



## Updated road traffic noise emission models in Sweden

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### ABSTRACT

The Nordic prediction model from 1996 is still used for road traffic noise predictions and noise mapping purposes in many cases in Sweden. The model is restricted to A-weighted levels and the vehicle categories only take light and heavy vehicles into account. Weather conditions and ground effects are simplified. The subsequent Nord2000Road model can be used for noise predictions in more complex situations. Nord2000Road uses third octave bands, an advanced outdoor propagation model and more categories for vehicles and ground. Recently the CNOSSOS-EU model has been developed in Europe and can be used for noise mapping purposes according to the European Noise Directive in the future. CNOSSOS-EU uses octave bands and similar vehicle categories as Nord2000Road. The source model as well as the propagation model differs from Nord2000Road. In 2015, a measurement campaign of noise emission in real traffic was conducted in Sweden. This paper presents updated input data for the Nord2000Road source model as well as national Swedish correction terms for rolling noise in the CNOSSOS-EU model to better represent the recent measurement results.

Keywords: Road traffic noise, noise emission, prediction model, Nord2000 Road, CNOSSOS-EU  
I-INCE Classification of Subjects Number(s): 76.1.1

### 1. INTRODUCTION

Today's model used for road traffic noise predictions in Sweden is the Nordic prediction model from 1996 (1). Since that model was established several projects have been carried out to develop prediction models, both in Scandinavia and in Europe. In other Nordic countries, for example, the prediction model Nord2000 Road (2) is used, and within Europe the model CNOSSOS-EU (3,4) will be used for noise mapping purposes according to the European Environmental Noise Directive (END) (5) from 2019. Nord2000 Road has the advantage that the model has a broader scope and can provide more detailed results compared with 1996 model, and there is a willingness to move to that model in Sweden. The model gives slightly higher estimated levels compared to the old 1996 model. Input data for the prediction model Nord2000 Road are based on measurements carried out in the Nordic countries and the latest measurements in Sweden are 10 years old. In 2015 new measurements of noise emissions from vehicles in real traffic on Swedish roads were carried out.

In Europe the noise prediction method CNOSSOS-EU should be used for noise mapping according to the European Environmental Noise Directive (END) from 2019. Default input data is available for typical European vehicle fleet on a reference road surface. However national corrections are needed to obtain representative levels.

#### 1.1 The Nord2000 Road source model

In Nord2000 Road the vehicle noise is separated into two components; rolling noise and propulsion noise. The speed dependent source sound power levels of rolling noise and propulsion noise respectively, are given in equations 1 and 2.

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$$L_{WR}(f) = a_R(f) + b_R(f) \lg \frac{v}{v_{ref}} \quad (1)$$

$$L_{WP}(f) = a_P(f) + b_P(f) \frac{v - v_{ref}}{v_{ref}} \quad (2)$$

where  $v_{ref} = 70$  km/h.

The vehicle is represented by 2 point sources, one at 0,01 m high and one at 0,3 m high for category 1 vehicles. For category 2 and 3 the source height of the highest source is 0,75 m instead. The sound power of the rolling noise is distributed 80% to the lowest source and 20% to the highest source. For the propulsion noise the distribution is the opposite, 20% to the lowest source and 80% to the highest one.

Vehicles are categorized in 5 main categories; 1) light vehicles, 2) medium heavy vehicles, 3) heavy vehicles, 4) Other heavy vehicles and 5) two-wheelers. Each category is divided in sub-categories, however, default input data are given for the main categories only.

Existing Nord2000 default coefficients  $a_R$ ,  $b_R$  and  $a_P$ ,  $b_P$  for each vehicle category are based on measurements performed mainly in Denmark, and are given in (6). Because of the use of studded tires in Sweden during winter the road surfaces normally differ from Danish ones. To take this into account a regional correction factor for rolling noise is applied to the  $a_R$  coefficients in the frequency range 250 Hz - 10 kHz to adapt the spectrum to Swedish conditions. The original adaptation terms are given in table 1, and should be added to vehicle categories 1, 2 and 3.

The propagation model is based on a physical model that takes the phase relation between direct and reflected sound into account (ref)

Table 1. Original corrections for Swedish roads to add to  $a_R$  in Nord2000 Road model

250	315	400	500	630	800	1k	1,25k	1,6k	2k	2,5k	3,15k	4k	5k	6,3k	8k	10k
1	1	1	1	2	2	2	2	-1	-2	-3	-4	-4	-3	-1	0	2

## 1.2 The CNOSSOS-EU source model

In principle the same source model equations are used for CNOSSOS-EU as for Nord2000 Road, but in octave bands. The total sound power is separated in rolling and propulsion noise which are given according to equations 1 and 2. However, only one source height, 0,05 m, is used for both point sources, and the coefficients are given in octave bands. The default coefficients  $a_R$ ,  $b_R$  and  $a_P$ ,  $b_P$  are different than the Nord2000 Road ones since the model is given in octave bands, they are adapted to different source and propagation models, and they are based on a different database. A comparison between A-weighted sound power levels in the Nord2000 Road and the CNOSSOS-EU for category 1 vehicles is shown in figure 1. The Nord2000 Road is here corrected to Swedish road surfaces using corrections according to table 1. However, both calculations are for the reference road surface, which is a combination of a DAC and SMA surface with 11 mm maximum aggregate size.

