Correcting the CNOSSOS-EU road noise emission values

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Summary

The EU Directive 2015/996 (CNOSSOS-EU) provides separate calculation models for the noise emission from road traffic, rail traffic, aircraft and industrial sources. The road noise emission model is comprehensive yet straightforward to implement. The Directive provides the formulas for calculating the noise emission, as well as default sound power coefficients: values that describe the noise emissions at 70 km/h and speed coefficients to calculate the levels for other vehicle speeds. The sound power coefficients have been derived from roadside noise measurements of passing vehicles. The pass-by noise is attributed to a single source height, using a calculation of the propagation from microphone to source. The current CNOSSOS-EU propagation model is, however, different from the Harmonoise model used to establish the sound power coefficients provided. There is currently a mismatch, therefore, between the CNOSSOS road noise emission factors and the propagation model.

The paper explains the acoustic description of both propagation models in the near-field, including the effect of the reflection of sound waves on the road surface. The results show that the current sound power coefficients in the 2015/996 Directive are a significant underestimation of the actual noise emission, with a magnitude depending on frequency. A procedure to establish correct coefficients for CNOSSOS is provided, and a new set of coefficients for the average European vehicle fleet are proposed. The measurement and analysis procedure given in this paper may also be used to update the noise emission factors in the future, or to derive regional values for individual Member States.

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1. Introduction

The EU Directive 2015/996 [1] describes the common assessment methods for road, rail, air traffic noise and industrial noise sources, developed within the CNOSSOS-EU project. The common noise assessment methods are to be used for establishing the strategic noise maps, required every 5 years from all EU Member States by the Environmental Noise Directive 2002/49/EC [2]. The methods, which are now commonly referred to as ‘CNOSSOS’, include separate calculation methods for road, rail and industrial noise emission. The directive also includes a common model for the noise propagation from the source to the environment, which is to be used for road, rail and industrial noise sources. For aircraft noise, a separate emission and propagation model are defined, generally following the prescriptions of ECAC Doc 29.

The directive 2015/996 specifies that these calculation methods should be implemented in national legislation for END noise mapping purposes by all EU Member States before 31 December 2018. In The Netherlands, as well as in some other MS, the government is considering to use the CNOSSOS models for other noise legislation purposes also, thereby replacing our current national noise calculation methods used for road, rail and industrial noise assessment. The National Institute for Public Health and the Environment (RIVM) is responsible for maintaining and updating the noise assessment methods, and is also responsible for the Dutch implementation of CNOSSOS. A research project was started by RIVM to investigate any issues involved with the implementation of CNOSSOS. M+P was contracted by RIVM to perform this research for the road noise emission model.

2. CNOSSOS road noise emission model

2.1. Source description

CNOSSOS describes the sound power of a single vehicle as a function of the vehicle speed v and the frequency f in octave bands from 63 Hz to 8 kHz. Sound power is calculated separately for the rolling noise generated by the tyre/road interaction (L_{WR}), and the propulsion noise generated by exhaust, inlet, engine, gearbox, etc., (L_{WP}), using equations (1) and (2).

$$L_{WR}(f) = A_R(f) + B_R(f) \cdot \log_{10}(v/v_{ref}) \qquad (1)$$

$$L_{WP}(f) = A_P(f) + B_P(f) \cdot \frac{v - v_{ref}}{v_{ref}}. \qquad (2)$$

The reference vehicle speed v_{ref} is 70 km/h for all vehicle categories. The sound power coefficients A_R and A_P represent the noise emission, for rolling and propulsion noise respectively, in octave bands at the reference vehicle speed, while the coefficients B_R and B_P determine the speed dependency of both contributions. The rolling noise has a logarithmic speed dependency, whereas the propulsion noise increases linearly with speed.

