HOW WELL CAN THE CLOSE-PROXIMITY (CPX) METHOD REPLACE THE STATISTICAL PASS-BY (SPB) METHOD IN THE EVALUATION OF THE NOISE REDUCING PERFORMANCE OF PAVEMENTS

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The assessment of the noise reducing performance of road pavements can be based on either the Statistical Pass-By (SPB) method, defined in ISO 11819-1 or the Close-Proximity (CPX) method defined in ISO 11819-2 with the test tyres specified in (draft) ISO/TS 11819-3. Both methods are frequently used since each method has advantages and limitations. When implementing the acoustic effect of the road surface in the calculation of the noise emission for road traffic, the SPB method is preferred. With the SPB-method one can obtain the acoustical performances for the different vehicle categories, over a wide speed range and in the specific frequency bands, required to make precise propagation calculations. The CPX method will fail to provide the necessary data. The application field for the CPX method is found in the conformity-of –production testing. Once a road surface type has been attributed with SPB based acoustic effects on the vehicle emission, the conformity of a specific surface with the specifications of the type can be estimated with CPX method. The main advantage of CPX is that it can be applied in conditions where no SPB measurement is allowed (heavy traffic, nearby reflecting objects) and that the evaluation can be done over consecutive sections over a large length of the road. In the paper such a system will be presented and experiences with SPB and related CPX measurements are reported. A reliable scheme implies that the relation between CPX and SPB values is well known. The paper will address the nature of the relation and will analyse the uncertainty issues involved in predicting SPB results based on CPX results. The analysis will be based on recent measurements on several road sections with different types of low noise pavements.

Keywords: Statistical Pass-by (SPB) method, Close-Proximity (CPX) method, low noise pavements

1. Introduction

The acoustic performance of a road surface can be determined with two ISO-based measurement methods, the Statistical Pass-By (SPB) method, defined in ISO 11819-1 (1) or the Close-Proximity (CPX) method defined in ISO 11819-2 (2). The acoustic effect of the road surface in the calculation of the noise emission for road traffic is often based on the SPB method, since this method shows resemblance with the method to establish emission data of vehicles, that also uses road side measurements of passing vehicles. Furthermore the SPB-method, when related to a reference surface, directly presents the acoustical performances for the different vehicle categories, over a wide speed range and in the specific frequency bands, required to make precise propagation calculations. The SPB method has its limitations in cases of dense or stop-and-go traffic or nearby reflective objects.

The CPX-method is often used for testing the conformity of production (COP) or for monitoring the acoustical properties in time (3). An advantage of the CPX-method over the SPB-method is that the evaluation can be done over a large length of the road or under conditions where SPB measurements are not allowed.

The issue addressed in this paper is how well can CPX replace SPB in the evaluation of the noise reducing performance of pavements.

2. Assessment of noise reducing performance of road pavements

Road surfaces are an essential part in the noise production of road vehicles. For this reason the road surface effects are implemented in the calculation schemes for the determination of the noise exposure in the vicinity of roads. In the present Dutch scheme for noise calculations the effect, referred to as C_{road}, is added to the noise production level of the road vehicles. The acoustic effect of the road surface (C_{road}) is defined as the difference between the pass-by levels of a certain category of vehicles on the specified road surface type relative to the levels on the reference surface type. The reference surface is defined as a Dense Asphalt Concrete of 0/11 to 0/16 grading of average age.

The C_{road} in the Netherlands (4) and proposed CNOSSOS schemes (5) differentiate between light and heavy vehicles, between the eight octave bands (63-8000 Hz) and include speed effects. The formulation of C_{road} is as follows:

$$C_{road} = \alpha_{i,m} + \beta_m \cdot \lg\left(\frac{v}{v_0}\right) \tag{1}$$

With:
i: octave band number (1: 63 HZ, …8: 8 kHz), *m:* vehicle class(1: light vehicles, 3: heavy vehicles), v_0*: reference speed*

The C_{road} definition thus consists of a set of 18 coefficients, namely $ß_{(m=1,2)}$, $\alpha_{(i=1\ldots8,\ m=1,2)}$.
Since the road surface effect applies to the difference in emission on a reference pavement and on the specified pavement, these 18 coefficients can be determined by comparing SPB-results on the reference road surface with those on the specified surface for the required vehicle categories and in consecutive octave bands. Using the CPX method it will be difficult to provide those data.