The propagation model in CNOSSOS-EU is based on the ISO 9613-2 model, and assumes uncorrelated addition of the direct sound and the ground reflection. This means that close to the road, the ground reflection in principle always gives +3dB according to CNOSSOS-EU, while it gives +6dB at low frequencies according to Nord2000. At higher frequencies it varies according to Nord2000, but is limited to maximum +6dB. The influence of the propagation model at short distances has to be considered when adapting source levels and road surface corrections, as will be discussed later in the paper.

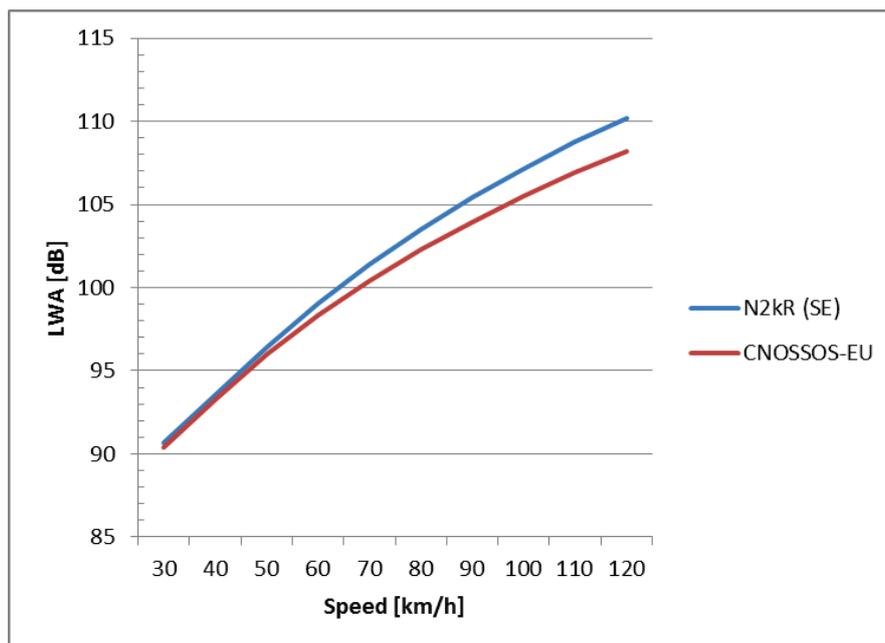


Figure 1, Comparison of A-weighted sound power levels in Nord2000 Road (N2kR) (with Swedish corrections) and CNOSSOS-EU (default data)

## 2. MEASUREMENTS

Measurements of sound emission of single vehicles in real traffic were performed in south-west part of Sweden during 2015. The measurements were performed on SMA 0/16 (stone mastic asphalt with maximum aggregate size 16mm) surfaces, which represent the most common road surface for high trafficked roads in Sweden. This road surface type is most commonly used on rural roads.

Measurement sites were selected based on a number of parameters, such as surface type (SMA0/16), age of the surface (2-8 years), slope ( $0^\circ$ ), background noise, straightness, traffic density etc. Beside the measurements presented here, additional measurements in a slope and on a porous asphalt surface was conducted. All measurement results and further analysis can be found in (ref SP rapport) (in Swedish).

The measurements were performed according to relevant parts of the NT ACOU 109 (7) and NT ACOU 117 (8) methods. A measurement distance,  $d$ , of 7,5 m from the vehicle center at the closest road lane was used, and the angle of integration for the pass-by measurements was  $\pm 5d$ , corresponding to  $\pm 37,5$  m. Thus sound exposure levels were measured for the total pass-by length of 75 m. The velocity of individual vehicles was measured by measuring the pass-by time using laser gates at the two ends of the measurement length to trigger the start and stop of the timer. Only single vehicle pass-by events were used for the further evaluation and analysis. Measurements were performed in dry road conditions, and wind speeds in general  $< 5$  m/s. Temperature varied between 17-26 °C at the different sites. Temperature and wind speed were logged during the measurements.

Three measurement heights were used; 0,5; 1,5 and 4,0 m above the road surface, all at 7,5 m distance from the vehicle center. In addition, a measurement position at 4,0 m height at 15-25 m distance, depending on the measurement site, was chosen in order to study maximum levels. However, in this paper only results from the 7,5 m distance are presented.



Figure 2 Three examples of measurement sites and road surfaces (SMA 0/16)

## 2.1 Sound power level

In order to determine the source strength and model coefficients from the measurements, the measured sound exposure levels needs to be converted to sound power levels. The relationship between sound power level,  $L_W$ , and sound emission level,  $L_E$ , is given by equation 3,

$$L_W = L_E + C(50) + 10 \lg \frac{v}{50} \quad (3)$$

where  $C(50)$  are transfer functions from sound exposure level to sound power level at the speed 50 km/h, and  $v$  is the velocity. The transfer functions are calculated for a point source of unit power moving at constant speed over the measurement length for each point source and receiver combination.

