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Comparison of Five National Noise Emission Calculation Methods for Rail Traffic

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Abstract

This paper contains comparison of five European national noise emission calculation methods for rail traffic, including RMR – interim calculation method for EU.
KEY WORDS: *railway, rolling stock, noise, level, measurement, calculation, prediction method.*

1. Introduction

During last few decades the development of surface transport has lead to rapid increase of noise level, especially in the areas of high-speed motorways and railways.

Accordingly to the results of French, Dutch and German scientist estimation (Lambert and others, 1998) around 120 million people in Europe (more than 30% of total population) incur the influence of louder than 55 dBA (equivalent A-weighted) transport noise, and 50 million people incur the influence of louder than 65 dBA transport noise. Thereby, significant part of Europe's population suffers from transport noise which affects people's health and life quality.

Therefore, during last years European Union has paid big attention to the problems of noise and vibration experimental investigation on railway transport, railway noise propagation prediction, noise mapping and development of noise and noise source reduction methods.

In many European countries national methods for railway rolling stock noise propagation prediction were developed already. Yet, many countries still don't have their own national methods.

Before development of new method for railway rolling stock noise propagation prediction it is useful to try to adopt and use one of the existing ones.

This paper provides description and comparison of the following national railway rolling stock noise propagation prediction methods:

RMR (the Netherlands, interim model for EU), Schall 03 (Germany), ON S5011 (Austria), NMT (Nordic countries), CRN (United Kingdom).

In general, the calculation procedure can be divided into the following parts: train category description, location of source(s), basic sound parameters, reference distance, speed influence, track conditions.

2. Train Categories

2.1. RMR

In RMR trains are divided into the following railway vehicles categories (these are primarily differentiated on the basis of drive unit and wheel brake system):

2.1.1. Brake-padded passenger trains (also electrical motor mail vehicle).
2.1.2. Disk-braked and brake-padded passenger trains.
2.1.3. Disk-braked passenger trains.
2.1.4. Brake-padded freight trains.
2.1.5. Brake-padded diesel trains.
2.1.6. Diesel trains with disk-brakes.
2.1.7. Disk – braked urban subway and rapid tram trains.
2.1.8. Disk-braked Inter City and slow trains.
2.1.9. Disk-braked and brake-padded high speed trains.
2.1.10. Provisionally reserved for high speed trains of the ICE-3(M) (HAST East) type.

Vehicles not mentioned here are allocated to the next appropriate category based on their drive unit, wheel brake system or maximum speed.

2.2. ON S5011

In ON S5011 four train categories are considered: Intercity trains with block brakes, disc brakes, combinations; railcar fast trains 4010; tandem railcars 4020; goods trains with 2 locomotive types (electric, diesel).

No further specifications of train length or brake types.

2.3. SCHALL 03

In SCHALL 03 are considered 14 train categories: ICE, EC/IC, IR, D/FD-Zug, Eilzug, Nahverkehrszug, S-Bahn (Triebzug), S-Bahn (Berlin), S-Bahn (Hamburg), S-Bahn (Rhein-Ruhr), Guterzug (Fernv.), Guterzug (Nahv.), U-Bahn, Strasenbahn/Stadtbahn with specific values of maximum speed, average train length and percentage of wagons with disc brakes in the train.

2.4. NMT

In NMT typical trains from Norway, Sweden and Finland are considered.

Norway: standard passenger train, B 65 (passenger), B 69 (passenger), B 70 (passenger), standard goods train all with electric engines.

Sweden: standard passenger train, fast passenger train X2, passenger train X10, standard goods train, standard goods train with diesel engine, if nothing specified, with electric engines.

Finland: passenger train Sm, Passenger train Sr1, standard goods train.

2.5. CRN

Passenger trains with tread brakes, disc brakes, 2, 4, 6 or 8 axles; freight trains with tread brakes, disc brakes, 2 or 4 axles; diesel locomotive with steady speed, under full power; electric locomotives.

Location of sources:

RMR: In RMR up to four different sources are considered. There are two different sources for train categories 1 to 8:

At the level of the railhead and 0.5 m above railhead.

