[0.4 + 0.6 * \cos(\psi - \pi/2)] \tag{7}$$

$$\Delta L^{bogie}_{vertical}(\psi) = 0 \tag{8}$$

As discussed in (5), the vertical directivities of wheel and rail noise can be simulated by a function of $10\lg[0.4 + 0.6 * \cos(\varphi)]$. However, the vertical directivity of total rolling noise depends also on the shielding effect of the train body and/or wheel skirts, as well as the near-track noise barriers where they presented. As these shielding effect varies with train type (and even with track section where near-track noise barriers are presented), a general vertical directivity function for total rolling noise was not specified because of lack of such data.

In ref. (6), a vertical directivity function was proposed for total rolling noise:

$$\Delta L^{R}_{vertical}(\psi) = (40/3) * \left[(2/3) * \sin(2\psi) - \sin(\psi)\right] * \lg\left[(f + 600)/200\right] \tag{9}$$

Today railway rolling noise can be properly predicted by advanced calculation software the TWINS (7). However, the TWINS is more research oriented. In engineering applications, the source data for rolling noise shall be collected using an engineering method, the indirect roughness method (8): By measuring the rail vertical vibration and the way-side noise of a train passage at typical speeds of 80 km/h and 160 km/h, the total roughness and total transfer function of the train-track system can be determined. Thus, the source data of rolling noise of the train-track system at other speeds can be calculated using the total roughness and total transfer function and the input parameter “train speed”.

The source data for aerodynamic noise shall be obtained also using an engineering method proposed in (9): (a) Measuring train pass-by noise at a typical high speed ($v_0 \geq 250$ km/h); (b) obtaining the source data of aerodynamic noise at this speed, $L_{W,aero}(f, v_0)$, by subtracting the rolling noise component from the total; (c) the source data of aerodynamic noise at other speeds can then be obtained by applying the spectrum shift, $f = f_0 * v / v_0$, and the speed dependence of the noise sound level,

$$L_{W,aero}(f, v) = L_{W,aero}(f * v_0 / v, v_0) + 60\log_{10}(v / v_0),\ \ f > 250\ \text{Hz} \tag{10}$$

$$L_{W,aero}(f, v) = L_{W,aero}(f * v_0 / v, v_0) + 40\log_{10}(v / v_0),\ \ f \leq 250\ \text{Hz} \tag{11}$$

2.5 Noise mitigation measure

Except noise barriers which will be handled by the sound propagation module, the effect of a noise mitigation measure shall be given in dB value, not in the type of the noise measure such as rail damper or wheel skirt. In this way, the uncertainty in noise measure will be deleted considering a possible variation of a few dB for the same type of noise measure. Thus, all applied noise mitigation measures except noise barriers will be integrated and described by a parameter “additional noise reduction”, given either in total level or in spectrum. For example, a noise reduction of 3 dB can be realized by different ways, such as by employing rail dampers and a low noise pantograph. Thus, in noise calculation, additional noise reduction of 3 dB will be chosen for all possible combinations of noise measures which produce a noise reduction of 3 dB.

3. DISCUSSION

In this paper the work steps for building up a source module of the new Swedish noise assessment method typically for high-speed railway noise are presented. As has been shown, a noise source module is not necessary to be comprehensive if only a special type of applications is considered. In other words, a source module for railway noise can be e.g. divided into three parts: one for high-speed trains, one for conventional trains, and one for low speed including idling situations. The source module for high-speed trains is relative simple then can be worked out quickly such as in a few months. Furthermore, a source module and a calculation module are not fully independent, because the two modules have impact on each other. For example, desired calculation quantities require proper classifications, while a dB-value description of noise measures will benefit noise calculations.

When considering a noise assessment method, the most important issue may be the balance between accuracy and calculation time. This issue is mostly concerned with a propagation module; however, it is not the case for this project because the Nord2000 propagation model has already been chosen as the propagation module. As discussed in the former section, a classification based on noise emission strength together with a dB-value description of noise mitigation measures will benefit noise calculations.

A classification based on train types is favored and a classification of noise calculation oriented is made. And, a classification based on vehicle types is thought noise measure oriented; it is neither convenient for noise calculation nor proper for high-speed applications because aerodynamic noise around bogie areas is related to the whole train, not only the bogies of individual vehicles. It is also not applicable when calculating maximum noise level of train passages.

The other consideration behind the modeling is that it should reduce, at least not increase, the burden in source data collection. Therefore, it is important to have classifications made properly: they shall be as simple as possible while not miss the important details. Moreover, to separate noise measures from other descriptors can be a choice if classifications are noise-calculation oriented.

A balance between accuracy and calculation time is the “rule” in choosing source heights. For rolling noise two source heights of 0.01 m and 0.5 m (above the railhead) are thought necessary and enough. And, for aerodynamic noise, 0.5 m is necessary which plus one of 4 m and 5 m will be enough. One can choose either 4 m or 5 m for describing the roof components of the noise type depending on what is favored. In the source module presented in this paper, 5 m was chosen as the second source height because pantograph noise is thought more important. Moreover, no source heights have been specified for viaduct noise; however, the center of the noise emission area could be an option if this noise type contributes.

How to carry out calculations is not intended to be discussed in this paper.

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