A proposal for improved source model for predicting railway noise in Sweden

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Preface

This pilot study is part of the project "Updated noise modeling" which is funded by the Swedish Transport Administration (Trafikverket), with the reference number (Diarienummer) TRV 2014/65258 and the case ID (Ärende-ID) 5761.

This pilot study was carried out at SP, SP Technical Research Institute of Sweden, during December 2014. Dr. Dag Glebe is the project leader. Dr. Xuetao Zhang and Dr. Hans Jonasson together prepared this report: Hans wrote Chapter 2 and Xuetao wrote the other chapters.

29 December, 2014, Borås

1 Introduction

The current noise prediction model used in Sweden for rail traffic noise, NMT96 [1], was finalised in 1996. Since then nearly 20 years passed. At European level, advanced noise prediction methods have been developed based on state-of-the-art scientific, technical and practical knowledge about environment noise assessment. Such examples can be e.g. TWINS for railway noise [2, 3], the Harmonoise-Imagine methods for road, railway, aircraft and industry noise [4, 5], and Nord 2000 Road for road noise in Nordic countries [6]. Moreover, for strategic noise mapping over European member states, it has recently been decided that the European common noise assessment method, CNOSSOS-EU [7], is mandatory to be used. To follow these developments in fighting environmental noise, the Swedish Transport Administration (Trafikverket) requires to update the prediction models for road and rail traffic noise as well as to elaborate noise emission data for the extended noise source models [8].

This pilot study aims at proposing an improved source model for railway noise, with railway track standard respected. Explicitly, rail roughness, track type, and noise measures on a track should be taken as input parameters in the source model.

The traditional Nordic method NMT96 and the following one Nord 2000 Rail are first reviewed in Chapter 2. In Chapter 3, the focus is put on discussing CNOSSOS-EU source model for railway noise, which is based on and differs only a little from the advanced Harmonoise-Imagine source model. This discussion serves as the starting point to propose an improved source model for railway noise, which is described in Chapter 4. The important practical issue, how to apply rail grinding technique to reduce rolling noise, is also discussed in Chapter 3. Finally, the report is ended by Chapter 5 wherein two issues are discussed: to collect source data and to verify the source model.

2 Noise emission from trains in Nordic models

2.1 NMT96

NMT96 [1] works with the octave bands 63 – 4000 Hz. When calculating $L_{eq,\,24h}$ an equivalent sound power level per meter track is used

$$L_{W0} = a \cdot \lg\left(\frac{v}{100}\right) + 10\lg(l_{24}) + b \qquad (2\text{-}1)$$

where the numerical values of *a*, *b* are given in Appendix B in [7], l_{24} is the total length for all trains passed during the 24 hours, *v* is the respective pass-by speed of the train type in *km/h*.

When calculating the maximum level the “real” sound power level per meter train is used

$$L_{Wt} = a \cdot \lg\left(\frac{v}{100}\right) + 10\lg(v) + b + 43{,}8 \qquad (2\text{-}2)$$

Eq. (2-1) and (2-2) show that

$$L_{Wt} = L_{W0} - 10\lg(l_{24}) + 10\lg(v) + 43{,}8 \qquad (2\text{-}3)$$

In ref. [1] the coefficients *a* and *b* are given for train types S-X2, S-Pass, S-Pass/W, S-X10, S-GodsDi, and S-Gods. In ref. [8] additional data are provided for electric motor carriages X31/32, X52/53 Regina and diesel-electric motor carriages Y31/32.

In NMT96 frequency dependent source heights relative to the railhead are used, see Table 1.1.

Table 1.1. Source height above the railhead according to NMT96

Frequency, Hz	63	125	250	500	1000	2000	4000
source height (m)	2	1,5	0,8	0,3	0,4	0,5	0,6

2.2 Nord 2000 Rail

Nord 2000 Rail [6, 9-11] uses, in principle, the same data as NMT96 in Eq. (2-2, 2-3) above. Note that the parameters *a* and *b* are defined differently in Nord 2000 Rail than has been the case in NMT96. Nord 2000 Rail has also extrapolated and interpolated NMT96 parameters both to extend the frequency range and to transfer octave bands to third octave bands. Nord 2000 Rail then corrects the NMT96 emission values to compensate for the different propagation models. NMT96 has a method based on uncorrelated addition of direct and reflected sound while Nord 2000 assumes a correlated addition.

Nord 2000 Rail uses 4 – 6 different source heights. Rail/wheel sources are divided equally between 3 different heights. It is recommended to separate engine noise from wheel/rail noise.

3 CNOSSOS-EU source model for railway noise

3.1 General

All European member states are required to make strategic noise mapping on a 5-year time basis. The European common noise assessment method, CNOSSOS-EU, and the noise indicators L_{den} and L_{night} should be used. L_{den} is defined as

$$L_{den} = 10 * \lg\left[\frac{12}{24}10^{L_{day}/10} + \frac{4}{24}10^{(L_{evening}+5)/10} + \frac{12}{24}10^{(L_{night}+10)/10}\right] \tag{3-1}$$

where L_{day}, $L_{evening}$ and L_{night} are equivalent SPLs over respective time period and they are determined based on yearly averaged noise source data.

CNOSSOS-EU is the mandatory method to be used by European member states for strategic noise mapping. By using the common method as well as the common noise indicators, strategic noise mappings over Europe become comparable and action plans can then be elaborated.

The propagation model in CNOSSOS-EU is based on the French NMPB 2008 model, wherein the concept “mean ground plane” was taken. It is claimed that NMPB 2008 is suitable for long-term noise calculations and therefore proper for strategic noise mapping. Calculations in CNOSSOS-EU will be made in octave bands with the centre frequencies from 125 Hz to 4 kHz, up to 800 m for a normal distance to the road/railway. A receiver height should not be less than 2 m above the local ground [7].

In CNOSSOS-EU source model for railway noise many parameters still remain to be quantified. Therefore, member states need to specify these parameters based on their own practical knowledge. In the following sections CNOSSOS-EU source model for railway noise will be discussed step by step and proposals will be made how to implement this source model with Swedish source data.

As CNOSSOS-EU source model is based on the Harmonoise-Imagine source model (for railway noise), discussions made in this Chapter will serve as the starting point of the next Chapter where an improved source model for railway noise will be discussed.

Moreover, in section 3.5, an important practical issue, to apply rail grinding technique to reduce rolling noise, will be discussed.

3.2 Source positions

In the Harmonoise-Imagine source model for railway noise, two source heights are assigned for rolling noise: 0 m (the height of the railhead) for the rail/track component of noise and 0,5 m for the wheel component of noise.

As CNOSSOS-EU method is prepared for strategic noise mapping, it is simplified in some aspects compared with the Harmonoise-Imagine method. In the source model, one simplification is to replace the source height 0 by 0,5 m. In other words, only one source height is assigned to rolling noise.

Source positions are listed in Table 3.1. In total, there are two source positions for all source types.

Table 3.1. Source positions

Source Type	Lateral Position	Vertical Position (w.r.t. railhead)	Note
rolling noise	the track centre	0,5 m	this source position is also used for impact noise, curve squeal noise and bridge noise
aerodynamic noise	the track centre	0,5 m	for bogie component
		4 m	for roof component as well as pantograph
traction noise*	the track centre	0,5 m	for gear transmission, electric motors, cooling fans, engine blocks
		4 m	for engine exhaust of diesel locomotives

* Louvers and cooling outlets can be located at various heights. However, for strategic noise mapping, such details can as believed be neglected.

3.3 Classifications

3.3.1 General discussion

Classifications aim at helping to make accurate noise predictions.