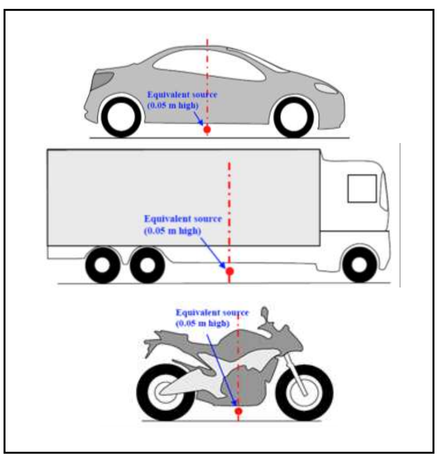

Figure 1. Vehicle categories and source height

CNOSSOS provides four main vehicle categories: light motor vehicles, medium heavy vehicles, heavy duty vehicles and powered two-wheelers. All vehicles are represented by a single source height at 5 cm height from the road surface (see Figure 1).

The source description in equations (1) and (2) and the corresponding sound power coefficients are valid under reference conditions:

- constant vehicle speed;
- a flat road;
- 20 °C air temperature and a dry road surface;
- a 'virtual reference' road surface: a mixture of dense road surface types, between 2 and 7 years old, in a representative maintenance condition.

For situations deviating from these reference conditions, correction factors have been derived for non-constant speed (at crossings), air temperature, road gradients, various road surface types and for studded tyres. See [3] or [4] for details.

2.2. Sound power coefficients

The sound power coefficients A_R, A_P, B_R and B_P for equations (1) and (2) have been previously derived in the EU 6th Framework project IMAGINE [4]. The distinction between the rolling noise and propulsion noise components is based on several dedicated measurement campaigns using on-board measurements on specific vehicles, pass-by and coast-by measurements on test tracks, and other data sets. The total overall noise levels has been calibrated using roadside pass-by noise measurements in several EU countries (NL, UK, PL, IT, DK). The resulting A and B coefficients are representative for the average European vehicle fleet under the reference conditions.

Sound power coefficients have been derived from roadside Sound Exposure Levels (SEL), measured at 7.5 m distance from centre of the rightmost driving lane. The measurements and analysis largely followed the ISO 11819-1 standard for SPB measurements, but with a microphone height of 3 meters, SEL instead of $L_{\max}$ and a frequency-dependent speed dependency (linear regression per 1/3-octave band).

Figure 2: IMAGINE pass-by measurements (Gdansk, 2006)

From these roadside SEL levels, the sound power coefficients need to be derived, using a noise propagation model to calculate the attenuation from the assumed point source to the microphone position, integrating from the vehicle trajectory within -80° to +80 opening angle (see Figure 3).

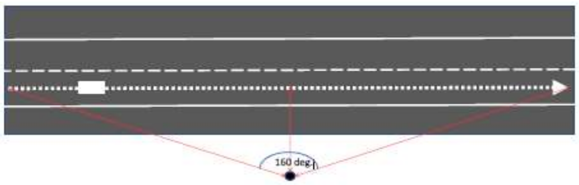

Figure 3: Integration angle sound propagation from pass-by SEL to L_W

3. Near-field sound propagation

3.1. Propagation aspects

For the roadside pass-by measurements, the microphone is at 7.5 m distance from the source. For sound propagation to such a nearby receiver, the most important factor for attenuation is the geometrical divergence A_{div}:

$$A_{div} = 20 \cdot \lg(R) + 11 \qquad (3)$$

where R is the 3D distance between source and receiver in meter. This equation regards a free-field point source, with spherical divergence of sound waves. A second, less important attenuation factor is the atmospheric absorption A_{atm}:

$$A_{atm} = \alpha_{atm} \cdot R/1000 \qquad (4)$$

where α_{atm} is the atmospheric absorption coefficient in dB/km, depending on frequency (see [5]).

Other factors influencing the propagation can be neglected: the ground is flat, there are no reflecting objects around and measurements have been performed at low wind speeds.

3.2. Ground reflection

Since the road noise source is close to the ground, it is important to consider how the reflection of the sound waves on the surface below the source is taken into account. For the IMAGINE pass-by measurements, performed under reference conditions, the road surface was dense and can be considered fully reflective. Due to the low source height, the reflection on the surface is close to the source and the path difference between the direct wave (R1) and reflected wave (R2) is small, as indicated in Figure 4.

