Compatibility of the ROSANNE noise characterization procedure for road surfaces with CNOSSOS-EU model

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ABSTRACT

The European project ROSANNE is preparing a procedure for the characterization of road surface noise properties, to be considered for standardization. The proposed procedure, presented in another paper, is based on tire-road noise measurements using the CPX method. The output will be useful to road administrations and road companies when referring to contractual values in legal documents for road surface construction. Moreover road and environmental administrations are also concerned by evaluating the impact of road surface properties on noise exposure, in particular when implementing the "Environmental Noise Directive" 2002/49/EC (END). The END requires Member States to produce noise maps and action plans, using a common calculation method, called "CNOSSOS-EU" and now published in European Directive 2015/996/EC. The purpose of the present study is to check that the road surface characterization delivered by ROSANNE is consistent with the road surface correction specified in the CNOSSOS-EU model for road traffic noise emission. In this paper, the main features of both systems are briefly presented and compared: noise indicators, frequency ranges, pavement definition, reference conditions and measurement conditions. Then recommendations are made on how the ROSANNE characterization procedure could provide valuable and compatible input to the European calculation method for road noise prediction.

Keywords: noise, road surface, pavement, classification, CPX, CNOSSOS-EU, road traffic, model
I-INCE Classification of Subjects Number(s): **11.7** Rolling contact noise sources and **52.3** Road traffic noise

1. INTRODUCTION

One of the objectives of the ROSANNE project is to develop a practical procedure for a representative and accurate characterization of road surface noise properties, to be submitted for International and European standardization. The proposed procedure is described in deliverable D2.4 of the ROSANNE project and presented at this conference in another paper (1). The procedure is based on tire-road noise measurements using the Close Proximity method (CPX). The output of this characterization is a set of CPX noise levels at different reference speeds, representing the reference noise property of a certain type of road surface. This reference will be useful for road manufacturers, to promote their low-noise road products in a European or international context. It will also be useful for road administrations and road construction companies and suppliers to refer to contractual values in official documents for road surface construction, renewal and/or monitoring. On the other hand, road administrations and environmental agencies are also concerned by the evaluation of the impact of road surface properties on noise exposure, both when applying their national regulations and when implementing the "Environmental Noise Directive" 2002/49/EC (END) (2). These regulations are often based on modelling and the calculation method is usually imposed, as is the case for the END. In these calculation methods, the noise property of a road surface is one of the input parameters of the road traffic noise emission model.

The END requires Member States to take a common approach to the management of environmental

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noise, by producing noise maps from transport and industry and drawing up actions plans to manage noise. The strategic noise maps and the action plans are based on modelling and the END stipulates that a common calculation method is to be required. This common method was developed within the framework "CNOSSOS-EU" and published in 2012 in (3). In 2015, after a formal vote by Member States, this method was fully described as an annex of the European Directive 2015/996/EC (4). Its use will be compulsory for the establishment of strategic noise maps from 31st December 2018. In the road traffic noise emission part of the model, the noise property of road surfaces is one of the input parameters.

There would be a clear benefit if ROSANNE characterization procedure could deliver consistent data for the harmonized noise model. This would result in a consistent European assessment system of road noise, from the source characteristics to the people noise exposure.

In this context, the objective of this study is to check the consistency of the ROSANNE characterization procedure with CNOSSOS-EU. More precisely, the study will investigate if the ROSANNE procedure can provide road surface data compatible with the European model for road traffic noise emission.

The ROSANNE procedure and the CNOSSOS-EU road traffic emission model are briefly described in respectively sections 2 and 3. An analytical comparison of both systems is presented in section 4. Finally, section 5 draws the conclusions and recommendations for ensuring consistency.

2. THE ROSANNE PROCEDURE FOR NOISE CHARACTERIZATION OF ROAD SURFACES

The proposed procedure is described in deliverable D2.4 of the ROSANNE project (to be published in October 2016). The main features are summarized here for an easier understanding.

The procedure is based on the measurement of tire-road noise using the CPX method as described in (5), with the two reference tires defined in (6):

- tire P1 representative of passenger cars: a "SRTT" tire defined in the American standard ASTM F2493-14, and having dimensions 225/60R16;
- tire H1 representative of heavy vehicles: a Avon Supervan tire AV4, dimensions 195R14C.