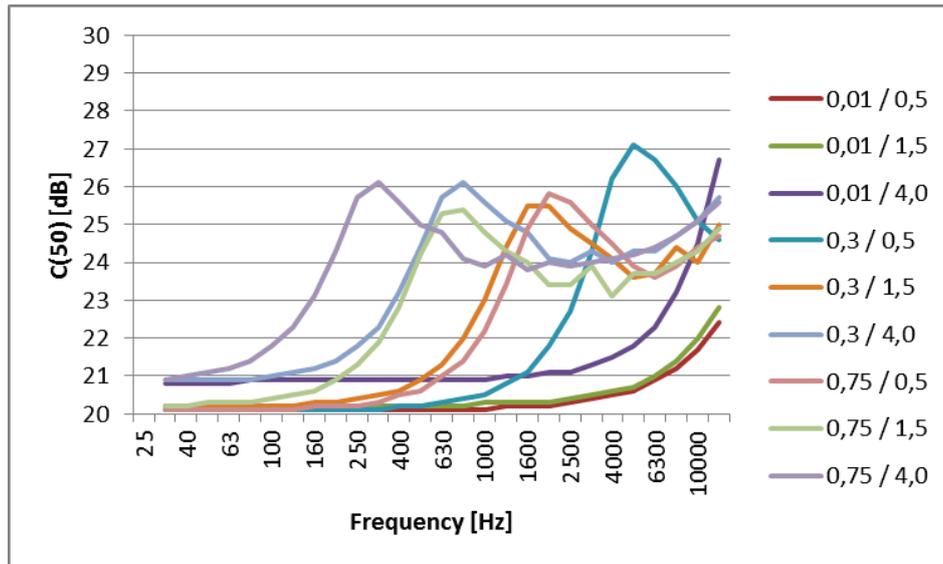


Figure 3. Transfer functions at 7,5 m distance from vehicle center for different source/receiver combinations according to Nord2000.

## 2.2 MEASUREMENT RESULTS

The measurement results of sound exposure levels at 7,5m distance and 4 m height are shown in figures 4-6 for lightweight (category 1), medium heavy (category 2) and heavy (category 3) vehicles respectively.

The number of passages for category 2 vehicles was rather limited. This may be explained by the selection of mainly rural measurement sites for the SMA 0/16 surface, where the heavy vehicles are dominated by long distance freight transport and there are fewer medium heavy delivery trucks as compared to urban areas. The selection of measurement sites also influences the speed distribution of the vehicle passages, where the dominating speed range is between 60-90 km/h.