In CNOSSOS-EU source model for railway noise, different vehicle types are classified. However, in Sweden, noise emission data are usually collected based on train types as those defined in NMT96 model. As the source data of rolling noise based on train types are averaged over several vehicle types e.g. the coaches and the locomotive, they may differ slightly from the source data for the coaches only, or, for the locomotive only. Thus, one might consider to re-collect source data based on vehicle types when making strategic noise mapping in Sweden, if collecting source data would be cheap.

To collect source data is very costly. On the other side, SP's experience of working with Harmonoise-Imagine source model shows that accurate noise predictions can be made by using source data based on train types [12]. Therefore, we propose to classify train types instead of vehicle types for the following reasons:

- Noise predictions using source data based on train types can be made equally accurate as those using source data based on vehicle types [12];
- From the point of view of methodology, a classification based on vehicle types may be problematic for high-speed trains because the bogie component of aerodynamic noise can only be defined properly based on train types, not based on vehicle types [13];
- Even for freight trains which can have large variation in wheel roughness, for noise prediction, using source data based on vehicle types is not likely to be better than using source data based on train types;
- However, a classification based on vehicle types can help with diagnose of the origin of acoustically 'bad' vehicles - those vehicles equipped with cast-iron brake blocks, or those vehicles with flattened wheels;
- For noise calculation, it is therefore not necessary to have source data based on vehicle types. If source data based on train types are the only source data available, it should be ok to use such data. Considering an even distribution of the sound power of

train pass-by noise onto the number of vehicles of the train, one obtains the averaged source data for each of the vehicles.

When using source data based on train types, the formula for noise calculation will be the same although some parameter values are changed: e.g. to replace vehicle length by train length, or to replace number of axles per vehicle by number of axles per train.

Driving conditions are classified for considering traction noise or/and braking-to-stop squeal noise. Emergency braking (of broad band noise) is thought less relevant for strategic noise mapping. And, accordingly, the traction parameter is removed from the classification of train types.

Classification of track types closely follows what was made in CNOSSOS-EU source model for railway noise, provided that the parameters were quantified.

3.3.2 Classification of train types

The vehicle classification parameters made in CNOSSOS-EU do indicate a difference in vehicles' noise emission although they have not explicitly been quantified. In Table 3.2 a classification of train types is specified and the parameters are quantified based on practical knowledge.

Table 3.2. Classification of trains

Train type	**Average number* of axles per railcar**	**Brake type**	**Wheel measure**
h high speed train (> 200 km/h)	2	**c** cast-iron block	**n** no measure
p** passenger train	3	**k** composite or sinter metal block	**d** wheel damper
f freight train	4	**n** non-tread braked, like disc, drum, magnetic	**s** wheel screen
c city tram or light metro train	etc.		**o** other
o other (maintenance car, etc.)			

* A more accurate way to count total number of axles of a train is: the number of axles per coach, the number of coaches, and the number of axles of the locomotive.

** Traction noise is important at low speed and will be considered according to driving conditions showed in Table 3.3. Moreover, wheel geometry can affect vehicle transfer function. Average vehicle transfer function of passenger trains will be used for this category (for strategic noise mapping). However, as should be aware of, trains with large wheels will emit more noise than trains with smaller wheels - their vehicle transfer functions can differ by a few dB(A). (In next Chapter, wheel size will be proposed as a classification parameter.)

The vehicle transfer function will be reduced by about 3~9 dB(A) if wheel dampers are mounted (with 4 dB(A) most likely), and about 6~9 dB(A) if wheel screens are mounted [14, 15] (7 dB(A) seems a safe choice). These noise reductions can be specified in spectrum if reliable data are provided.

Wheel skirts provide about 1 dB(A) reduction in the wheel component of rolling noise [14]. Such an ineffective measure is usually not considered.

Wheel roughness depends mainly on brake type. Average roughness level of wheels with disc brakes shall be determined based on available data, or the one presented in [16, 38]. For wheels with cast-iron brake blocks, a roughness level of 10 dB higher than wheels with disc brakes is assumed.

3.3.3 Classification of driving conditions

As has been mentioned before, classification of driving conditions, given in Table 3.3, is for specifying traction noise (important at low speeds) or/and braking-to-stop squeal noise. Station areas are mainly concerned with these two noise types.

Table 3.3. Classification of driving conditions

Speed Range	Category	Specification
conventional speed (50 – 200 km/h),or, high speed (< 200 km/h)	-	irrelevant*
low speed (< 50 km/h)	1	accelerating
	2	cruising or decelerating
	3	braking to stop
	4	idling**

* At an emergency braking can happen even at a conventional speed, or, at a high speed. Such an unusual situation is thought irrelevant for strategic noise mapping.

** This category is believed irrelevant for strategic noise mapping.

3.3.4 Classification of track types

When default rail roughness level and default track transfer function are used, classification of track types provides information if the noise emission level of rolling noise will be higher or lower than that under the default conditions.

In Sweden, only soft rail pads are used. Therefore, this parameter is removed.

Embedded rail and embedded track mean the same thing. This redundancy is removed.

Classification of track types is given in Table 3.4 in the following. The parameters therein need to be quantified for making noise calculations.

A straight, normally maintained ballasted track without a special noise mitigation measure (its classification code is BMNNN) is assigned to have the default rail roughness level as well as the default track transfer function. These two default quantities will be specified in the following.

For rail roughness, category M is assigned for the average roughness level of a railway network, or, the average level of all measured rail roughness data while, if possible, excluding those of corrugated rails. Category M is taken as the default rail roughness level of the railway network. Category E is then estimated as 5 dB lower than category M, and category N or B are 5 dB or 10 dB higher than category M, respectively.

Note: The default rail roughness level, or the average rail roughness level of a railway network, is likely to be above the upper limit defined in ISO 3095 [17].

The other parameters used in the classification will affect track transfer function.

Table 3.4. Classification of track types

1	2	3	4	5
Track base	**Rail roughness**	**Additional measure**	**Rail joint**	**Curvature R (radius of curvature in m)**
B ballast	E well maintained and very smooth	N none	N none	N straight
S slab track	M normally maintained	D rail damper	S single joint or switch	L low (1000-500m)
L ballasted bridge	N not well maintained	B low barrier	D two joints or switches per 100m	M medium (<500-300m)
N non-ballasted bridge	B not maintained and bad condition	A absorber plate on slab track	M more than two joints or switches per 100m	H high (<300m)
T embedded track		O other		
O other				

An embedded track is about 3 dB quieter than a ballasted track, while a slab track is about 3 dB noisier than a ballasted track [14]. Mounting absorber plates on a slab track will reduce noise by about 3 dB, which makes the slab track equivalent to a conventional ballasted track with concrete sleepers. Similarly, a non-ballasted bridge is estimated about 3 dB noisier than a ballasted bridge if other parameters are comparable.

The increased noise emission due to bridge noise depends on bridge type; it can be determined by measuring noise at the bridge site as well as at a shifted position where the bridge noise becomes unimportant.

Rail dampers will reduce the rail component of noise by about 6 dB [14]; a near track low barrier will reduce rolling noise by about 6 dB while it varies with train type [14, 18].

Impact noise will be handled by introducing an extra roughness level

$$L_{r,impact} = L_{r,impact-single} + 10\lg\left(n_l / 0.01\right) \text{ dB} \qquad (3\text{-}2)$$

where n_l is number of joints per 100 m length. $L_{r,impact-single}$ is provided in tabular form as given in Table 3.5. After adding impact effect, the total roughness level becomes

$$L_{r,tot+impact} = 10\lg\left(10^{L_{r,tot}/10} + 10^{L_{r,impact}/10}\right) \qquad (3\text{-}3)$$

For curve squeal noise, 8 dB will be added for curves of a curvature R < 300 m and 5 dB for 300 m < R < 500 m to rolling noise sound power level, for all frequencies. At least 50 m length of the track will be concerned. Moreover, for category L, it is not likely to have squeal noise; thus, 0 dB is assigned for this category.