The procedure is developed for three possible applications, each of them requiring a specific implementation of the measurements:

1. the characterization of new road surface type ("labelling"): in this application, CPX noise levels are measured at all reference speeds where the road surface is expected to be used. These reference speeds can be 50 km/h, 80 km/h and 100 km/h. The measurements are then repeated on several sections laid with the same type of pavement in order to average the construction variability on different sites. Road surfaces must be in relatively new conditions. The resulting average CPX noise level provides the acoustic "label" of the type of pavement. It can be used for comparing pavement performances, or as a reference target of performance in road renewal contracts.
2. the test of the conformity of production ("COP") of a specific road surface on an existing work site: in this application, CPX measurements are performed at the reference speed imposed by the road authority. The conditions of implementation of the method must be strict enough so that a high accuracy is obtained, as legal aspects are concerned.
3. the "monitoring" of acoustic properties of existing road sections or networks. This application can be used for gaining knowledge on the acoustic aging of road surfaces, or for checking the good condition of a pavement or a set of sections on a road network. The requirements in terms of accuracy are less stringent unless legal aspects are under consideration (e.g. in the case durability requirements were introduced in the contract for repaving). Measurements are performed at the most adapted reference speed with regard to speed limit on the sections.

3. THE EU-HARMONISED MODEL FOR ROAD TRAFFIC NOISE EMISSION (CNOSSOS-EU)

3.1 Model for road traffic noise emission

3.1.1 General principle

The road traffic noise model is described in chapter 2.2 of the Annex of the Directive (4). In this model, road traffic sound power levels are calculated in octave bands from 63 Hz to 8 kHz. They result from the addition of the noise emission of each individual vehicle forming the traffic flow. These vehicles are grouped in five categories with regard to their characteristics of noise emission:

- 1. Light motor vehicles,
- 2. Medium heavy vehicles
- 3. Heavy vehicles,
- 4. Powered two-wheelers
- 5. An open category for future vehicles with sufficiently different noise emission from vehicles in the previous four categories

All the vehicles in these categories are modeled by one single point source placed 0.05 m above the road surface, and radiating uniformly into the half-space above the road (the first reflection on the road is treated implicitly).

3.1.2 Sound power of individual vehicles

For light, medium and heavy categories (1, 2 and 3), the sound power level of individual vehicles corresponds to the energetic sum of the rolling noise and the propulsion noise.

$$L_{W,i,m}(v_m) = 10 \times log\left(10^{L_{WR,i,m}(v_m)/10} + 10^{L_{WP,i,m}(v_m)/10}\right) \quad (1)$$

where $L_{WR,i,m}$ is the sound power level for rolling noise and $L_{WP,i,m}$ is the sound power level for propulsion noise, i is the number of the octave band and m the number of the vehicle category.

For two-wheelers (category 4), the rolling noise contribution is neglected.

$L_{WR,i,m}$ and $L_{WP,i,m}$ can be calculated for each vehicle category m as a function of the average speed v_m, considering a reference situation, and adding correction coefficients for deviations with regards to this reference.

3.1.3 Reference conditions

The reference situation is defined by the following conditions:

- an air temperature of 20 °C
- a traffic with constant vehicle speed and no vehicles with studded tires
- a flat and dry road, with a virtual reference road surface defined according to average noise emission properties on:
  - a mix of Dense Asphalt Concrete (DAC) 0/11 and Stone Mastic Asphalt (SMA) 0/11
  - all between 2 and 7 years old and
  - in a representative maintenance condition

3.1.4 The rolling noise

The rolling noise sound power level in the octave band i for a vehicle of class m=1,2 or 3 is defined by:

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m} \times log\left(v_m / v_{ref}\right) + \Delta L_{WR,road,i,m} + \Delta L_{studded,i,m} + \Delta L_{WR,acc,i,m} + \Delta L_{W,temp} \quad (2)$$

where $\Delta L_{WR,road,i,m}$ accounts for the effect on rolling noise of a road surface with acoustic properties different from those of the virtual reference. It includes both the effect on propagation and on generation.

$\Delta L_{studded,i,m}$ is a correction coefficient accounting for the higher rolling noise of light vehicles equipped with studded tires.

$\Delta L_{WR,acc,i,m}$ accounts for the effect on rolling noise of a crossing with traffic lights or a roundabout. It integrates the effect on noise of the speed variation.

$\Delta L_{W,temp}$ is a correction term for an average temperature different from the reference temperature of 20 °C.

The coefficients $A_{R,i,m}$ and $B_{R,i,m}$ are provided in Appendix F of the annex of (4) in octave bands for each vehicle category and for a reference speed v_{ref} = 70 km/h. They were derived from large databases of noise spectra (at least for vehicles of category 1), and come from the extensive work undertaken through the development of the NORD2000, HARMONOISE and IMAGINE European projects, as well as the technical work undertaken by the Member States within the CNOSSOS-EU Working Group WG/DT2. It is assumed that they provide a good representation of the vehicle fleets in evidence across the EU, i.e. a vehicle fleet for which the characteristics correspond to the values found in IMAGINE report D11 (7), namely:

- 187 mm tire width for category 1
- 19% diesel for category 1
- 10.5% delivery vans in category 1
- 4 axles for category 3
- 35% IRESS (illegal replacement exhaust silencing systems) for category 4, 1% for other

categories 1 to 3.