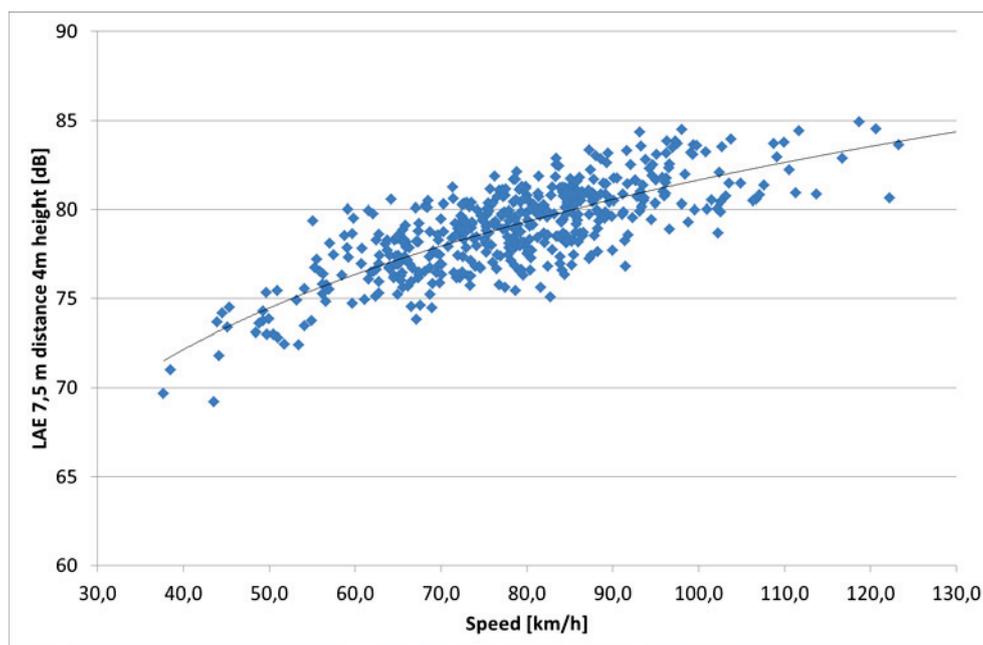


Figure 4 Measurement results for category 1 vehicles

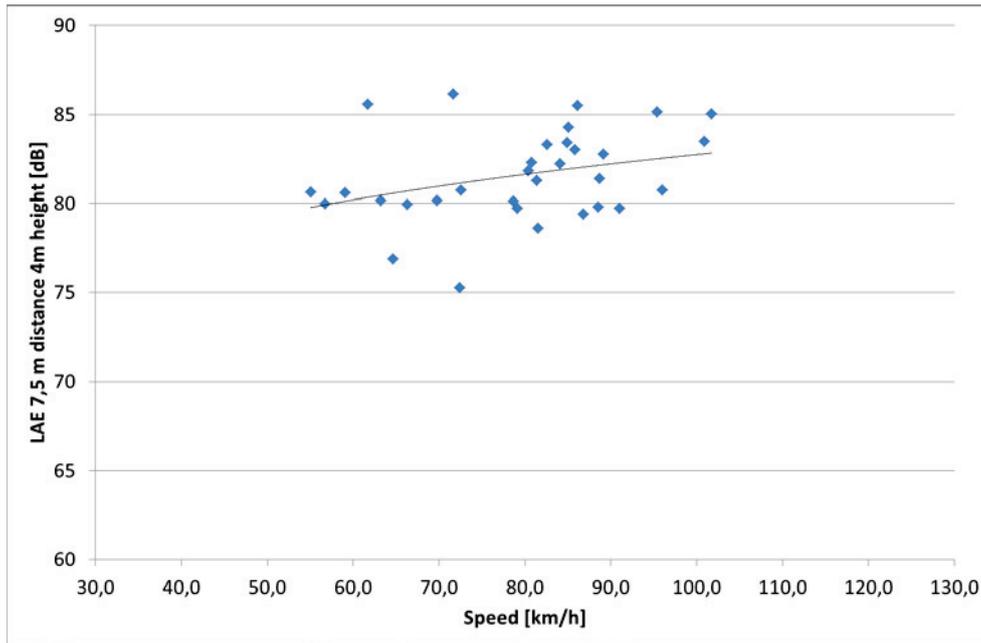


Figure 5 Measurement results for category 2 vehicles

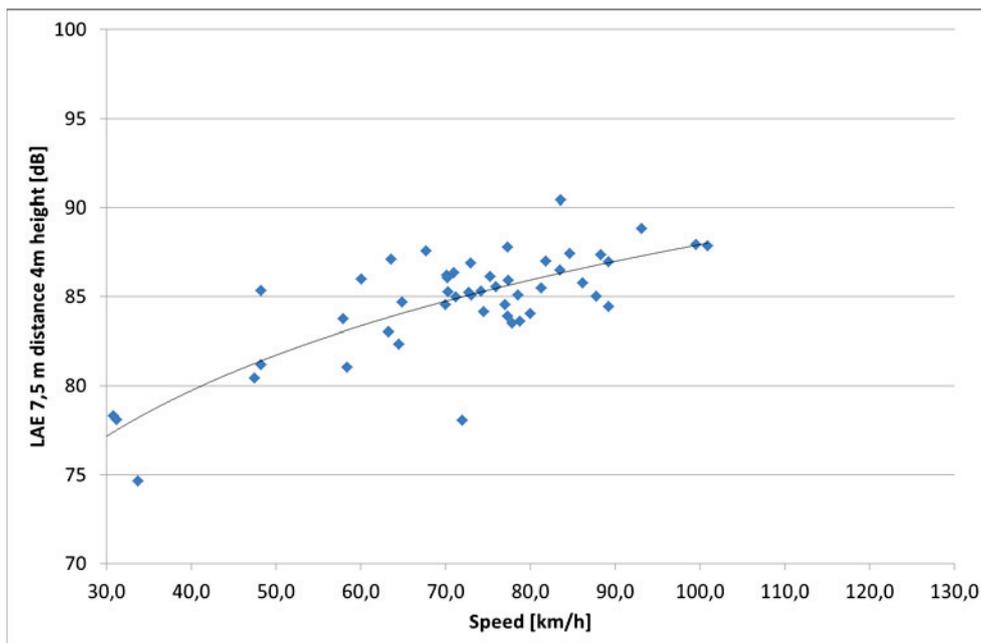


Figure 6 Measurement results for category 3 vehicles

### 3. Comparison to road traffic noise models

#### 3.1 Comparison to Nord2000 Road

Here only results for vehicle category 1 are presented. A-weighted sound power levels as function of  $10\lg(v/70)$  are shown in figure 7, together with model results for default data (DK) and with the Swedish corrections (SE). Both model results show the same speed dependence as the measurements, so the existing speed coefficients are confirmed. Only small deviations are found for the A-weighted sound power levels.

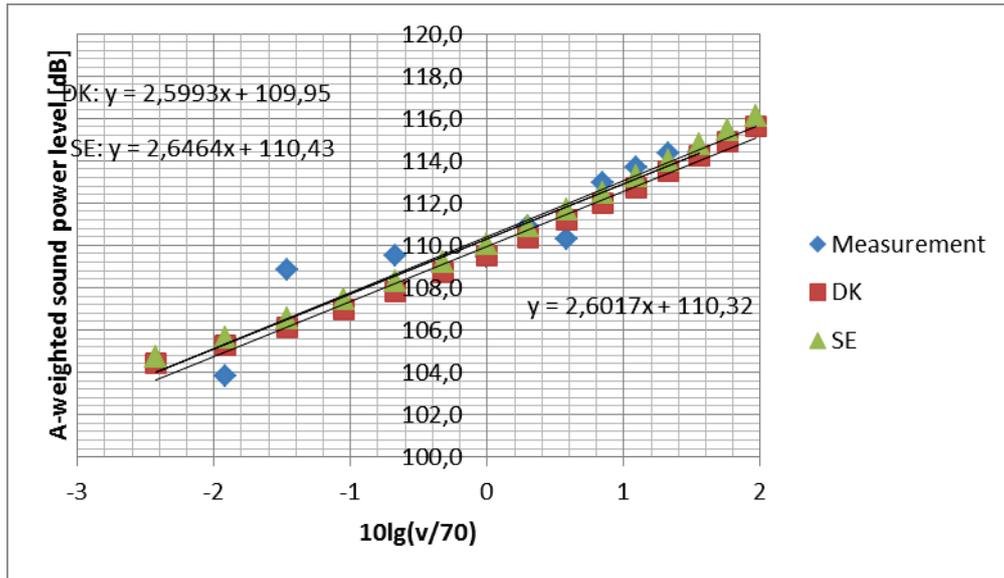


Figure 7 Speed dependence of measured and calculated sound power levels for category 1 vehicles. Calculations using Nord2000 Road model with (SE) and without (DK) spectral adaptation to Swedish roads.

