RAIL TRAFFIC NOISE MODELLING WITH CNOSSOS

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Rosão, Vitor.
SCHIU, Vibration and Noise Engineering, Faro, Portugal, vitorrosao@schiu.org

Grilo, Álvaro.
INERCO Acústica, S.L., Sevilla, Spain, agrilo@inerco.com

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ABSTRACT.

The way of entering the base data, in the CNOSSOS method, is quite different from what happened with the SRMII method, for the rail traffic noise modelling. There are some "conversion" guidelines from base data associated with the SRMII method to base data associated with the CNOSSOS method. This paper compares the results obtained with the SRMII method and with the CNOSSOS method, using the "conversion" guidelines, and also compares these results with some *in situ* measurements. Thus, some difficulties in rail traffic noise modelling are pointed out, and some associated guidelines are presented.

1. INTRODUCTION

Publication, in 2002, of Directive 2002/49/EC [1] specifically the chapter "*2.2 Recommended interim computation methods*" of its (old) Annex II, led to the use of the interim methods recommended by the Directive in many countries. Was this the case of Portugal and Spain.

In the case of railway noise, the recommended interim method corresponds to the Netherlands national computation method, usually called SRMII [2].

In the case of Portugal, the reference [3] establishes the ways of adapting the Portuguese trains so that the SRMII method [2] could be used. In the case of Spain the reference [4] establishes the ways of adapting the Spanish trains so that the SRMII method [2] could be used.

This paper, although more focused on Portuguese trains, can easily be adapted to other trains, especially in Europe.

Table 1 presents the forms of conversion for some of the existing trains in Portugal, according to the reference [3].

For example, the passage of 3 CPA 4000 trains ("Alfa pendular") must be modelled, according to reference [3], with the SRMII method, using 3x2=6 "trains" of category C09 (railcar; C09r) and 3x4=12 "trains" of category C09 (carriage; C09c).

Table 1 – Form of conversion of Portuguese trains into SRMII method categories

Portuguese trains	**SRMII Category**	**Quantity of "SRMII Category" per each "Portuguese train"**	**≈dB to add**
UQE 3150/3250	C02	4.6	+6.6 dB
UQE 2X00+UQE2X00	C02	25	+14.0 dB
UQE 3500	C08	14.6	+11.6 dB
UTE 2240	C03	3	+4.8 dB
UDD 450	C05 (diesel) C06	1 1	+0.0 dB +0.0 dB
CPA 4000	C09 (railcar) C09 (carriage)	2 4	+3.0 dB +6.0 dB
LOC5600/2600	C03 (motor)	1	+0.0 dB
LOC1930/1960	C05 (diesel)	1	+0.0 dB
Carriage Corail/Sorefame	C01	2.5	+4.0 dB
Freight wagon	C04	1	+0.0 dB

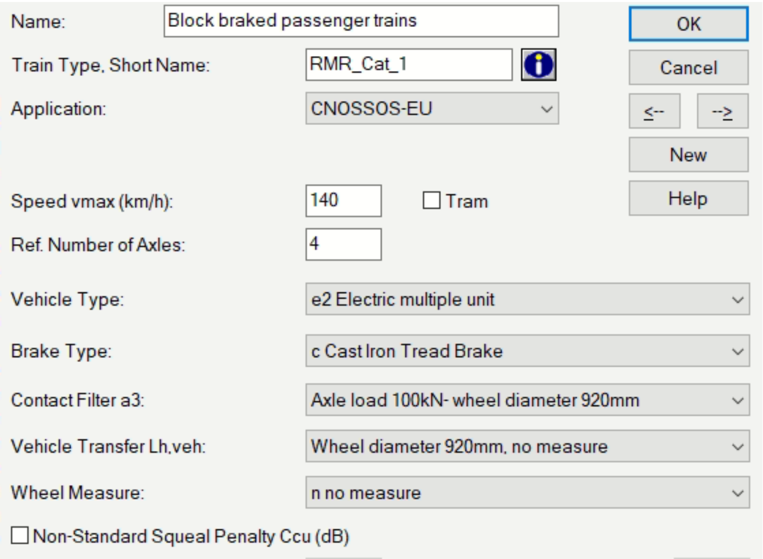
2. SRMII TO CNOSSOS CONVERSION

The reference [5] presents the conversion of National Method, including SRMII (called RMR on the reference [5]) to CNOSSOS Method.