3.2 The effect of road surface characteristics in the CNOSSOS-EU model

The rolling sound power emission of vehicles depends on the road surface characteristics through the correction coefficient $\Delta L_{WR,road,i,m}$ and implicitly through the reference conditions that define the reference sound emission. The correction coefficient is defined by:

$$\Delta L_{WR,road,i,m} = \alpha_{i,m} + \beta_m \times log\left(v_m / v_{ref}\right) \tag{3}$$

$\alpha_{i,m}$ is the spectral correction in dB at the reference speed v_{ref} for category m (1, 2 or 3) and octave band i. In the case of a porous road surface the $\alpha_{i,m}$ coefficient will decrease the propulsion noise, but dense surfaces will not increase it.

β_m is the speed effect on the rolling noise effect for category m (1, 2 or 3) and is supposed identical for all frequency bands

$\alpha_{i,m}$ and β_m are derived to be representative for the acoustic performance of the road surface type averaged over its representative lifetime and assuming proper maintenance.

Table 1 gives the list of the 14 road surfaces for which $\alpha_{i,m}$ and β_m data are provided in Appendix F of (4) and the associated speed range for validity. They are originated from the current Dutch road traffic calculation method.

Table 1 – Road surfaces types for which data are provided in (4) and associated speed range

Code	Road surface	Speed range for validity (km/h)
	Reference surface (virtual) corresponding to a mix of DAC11 and SMA 11 : no correction	All speeds
NL01	1-layer ZOAB	50 - 130
NL02	2-layer ZOAB	50 – 130
NL03	2-layer ZOAB (fine)	80 – 130
NL04	SMA-NL5	40 – 80
NL05	SMA-NL8	40 – 80
NL06	Brushed down concrete	70 – 120
NL07	Optimised brushed down concrete	70 – 80
NL08	Fine broomed concrete	70 – 120
NL09	Worked surface	50 – 130
NL10	Hard elements in herring-bone	30 – 60
NL11	Hard elements not in herring-bone	30 – 60
NL12	Quiet hard elements	30 – 60
NL13	Thin layer A	40 – 130
NL14	Thin layer B	40 - 130

3.3 Guidelines on the conversion of existing road source data to use CNOSSOS-EU

As part of the CNOSSOS-EU methodology, the so-called "quality framework" requires that the most influential parameters on the source definition are originated from real data, not defaults, unless costs associated with the data collection are disproportionately high (8). Therefore, it is expected that besides the adaptation of existing experimental data and emission models, in the future, Member States will collect new data to be input in the CNOSSOS-EU database format. However, currently, an interim approach was developed to enable data, and knowledge, relevant to existing national methods to be applied to the harmonized model, in particular to identify how national categories of vehicles and road surfaces may be represented in CNOSSOS-EU. Guidelines on the process applied to establish CNOSSOS-EU / national method equivalence for road source data are drafted in (9).

The document specifies how the national vehicle categories and road surfaces can be converted to be used in a CNOSSOS-EU. Most national methods use calculations of overall dB(A) emission levels, often as a SPL at a reference distance from the virtual source(s) location. In CNOSSOS-EU, sound power levels are calculated in octave bands. Data formats have been investigated for seven major national models in Europe (NMPB 96, CRTN, Nord2000, RLS90 2006, NMPB 2008, RMG:SRM 2012, RVS 4:02:11 2006). For the road surfaces, look-up tables have been developed in order to connect each of the national road surface types to one of the "Dutch-CNOSSOS-EU" road surface listed in table 1.

The annex 1 of the Guidelines (9) provides a state-of-the-art on the measurement of road surface effect. It mainly refers to the procedure developed in the EU FP5 project SILVIA for the determination of the road surface correction, without providing the details for the derivation of α and β coefficients. The report states that: "… *the mandatory measurement method is the SPB method, ISO 11819-1*(…). *Although the SPB method is slightly different from the preferred method applied in the IMAGINE study, the CPX method, it can be used since we only use it as determination of a difference and not an absolute value."*

4. COMPARISON BETWEEN ROSANNE AND CNOSSOS-EU METHODOLOGIES

An analytical comparison was made between the features of ROSANNE classification procedure and CNOSSOS-EU road traffic emission model. The objective is to highlight the potential to use the output of ROSANNE procedure as an input in CNOSSOS-EU model, and to identify the scientific barriers to be crossed for this purpose.

4.1 The sound source

First of all, both procedures consider rolling noise as a separate noise source in the vehicle noise.