The source heights for category 9 are 0.5 m, 2.0 m, 4 m and 5 m above railhead.

SCHALL03: the source height is assumed to be at the level of the railhead.

ON S5011: the source height is assumed to be 0.3 m at the level of the railhead.

NMT: each octave band has its own individual source height as shown in the following table:

Table 1

Location of sources NMT

Octave band, Hz	Source height, m
63	2
125	1.5
250	0.8
500	0.3
1000	0.4
2000	0.5
4000	0.6

CRN: the source height is assumed to be at the level of the railhead [1].

3. Basic Sound Parameter, Reference Distance, Speed Influence

3.1. RMR

For the RMR the basis of the calculation is the sound power level per meter rail length for each source and each octave band between 63 Hz and 8 kHz as logarithmic function of train speed. For emission measurements the microphone distance is 7.5 m and 1.2 m above railhead. If sources above 0.5 m height have to be considered a second microphone height at 3.5 m must be added. The time signal is registered as an equivalent unweighted octave spectrum and third-octave spectrum, total A-weighted and unweighted levels. The measurement time T is also registered, which is the passage time including the 10 dB-down flanks. For a group of wagons within a train, the buffer-to-buffer time (speed/length) is taken.

The train speed is measured and must be within 5 km/h of the nominal speed for speeds below 100 km/h and 10 km/h for speeds above 100 km/h.

For vehicles with traction or aerodynamic sources at heights of 2 m and above, such as locomotives and high speed trains, additional measurements are carried out at 4 m of the track axis at a height of 1.2 and 4.5 m (± 0.2 m); only at one cross-section.

The condition of the track should be as good as possible to minimise its influence.

The emission is calculated from these measurement results for each noise source and each octave band. In this step also the A-weighting is applied. The emission results are then approximated by logarithmic speed functions of the form

$$E = a + b \log(v/v_0), \quad (1)$$

where a and b are correction coefficients; v is train speed, km/h; v_0 is reference speed, 1 km/h.

The emission represents the sound power of the considered source for one train per hour under reference track conditions. In cases where the deviations of the measurement results are higher than 1 dB, the speed range is split into different ranges and the regression calculation is done for each range separately.

To calculate the emission that is representative for the considered time interval “corrections” for the number of trains, type of locomotive (electric or diesel), the brake, the rail roughness, the wheel roughness and the type of superstructure have to be applied to the basic speed dependent emissions.

RMR provides also a simplified calculation method for the overall A-weighted emission. The basic formula is as follows:

$$E = 10\,\lg\left(\sum_{c=1}^{y} 10^{E_{nr,c}/10} + \sum_{c=1}^{y} 10^{E_{r,c}/10}\right) \tag{2}$$

where $E_{r,c}$ is emission term for braking trains; c is train category; $E_{nr,c}$ is emission term for non braking trains; y is total number of categories present.

The emission values per rail vehicle category are determined from:

$$E_{nr,c} = a_c + b_c\,\lg(v_c/v_0) + 10\,\lg(Q_c/Q_0) + C_{b,c} \tag{3}$$

$$E_{r,c} = a_{r,c} + b_{r,c}\,\lg(v_c/v_0) + 10\,\lg(Q_{r,c}/Q_0) + C_{b,c} \tag{4}$$

where Q_c is average quantity of non braking trains of the considered rail vehicle category, h^{-1}; $Q_{r,c}$ is average quantity of braking trains of the considered rail vehicle category, h^{-1}; Q_0 is reference value, 1 h^{-1}; v_c is average speed of rail cars, km/h; v_0 is reference speed, 1 km/h; b is track type.

The standard regression coefficients are given in table 3.

Trains are considered "braking" when the brake system is active.

To determine the emission value E, the defined train categories are used, distinguishing between braking and non-braking trains.

3.2. SCHALL03

The basic emission value is the equivalent noise level per train per hour at a distance of 25 m and a height of 4 m above railhead. 25 m is also the distance for measurements. To get the equivalent sound level for the reference time intervals (day/night) corrections have to be added to consider different train classes, train length and superstructure. Rail or wheel roughness or brake influence is not taken into account.