When reliable data are provided, correction for curve squeal noise will be given in spectrum.

Table 3.5. The 1/3 octave band spectrum for $L_{r,impact-single}$

Wavelength (cm)	$L_{r,impact-single}(\lambda)$ **(dB)**		**Wavelength (cm)**	$L_{r,impact-single}(\lambda)$ **(dB)**
63	22.4		2.5	10
50	23.8		2	6
40	24.7		1.6	1
31.5	24.7		1.2	-4
25	23.4		1	-11
20	21.7		0.8	-16.5
16	20.2		0.63	-18.5
12	20.4		0.5	-21
10	20.8		0.4	-22.5
8	20.9		0.32	-24.7
6.3	19.8		0.25	-26.6
5	18		0.2	-28.6
4	16		0.16	-30.6
3.2	13		0.13	-32.6

3.4 Noise calculation

3.4.1 Rolling noise

3.4.1.1 Sound power level

According to the indirect roughness method

$$L_{eq,T_0}(f) = 10\lg\left(\frac{N_{axle}}{L_{wagon}}\right) + L_{H,tot}(f) + L_{r,tot}\left(\frac{v}{f}\right) \qquad (3\text{-}4)$$

where T_0 is the pass-by time, N_{axle}/L_{wagon} the number of axles per wagon length, $L_{H,tot}(f) = L_{H,veh}(f) \oplus L_{H,tr}(f)$ the total transfer function, $L_{r,tot}(v/f)$ the effective total roughness, v is the train speed, and $v/f = \lambda$ the roughness wavelength.

The effective total roughness, $L_{r,tot}(\lambda) = L_{r,r}(\lambda) \oplus L_{r,w}(\lambda) + CF$, contains three components of rail roughness $L_{r,r}(\lambda)$, wheel roughness $L_{r,w}(\lambda)$, and contact filter *CF*. For making noise calculations, it is not necessary, also not smart, to separate the effective total roughness into its components, because by doing so it will introduce extra errors in the noise calculation. In a theoretical model like TWINS these three components are used to determine the effective total roughness level, which clearly shows the excitation mechanism of rolling noise.

Moreover, the effective total roughness obtained using the indirect roughness method is the actual roughness 'felt' by the wheel-rail contact, hence the roughness excitation itself. Direct roughness methods have limited accuracy in determining the effective total roughness due to the uncertainty in contact filter effect.

For strategic noise mapping, only one source height is assigned for rolling noise. Accordingly, the total transfer function does not need to be separated into its components.

As described in [13], by applying relevant tabular values which are also given in Table 3.6, noise emission sound power level of a train pass-by is obtained

$$L_{W,0}(f) = L_{eq,T_0}(f) + 10\lg(L_{train}) + \textit{the tabular value} \tag{3-5}$$

(Note: For a locomotive its N_{axle} / L_{wagon} can differ from that of coaches; this small error is tolerated in order not to make the formulation too complicated).

Table 3.6. $L_{W,0}(f) - L_{eq,T_0}(f) - 10\lg(L_{train})$ *(for source height 0,5 m above railhead)*

Freq. (Hz)	(dB)		Freq. (Hz)	(dB)
25	9,4		**630**	15,5
31,5	9,4		**800**	15,5
40	9,5		**1000**	14,7
50	9,8		**1250**	14,7
63	10,8		**1600**	14,9
80	13,9		**2000**	15,0
100	15,1		**2500**	15,1
125	13,0		**3150**	15,3
160	12,4		**4000**	15,5
200	13,3		**5000**	15,9
250	17,0		**6300**	16,3
315	18,1		**8000**	16,7
400	16,5		**10000**	17,5
500	16,4			

The directional sound power level of train pass-by noise is obtained in the way

$$L_{W,0,dir}(\varphi,\psi) = L_{W,0} + \Delta L_{W,dir,hor}(\varphi) + \Delta L_{W,dir,vert}(\psi) \tag{3-6}$$

Assuming there are *Q* trains of a type passing by within *T* hours and at an average speed *v*, on average at each moment in time there will be an equivalent number of *Q/*(*Tv*) trains of the type passing by the rail section. The corresponding directional sound power level per meter (rail) length is given by

$$L_{W,T,line}(\varphi,\psi) = L_{W,0,dir}(\varphi,\psi) + 10\lg\left(\frac{Q}{1000Tv}\right) \quad (3\text{-}7)$$

where v is given in km/h.

Within these T hours, there may be some trains of the type passing by at other average speeds; and, there may be other train types passing by. Summing over these two parameter values, the total sound power level of rolling noise will have been determined

$$L_{W,T,dir,rolling} = 10\lg(\sum_{t,v} 10^{L_{W,T,line}/10}) \quad (3\text{-}8)$$

where the parameter t is for train type. T hours can be chosen as e.g. 12 hours for day time, 4 hours for evening time and 8 hours for night time, respectively.

3.4.1.2 Source directivity

In the horizontal plane dipole directivity has been assigned for rolling noise, impact/ squeal/braking noise, aerodynamic noise, and fan noise, which is written as [7]

$$\Delta L_{W,dir,hor}(f,\varphi) = 10\lg\left[0.01 + 0.99\sin^2(\varphi)\right] \quad (3\text{-}9)$$

where at the wayside direction the horizontal angle $\varphi = 90^o$.

In the vertical plane, for rolling noise, the directivity is written as [7]

$$\Delta L_{W,dir,vert}(f,\psi) = \left|\frac{40}{3} * \left[\frac{2}{3}\sin(2\psi) - \sin(\psi)\right] * \lg\left(\frac{f+600}{200}\right)\right| \quad (3\text{-}10)$$

where the vertical angle ψ is defined w.r.t. the horizontal plane.

3.4.1.3 Bridge noise

Additional noise generated by bridge vibration is handled in a simple manner: to add a constant, C_{bridge}, into Eq (3-7); this constant depends on bridge type and can be measured as has been mentioned before (see discussions after Table 3.4).

Currently no such source data are provided.

3.4.1.4 Practical issues

For strategic noise mapping noise source data can be one of the following alternatives:

- the default effective total roughness and default total transfer function. These default source data are obtained by averaging over all available source data, while passenger trains and freight trains are distinguished, as well as corrugated rail sections are better excluded.
- the default source data, plus corrections according to train type, track type and track conditions (recommended).
- respective effective total roughness and total transfer function for each train-track type, if such source data are available.

For detailed noise studies the last option should be considered.

3.4.2 Aerodynamic noise

Currently there are no high speed trains in Sweden.

In fact, CNOSSOS-EU source model only proposes a simple formula for describing railway aerodynamic noise. This formula has not been validated and no source data are provided. As the project of CNOSSOS-EU will be finished in 2015, this part of the source model should be improved in some way.

Each member state has to decide how to handle aerodynamic noise.

3.4.3 Traction noise

Traction noise will be considered at low speeds, usually < 50 km/h. This is often the case even for traction by a diesel-electric locomotive [19].

In the same report [19] it is also shown that an old type of diesel locomotive can be 10 ~ 12 dB noisier than a modern diesel-electric locomotive, indicating that traction noise should be considered even at about 100 km/h if such noisy diesel locomotives are in traction. While this kind of noisier diesel locomotives will not be considered because they are believed irrelevant for strategic noise mapping in Sweden.