For example, the software Cadna A [6] includes this conversion.

Figure 1 shows the example of the Cadna A window with the CNOSSOS method data considered to simulate the C01 category of the SRMII method.

Table 2 shows the data from the CNOSSOS method considered for all categories (C01 to C10) of the SRM II method.



Name: Block braked passenger trains
Train Type, Short Name: RMR_Cat_1
Application: CNOSSOS-EU
Speed vmax (km/h): 140
☐ Tram
Ref. Number of Axles: 4
Vehicle Type: e2 Electric multiple unit
Brake Type: c Cast Iron Tread Brake
Contact Filter a3: Axle load 100kN- wheel diameter 920mm
Vehicle Transfer Lh,veh: Wheel diameter 920mm, no measure
Wheel Measure: n no measure
☐ Non-Standard Squeal Penalty Ccu (dB)

Figure 1 – Example of the Cadna A CNOSSOS window for SRMII C01 category

Table 2 – CNOSSOS data for all SRMII train categories / classes according to [5] and [6]

SRMII Classes	**Speed vmax**	**Ref Mumber of Axles**	**Vehicle Type**	**Brake Type**	**Contact Filter A3**	**Vehicle Transfer Lh,veh**
C01	140	4	e2 Electric multiple unit	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C02a coaches	160	4	o other	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C02b loco	160	4	e1 Electric locomotive	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C03	140	4	e2 Electric multiple unit	n Disk Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C04	100	4	a generic freight vehicle	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C05a DE1 a DE3	140	4	d3 Diesel multiple unit	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C05b e C05c 2200&2300 2400&2500	140	4	d1 Diesel locomotive (c. 800kW)	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C06	120	4	d3 Diesel multiple unit	n Disk Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C07	100	3	e2 Electric multiple unit	n Disk Brake	Axle load 50kN – wheel diameter 680mm	Wheel diameter 680 mm, no measure
C08a ICM	160	4	e2 Electric multiple unit	n Disk Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C08b DDM	160	4	e2 Electric multiple unit	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C09a TGV power car	300	4	e2 Electric multiple unit	c Cast Iron Tread Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C09b TGV trailer car adj.	300	3	o other	n Disk Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C09c TGV trailer car other	300	2	o other	n Disk Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure
C10	330	4	e2 Electric multiple unit	n Disk Brake	Axle load 100kN – wheel diameter 920mm	Wheel diameter 920 mm, no measure

3. CONVERSION DEVIATIONS

Table 3, Table 4 and Table 5, shows the values predicted by the Cadna A software [6], on a receiver at a distance of 7.5 m from a railway line, at 4 m height, for a hard ground (ground absorption = 0) and for the passage of 1 vehicle/train per hour.

Were assumed the following characteristics:

- SRMII: Superstructure (bb): Concrete sleepers in gravel; Disconnections (m): jointless rails.

- CNOSSOS: Type of track: BH bi-block sleeper / Hard Pad; Railhead roughness: E Well maintained; Noise reduction at rail: none; Bridge: no bridge; Radius of curvature: none; Rail joins: 0.

Table 3 presents the values for category C02/SRMII, UQE 3150/3250 (Portuguese train, according [3] conversion), C02a/CNOSSOS, C02b/CNOSSOS and C02a⊕C02b (energetic/logarithmic sum).

Table 4 presents the values for category C05d/SRMII, C06/SRMII, UDD 450 (Portuguese train, according [3] conversion), C05a/CNOSSOS, C06/CNOSSOS and C05a⊕C06 (energetic/logarithmic sum).

Table 5 presents the values for category C09r/SRMII, C09c/SRMII, CPA 4000 (Portuguese train “Alfa pendular”, according [3] conversion), C09a/CNOSSOS, C09b/CNOSSOS and C09c/CNOSSOS.

Figure 2, shows the example of the spectrum for C02/SRMII, C02a/CNOSSOS and C02b/CNOSSOS, respectively for a speed of 50 km/h, 100 km/h and 140 km/h, for the same conditions of Table 3.

It can be seen, that there are significant deviations for different speeds of circulation, both in terms of overall value and in terms of spectrum, which suggests that special care must be taken when carrying out "standard" conversions.