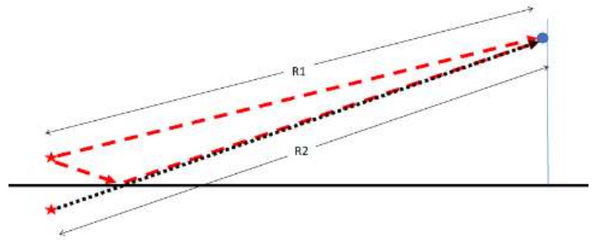

Figure 4: Reflection on the ground below the source is taken into account using a mirror source

3.3. Harmonoise

The Harmonoise propagation model assumes coherent point sources [6], so the direct sound wave and the sound wave reflected on the ground need to be added including their phase relation. If the sound source is on the ground ($z_s = 0$), the phase difference is zero and the sound power increases by 6 dB due to the presence of the surface. For $z_s > 0$, interference between both waves leads to frequency-dependent interference, expressed by the attenuation factor A_{ground} in equation (5). A negative attenuation indicates an amplification of sound. The influence of the presence of the reflective surface is shown in Figure 5 [7].

$$A_{ground} = -20 \cdot \lg\left[1 + \frac{R1}{R2} \cdot \cos\left(k \cdot (R1 - R2)\right)\right] \qquad (5)$$

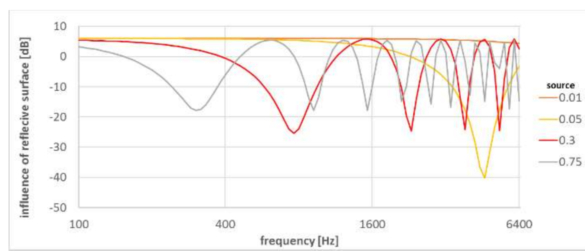

Figure 5: Influence of the presence of a reflective surface, with coherent addition of the direct and reflected path, for different source heights (0.01 to 0.75 m) and a receiver position at 7.5 distance and 3.0 m height.

3.4. CNOSSOS / NMPB

The CNOSSOS propagation model is derived from the French NMPB road noise assessment method. The CNOSSOS and NMPB models are energy-based models, assuming incoherent addition of sound waves. For CNOSSOS, therefore, the presence of the reflective surface leads to a doubling of sound energy, and an increase of the sound power of 3 dB, independent of frequency. This is expressed in section 2.5 of the 2015/996 directive [1] by the statement:

$$\text{if } G_{path} = 0\text{: } A_{ground,H} = -3 \text{ dB} \qquad (6)$$

3.5. Effect of propagation on sound power

In Figure 6 the transfer function, e.g. the difference between the sound power L_W and the roadside sound exposure level, integrated over the vehicle trajectory at 70 km/h, is given. The figure shows the result for the Harmonoise propagation model and the CNOSSOS propagation model.

The Harmonoise transfer functions have been taken from the final IMAGINE deliverable [4]. In the Harmonoise/IMAGINE project, the road noise vehicles were described using multiple source heights at 1 cm / 30 cm for light vehicles and PTW and 1 cm / 75 cm for (medium) heavy vehicles (see paragraph 4). It is clear from this figure that the attenuation from L_W to SEL is 3 dB higher for the CNOSSOS transfer function compared to the Harmonoise functions at low frequencies. For higher frequencies, the difference is smaller and for higher sources, the CNOSSOS attenuation is even below the Harmonoise curves for specific frequencies.

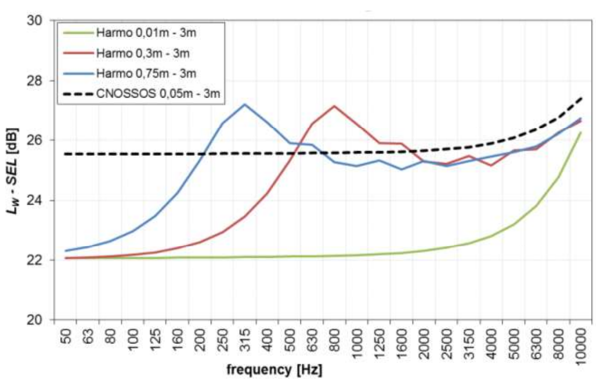

Figure 6: Transfer functions from L_W to SEL using Harmonoise propagation model (1, 30, and 75 cm source heights) and CNOSSOS propagation model (5 cm source height), for a vehicle speed of 70 km/h, including geometric divergence and atmospheric absorption.