A comparison of spectra of the sound exposure levels at different speeds is shown in figure 8. The figure shows the difference between measured results and calculated using the default input data for the calculation, i.e. DK data, but calculated for the road surface type SMA0/16. The model overestimates levels at low frequencies, below approximately 200-250 Hz. In this frequency range the noise emission is dominated by propulsion noise. In the frequency range around 1kHz the model underestimate the sound exposure somewhat. This frequency range also dominates the A-weighted level and is mainly dominated by rolling noise. At higher frequencies, the model again overestimates the levels. Similar results are also found for categories 2 and 3 (9).

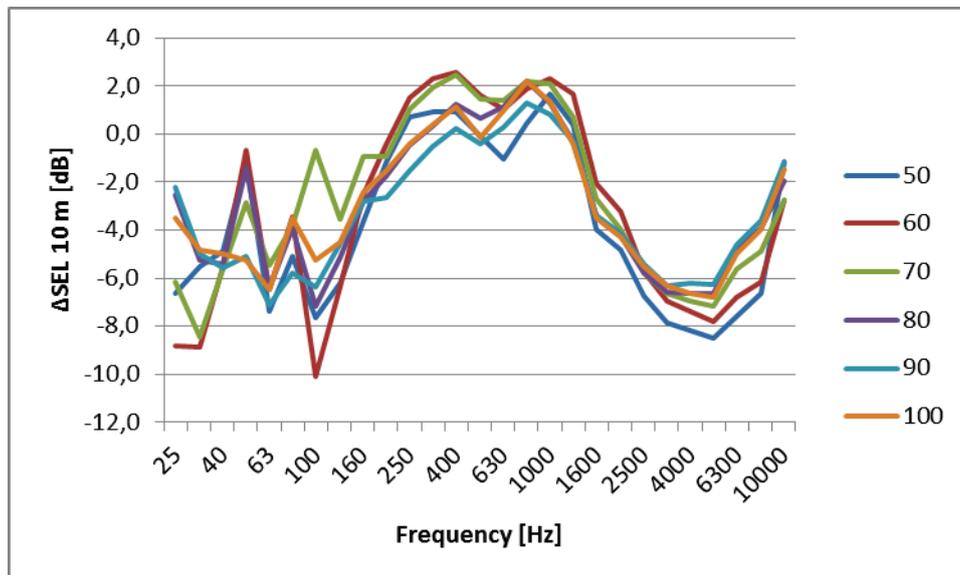


Figure 8 Spectrum of the difference between measured and calculated sound exposure level at 10 m distance.

### 3.2 Comparison of light vehicles to CNOSSOS-EU

For CNOSSOS-EU sound exposure levels at 10 m distance are compared with the Nord2000 Road model using default data (DK) since these data are based on a larger database than the Swedish ones.

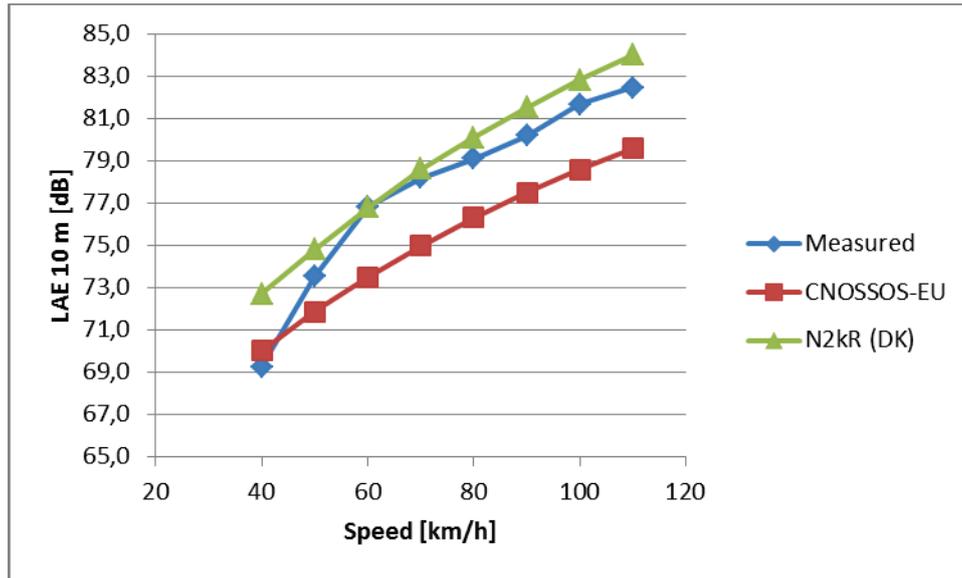


Figure 9. Sound exposure level at 10 m distance for category 1 vehicles.