Table 3 – Noise levels forecast for C02/SRMII, C02a/CNOSSOS and C02b/CNOSSOS

Speed [km/h]	**Noise Level [dB(A)] at 7,5 m distance, hard ground and the passage of 1 vehicle per hour**				
	C02 SRMII method	**UQE 3150/3250 C02 + 6.6dB SRMII method**	**C02a CNOSSOS method**	**C02b CNOSSOS method**	**C02a ⊕ C02b CNOSSOS method**
50	51.9	58.5	51.4	51.4	54.7
60	52.9	59.5	51.8	51.8	55.0
70	53.8	60.4	52.2	52.6	55.4
80	54.8	61.4	52.9	53.2	56.1
90	55.7	62.3	53.4	53,7	56.6
100	56.7	63.3	54.2	54.4	57.3
110	57.7	64.3	54,8	54.9	57.9
120	58.6	65.2	55.5	55.6	58,5
130	59.5	66.1	56.2	56.2	59.2
140	60.4	67.0	56.7	56.7	59.7

Table 4 – Noise levels forecast for C05d/SRMII, C06/SRMII, C05a/CNOSSOS and C06/CNOSSOS

Speed [km/h]	**Noise Level [dB(A)] at 7,5 m distance, hard ground and the passage of 1 vehicle per hour**					
	C05d SRMII method	**C06 SRMII method**	**UDD 450 C05d ⊕ C06 SRMII method**	**C05a CNOSSOS method**	**C06 CNOSSOS method**	**C05a ⊕ C06 CNOSSOS method**
50	53.5	44.9	54.1	51.7	45.0	52.5
60	55.4	45.9	55.9	52.0	45.2	52.8
70	55.6	47	56.2	52.4	45.5	53.2
80	55.8	48.1	56.5	53.0	45.9	53.8
90	56.1	49	56.9	53,5	46.2	54.2
100	56.5	49.9	57.4	54.3	46.6	55.0
110	56.8	50.7	57.8	54.9	46.9	55.5
120	57.2	51.4	58.2	55.5	47.3	56.1

Table 5 – Noise levels forecast for C09r/SRMII, C09c/SRMII, C09a/CNOSSOS, C09b/CNOSSOS and C09c/CNOSSOS

Speed [km/h]	**Noise Level [dB(A)] at 7,5 m distance, hard ground and the passage of 1 vehicle per hour**					
	C09r SRMII method	**C09c SRMII method**	**CPA 4000 (C09r+3dB) ⊕ (C09c+6dB) SRMII method**	**C09a CNOSSOS method**	**C09b CNOSSOS method**	**C09c CNOSSOS method**
50	48.2	45.5	54.4	51.5	42.2	40.4
60	49.5	46.8	55.7	51.8	42.8	41.0
70	50.7	47.8	56.8	52.3	43.3	41.6
80	51.7	48.8	57.8	52.9	43.9	42.1
90	52.6	49.6	58.6	53.5	44.4	42.6
100	53.4	50.3	59.4	54.2	44.8	43.1
110	54.2	51.0	60.1	54.8	45.2	43.5
120	54.9	51.6	60.8	55.5	45.7	43.9
130	55.6	52.2	61.4	56.2	46.1	44.4
140	56.2	52.7	62.0	56.7	46,5	44.7
150	56.9	53.2	62.6	57.3	47.0	45.2
160	57.4	53.7	63.1	57.9	47.5	45.7
170	58.0	54.1	63.6	58.4	47.9	46.1
180	58.6	54.6	64.1	58.8	48.2	46.4
190	59.1	55.0	64.6	59.5	48.7	46.9
200	59.6	55.3	65.0	60.0	49.1	47.4