The sound power coefficients for CNOSSOS have been derived in the IMAGINE project using the Harmonoise propagation model. During the development of CNOSSOS, a switch was made from the Harmonoise to the NMPB-based propagation model. The sound power coefficients, however, have not been adapted: the values currently presented in Appendix F, table F-1 of the Directive 2015/996 are the same as the IMAGINE values, with the only difference that the 1/3-octave band values have been summed to 1/1-octave bands.

As a consequence, the current predictions for the road noise emission using the 2015/996 Directive are incorrect: the calculated sound immission using the sound power coefficient in Table F-1 in combination with the CNOSSOS propagation model does not represent the actual noise immission found from the roadside measurements. For most of the frequency range, CNOSSOS will give an underestimation of the noise levels of up to 3 dB, caused by the change in propagation models. For specific frequencies, the difference is smaller or the CNOSSOS model gives a small overestimation.

3.6. Definition inconsistency

Besides the fact that the switch of propagation models has introduced an error in the road noise sound immission calculated with CNOSSOS, there is an inconsistency in the text of the Directive 2015/996 regarding the road surface reflection.

The 2015/996 Directive states ([1], page 7):

> *In this method, each vehicle (category 1, 2, 3, 4 and 5) is represented by one single point source radiating uniformly into the 2-π half space above the ground. The first reflection on the road surface is treated implicitly.*

This text assumes a 'semi-free field' or 'hemispherical' point source. This was never the case in the IMAGINE/Harmonoise project, however: the sound power coefficients have been derived for a free-field point source radiating into the 4-π space. The first reflection on the road surface is not treated implicitly and should be part of the propagation model.

In fact, the CNOSSOS propagation model <u>does</u> include the reflection of the road surface. The road surface reflection leads to the 3 dB increase expressed by equation (6). If the sound emission model would be hemispherical (2-π), the A_{ground} factor would have to be 0 (zero).

So, if the sound emission is calculated using the equations (1) and (2) in combination with the prescribed sound power coefficients and the CNOSSOS propagation model, the result is correct and the effect of the presence of the reflecting road surface is right. The text on page 7, cited above, should be neglected or corrected to represent a free-field (4-π) point source, where the first reflection on the road surface is treated by the propagation model.

An adaption to the sound power coefficients, to correct for the switch from the 'coherent' Harmonoise to the 'incoherent' CNOSSOS/NMPB propagation model is required, however, to obtain accurate results.

4. Establishing correct sound power coefficients

To calculate correct sound power coefficients for CNOSSOS, we derived a procedure to adapt the current coefficients as listed in the Directive 2015/996 Table F-1 (from IMAGINE) to the CNOSSOS propagation model.

For this, it is necessary to know that the IMAGINE model used a different source height composition:

- one source at 0,01 m height, to which 80% of the rolling noise and 20% of the propulsion noise was attributed,
- one source at 0,3 m height, for light motor vehicles and powered two-wheelers, or 0,75 m height for (medium) heavy vehicles, to which 20% of the rolling noise and 80% of the propulsion noise was attributed.

To correct the CNOSSOS sound power coefficients for the change in propagation models, we follow the following procedure:

1. Start with the IMAGINE A_R and A_P coefficients, which are equal to the Directive 2015/996 Table F-1 values, but in 1/3-octave bands.
2. Using the Harmonoise transfer functions, as shown in Figure 6, calculate the rolling and propulsion noise SEL levels at the measurement position (7.5 m distance, 3.0 m height), for each of the IMAGINE source heights (1, 30, 75 cm).
3. For each vehicle category, calculate
   a. the total rolling noise contribution, by adding 80% of the sound energy at the lowest source (1 cm) and 20% of the energy at the highest source (30 or 75 cm), and
   b. the total propulsion noise contribution, by adding 20% of the lowest source and 80% of the highest source.
4. Calculate the total SEL at the measurement position by adding the rolling noise and propulsion noise from 3a and 3b. These levels are exactly equal to the average SEL levels found from the measurements.
5. Calculate the total sound power for the CNOSSOS sound source at 5 cm height, using the transfer functions calculated with the CNOSSOS propagation model (see Table I).
6. Divide the sound power between rolling noise and propulsion noise contributions, using the original values:
   a. rolling noise = result step 5 – (result step 4 – result step 3a),
   b. propulsion noise = result step 5 – (result step 4 – result step 3b).
7. Calculate the CNOSSOS-EU coefficients for rolling and propulsion noise by summing the 1/3-octave band values to 1/1-octave bands.