Table 2 – Comparison ROSANNE/CNOSSOS-EU regarding sound source

	ROSANNE	CNOSSOS-EU
Sound source	Rolling noise (of a tire)	Rolling noise (of a vehicle)
Type of source	One or two specific test tires: - Tire P1 representative of passenger cars (tire width 225 mm) - Tire H1 representative of heavy vehicles (tire width 195 mm)	Three vehicle classes with non-zero rolling noise component: - Category 1: light vehicles - Category 2: Medium heavy vehicles - Category 3: Heavy vehicles Data corresponding to average tire width 187 mm for cat. 1

In CNOSSOS-EU, rolling noise data have been extracted from vehicle pass-by measurements, resulting in a sound source representative of the whole rolling noise in a vehicle. In ROSANNE, the CPX method will directly and exclusively measure the rolling noise of a reference tire. The reference tire P1 was selected for its ability to classify the acoustic properties or road surfaces in a similar manner to the majority of passenger car tires (category 1 in CNOSSOS-EU). It is, however, much larger (225 mm) than the average tire width (187 mm) for passenger car data in the model.

Similarly, the reference tire H1 was selected for its sensitivity to road surfaces comparable to heavy vehicles (category 3 in CNOSSOS-EU). The correlation between the noise emitted by any of these reference tires and the noise emitted by medium heavy vehicles (category 2) was not investigated so far. However, when looking at the data provided in CNOSSOS-EU database, the correction coefficients for road surfaces (i.e. the spectral correction $\alpha_{i,m}$ and the speed effect β_m) are fully identical for categories 2 and 3.

Therefore at present state, the ROSANNE methodology is compatible with the European road noise emission model with what concerns the sound source.

4.2 The Reference conditions

The reference conditions constitute a central element in the CNOSSOS-EU model, as nearly all parameters are defined in relation to these conditions. They include definitions of the reference road surface, of the reference road environment and of the operation conditions of the vehicles in the traffic.

Table 3 – Comparison ROSANNE/CNOSSOS-EU regarding reference conditions

	ROSANNE	CNOSSOS-EU
Reference road surface	No reference road surface Road surfaces are in relatively new conditions	A virtual reference road surface, consisting of an average of DAC 0/11 and SMA 0/11, between 2 and 7 years old, and in a representative maintenance condition
Reference on road and environment conditions	no bend, at least 20 m long (100 m preferable) an air temperature T_{ref} = 20 °C a dry road surface	a flat road an air temperature T_{ref} = 20 °C a dry road surface
Reference on operating conditions of vehicles	Test at constant speed Speed categories are defined No studded tires	A constant vehicle speed No studded tires.

4.2.1 Reference road surface

A virtual reference road surface is defined in CNOSSOS-EU, corresponding to an average of Dense Asphalt 0/11 and Stone Mastic Asphalt 0/11, between 2 and 7 years old and in a representative maintenance condition. The effect of other road surfaces is defined as a difference with this reference. On the contrary, ROSANNE method works on absolute noise performances of road surfaces. However, the connection between both approaches should be easy as the virtual road surface in CNOSSOS-EU corresponds to a sound power spectrum for each vehicle category, from which a CPX sound pressure level can be calculated by assuming a simple source and propagation model (see 4.3).

The definition of a reference road surface in the harmonized road noise model has no effect on the consistency with ROSANNE method

4.2.2 Reference on road environment

In CNOSSOS-EU reference conditions, the road should be flat, the surface dry and the air temperature of 20°C. In ROSANNE, the road surface should also be dry and the reference air temperature is 20°C. There is no specific requirement regarding the flatness of the road. Therefore, the reference conditions on road environment are fully consistent.

However, it is important to mention that although the reference air temperature is the same, the temperature correction law for expressing rolling noise at T_{ref} = 20°C is different.

In the harmonized model, it is indicated in section 2.2.3 of (4) that the road surface noise shall be corrected with regard to yearly average air temperature (T):

$$\Delta L_{WR,road,i,m}(T) = \Delta L_{WR,road,i,m}(T_{ref}) + K_m(T_{ref} - T) \tag{4}$$

A generic coefficient K is provided for all road surfaces and all frequencies (although in principle this coefficient depends on the road surface and the tire characteristics, and exhibits some frequency dependence). For passenger cars K_1=0.08 dB/°C; for heavy vehicles $K_2 = K_3$ = 0.04 dB/°C.

The ROSANNE method refers to the CPX standard (5) completed with the standard on reference tires (6) in which:

$$L_{CPX}(T) = L_{CPX}(T_{ref}) + \gamma_t(T_{ref} - T) \tag{5}$$

where the subscript t indicates the test tire and γ_t depends on type of road surface and the vehicle speed (v):

- For dense asphaltic surfaces (DAC, SMA, chip seals) $\gamma_{P1} = \gamma_{H1} = -0.14+0.0006\ v$;
- For cement concrete surfaces of all types $\gamma_{P1} = \gamma_{H1} = -0.10+0.0004\ v$;
- For porous asphalt surfaces, $\gamma_{P1} = \gamma_{H1} = -0.08+0.0004\ v$

The linear correction of rolling noise with regard to temperature is thus consistent between the two methods in its principle. However, one must admit that the recommended coefficients are rather inconsistent, although the impact on the result may be small.