Table 3-7. The sound power level of diesel-electric locomotive EMD type JT42CWR, Class 66 in GB, modified to comply with Swedish requirements [19]

Frequency (Hz)	$L_{W,0}(traction)$ **(dB)**	**Frequency (Hz)**	$L_{W,0}(traction)$ **(dB)**
25	100,3	630	107,2
31,5	110,2	800	107,2
40	106,8	1000	107,3
50	108,9	1250	108,0
63	110,5	1600	107,2
80	116,1	2000	106,0
100	116,4	2500	105,6
125	114,1	3150	103,4
160	106,9	4000	101,6
200	106,2	5000	99,0
250	107,5	6300	95,4
315	107,3	8000	93,6
400	106,7	10000	91,0
500	106,1		

In CNOSSOS-EU source model for railway noise, emission data have been provided for a typical electric locomotive and for a typical electrically motored unit (EMU) with gears. The sound power is evenly distributed over the two source heights, 0.5 m and 4 m above the railhead.

The sound power level of a diesel-electric locomotive (EMD type JT42CWR, Class 66 in GB, modified to comply with Swedish requirements) is given in Table 3-7.

3.5 Acoustical grinding and rail roughness monitoring

3.5.1 Rail and wheel roughness

The effective total roughness, $L_{r,tot}(\lambda) = L_{r,rail}(\lambda) \oplus L_{r,wheel}(\lambda) + CF$, which is the actual roughness ‘felt’ by the wheel-rail contact, hence the roughness excitation itself, consists of three components: rail roughness $L_{r,rail}(\lambda)$, wheel roughness $L_{r,wheel}(\lambda)$, and contact filter *CF*.

The contact area of a wheel and a rail has approximately the shape of an ellipse (of typical dimensions 10-15 mm) and depends on geometries of rail and wheel as well as the contact pressure (loading), see Fig. 3.1. Roughness with wavelengths shorter than the dimension (2*a*) of the contact patch in rolling direction tends to be attenuated in its excitation of the wheel-rail system [14]. This effect is described by the contact filter. In CNOSSOS-EU source model for railway noise contact filters for several specific common cases are provided [7].

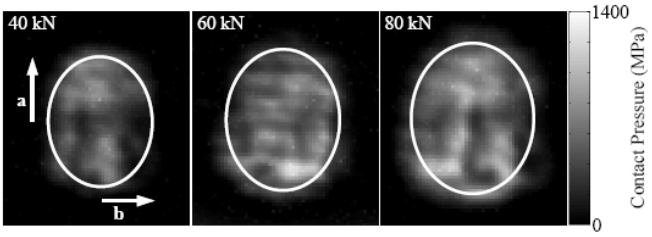

Fig. 3.1. Un-Used Wheel/Rail Contact Pressure Maps [20].

Explicitly, *CF* has filtering effect on roughness with wavelengths 1 cm or shorter. The shorter the wavelength, the larger the *CF* filtering effect. For roughness with 1 cm wavelength, the corresponding frequency is about 2778 Hz at train speed 100 km/h and 4444 Hz at 160 km/h. This partially explains why at low speed rail radiation dominates (considering that wheel modes are of frequencies about 2 kHz or higher).

Wheel roughness depends largely on the braking system of a rolling stock. The Dutch study on monitoring roughness growth showed that the effect of reprofiling or truing wheel treads is restricted to only a few weeks (cast-iron brake blocks) or about two months (composite brake blocks) of service. In other words, wheel roughness levels grow quite quickly after having wheels reprofiled. To the contrary, the effect of grinding rail running surface can last over a year [21]. This understanding suggests that, for each type of rolling stock, typical wheel roughness level can be obtained. Moreover, it also means that reprofiling or truing wheel treads is not an effective measure to reduce rolling noise.

The range of roughness levels found on rails is larger than that seen for wheels. In the presence of short pitch rail corrugations (25mm-80mm in wavelength), the noise level can be 10 dB higher than the normal level for tread-braked stocks. The normal remedy for such a bad rail condition is to make acoustical grinding on the rail, although most rail grindings are made for non-acoustic reasons to prevent rail defects and fatigue cracks. In Germany, rail grinding is carried out according to the acoustic criteria, 6 dB reduction in rolling noise [14]. Rail grinding in Germany covers almost 1000 km of the DB network and allows for a 3 dB reduction in noise exposure calculations. A typical grinding interval is about four years, depending on the traffic levels.

There are many factors that affect the development of rail roughness in general and rail corrugation in particular [14]. The former is still less well understood. For the latter, short pitch corrugation on straight track is believed to be related to anti-resonances of the track vertical dynamics. There is a strong anti-resonance associated with the pinned-pinned mode at around 1 kHz for excitation above a sleeper, and an anti-resonance in the region 200-500 Hz associated with the sleeper acting as a vibration absorber. Which of these two anti-resonances is involved in corrugation formation depends on train speed. In both cases it is advantageous to use soft rail pads [14].

Rail corrugation has peak-to-peak amplitudes of 120 µm and greater. The presence of corrugations can reduce component life and lead to premature failure. Severe corrugation can increase rolling noise from disc-braked vehicles, which have comparatively smooth running surfaces, by up to 20 dB [22].

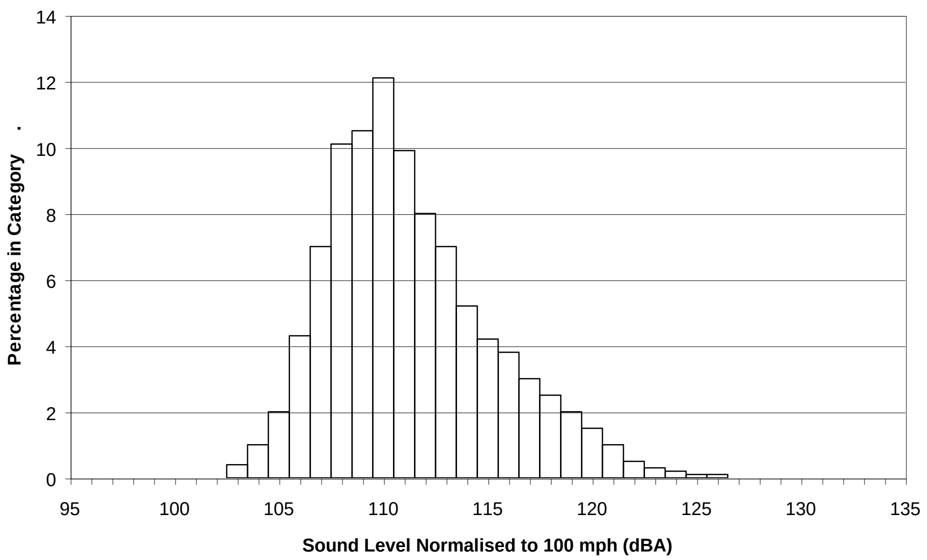

Fig. 3.2. Typical speed-normalised distribution of under-floor rolling noise [22]

In Fig. 3.2 noise sound recorded by a monitoring car running on British railway network is presented; the data has been normalised to a chosen speed 160 km/h. Over any typical route in the UK, the normalised under-floor rolling noise has been found to follow the same distribution characteristic shown in Fig. 3.2 [22]. The bulk of track is of a typical roughness that leads to rolling noise (in the example) 110 dB, with 5 dB noisier than smooth sections where rolling noise of 105 dB was recorded, and with 15 dB quieter than corrugated sections where rolling noise of 125 dB was recorded.