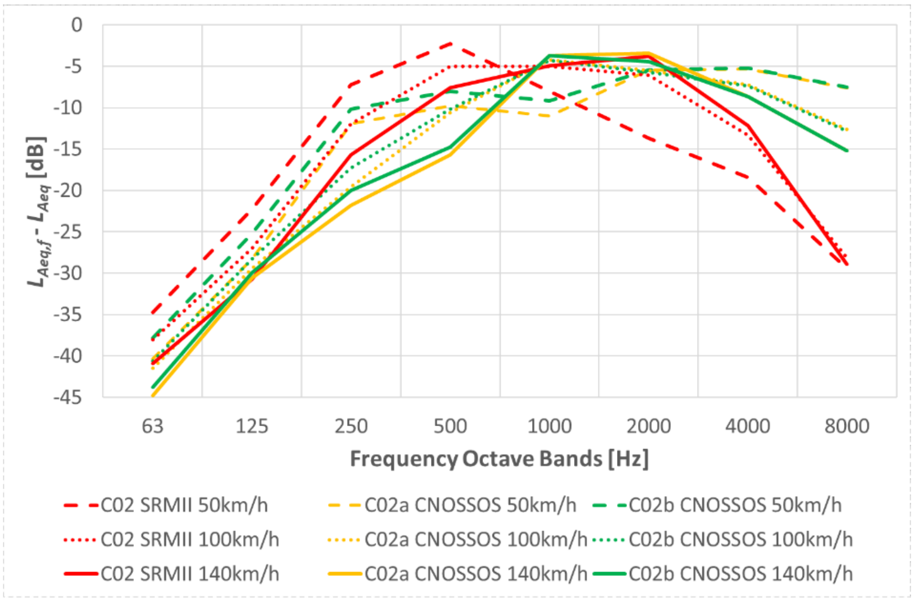


Figure 2 – Example of the C02/SRMII, C02a/CNOSSOS and C02b/CNOSSOS spectrums, for 50 km/h, 100 km/h and 140 km/h

4. NOISE MEASUREMENTS

Considering the aforementioned deviations, it is recommended that, whenever possible and for greater accuracy of results, *in situ* noise measurements are carried out at the passage of different trains on a given line. The forecasts of the CNOSSOS method must be adjusted accordingly, by comparing the measured with the predicted values for the same point.

ISO 1996-1 [7] and ISO 1996-2 [8] standards must be used for measurements, according to “old” chapter “*3. Interim measurement methods for* L_{den} *and* L_{night}” of the Annex II of the Directive [1] (version before Directive 2015/996 [9]) and according to “new” chapter “*4. Measurement methods*” of the Annex II of the Directive [1] (version after [9]).

According to chapter "*7.3.1 Leq measurement*" of ISO 1996-2 [8], the number of measurements (the number of train pass-byes) required depends on the required precision.

According to chapter "*2.1.2. Quality framework / Accuracy of input values*" of Directive 2015/996 [9], we have:

> "*All input values affecting the emission level of a source shall be determined with at least the accuracy corresponding to an uncertainty of ± 2dB(A) in the emission level of the source (leaving all other parameters unchanged)*".

Formula 8 and other associated comments of ISO 1996-2 [8], establish for the measurement uncertainty associated with each vehicle class:

$$u_{sou} = 5/\sqrt{n} \tag{1}$$

5 dB is the standard deviation assumed.

Thus, making u_{sou} = 2 dB, results:

$$n = (5/2)^2 \approx 6 \tag{2}$$

Therefore, it is recommended to measure at least 6 trains of each category of interest.

For the same type of train, if significant speed differences may occur (for example, when the same train may or may not stop at a certain station; or other type of significant difference) it is recommended to distinguish as corresponding to 2 different subcategories and carry out at least 6 measurements of each of the subcategories.

The measurement at the passage of each train, according to the chapter "*9.3.2.3 Sound exposure level during the time interval T, $L_{E,T}$*", of ISO 1996-2 [8], must be carried out as measurements of 125ms steps (Fast time weighting), selecting only the results between -10dB below the maximum, before and after the maximum of the pass-by.

To be more accurate and if possible, the method of ISO 3095 [10] must be used, as illustrated in Figure 3:

> *"… the recording time interval T_{rec} shall be chosen, so the record starts when the AF-weighted sound pressure level history $L_{pAF}(t)$ or the short term $L_{pAeq,125ms}(t)$ is at least 10 dB lower than found when the front of the train is opposite the microphone position. The record shall not end before the A-weighted sound pressure level is 10 dB lower than found when the rear of the train is opposite the microphone position …*".