4.2.3 Reference on operating conditions of vehicles

In CNOSSOS-EU reference conditions, the vehicles in the traffic should drive at a constant speed and they should not be equipped with studded tires.

These conditions are fully consistent with ROSANNE method.

4.3 The measurement method and the indicators

Although CNOSSOS-EU is not intended to be a measurement method, the noise calculation model is and will be supplied with input parameters derived from measurements. One of the key issues regarding the consistency between the harmonized European model and the ROSANNE classification procedure is related to the measurement method and the resulting indicators for road surface characterization.

Table 5 – Comparison ROSANNE/CNOSSOS-EU regarding indicators

	ROSANNE	CNOSSOS-EU
Measurement method	Based on CPX measurements	Based on SPB measurements
Indicator	LCPX or CPXI	$\Delta L_{WR,road}$ derived from SPB level
Frequency range	Overall level in dB(A) and 1/3 octave bands between 315 Hz and 5 kHz	1/1 octave bands between 63 Hz and 8 kHz
Speed range	At 50 km/h, 80 km/h and 100 km/h	Expressed at 70 km/h. Speed coefficient provided for the maximum range [30 – 130 km/h]. The range can be smaller according to pavement type

4.3.1 Measurement methods

The road surface corrections proposed in (4) were derived from Statistical Pass-By measurements (SPB), and, as reminded in section 3.3, the methodology proposed in the Guidelines (9) for defining additional road surface coefficients is also based on SPB measurements. Although the Guidelines state that "*the SPB method is slightly different from the preferred method applied in the IMAGINE study, the CPX method, it can be used since we only use it as determination of a difference and not an absolute value*", the consistency of road surface corrections obtained with SPB and with CPX measurements should be carefully addressed.

In ROSANNE Deliverable D2.3 (10), an analysis was performed of the relationships between measurements of the acoustic properties of road surfaces made with different methods, in particular SPB and CPX. In the study, a comprehensive set of CPX noise levels and SPB noise levels measured in different EU countries, on the same pavements at approximately the same time, were collected and analyzed.

The conclusions for passenger cars can be summarized as:

- For data where both types of noise levels had been recorded at the same reference speed, namely 80 km/h, there was a rather clear correlation (correlation coefficient R^2=0.94 after eliminating the outliers) between CPX noise levels measured with standard P_1 reference tire ($CPXP$) and pass-by noise levels (L_{AFmax}):

$$L_{AFmax,80} = 0.95 \cdot CPXP_{80} - 15.6 \text{ dB} \tag{6}$$

- Considering the typical CPXP levels, an average 1:1 relationship between CPX noise levels measured with tire P_1 and SPB noise levels from passenger cars can reasonably be derived (as long as both types of noise levels are measured at the same reference speed), yielding a 20.5 dB average difference between the two measured quantities and with almost 90 % of all data being within ±1 dB around this trend line.
- Sets of data where the CPX noise levels had been measured at 80 km/h reference speed while the vehicle pass-by noise levels had been measured at 110 – 120 km/h reference speeds did not show the same clear pattern. When data are adjusted to the same reference speed, the correction introduces some bias and makes the correlation poorer.

For heavy vehicles:

- There is no clear correlation between *CPXP* levels measured with tire P_1 and SPB noise for heavy vehicles
- For multi-axle trucks on dense road surfaces, pass-by noise levels show a moderate linear relationship with CPX noise levels measured with the H_1 reference tire (Avon AV4) (correlation coefficient R^2=0.52), given by:

$$L_{AFmax,80} = 0.65 \cdot CPXH_{80} + 24.0 \text{ dB} \tag{7}$$

- Considering the typical *CPXH* levels at 80 km/h, the average pass-by noise levels from multi-axle trucks on dense pavements is 9.5 dB lower than the CPX noise levels measured with H_1 tire. For two-axle trucks, the corresponding difference is 12.0 dB.

From this analysis - based on overall noise levels - it can be concluded that the CPX measurement method as proposed in the ROSANNE procedure can provide noise levels relatively consistent with statistical pass-by levels as used in CNOSSOS-EU provided that the test tire is adapted to the vehicle category (P_1 for category 1 and H_1 for category 2 and 3 with the restriction that in this later case, the correlation is lower) and adapted to the reference speed that should be as close as possible to the average speed of the traffic flow for the category of vehicles. However, deeper knowledge is necessary to validate and generalize this assumption, for wider speed range and frequency range.