3. Measuring acoustic road surface properties with the CPX-method

3.1 Vehicle categories

It is known that the effect of a road surface differs for light and heavy vehicles. For that, there are described two types of test tyres in the CPX method. Each tyre type is considered to be representative for a vehicle class.

One type is the Standard Reference Test Tyres (SRTT). This tyre is defined in American Standard ATM F2493-06 and is referred in ISO/TS 11819-3 (6) as reference tyre P1, being representative for passenger car tyres. The other type is the AVON, type Supervan AV4, size 195 R14. This tyre is referred to as tyre H1, being representative of heavy vehicle tyres. The photograph below gives pictures of the two tyres (see Fig. 1).

Figure 1: Picture of the two standard tyres used for CPX-measurements. Left: SRTT (P1), right: Avon AV4 (H1).

3.2 Frequency range

A significant difference between the SPB- and CPX-method is the first calculates noise levels in a wide frequency range in full octave band levels centred from 63 Hz to 8kHz. The CPX measurements produces results in 1/3 octave bands and the validity is restricted from 315 to 5kHz. This corresponds to full octave bands from 500 Hz to 4 kHz. The lower limit of the frequency range of CPX-measurements is due to the possible influence of aerodynamic noise during the measurements and also to the short distance of the source to microphones with regard to the wavelength.

When the acoustic properties of road surfaces are measured by the CPX-method, only a part of the essential spectral information can be determined.

3.3 Speed range

CPX-measurements will usually be performed at specified reference speeds. That implies that the results of a CPX-measurement are representative for one specified speed and that no information about the dependency of sound levels to the speed is determined. To investigate the speed effect on a specific road surface with the CPX-method, measurements at different speeds are required.

4. Relation between measurement results obtained with SPB and CPX

To evaluate the feasibility of the CPX method as a useable method to obtain *Croad* values, it is necessary to know the relation between SPB and CPX measurements. In the ideal situation the difference between the reference road surface and the specified surface found with the CPX-method is the same as for the SPB-result. That implies that when CPX and SPB results of road surfaces are compared in an x-y plot, all points will follow a straight line with a slope of 1:1. We have investigated if this is the case by studying a series of Dutch road sections where both SPB- and CPX-measurements are performed.

4.1 Relation SPB CPX overall values

For this study we used a data set with recent (2013-2017) measurement results. In our dataset we have access over 153 locations where both SPB and CPX measurements are performed. SPB data with heavy vehicles was compared with CPX levels using tyre type H1 and SPB data for cars was compared with CPX results using the P1 tyre. SPB and CPX results refer to the same speed. For the relation of light vehicles measurements with the reference speeds 50, 60, 70 and 80 km/h were available. For heavy vehicles only results with a reference speed of 80 km/h were available. SPB results are obtained with a microphone height of 3,0 m to comply with emission measurements in the EU-CNOSSOS model.

To improve the quality of the relation only the results of measurements are used with low uncertainty values. That implies for the SPB regression line of sound level versus (logarithm of) speed that:

- The 95% confidence interval around $L_{SPBcars}$ is 0,3 dB or lower at the reference speed;
- The 95% confidence interval around $L_{SPBtrucks}$ is 0,8 dB or lower at the reference speed;

For CPX-results:

The maximal variation (min-max) of the L_{CPXP} or L_{CPXH} in the 100 m road section around the SPB-position is 1,0 dB.

Table 1: numbers of road sections

	Relation light vehicles	Relation heavy vehicles
Total number of locations/test sections	153	18
Stone Mastic Asphalt 0/8 (SMA8)	*86*	*4*
Thin Surface Layer 0/6 (TSL6)	*47*	*2*
Single layered porous asphalt 0/8 (1LPA8)	*7*	*4*
Double layered porous asphalt (2LPA8)	*9*	*6*
other	*4*	*2*

In table 1 an overview is given of the (noise reducing) road surface types that are included in the study.

The results are expressed in a scatter diagram with the CPX value at the x-axis and the SPB value at the y-axis (see Fig. 2). Only SPB- and CPX-results that met the above-mentioned uncertainty conditions are shown in this figure.