Knowing the linear average T_{rec}, in seconds, and the linear average $L_{Aeq,global.pass\text{-}by}$, during T_{rec}.,, linear average of $L_{AE,pass\text{-}by}$ can be calculated with:

$$L_{AE,pass-by} = L_{Aeq,global,pass-by} + 10\log\left(T_{rec}\right) \tag{3}$$

Or, during T_{rec},:

$$L_{AE,pass-by} = 10\log\left(\sum 10^{\frac{L_{pAeq,125ms}}{10}}\right) - 10\log\left(8\right) \tag{4}$$

Calculating the standard deviant σ, for each train class, can be seen if the assumed 5 dB is correct, and if it is necessary less or more than 6 pass-byes (in the next formula n is the number of pass-byes, x_i each L_{Aeq} or L_{AE} value and the $\bar{x}$ the linear average of L_{Aeq} or L_{AE} values):

$$\sigma = \sqrt{1/n \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{5}$$

According to formula D.18 of ISO 1996-2 [8], we can write, for 1 vehicle per hour (13 vehicles during the Portuguese daytime period (7am-8pm), 3 vehicles during the Portuguese evening period (8pm-11pm) or 8 vehicles during the Portuguese night period (11pm-7am)):

$$L_{Aeq,1veh/hour} = L_{AE,pass-by} - 10\log(3600) \tag{6}$$

It is thus possible to compare this average measured value, for a certain train category, with the predicted value, for a point in the simulation software like the measurement point, for a category in the modelling software considered adequate, considering the passage of 1 vehicle per hour, and adjusting so that the measured and predicted values match (care must be taken in terms of the measured and predicted spectrum).

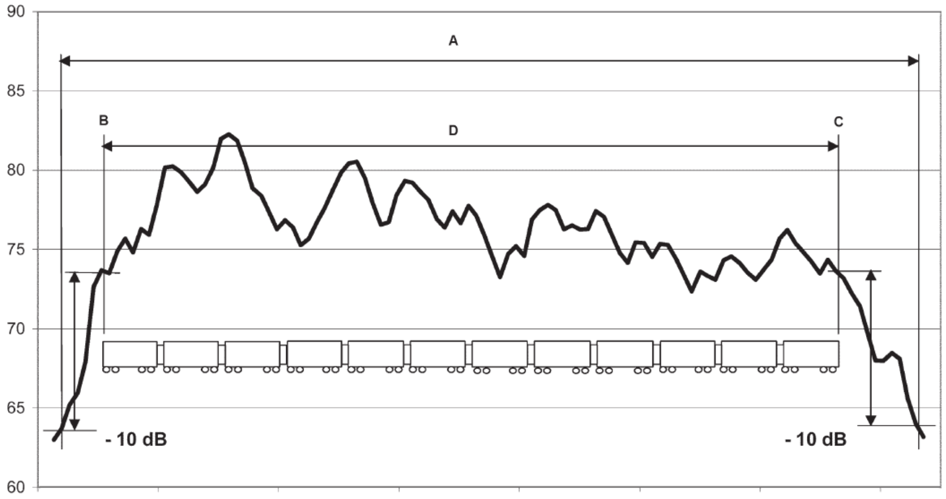


Figure 3 – Time of measurement to be account during train pass-by

5. EXAMPLE

Figure 4 shows an example of a pass-by $L_{Aeq,125ms}$ values, associated with a measurement of a Portuguese “Alfa Pendular” passing at 130 km/h at a certain point.

The associated $L_{AE,pass\text{-}by}$ and $L_{Aeq,1veh/hour}$, are: $L_{AE,pass\text{-}by}$ and ≈ 81.4 dB(A); $L_{Aeq,1veh/hour}$ ≈ 45.8 dB(A).

As a first approach was decided to model the CPA 4000 (Alfa Pendular), and the railway line in question, with CNOSSOS method, with the data presenting in Figure 5.

For 1 vehicle per hour in the model the forecast L_{Aeq}, for the measured point, was: $L_{Aeq,1veh/hour}$ ≈ 46.1 dB(A). The difference with the measured value is just 0.3 dB.

Figure 6 shows the comparison of the measurement and prevision spectrum. Seems that the measured values have more low frequency components.

Ideally, other influencing parameters should be measured, namely the roughness of the rail [11], allowing the situation to be modelled as accurately as possible (including the spectrum) and maintaining the possibility of using the CNOSSOS method for a possible definition of noise mitigation measures. See, e.g., the reference [12].

An alternative hypothesis is to use the sound emission parameters, regardless of the railway and train characteristics, and adjust them to obtain the measured spectrum. Table 6 shows the original sound power L_w spectrum data assumed by the model and the calculations done to obtain a new L_w values that give a prevision values (including spectrum) according with the measurement.