Figure 9 shows a comparison of A-weighted sound exposure levels at 10 m distance between the default CNOSSOS-EU model, the default Nord2000 Road model (N2kR (DK)) and the measurements for category 1 vehicles. The models seem to differ substantially at short distance, and the CNOSSOS-EU model underestimates the sound exposure. This is probably because of the differences in propagation models, as well as difference in default source data. The same reference road surface is used for the comparison.

#### 4. ADAPTATION OF NORD2000 ROAD SOURCE MODEL

Following from the results shown in figure 8 and the corresponding data for category 2 and 3 vehicles new spectrum adaptations can be calculated that minimizes the difference between the measured and calculated sound exposure level at 10 m distance. The results are shown in table 2. The spectrum corrections are suggested to be added to  $a_R$  for vehicle categories 1, 2 and 3.

Table 2. Proposal for updated corrections to add to  $a_R$  in Nord2000 Road for Swedish roads

250	315	400	500	630	800	1k	1,25k	1,6k	2k	2,5k	3,15k	4k	5k	6,3k	8k	10k
1	1	1	1	1	1	1	1	-1	-2	-3	-4	-5	-4	-3	-2	1

The new measurements indicate that powertrain noise has been reduced compared to previous measurements, which were conducted 10 years ago. During the last decade the Swedish vehicle fleet has changed substantially. The proportion of passenger cars with Diesel engines in the vehicle stock has increased and fuel consumption and engine efficiency have improved. This might also influence the noise emission. The model Nord2000 Road seems to overestimate propulsion noise. Therefore, for propulsion noise a correction of -3 dB is proposed to be added to  $a_p$  for vehicle categories 1, 2 and 3 for all frequencies 25Hz – 10 kHz as a regional correction of the vehicle fleet. The same correction is applied for all vehicle categories. Further work and more measurement data is needed to find differentiated corrections for vehicle categories.

Figure 10 shows the calculated sound exposure level at 10 m distance implementing the proposed new corrections for rolling and propulsion noise in Nord2000 Road compared to the measurement results from the 2015 measurement campaign.

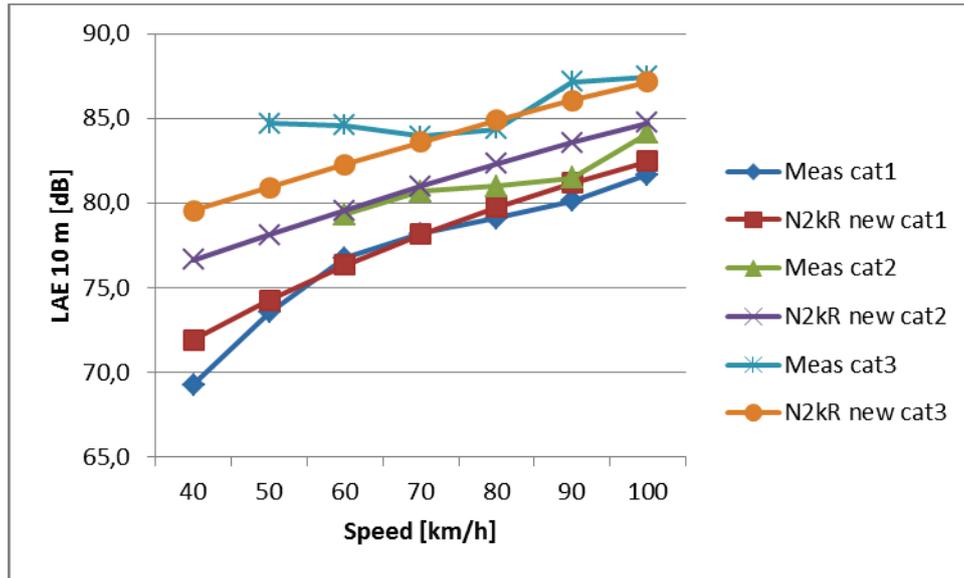


Figure 10 A-weighted sound exposure levels at 10 m calculated with proposed new corrections in Nord2000 Road compared with measurements.

### 5. ADAPTATION OF CNOSSOS-EU SOURCE MODEL TO NORD2000 ROAD

Since both the source models as well as the propagation models differ between Nord2000 Road and CNOSSOS-EU models, the adaptation of the CNOSSOS-EU source model is based on the sound exposure levels at 10 m distance from the center of the vehicles. The CNOSSOS-EU model allows for corrections for the influence of different road surfaces on the rolling noise (ref) according to equation (4).

$$\Delta L_{WR} = \alpha + \beta \cdot \lg\left(\frac{v}{v_{ref}}\right) \tag{4}$$

where  $v_{ref} = 70$  km/h. The coefficients  $\alpha$  and  $\beta$  may be frequency dependent and may be adapted for each vehicle category.

As a starting point the CNOSSOS-EU model is adapted to the Nord2000 Road model with default data, since it is based on a larger database than the Swedish data. The coefficients  $\alpha$  and  $\beta$  are calculated by minimizing the difference in sound exposure level at 10 m distance using the Nord2000 Road model and the CNOSSOS-EU model respectively, both models with default data and for the reference road surface. Here, a linear regression is used for the A-weighted levels, hence the coefficients  $\alpha$  and  $\beta$  are assumed to be constant and not frequency dependent. The results are shown in figure ? and table 3. The determination of the corrections is made for speeds above 70 km/h in order to ensure that the sound emission is dominated by rolling noise.