If grinding criterion is setup to 5 dB, track sections with under-floor rolling noise of 115 dB or higher will be defined for grinding. In Germany, the grinding criterion is 6 dB [14].

3.5.2 Acoustical grinding

- Acoustical grinding, i.e. grinding as a noise reduction measure, should be considered only if it becomes an effective measure to reduce rolling noise. For making a judgement of whether or not acoustical grinding is a proper measure, a rail roughness monitoring system is required and an acoustical criterion for rail grinding needs to be setup.

- Dutch experience [16, 21]:
  a. if the acoustical grinding criterion is set to 7 dB(A), 2% of the total network need to be ground, resulting in 0.5 dB(A) reduction of the network's average noise emission.
  b. For a single line with many corrugated sites, the reduction of the average noise emission will be between 0.5 dB(A) and 7 dB(A).
  c. The effectiveness of grinding, with respect to noise reduction, decreases rapidly with grinding length. For example, if the network's average noise emission would be reduced by 0.9 dB(A), nearly 20% of the total network would need to be ground.
  d. Ground rails typically show roughness spectra around – 10 dB (re 1 μm). The average rail roughness spectra over 30 sites is 10 dB at 31,5 cm and linearly down to ~ - 7dB at 0,5 cm, similar as average wheel roughness of disc brakes.
- German experience: with grinding criterion 6 dB, 3 dB(A) noise emission bonus is granted to regularly ground lines with less than 80% cargo service [20].

The Dutch experience indicates that acoustical grinding should be applied for those track sections where the rails are rough or corrugated. The acoustical grinding criterion can be set between 5 ~ 7 dB(A) reduction in rolling noise, depending on the ambition in local noise control as well as cost-efficiency consideration.

There may be some track sections that are rough while located at sites where noise is not a concern, e.g. no people live nearby. In this case grinding should also be considered while having a different purpose: for preventing premature failure of the track system. Accordingly, a higher grinding criterion may be setup, e.g. 10 dB(A).

The generation and growth of rail roughness is a complicated matter, as often a transition between smooth and corrugated rails occurs without corresponding changes in track components. What facts have been known are that rail roughness varies with amount of axle load passed [24], and that the rate of growth appears to increase with roughness level [23]. How rail roughness starts and how fast it will grow are the questions still unable to answer at this time. Track dynamics should be the key factor in determining rail roughness generation and roughness growth rate, because with same amount of axle load passed, rail roughness on different track sections can vary a lot. One interesting example is that the Dutch data had shown that the smoothest track had not been ground since it was renewed 18 years before the roughness measurements [16].

Two options are proposed for dealing with rail roughness variation in a prediction model [16]:

- Using an average rail roughness for the network. The consequence of this approach is that noise prediction may deviate considerably from the actual noise at smooth or corrugated track sections.
- Using measured rail roughness per section of track, by monitoring rail roughness regularly. This raises the accuracy of noise prediction while price is high: apart from monitoring, also the database with source data and hence the calculations have to be updated regularly.

If acoustical grinding is applied, the first option can also produce fair accurate noise predictions.

In ref. [24] it is proposed that, based on average, to control 1 dB(A) variation in noise level duo to rail roughness variation, it is necessary to monitor at intervals of about 25 megatons of axle load passed. (Comment: This is likely not applicable for a railway line where freight traffic is intensive – see the calculations presented in Table 3.8.) This criterion is as understood for average growth rate of rail roughness of "normal" track sections. However, there are exceptions: for some track sections the growth rate of rail roughness is very low, and for some other track sections where rail corrugation is prone to appear the growth rate of rail roughness is very high.

The last issue is about railway lines where freight traffic is intensive. As freight trains usually have rough wheels (due to cast-iron brake blocks), say 10 dB or more rougher than those wheels with disc brakes, rail roughness variations will result in a much less variation in the total roughness and in turn in the rolling noise, as illustrated in Table 3.8. In this case only corrugated track sections need to be ground.

Table 3.8. Variation in total rolling noise due to variations in rail roughness level, taking rail roughness level of 10 dB as a reference and taking wheel roughness as a parameter.

Rail roughness	5	10	13	16	19	22	25	28	31	34
Wheel roughness 10 dB										
Total roughness	11,2	13,0	14,8	17,0	19,5	22,3	25,1	28,1	31,0	34,0
Level difference in sound	-1,8	0,0	1,8	4,0	6,5	9,3	12,1	15,1	18,0	21,0
Wheel roughness 20 dB										
Total roughness	20,1	20,4	20,8	21,5	22,5	24,1	26,2	28,6	31,3	34,2
Level difference in sound	-0,3	0,0	0,4	1,0	2,1	3,7	5,8	8,2	10,9	13,8

In summary, a grinding criterion can be setup as:

- Carrying out a monitoring measurement of the railway network and prepare the results the same as that shown in Fig. 3.2 (either by using measured sound levels or by using measured acceleration levels); finding the typical roughness level for the bulk of track sections.
- Choosing a value of noise variation between 5 dB and 7 dB as the grinding criterion for track sections where passenger train traffic dominates and the rail traffic noise is an environment concern. (To grind the rail sections in order to reduce rolling noise.)
- Choosing 10 dB as the grinding criterion for other track sections. (To grind corrugated rail sections in order to prevent premature failure of the track system.)

4 An improved source model for general applications

4.1 General

An improved source model of railway noise for general engineering applications should, for rolling noise, be based on Harmonoise source model, which is the only one based on the physics of rolling noise. However, for other noise types Harmonoise source model is still less satisfactory and need to be improved in many aspects.

An improved source model does not necessarily have to be a complete model; in fact, in railway noise engineering one cannot expect such a complete source model to handle all types of railway noise sources in a satisfactory manner. One has to focus on handling the most important source types first, i.e. rolling noise and aerodynamic noise, as well as traction noise which is mainly of concern at low speeds and near station areas. The other source types will be handled individually according to each of their typical situations.

CNOSSOS-EU source model for railway noise, discussed in Chapter 3, differs a little from Harmonoise source model. To reduce redundancy, Harmonoise source model for rolling noise will not be repeated here. In this Chapter Harmonoise source model is taken as the starting point and the discussions will be focused on those parts that need to be improved.

4.2 Rolling noise

4.2.1 Separating wheel and rail/track components of noise

In CNOSSOS-EU source model there is only one source height, 0,5 m above the railhead, assigned for rolling noise. In Nord 2000 Rail, four source heights have been used: 0 for the rail/track component of noise, [0,25 0,5 0,75]*(wheel diameter) for the wheel component of noise. In Harmonoise source model, taking a compromise between calculation accuracy and cost-efficiency in noise prediction/mapping, two source heights have been taken: 0 for the rail/track component of noise and 0,5 m for the wheel component of noise. Considering that Harmonoise source model has been validated at European level, these two source heights are considered good enough for railway noise engineering purposes. However, as wheel noise mainly emits from the wheel's web area, more source heights may be used in a case study such as investigating noise shielding effect of near-track low barriers.

According to Eq. (3-4), the sound power of rolling noise will first be determined using the indirect roughness method. Because this sound power needs to be further distributed onto the two source heights according to the contributions from the wheels and from the rail/ track which are described by respective transfer function, the total transfer function of rolling noise, $L_{H,tot}(f) = L_{H,veh}(f) \oplus L_{H,tr}(f)$, needs to be separated into its two components, the vehicle transfer function $L_{H,veh}(f)$ and the track transfer function $L_{H,tr}(f)$.