The basis emission is given by the following formula:

$$L_m = 10\log(l / l_0) + 10\log(5 - 4p) + 20\log(v / v_0) - 9 \tag{5}$$

where l is the length of the train, m; p is the percentage of wagons with disk brakes in fractions of 1; v is train speed, km/h; v_0 is reference speed, 1 km/h; l_0 is reference train length, 1 m.

The superstructure is ballast with wooden sleepers. No spectral calculation is foreseen.

In contradiction to the other calculation methods no individual speed influence is considered.

Table 2

Standard regression line coefficients as function of railway category c (RMR)

Category	Non-braking trains		Braking trains	
	a_c	b_c	$a_{r,c}$	$b_{r,c}$
1	14.9	23.6	16.4	25.3
2	18.8	22.3	19.6	23.9
3	20.5	19.6	20.5	19.6
4	24.3	20.0	23.8	22.4
5	46.0	10.0	47.0	10.0
6	20.5	19.6	20.5	19.6
7	18.0	22.0	18.0	22.0
8	25.7	16.1	25.7	16.1
9	22.0	18.3	22.0	18.3

3.3. ON S5011

The basic emission parameter is the sound power level per meter rail. As for the RMR method the calculation is executed for octave bands separately using the same frequency range (63Hz to 8kHz).

Measurements are carried out in 7.5 m and 15 m distance from the source (straight line between source and microphone) and 4 different heights.

The emission values are related to a ballast superstructure with wooden or concrete sleepers and rails in good conditions. A correction for rail or wheel roughness is not foreseen.

The approach is similar to the RMR but there is only one source considered and no other influencing parameter.

3.4. NMT

Also the NMT is based on the sound power levels per meter track in octave bands between 63 Hz and 4000.

The sound power levels are calculated from measurements of sound exposure levels (SEL) for a given train type and track type. The measurements have to be carried out in different speed intervals and octave bands between 63 and 4000 Hz. The measurement distance is between 7.5 m and 30 m from the track centre line. The full height of both rails must be visible from the measuring position, the elevation angle should be less than 20°.

The measurement results are then normalised to a reference distance of 10 m and a height of 2 m. Corrections for ground effects (in octave bands), train length and A-weighting have to be applied during this normalisation process. The sound power levels per meter track can then be calculated by adding 16 dB to the SEL.

Then approximation functions for the results at different speeds are calculated using logarithmic speed function of the following form:

$$L_w = a + b \log(v / v_0), \tag{6}$$

where v is the train speed, km/h; v_0 is reference speed, 100 km/h; a and b coefficients are tabled for each train and each octave band.

Finally L_w will be corrected for track conditions. The 24 h energy equivalent noise level L_{eq}, which is one of the noise indicators of the NMT is then calculated by summarising the contributions of each train during the 24 h time period and by applying all the corrections necessary to consider the propagation from the source to the receiver.

Besides the equivalent noise level a second noise indicator for the maximum noise level at a given receiver is calculated. This indicator is based on the energy average over the maximum range of the instant noise level signal during the passage of a train. This value is then transformed into a power level per meter track in an analogue way as for the equivalent noise level.

3.5. CRN

CRN aims to predict either daytime or night time equivalent A-weighted noise level. CRN mainly works with the sound exposure level for each train which is converted, after allowances for distance, ground effect, reflections, gradient, source enhancements (e.g. by bridges), angle of view, screening and the number of trains, into the required A-weighted equivalent sound level.

The reference SEL for a train depends on its speed and is predicted by:

$$\mathrm{SEL}_{ref} = 31.2 + 20 \log(v / v_0) + 10 \log(N), \tag{7}$$

where v is the train speed, km/h; v_0 is reference speed, 1 km/h; N is the number of vehicles in the train.

The distance correction is given by:

$$C_{dist} = -10 \lg(d / (25\, d_0)), \tag{8}$$

where d is the normal distance from the track segment to the observer, m ($d > 10$ m); d_0 is reference distance, 1 m.