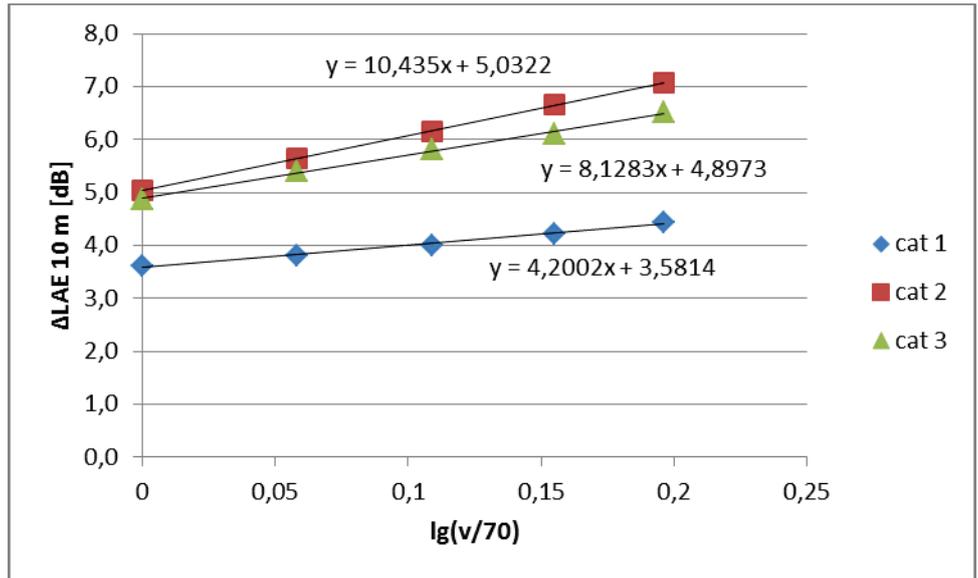


Figure 11. Difference between sound exposure levels at 10 m calculated with Nord2000 Road and CNOSSOS-EU.

Table 3 coefficients  $\alpha$  and  $\beta$  for equation 4.

Category, m	$\alpha_{i,m}$ 63	$\alpha_{i,m}$ 125	$\alpha_{i,m}$ 250	$\alpha_{i,m}$ 500	$\alpha_{i,m}$ 1000	$\alpha_{i,m}$ 2000	$\alpha_{i,m}$ 4000	$\alpha_{i,m}$ 8000	$\beta_m$
1	3,6	3,6	3,6	3,6	3,6	3,6	3,6	3,6	4,2
2	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	10,4
3	4,9	4,9	4,9	4,9	4,9	4,9	4,9	4,9	8,1

Implementing the corrections according to table 3 into the CNOSSOS-EU source model and calculating the sound exposure level with the updated data will yield the results presented in figure 12 -14 for light (category 1), medium heavy (category 2) and for heavy (category 3) vehicles respectively.

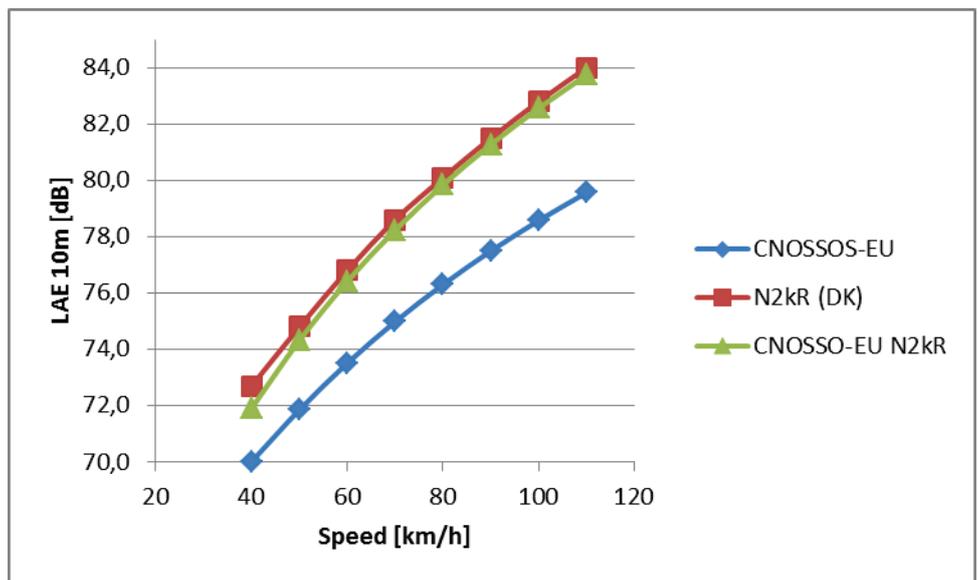


Figure 12 Sound exposure levels at 10 m, category 1 vehicles, implementing the corrections in table 2.