The ideal way to make this separation is to use a measurement vehicle with small wheels, around 650 mm in diameter or smaller. By using such a vehicle with small wheels and moving it at a speed around 50 ~ 100 km/h, the wheel component of noise will be negligible compared with the rail/track component of noise. Thus, the track transfer function can, with a good accuracy, be determined as,

$$L_{H,tr}(f) \approx L_{H,tot}(f) = L_{H,veh}(f) \oplus L_{H,tr}(f), \qquad L_{H,veh}(f) << L_{H,tr}(f) \qquad (4\text{-}1)$$

Whence the track transfer function has been determined, the vehicle transfer function for each train type can be determined straightforwardly, as the total transfer function can be determined accurately by measuring pass-by noise on the same track using the indirect roughness method.

However, it is often the case such a measurement vehicle with small wheels cannot be arranged. Thus, one has to use default track transfer function as a reference to estimate the real track transfer function. In Harmonoise source model, such default transfer functions are provided. By trial-and-error, useful track transfer functions can be obtained by referring to these default transfer functions as indicated in the exercise made in [12].

4.2.2 Other issues

4.2.2.1 Wheel geometry

Wheel geometry, practically mainly wheel diameter, is an important parameter to classify vehicle/train types. A small wheel has smaller emission area, while the most important is that its eigenmodes are shifted to higher frequencies and then more eigenmodes are filtered out by the contact filter.

Wheel skirt has a small effect in shielding wheel emission [14]. However, when combined with other noise measure, e.g. near-track low noise barrier, it may contribute extra 2 dB noise reduction [18].

4.2.2.2 Classification

As proposed in [13], an extra classification of noise calculation oriented is an interesting option.

The main concern is in two folds: (1) the nominal value of a noise measure can differ from the real value of the measure implemented; (2) and, if several noise measures are applied the resulted in noise reduction is in general not equal to the summation of the noise reductions of the individual measures. Consequently, when using the classifications shown in sub-sections 3.3.2 and 3.3.4 (Tables 3.2 and 3.4) and applying respective parameter values, errors may be introduced into noise calculation.

A classification of noise calculation oriented aims at making noise calculation fast as well as accurate, while not at diagnosing the origin of noisier sources. Based on noise calculation experience, all train-track combinations can be classified into several groups:

- Class 1: those fulfil the TSI noise requirements;
- Class 2: those 3 dB or more quieter than Class 1;
- Class 3: those 3 ~5 dB noisier than Class 1;
- Class 4: those 6 ~ 10 dB noisier than Class 1;
- …

It is then proposed that (1) to make the classifications shown in Tables 3.2 and 3.4 in order to have the source model being advanced; and (2) to have an extra classification of noise calculation oriented in order to benefit noise calculations.

4.2.2.3 Parameter values

The nominal values of the noise measures proposed in sub-sections 3.3.2 and 3.3.4 are based on the state of art of practical knowledge at European level.

However, some lower values were proposed for e.g. rail and wheel dampers [25]. This difference could be due to unclear local effects while it suggests that, when implementing these noise measures in railway noise engineering, some corrections on their nominal noise reduction values may apply.

4.3 Aerodynamic noise

In Harmonoise source model for railway noise, the proposed formula for aerodynamic noise has not been validated.

As stated in [14], quantification of the strengths of aero-noise components remains difficult and the modeling has been used only within the research environment, mostly limited to very simple configurations. Therefore, for handling the aero-component of the noise impact from high speed trains, one has to work out some empirical method.

Such an empirical method has been proposed in [26], and the proposed empirical method works quite well considering a wide speed range, 70 km/h ~ 270 km/h, has been covered. This work has been reported to railway noise experts in the conference IWRN11 (the Eleventh International Workshop on Railway Noise) and the paper has been reviewed and accepted to publish [27].

4.4 Other noise types

After several decades noise engineering traction units have now been made much quieter than before. As a result, in noise calculation, traction noise is now much less important than rolling noise and aerodynamic noise. In general, traction noise will be considered at low speed, say < 50 km/h and not unusual < 30 km/h [19], and is mainly concerned in station areas.

Although much efforts have been paid on studying this noise type, only preliminary description of it has been achieved [28]. The source data of this noise type shall be collected for each individual traction type.

Braking noise has two types, braking-to-stop will produce braking squeal noise which is of tonal character while braking at speed will produce broad band noise. Together with curve squeal noise and bridge noise, methods to handle these noise types need to be further developed.

4.5 Directivity

A systematic study on the directivity of railway noise has been published [29]. Directivity functions proposed therein differ from those proposed in [7].

It should be understood that, for train pass-by noise, the horizontal directivity will have a limited effect which is less than 3 dB. (Note: Important railway noise sources have their directivities between a monopole and a dipole; the directivity effects on pass-by noise between a monopole and a dipole differ by 3 dB because $\frac{1}{\pi}\int_0^{\pi}\cos^2(\varphi)d\varphi = 1/2$). This explains why railway noise engineering still works even without a correct description of the horizontal directivity.

However, when a type of horizontal shielding presents, a correct description of the horizontal directivity will become important. Moreover, the vertical directivity is important for evaluating noise impact on near-track high buildings.

4.6 How to use existing data

It is extremely important to properly define the usage of existing data in an advanced source model, because data collection is very costly.

One of the tasks for this pilot study is to define the usage of the noise monitoring data which have been collected in Sweden over several years with data-collection frequency twice a year [30].

As shown in Fig. 3.2 in sub-section 3.5.1, with this typical speed-normalised distribution of under-floor rolling noise, one can clearly define how to use this information to benefit noise prediction over the whole network.

Equivalently while except at a few anti-resonance modes of the wheel, a monitoring measurement using a measurement system based on axle-box acceleration will produce similar speed-normalised distribution while of the axle-box acceleration.

1 dB variation in the under-floor rolling noise, or similarly, 1 dB variation in the axle-box acceleration, corresponds to 1 dB variation in the excitation of the wheel-track system and in turn 1 dB variation in the emission sound power. Therefore, obtaining accurate source data of the effective total roughness determined at one or several typical sites using the indirect roughness method, the source data of the effective total roughness over the whole network can straightforwardly be determined by referring to the monitoring data. In other words, monitoring measurements of rail roughness distribution can also greatly benefit noise prediction over the network.

As has been discussed in sub-section 3.4.1, for noise calculations it is not recommendable to use the components data of the effective total roughness (because the contact filter is an estimated quantity). For the concern of rail grinding, rail roughness data derived from monitoring measurements are equivalent to the raw data, i.e. the speed-normalised distribution of the axle-box acceleration. However, these two set of data are not the same good for noise calculation (the former is less good than the latter). Of course, if there are no other data available, these rail roughness data can be used in noise calculations – in the case one also needs other two component data, the wheel roughness and the contact filter.

5 Collecting source data and verifying the source model

5.1 General

The source data of rolling noise should be collected using the indirect roughness method, if the advanced source model discussed in Chapter 3 or in Chapter 4 is used. By using this method, the effective total roughness and the total transfer function will be determined.

In sub-section 4.2.1 it has been discussed how to separate the total transfer function into its two components, the vehicle transfer function and the track transfer function. This separation is necessary for making an accurate noise calculation.

To separate the effective total roughness into its three components, the rail roughness, the wheel roughness, and the contact filter, one needs to know two of the three component data. One can also separate them by referring to the default component data while the accuracy of the resulted data will in general be lowered. As has been mentioned before, for noise calculations, it is not necessary to make such a separation.

Rail roughness, as well as wheel roughness, can be measured using a direct method. However, the contact filter as well as the transfer functions can only be deduced, not measured. For example, with accurate data of rail roughness, wheel roughness, and the effective total roughness, the contact filter can be deduced. Or, with data of the effective total roughness and the pass-by equivalent SPL, the total transfer function can be deduced. (Note: These two deductions can be made because of the relevant TWINS calculations. And, in fact, the effective total roughness is a calculated quantity.)