The railway noise scheme also has an explicit allowance for air absorption given by:

$$C_{abs} = 0.2 - 0.008\, (d / 25), \tag{9}$$

where d is the normal distance from the track segment to the observer, m.

The ground effect correction for propagation over acoustically soft ground is given by:

$$\left.\begin{aligned} &C_{ground} = -3\, P_d \lg\left(\frac{d}{25\, d_0}\right), \quad \text{then } H \le 1 \text{ m};\\ &C_{ground} = -0.6\, P_d \left(6 - \frac{H}{h_0}\right) \lg\left(\frac{d}{25\, d_0}\right), \quad \text{then } 1 \text{ m} < H \le 6 \text{ m};\\ &C_{ground} = 0, \quad \text{then } H > 6 \text{ m} \quad \text{or} \quad 10 \text{ m} < d < 25 \text{ m}; \end{aligned}\right\} \tag{10}$$

where d is the normal distance from the track segment to the observer, m; d_0 is reference distance, 1 m; H is the mean propagation height, m; P_d is the fraction of absorbing ground between the source and receiver.

If the required measurement conditions are fulfilled, then the barrier correction $C_{barrier}$, reflection related correction $C_{reflection}$ and view correction C_{view} are equal to zero.

The corrected SEL value at the receiver point is:

$$\mathrm{SEL}_{tot} = \mathrm{SEL}_{ref} + C_{dist} + C_{abs} + \max(C_{ground}, C_{barrier}) + C_{view} + C_{reflection} \tag{11}$$

The next step is calculation of component $L_{A\,eq}$ levels for each train type on each track segment using:

$$L_{A\,eq\,c\,night} = \mathrm{SEL}_{tot} - 43.3 + 10\lg Q_{NIGHT}$$
$$L_{A\,eq\,c\,day} = \mathrm{SEL}_{tot} - 48.1 + 10\lg Q_{DAY}, \tag{12}$$

where Q_{NIGHT} is the number of each train type passing the receiver in the period midnight to 6am; Q_{DAY} is the number of each train type passing the receiver in the period 6am to midnight.

The overall $L_{A\,eq\,tot}$ level is calculated by combining component $L_{A\,eq}$ values for each track segment and train type using the logarithmic summation equation [2]:

$$L_{A\,eq\,tot} = 10\lg\left(\sum_i 10^{L_{A\,eq\,c(i)}/10}\right) \tag{13}$$

4. Track Influence

4.1. RMR uses the following track classification:
1. Railway tracks with single block or double block (concrete) sleepers, in ballast bed (index code bb = 1).
2. Railway tracks with wooden or zigzag concrete sleepers, in ballast bed (index code bb = 2).
3. Railway tracks in ballast bed with non-welded tracks, tracks with joints or switches (index code bb = 3).
4. Railway tracks with blocks (index code bb = 4).
5. Railway tracks with blocks and ballast bed (index code bb = 5).
6. Railway tracks with adjustable rail fixation (index code bb = 6).
7. Railway tracks with adjustable rail fixation and ballast bed (index code bb = 7).
8. Railway tracks with poured in railway lines (index code bb = 8).
9. Railway tracks with level crossing.

Furthermore distinctions are also made, according to how many track disconnections occur on the emission route concerned:
1. Jointless rails (fully welded tracks) with or without jointless switches or crossings (index code m = 1).
2. Rails with joints (= tracks with joints) or an isolated switch (index code m = 2).
3. Switches and crossings with joints, 2 per 100 meters (index code m = 3).
4. More than 2 switches per 100 meters (index code m = 4).

For jointless rails (m = 1) the track correction $C_{bb,m}$ can be taken from the following table.