4.3.2 **Indicators**

In the ROSANNE method, the output indicator is either a CPX sound pressure level for a certain test tire (P_1 or H_1) or a CPXI, an index based on the weighted sum of two CPX sound pressure levels. In the harmonized model, the road surface correction $\Delta L_{WR,road,i,m}$ is a sound power level difference. Sound power levels (L_W) can be derived from a sound pressure level (SPL) by retro-fitting a propagation model. If we assume that tire/road noise can be modelled by a point source close to the contact patch, then:

$$L_{WR} = L_{pmax} + 10\log(4\pi d^2) - A_{SPB} \quad (8)$$

where d is the distance and A_{SPB} the ground attenuation between the point source and the microphone measuring the maximum pass-by noise. A_{SPB} can take any value between -∞ and +6 dB depending on the geometry, the ground surface and the phase relationship between the direct and the reflected wave. For a purely reflecting surface and a point source at very low height above it, A_{SPB} = 6 dB.

Then, when comparing pass-by noise on two different road surfaces, the difference in sound power level is:

$$\Delta L_{WR} = \Delta L_{pmax} - \Delta A_{SPB} \quad (9)$$

For similar ground surface between the source and the microphone $\Delta A_{SPB} = 0$ and $\Delta L_W = \Delta L_{pmax}$. But in case of ground surfaces of different acoustic properties, for example for a porous road surface, $\Delta A_{\mathrm{SPB}} \neq 0$ and needs to be calculated by sound propagation models.

It is unclear how this propagation effect has been taken into account for the calculation of $\Delta L_{WR,road,i,m}$ from SPB measurements in CNOSSOS-EU. The annex of the directive 2015/996/EC states that "*the sound power of the source is defined in the semi-free field, thus the sound power includes the effect of the reflection of the ground immediately under the modelled source where there are no disturbing objects in its immediate surroundings except for the reflection on the road surface not immediately under the modelled source*". The annex 1 of the Guidelines (9) states that: "*in the presented reduction values, the local reflection is already included in the surface effect and shall not be included in propagation calculations*". This can be interpreted as an effective road surface correction:

$$[\Delta L_{WR}]_{\text{CNOSSOS-EU}} = [\Delta L_{WR}]_{\text{true}} + \Delta A_{SPB} = \Delta L_{pmax} \quad (10)$$

Similarly for CPX measurement positions, assuming that both microphone positions are equivalent:

$$[\Delta L_{WR}]_{\text{true}} = \Delta L_{CPX} - \Delta A_{CPX} \quad (11)$$

Note that this relation assumes a point source emission, which can be critical for a CPX configuration where the receiver is close to the source. Sidewall radiation and sources in the contact patch are not exactly point source, especially at low frequency.

Finally, the relation between ΔL_{CPX} and $[\Delta L_{WR}]_{\text{CNOSSOS-EU}}$ becomes:

$$\Delta L_{CPX} = [\Delta L_{WR}]_{\text{CNOSSOS-EU}} + \Delta A_{CPX} - \Delta A_{SPB} \quad (12)$$

For reflecting road surfaces (dense surfaces), ΔL_{CPX} and $[\Delta L_{WR}]_{\text{CNOSSOS-EU}}$ are fully equivalent.

For road surfaces with porosity, there is a difference due to the difference in ground effect between the two measurement configurations. This difference should be further investigated and evaluated for typical values of sound impedance of porous road surfaces. However, this effect due to different propagation effect is already included in the CPX/SPB data for which a correlation was looked for. And we have seen that *CPXP* is fairly correlated with SPB for light vehicles.

So we can assume at this stage that the difference of ground effect in the case of porous surfaces prevents the full equivalence between road surface correction in CNOSSOS-EU and in ROSANNE but is probably of secondary importance. This point needs to be further investigated.

4.3.3 Frequency range

A significant difference between CNOSSOS-EU modelling method and ROSANNE characterization procedure is that the first one calculates noise levels in full octave bands, whereas the later essentially produces overall levels or index. Of course, the CPX measurement method produces results in 1/3 octave bands, however, the characterization procedure described in ROSANNE aims at the evaluation for comparison of overall noise performances.

Therefore, it is important that the labelling procedure in ROSANNE imposes the production of 1/1 or 1/3 octave bands.

More problematic is the frequency range. In CNOSSOS-EU, the input data are provided for each octave bands centered from 63 Hz to 8 kHz. The range of validity of CPX is restricted to 1/3 octave bands centered 315 Hz to 5 kHz. It corresponds to 1/1 octave bands from 500 Hz to 4 kHz. The upper limit is similar to SPB method. The lower limit is physical. It is due to possible contamination of the measurements by aerodynamic noise, and also by near field effects (source and receivers are at very short distance with regard to the wavelength).