In section 5.2 to collect source data of rolling noise using the indirect roughness method will be described. To collect source data for other noise types will be discussed in section 5.3, while in a simple way. In section 5.4 the way to verify the source model will be proposed.

5.2 Collecting source data of rolling noise

According to the indirect roughness method [31, 32], the basic measurement setup is shown in Fig. 5.1.

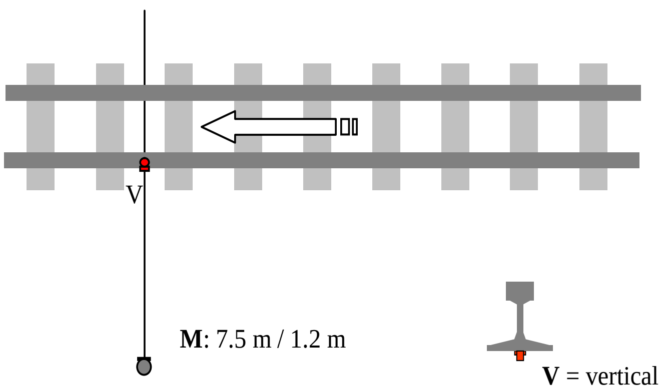

Fig. 5.1. The measurement setup for collecting the time history data of rail vertical vibration and noise emission during a train pass-by.

One extra accelerometer is proposed to use: it should be located about 30~50 m away from the first accelerometer and be used also for measuring rail vertical vibration. The advantage by using this second accelerometer is: (1) train speeds can be determined based on the recordings on the two accelerometers; (2) it becomes possible to improve the accuracy of the determined track decay rate by averaging over the data collected at two positions; (3) the effective total roughness will be determined not only by averaging over many wheels' roughness but also by averaging over the rail roughness at two positions.

The reason for the proposed distance shift, 30~50 m, is of two aspects: (1) a longer distance shift may be difficult to arrange and (2) the maximum cable length is technically limited according to the instrument specifications. (For example, when using 01dB measurement system together with ICP-accelerometer the maximum cable length is 85 m for covering one-third octave band 5 kHz, or, 42 m if covering 10 kHz [33].)

Two types of quantities are recorded:

- Microphone recordings of time history data of sound pressure level during a train pass-by (in short, the mic-data);
- Accelerometer recordings of time history data of rail vertical vibration level during the train pass-by (in short, the acc-data).

Three types of quantities are determined:

- The vertical track decay rate, using the acc-data;
- The effective total roughness, using the acc-data and the vertical track decay rate;
- The total transfer function, using the mic-data and the effective total roughness.

The indirect roughness method separates pass-by sound pressure spectra (not sound power spectra) into the effective total roughness and the total transfer function of the vehicle and the track. The effective total roughness and the total transfer function are given as $1/3$ octave band spectra. The separation is accurate within ± 3 dB per $1/3$ octave band. Combination of the effective total roughness, the total transfer function and the axles per meter gives an estimation of the pass-by sound pressure spectra, which is accurate within ± 1 dB(A).

For collecting source data with good accuracy, it is required that, to avoid interference from accompanying wheel types, recordings containing at least two adjacent vehicles of the same type should be used to characterise a vehicle type, see Fig. 5.2. Such a time history recording of the rail acceleration levels is shown in Fig. 5.3. The average acceleration level and the equivalent SPL over the time interval T_p will be determined for each vehicle type as well as for each train pass-by.

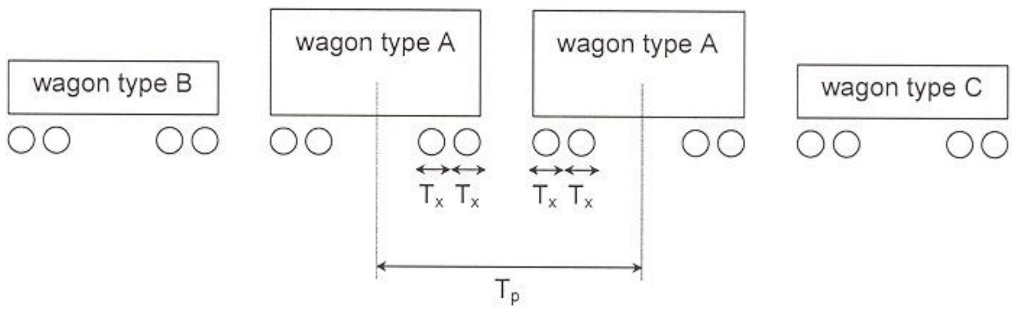

Fig. 5.2. To measure vehicle type A, at least two wagons are required.

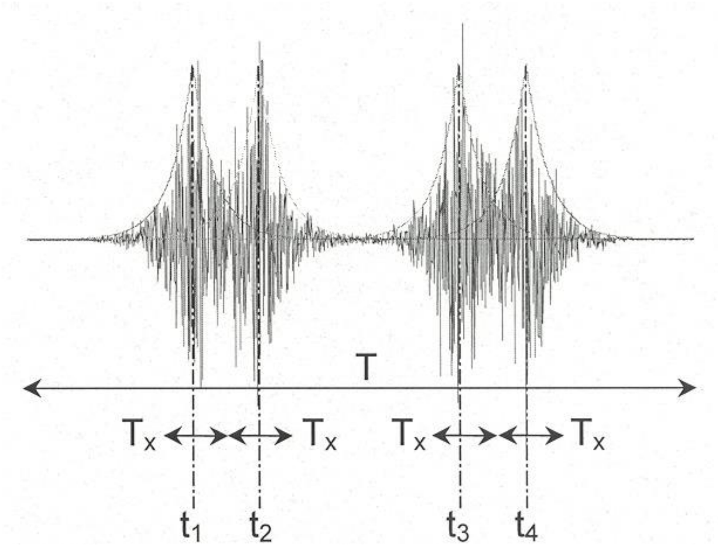

Fig. 5.3. Vertical acceleration recording during four wheel passages.

The accuracy of the indirect roughness method is analysed theoretically and by verification measurements, which show a maximum systematic error of ± 3 dB per $1/3$ octave band in a frequency range from 100 to 3150 Hz. This frequency range directly restricts the wavelength range in which roughness levels can be obtained at a certain speed. For example, at a train speed of 100 km/h, the wavelength range is limited to between 0.278 m and 0.009 m ($v = f\lambda$). If two speeds of 55 km/h and 160 km/h are used, the wavelength range will be from 0.444 m to 0.005 m.

Using the measured rail vertical acceleration level, together with a few functions based on TWINS calculations, the effective total roughness level is determined from

$$L_{r,tot}(f) = L_{a,meas}(f) - A_1(f) - A_2(f) - A_4(f) - 40\lg(2\pi f) \qquad (5\text{-}1)$$

where $L_{a,meas}(f)$ is the one-third octave band levels of measured equivalent vertical rail acceleration, averaged over wheel passage interval T_p; $A_2(f) = L_{x,contact}(f) - L_{r,tot}(f)$ is the level difference between the vibration displacement at the contact point on the railhead and the combined effective roughness; $A_4(f) = L_{a,head}(f) - L_{a,contact}(f)$ is the level difference between the vibration at the contact point and the vibration of the railhead; $L_{a,contact}(f) - L_{x,contact}(f)$ is equal to $40\lg(2\pi f)$; and, approximately, $A_1(f) = L_{a,meas}(f) - L_{a,head}(f) \approx 0$.