Table 3

Correction factor $C_{bb,i}$ as a function of structures above station compounds/railway track condition (bb) and octave band (i)

band	$C_{bb,i}$							
i	bb = 1	bb = 2	bb = 3	bb = 4	bb = 5	bb = 6	bb = 7	bb = 8
1	0	1	1	6	6	-	6	5
2	0	1	3	8	8	-	1	4
3	0	1	3	7	8	-	0	3
4	0	5	7	10	9	-	0	6
5	0	2	4	8	2	-	0	2
6	0	1	2	5	1	-	0	1
7	0	1	3	4	1	-	0	0
8	0	1	4	0	1	-	0	0

Furthermore, special corrections for other track disconnection classes and bridges are provided. In addition RMR offers the possibility to consider the influence of local rail and wheel roughness in relation to average values for the whole country.

4.2. SCHALL03 distinguishes between the following track classes: grass covered superstructure (– 2 dBA), ballast with wooden sleepers (0 dBA), ballast with concrete sleepers (2 dBA), hard ground (5 dBA).

4.3. ON S5011 uses the same track classes and correction values as SCHALL 03 except class 1.

4.4. NMT: the correction for track conditions is less specific than for the other methods. The correction is zero for ballasted tracks with continuously welded rails on concrete or wooden sleepers and typical maintenance procedures for the considered country.

If the rail or wheel surface is somewhat rougher than normal + 1 to + 3 dB should be used as correction. For very rough rails and/or wheels + 4 to + 6 dB should be used.

For particularly well maintained tracks – 1 to – 3 dB may be used. When the track and the wheels permanently have very smooth running surfaces larger negative values up to – 6 dB may be used. The use of negative values must be based on well documented and appropriate field measurements.

In addition the following corrections have to be applied to consider the influence of joints, switches, crossings or bridges: rails with joints + 3 dB; 10 m track length for each unit of switches and crossings + 6 dB; partial track length on a bridge without ballast + 6 dB; partial track length on a bridge with ballast + 3 dB.

4.5. CRN specifies the following track correction: jointed track (2.5 dBA), points and crossings (2.5 dBA), slab track (2.0 dBA), concrete bridges and viaducts (2.0 dBA), steel bridges (4.0 dBA), box girder with rails fitted directly to it (9.0 dBA).

5. Summary and Assessment

The by far most detailed and specific emission calculation method is provided by RMR, followed by NMT. Compared with these methods the emission modeling of SCHALL 03 can only be considered as a survey method, whereas the differentiation of this method is lower than that of the simplified option (dB(A)-option) of the RMR. The CRN and ON S5011 are ranked between the NMT and SCHALL 03. In detail the differences between the emission calculations of the 5 methods are summarised in table 4.

Table 4

Methods differences

Characteristics	Method				
	RMR	SCHALL03	ONS5011	NMT	CRN
Basic noise parameter	Octave band sound power level, calculated from measurements at different distances and heights, the emission is a function of train category and speed, locomotive and brake influences are considered separately	LAeq at reference distance 25 m and 4 m height, based on measurements, the emission is a function of train category, length, percentage of disc wheels and speed	Octave band sound power level, calculated from measurements at different distances and heights, the emission is a function of train category and speed	Octave band sound power level, calculated from measurements at different distances and heights, the emission is a function of train category and speed	LAeq at reference distance 25 m and 1,2 to 4 m height, calculated based on SEL levels, the emission is a function of train category, speed and number of vehicles in the train
Frequency range	From 63 Hz to 8000 Hz	-	From 63 Hz to 8000 Hz	From 63 Hz to 8000 Hz	-
Location of source	Up to 4 sources with different heights, at railhead, 0,5 m, 2 m, 4 m, 5 m above railhead, representing different mechanisms	One source at railhead level	One source 0,3 m above railhead	One source for each octave band with its specific source height	One source at railhead level
Speed dependency	For each octave band and source	For A-weighted levels	For each octave band	For each octave band	For SEL and A-weighted levels
Track influence	9 different classes, corrections are frequency dependent	4 different classes, no frequency dependency	3 different classes, no frequency dependency	Corrections from – 6 dB to + 6dB, but no specific classification, no frequency dependency	6 different classes, no frequency dependency
Influence of joints, switches, crossings and bridges	Correction table, correction are frequency dependent	–	–	Correction table, correction are not frequency dependent	Correction table, correction are not frequency dependent
Specific parameter	Local rail and wheel roughness consideration	–	–	–	–

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