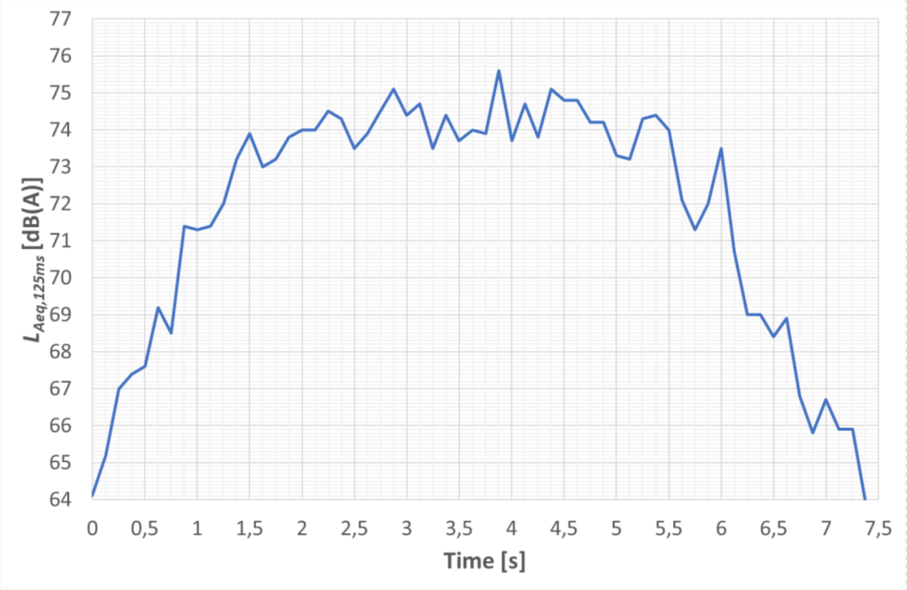
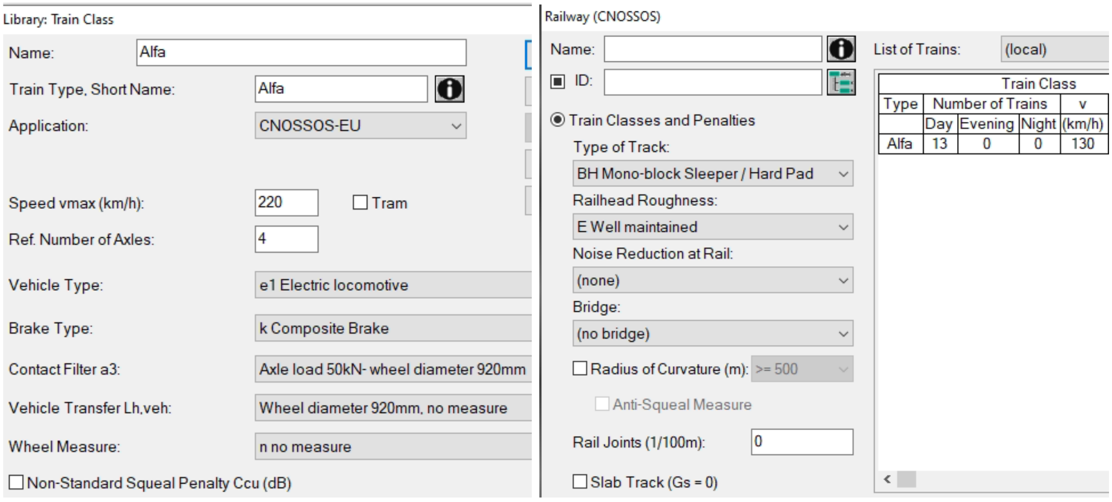


Figure 4 – Example of a $L_{pAeq,125ms}$ pass-by measurement


Library: Train Class

Name: Alfa

Train Type, Short Name: Alfa

Application: CNOSSOS-EU

Speed vmax (km/h): 220 ☐ Tram

Ref. Number of Axles: 4

Vehicle Type: e1 Electric locomotive

Brake Type: k Composite Brake

Contact Filter a3: Axle load 50kN- wheel diameter 920mm

Vehicle Transfer Lh,veh: Wheel diameter 920mm, no measure

Wheel Measure: n no measure

☐ Non-Standard Squeal Penalty Ccu (dB)