The level difference A_2 describes to which extent roughness induces rail vibration. It is the result of the wheel-rail interaction. As shown in literature [34]:

$$A_2 = 20\lg\left(\frac{|\alpha_R|}{|\alpha_R + \alpha_W + \alpha_C|}\right) \qquad (5\text{-}2)$$

where α_R stands for rail receptance, α_W for wheel receptance, and α_C for receptance of the contact stiffness. In ref. [34], the spectrum A_2 is determined for a range of parameter values using TWINS software. The pad stiffness is shown to be the most influential parameter. In the frequency range from 100 to 3150 Hz inclusive, the spectrum A_2 has been determined to an accuracy of ± 3 dB for application to conventional wheels, provided that the rail pad stiffness can be allocated to one of the three categories, as listed in Table 5.1.

Table 5.1. Spectra A_2 for three categories of rail pad stiffness [32]

Frequency (Hz)	Soft pad	Medium pad	Stiff pad
63	1.0	−3.0	−3.0
80	4.1	2.3	2.3
100	2.7	2.6	2.6
125	0.9	0.8	0.8
160	0.1	0.0	0.0
200	0.0	0.0	0.0
250	−0.6	0.0	0.2
315	−1.2	−2.6	−0.1
400	−1.3	−3.9	−2.8
500	−0.9	−4.8	−6.5
630	−0.9	−3.2	−8.1
800	−1.6	−2.6	−6.9
1000	−2.7	−4.3	−5.0
1250	−5.6	−6.2	−4.4
1600	−8.0	−7.5	−6.4
2000	−9.5	−8.8	−8.4
2500	−10.0	−9.8	−9.5
3150	−11.3	−11.2	−11.1
4000	−13.7	−13.6	−13.6
5000	−14.9	−14.8	−14.8

The conversion spectrum A_4 depends on the spatial vibration decay *D* of the track [31]

$$A_4(f) = 10\lg\left\{\frac{8{,}686}{vDT_x}\left[1 - e^{\left(-\frac{vDT_x}{8{,}686}\right)}\right]\right\} \qquad (5\text{-}3)$$

The frequency dependent decay per meter, *D(f)*, depends on the track characteristics. Track characteristics change during the track lifetime or even during a train passage. Especially the stiffness and damping of the rubber rail pad depends on temperature, lifetime, pre-load and the loading history.

The vibration decay *D* can be derived from hammer impact measurement (for an unloaded track), or, from pass-by measurement (for a loaded track). For the former, a standard method has been defined [35]. And, for the latter, there are two methods that have been proposed [36, 37].

Once the effective total roughness has been determined, also having the equivalent SPL of the train pass-by, L_{eq,T_0}, the total transfer function of the vehicle-track combination can be determined

$$L_{eq,T_0}(f) = 10\lg\left(\frac{N_{axle}}{L_{wagon}}\right) + L_{H,tot}(f) + L_{r,tot}\left(\frac{v}{f}\right) \qquad (5\text{-}4)$$

On a smooth rail section, wheel roughness can be determined from the effective total roughness if the contact filter can be specified.

Check points when carrying out such measurements:

- Other noise types should be negligible;
- No wheel flats present; no rail joints are found within 20 m;
- No other visible damages are found on the track.
- The running surface conditions of the two rails of a rail pair should be comparable;

It should be indicated that, to collect accurate source data using the indirect roughness method needs much more time to work with the raw data than to collect source data only using microphone recordings. For the former one needs to work with the pass-by time history of both noise and acceleration data in each of all relevant one-third octave bands as well as to make average over many train passages, for each train-track type. However, one needs only to collect such accurate source data at several typical track sites (while covering all train types of interesting). Having had the monitoring data of the rail roughness distribution, or, the raw data of the axle-box acceleration or of the under floor noise level, accurate noise prediction over the whole network can be made.

5.3 Collecting source data of other noise types

The source data of traction noise should be measured according to the standard method described in ISO 3095:2013.

For aerodynamic noise, it should be measured at the standard position, 25 m from the track centre and 3.5 m above the railhead. Train speed should be a typical high speed, not less than 250 km/h. The source data can be determined in the way as proposed in [12].

For other noise types, each of their source data will be collected using a measurement method as good as one can make, because no standard method is currently available for measuring these noise types.

5.4 Verifying the source model

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

For the part describing rolling noise, Harmonoise source model for railway noise has already be validated at European level. For the improved source model proposed in

Chapter 4, it is based on Harmonoise source model while with Swedish source data implemented. The verification will then be focused on these source data.

Two kinds of source data verifications can be considered, as discussed in the following.

The first kind verification is for the source data determined using the indirect roughness method. Reviewing the method described in section 5.2, one can find out that the effective total roughness is based on the wheel roughness averaged over two or more wheels (see Fig. 5.2, one should take as many wagons of the same type as possible to determine the source data), and based on the rail roughness at only one position. Although the rail/track conditions should have been checked when choosing a measurement position, there is still a risk that the collected effective total roughness (and the corresponding rail roughness) may not be the representative one for the rail section. It is then proposed that to use three points at each chosen site to determine the effective total roughness and to compare the resulted effective total roughness using the data at one point, or at two points. By economic reason, one expects, if acceptable, to use small number of measurement points. Thus, it will be fine if the verification study would suggest that one point measurements could produce good results. If not, one needs to consider to make average over at least two measurement points.

The second kind of verification is to check if it will be good to prepare the source data using the rail roughness data which are derived from the monitoring measurements, because quite much such rail roughness data have been collected [30]. To make this kind of verification, one needs to first determine the accurate source data using the indirect roughness method at one or several chosen sites, because this kind of source data have proved accuracy. These source data will then be compared with the source data prepared by using the rail roughness data which are derived from the monitoring measurements. In making this comparison, several train types need to be covered because relevant wheel roughness and contact filters can differ significantly.

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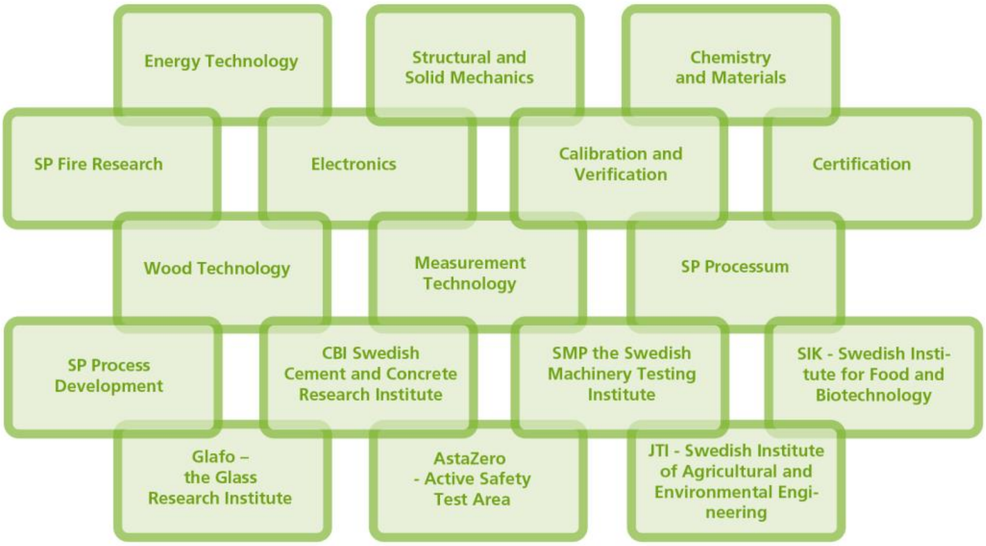

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