This procedure results in the correct CNOSSOS A_P and A_R coefficients, representative for the average EU vehicle fleet under reference conditions, at 70 km/h. The B_P and B_R coefficients are not changed and are equal to the 2015/996 Table F-1 values. The change in propagation models does not affect the speed dependency of the sound power levels.

During the application of this procedure, it was found that there was an error in the Harmonoise transfer functions used in the IMAGINE project back in 2006. This error has also been corrected, leading to a difference of 1 to 1,5 dB in the coefficients for (medium) heavy vehicles and PTW. There was no error in the values for light motor vehicles.

5. Results

Following the procedure above, new sound power coefficients have been derived that match the CNOSSOS-EU propagation model. As explained in paragraph 3.5, the corrected CNOSSOS-EU values are higher than the existing values. Figure 7 shows the original and corrected A_P and A_R coefficients for light motor vehicles (category 1), for each octave band. The difference is up to 3 dB. The propulsion noise coefficients show smaller differences for frequencies around 1000 Hz, which corresponds to

Table I: CNOSSOS transfer function from L_W to SEL at 70 km/h, including atmospheric absorption and ground reflection; source at 5 cm height, receiver at 7.5 m distance, 3.0 m height

50 Hz	*63 Hz*	*80 Hz*	*100 Hz*	*125 Hz*	*160 Hz*	*200 Hz*	*250 Hz*	*315 Hz*	*400 Hz*	*500 Hz*	*630 Hz*
25.53	25.53	25.53	25.53	25.54	25.54	25.54	25.55	25.55	25.56	25.56	25.57
800 Hz	*1 kHz*	*1.25 kHz*	*1.6 kHz*	*2 kHz*	*2.5 kHz*	*3.15 kHz*	*4 kHz*	*5 kHz*	*6,3 kHz*	*8 kHz*	*10 kHz*
25.58	25.59	25.60	25.62	25.65	25.70	25.77	25.89	26.07	26.35	26.77	27.40

the smaller difference in transfer functions for the 0,3 m source height (see Figure 6).

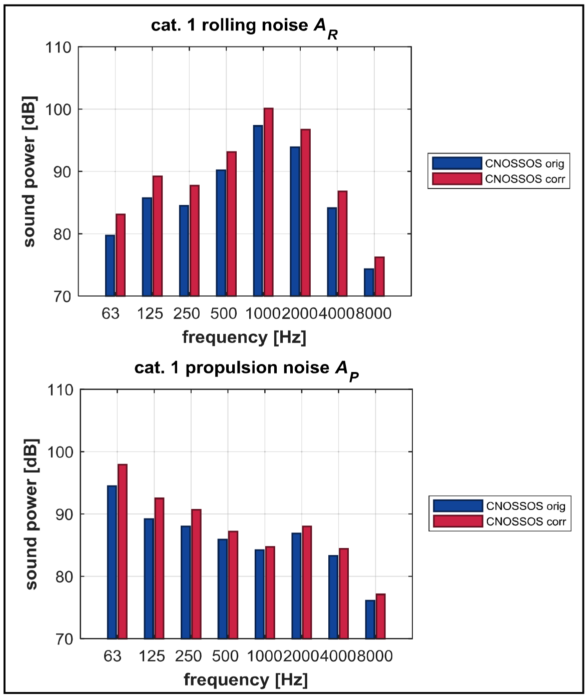

Figure 7: Corrected vs. original CNOSSOS-EU sound power coefficients for light motor vehicles; top: rolling noise A_R, bottom: propulsion noise A_P

In Figure 8 and , the total sound power levels are shown for rolling noise, propulsion noise and total noise, for light motor vehicles and heavy duty vehicles. This figure shows that the overall levels are higher when the corrected sound power coefficients are used, compared to the original 2015/996 values.