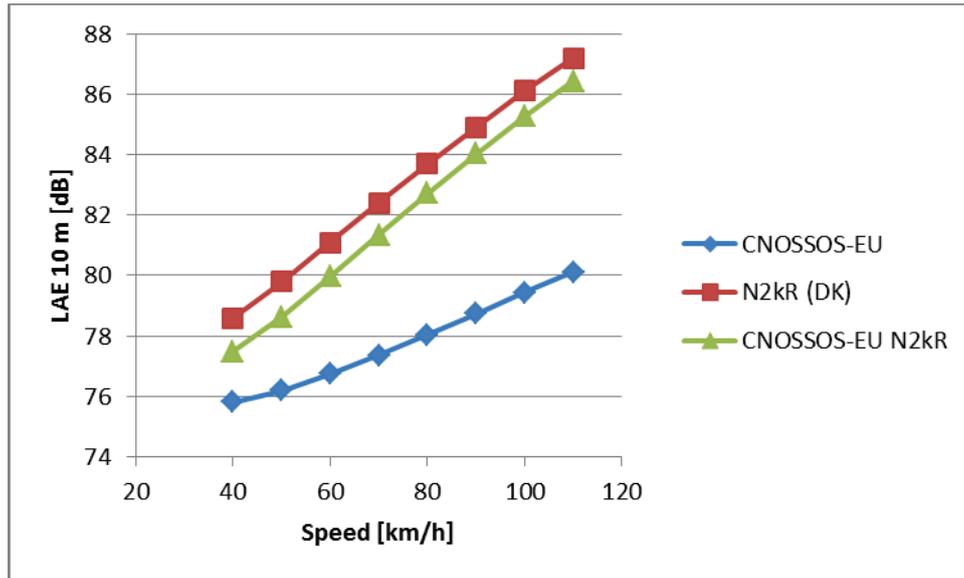


Figure 13 Sound exposure levels at 10 m, category 2 vehicles, implementing the corrections in table 2.

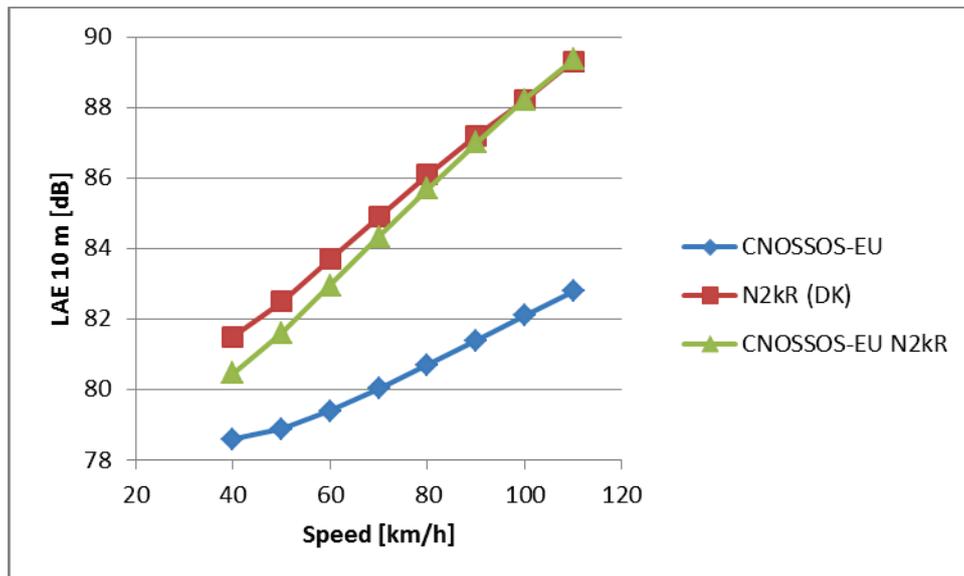


Figure 14 Sound exposure levels at 10 m, category 3 vehicles, implementing the corrections in table 2.

## 6. DISCUSSION AND CONCLUSIONS

A measurement campaign of noise emission of individual vehicles in real traffic was performed in Sweden in 2015. Measurement of sound exposure levels during pass-by at constant speed were measured on SMA0/16 surfaces in south-west part of Sweden. The measurement data is used to investigate the need for updating the Nord2000 Road model and to adapt the CNOSSOS-EU model to Swedish conditions.

The results show that the source data to Nord2000 Road needs to be updated to represent current Swedish conditions. The results indicate that the current Nord2000 Road model overestimate propulsion noise emission levels and a proposal for adjusted input data is presented, by subtracting 3 dB to the propulsion noise source coefficients as a regional vehicle fleet correction. The latest measurements of noise emission in real traffic are 10 years old, and the changes in the vehicle fleet in the last decade when it comes to engine fuel efficiency and tighter emission requirements might have influenced noise emission. The spectrum adaptations for rolling noise to Swedish conditions are revised. The measurements confirm, however, speed coefficients for Swedish conditions.

The CNOSSOS-EU model seems to underestimate sound exposure levels at short distances, compared to the measurements, as well as with the Nord2000 Road model. The CNOSSOS-EU allows for correction of the rolling noise by frequency dependent corrections. However, in this paper frequency independent corrections for rolling noise emission adapted to minimize the error in sound exposure level at 10 m compared with Nord2000 Road are presented. Further analysis and adaptation of the CNOSSOS-EU model is needed to find relevant frequency dependent corrections and corrections for other Swedish road surfaces.

## **ACKNOWLEDGEMENTS**

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