Railway (CNOSSOS)

Name:

☐ ID:

● Train Classes and Penalties

Type of Track: BH Mono-block Sleeper / Hard Pad

Railhead Roughness: E Well maintained

Noise Reduction at Rail: (none)

Bridge: (no bridge)

☐ Radius of Curvature (m): >= 500

☐ Anti-Squeal Measure

Rail Joints (1/100m): 0

☐ Slab Track (Gs = 0)

List of Trains: (local)

Train Class				
Type	Number of Trains			v
	Day	Evening	Night	(km/h)
Alfa	13	0	0	130

Figure 5 – Cadna A CNOSSOS windows assumed for CPA 4000 (Alfa Pendular) and for the railway line

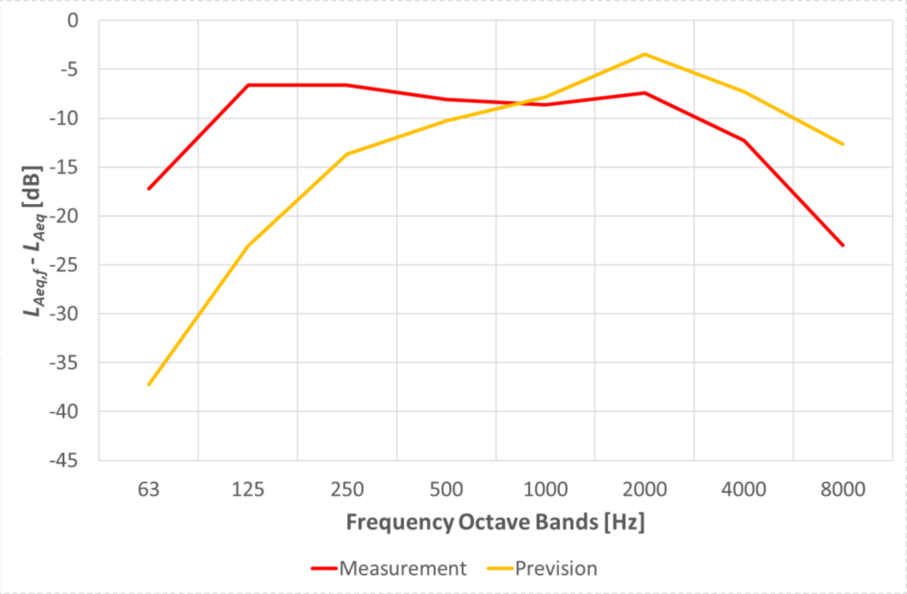


Figure 6 – Comparison of measurement and prevision spectrum

Table 6 – Calculation done to obtain a new L_w from the original L_w

	L_w original	L_{Aeq} associated prevision	L_{Aeq} Adjust (-0.3dB) for global value	Associated relative spectrum (ARS)	Intended relative spectrum (IRS)	New *Lw* (L_w - 0.3 + (PRS-ARS))
63Hz	56.5	8,9	8,6	-37,2	-17,2	76,2
125Hz	60.6	23,1	22,8	-23	-6,6	76,7
250Hz	62.5	32,5	32,2	-13,6	-6,6	69,2
500Hz	60.5	35,8	35,5	-10,3	-8,1	62,4
1kHz	60.6	38,2	37,9	-7,9	-8,6	59,6
2kHz	63	42,6	42,3	-3,5	-7,4	58,8
4KHz	59.8	38,8	38,5	-7,3	-12,3	54,5
8kHz	58.2	33,5	33,2	-12,6	-23,0	47,5
Global	69.7	46,1	45,8	0	0	80

6. CONCLUSIONS

Although there are "standard" indications for converting national rolling stock to the CNOSSOS method, it can be seen, as previously explained, that there may be significant deviations.

It is therefore recommended, whenever possible and for a greater accuracy of results, that *in situ* measurements are carried out for each relevant train category.

This paper indicates some specificities to be taken into account in the measurements and a way to be possible to compare the measure results with the predict results, and how to adjust – when necessary – the CNOSSOS noise emission accordingly.

ACKNOWLEDGMENTS

We would like to thank Rafael Tadeia for his help in placing data in Cadna A, from which some of the graphs and tables presented here were developed.

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