Therefore, there is a physical limitation in ROSANNE procedure to produce valid road surface correction data in the octave bands from 63 Hz to 250 Hz. However, in the 63 Hz and partly in the 125 Hz octave bands, the noise levels are dominated by propulsion noise for which road surface characteristics are not significant.

4.3.4 Speed range

The road surface correction data in CNOSSOS-EU are expressed at the reference of 70 km/h. The speed effect is provided, as an overall value (β_m coefficient) and makes possible the calculation of road surface effect at any speed. The specified reference speeds in ROSANNE are 50, 80 and 100 km/h. The ROSANNE system defines three road speed categories, low, medium and high road speed categories corresponding to traffic operating at an average speed respectively below 65 km/h, between 65 and 99 km/h, and at 100 km/h and above.

The consistency between both approaches will be achieved if the ROSANNE characterization procedure includes a systematic determination of the speed coefficient. This has to be added to the present version of the procedure. The alternative would be to refer to generic speed coefficients β_m as defined in appendix F of (4).

4.4 The road surfaces definition

The definition of road surface types can also be a source of inconsistency. In ROSANNE procedure D2.4, a long list of road surface standard definitions is provided. It is based on the work performed in the HARMONOISE EU-project (11) and refers whenever possible to international standards. Road surfaces are defined by acronym and grading size, such as SMA 0/8 (Stone Mastic Asphalt with maximum aggregate size 11 mm), DAC 0/11 (Dense Asphalt Concrete with maximum aggregate size 11 mm), TLPA 0/6 (Thin Layer Porous Asphalt with maximum aggregate size 6 mm), etc. In the harmonized model (4), a list of 14 pavements is provided together with associated correction coefficients and speed range (see table 1). It is originated from a Dutch database and includes both traditional road surfaces and specific pavements for urban areas. Several names, such as “Hard elements in herring-bone” or “Worked surface”, are even unknown in the international technical language. Furthermore, there is no grading size mentioned in the surfaces, despite this is an essential parameter for noise performances.

Definitions of pavement names in ROSANNE and in CNOSSOS-EU are not consistent. The issue may not be essential as it is shown in the Guidelines (9) in which look-up tables propose conversion of national road surface corrections for each relevant type of pavements. However the pavement definitions in ROSANNE, more precise and corresponding to international standards could benefit to the implementation of CNOSSOS-EU. Of course, when performing noise mapping, a precise knowledge of pavement characteristics (including porosity grading size, porosity, thickness, etc.) may be missing in many situations. In this case, the monitoring procedure described in ROSANNE could be a helpful tool to overcome this issue.

4.5 Consistency of road noise performance data

The central issue in this work is the consistency of road surface noise performance data in both systems. There are basically three important questions raised:

- the equivalence in ROSANNE procedure of the reference road surface noise defined in CNOSSOS-EU;

- how the age of the road surfaces is treated in the respective methods;
- the comparability of tabled road surface corrections in CNOSSOS-EU with the values that the ROSANNE procedure will produce.

There is no clear answer to the last two points at the moment. ROSANNE procedure is still new and did not produce enough results yet, in particular data for estimating the average noise over a representative lifetime of road surfaces. However, it will be possible in the future to obtain such data.

Regarding the reference road surface noise, as already seen, the sound power level of vehicles on the virtual reference road surface can be easily calculated. Under the assumption of the far field of a point source, the CPX level can be estimated from the rolling noise contribution of one single tire, L_{WR} -6 dB, the -6 dB terms deriving from the assumption that the rolling noise contribution is equally distributed between the four tires:

$$L_{CPX,i,m} = L_{WR,i,m} - 6 - 10\log(4\pi d_{CPX}^2) + A_{CPX} \tag{13}$$

For pure reflection conditions on the road surface, A_{CPX} = 6 dB and the distance $d_{CPX} = \sqrt{0.2^2 + 0.2^2 + 0.1^2} = 0.3$ m

The resulting spectra and overall values in dB and A-weighted dB at 80 km/h for the first three categories are shown in figure 1.