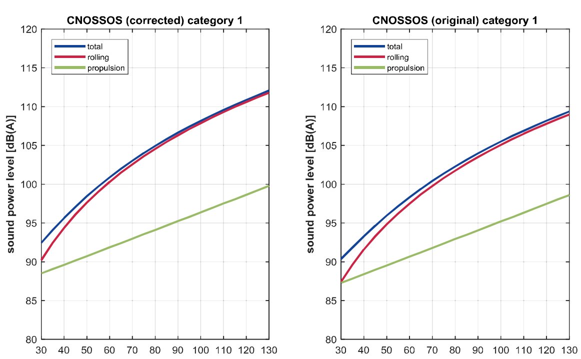

Figure 8: Corrected (left) vs. original (right) CNOSSOS-EU total sound power in dB(A) vs. vehicle speed, for light motor vehicles

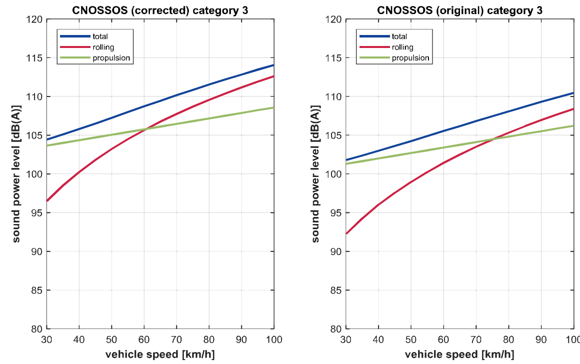

Figure 9: Corrected (left) vs. original (right) CNOSSOS-EU total sound power in dB(A) vs. vehicle speed, for heavy duty vehicles

6. Conclusions and recommendations

6.1. Conclusions

The sound power coefficients for road traffic noise emission, as proposed in Directive 2015/996 Table F-1, are incorrect. They have been derived using a different propagation model, based on coherent addition of the direct sound wave and the sound wave reflected on the road surface. The current CNOSSOS propagation model assumes incoherent sources. Combining this propagation model with the suggested sound power coefficients will lead to an underestimation of the road noise emission.

A procedure has been applied to derive corrected road noise emission values from the original roadside SEL measurement values, using the CNOSSOS propagation model. The corrected coefficients are 0 to 5 dB higher, depending on frequency and vehicle category.

6.2. Recommendations

It is highly recommended that member states do not use the sound power coefficients suggested in the Directive 2015/996 Table F-1. Instead, the corrected coefficients, derived with the method presented in this paper, should be used to represent the EU average vehicle fleet.

We recommend that the Commission updates the values in Table F-1 in a future update of the 2015/996 Directive. In the meantime, the Commission has stated that the values presented in Appendix F are not mandatory. Therefore, Member States are free to use different, corrected values.

For Member States that wish to use individual national values, the method described in this paper may also be used to derive sound power coefficients from local pass-by measurement values. This analysis has been done for the Dutch implementation of CNOSSOS as well. A measurement and analysis method has also been developed in this project and is described in a separate report [8], available from the authors of this paper.

Acknowledgement

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References

[1] Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council;

[2] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise;

[3] Bert Peeters: CNOSSOS-NL: Issues for national implementation of the EU road noise emission model, Proceedings ICSV24, London, July 2017;

[4] Gijsjan van Blokland, Bert Peeters: The noise emission model for European road traffic, Deliverable 11 of the IMAGINE project, IMA55TR-060821-MP10, July 2007;

[5] ISO 9613-1: Acoustics -- Attenuation of sound during propagation outdoors -- Part 1: Calculation of the absorption of sound by the atmosphere, 1993;

[6] D. van Maercke et al.: A general approach for extending the range of application of standard noise mapping methods, Proceedings Acoustics 2012, Nantes;

[7] Bert Peeters, Gijsjan van Blokland: Interface between the CNOSSOS-EU road traffic noise emission model and the propagation model, M+P report M+P.RIVM.17.03.1, 13 October 2017;

[8] Gijsjan van Blokland, Bert Peeters: Proposal for a procedure to determine the sound power of road vehicle for CNOSSOS-EU, M+P report M+P.RIVM.17.03.4, 2 October 2017.