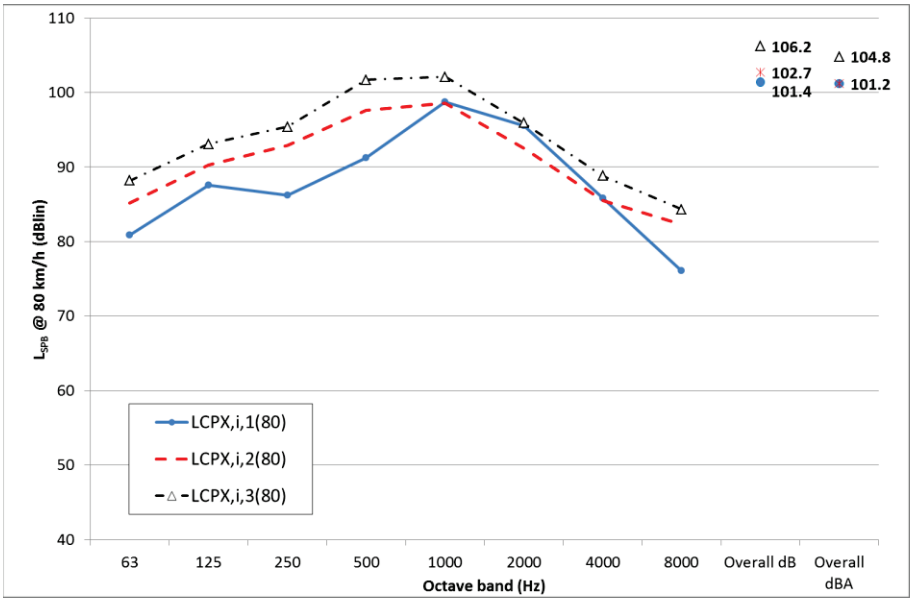

Figure 1 – Predicted sound pressure spectra at 80 km/h at CPX position for categories 1, 2 and 3 of vehicles

Similarly, the SPB noise level can be calculated from the total sound power level of the vehicle, using the relationship:

$$L_{SPB,i,m} = L_W - 10\log(4\pi d^2) + A_{SPB} \tag{14}$$

with A_{SPB} = 6 dB, the ground attenuation above a reflecting surface. The distance $d = \sqrt{7.5^2 + 1.2^2}$ =7.6m

The comparison between predicted CPX and SPB overall sound pressure levels is presented in Table 6.

Table 6 – Predicted overall A-weighted levels for CPX and SPB configurations at 80 km/h

Category	CPX dB(A)	SPB dB(A)	Difference dB(A)
1 - Light vehicles	101.2	79.7	21.5
2 – Medium vehicles	101.2	82.9	18.3
3 - Heavy vehicles	104.8	85.5	19.3

The predicted difference between CPX and SPB obtained for light vehicles is 21.5 dB(A), which is very close to the average difference observed in the measurement data collected in ROSANNE (20.5 dB(A)). This is a very encouraging result for proving consistency between CNOSSOS-EU and

ROSANNE.

The predicted difference for medium heavy vehicles and heavy vehicles is respectively 18.3 dB(A) and 19.3 dB(A). This is much higher than the average difference obtained in ROSANNE (respectively 9.5 and 12.0 dB(A)), which leads to the conclusion that for heavy trucks the consistency between ROSANNE and CNOSSOS-EU seems to be more difficult to obtain.

5. CONCLUSIONS AND RECOMMENDATIONS

There would be a clear benefit if ROSANNE characterization procedure could deliver consistent data for the harmonized noise model. A number of features in relation to the road surface characteristics in ROSANNE procedure and in CNOSSOS-EU road traffic noise model have been reviewed and compared. It appears that globally, the consistency between both systems is rather good and there is a good chance that one might eventually in a near future, use the ROSANNE procedure to supply CNOSSOS-EU database on road surfaces. Both systems are fairly but not fully consistent at the moment. Some of the remaining issues can be still addressed during last part of the ROSANNE project before the final publication of the procedure, others probably need more investigations. In turn, the ROSANNE definition of road surfaces together with the general procedure could bring valuable input to the Guidelines of CNOSSOS-EU model and to its application within the Member States.

The main issue at the moment is linked to the different measurement methods, CPX in the case of the ROSANNE procedure and SPB in the case of the CNOSSOS-EU model. Significant progress has been made on the relation between these two methods but some issues are still to be further investigated. In particular, it will be necessary to extend the investigation on the relation CPX/SPB in regard to the frequency domain and to the category of heavy vehicles.

Regarding the ROSANNE method, additional requirement could be easily added in order to ensure consistency with CNOSSOS-EU system e.g.:

- the systematic inclusion of spectral results in the labelling procedure and in the monitoring procedure;
- a systematic determination of the speed coefficient in the labelling procedure;
- the introduction of a “label-type” procedure for “mid-life” road surface performance.

However, due to limitations imposed by physics, it is foreseen that some issues will still remain, e.g.:

- the extension of ROSANNE procedure to the lowest octave bands 63 Hz and 125 Hz frequencies, as the range of validity of CPX measurements is limited to the 1/3 octave bands between 315 Hz and 5 kHz;
- the representativeness of the ROSANNE procedure for heavy trucks and medium heavy trucks .

Finally, the ROSANNE procedure is still new and needs to get some experience before significant knowledge is gained and database built. CNOSSOS-EU is also quite recent although there is already some experience on it. It is therefore appropriate to work as soon as possible on the complementarity between both systems.

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