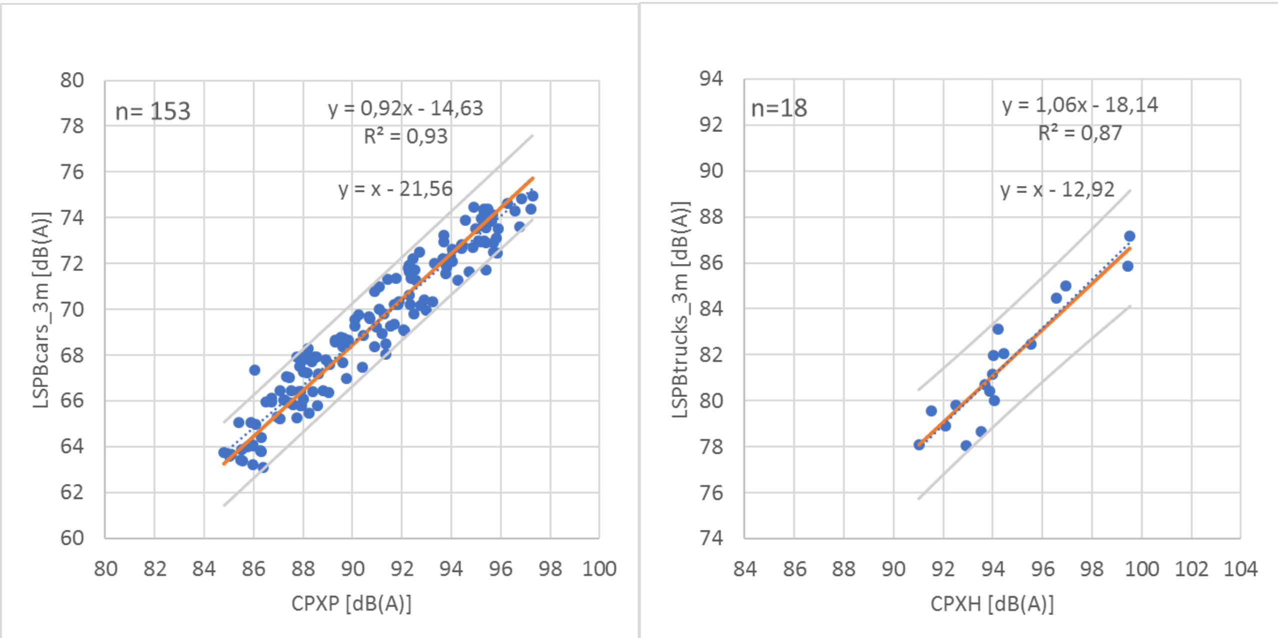


Figure 2: relationship between CPX- and SPB-results, left for passenger cars, right for heavy vehicles. In both graphs the 95% prediction interval is given by the grey lines.

Through the data points in the scatter diagrams a linear function is drawn, one with a best fitting slope and one with a fixed 1:1 slope. With the fitted function with the 1:1 slope, the residual variation is calculated. This value gives the standard deviation of the individual points around the regression function. The grey line in the graphs, indicate the area of + and – 2 times the residual variation.

For both vehicle types there is a clear correlation between the SPB and CPX-levels. In both situations a nearly 1:1 relationship has been found, 0.92**CPXP*-14.63 (R^2=0.93) for passenger cars and 1.06**CPXH*-18.14 (R^2=0.87) for heavy vehicles. When a 1:1 relationship is presumed, the average difference of SPB_{cars} noise levels and the *CPXP* level is 21.6 dB. For SPB_{trucks} levels and *CPXH* levels the average difference is 12.9 dB.

Results are given in Table 2.

Table 2: parameters relation SPB-CPX

Category	Light vehicles	Heavy vehicles
Total number of locations/test sections	153	18
Coefficient of correlation (R^2)	0.93	0.86
CPX-L_{SPB} (1:1 slope)	21.6	12.9
Residual variation [dB]	0.90	0.97

The residual variation in the SPB-levels is 0.90 dB for passenger cars and 0.97 dB for heavy vehicles. This figure presents the standard uncertainty in the prediction for a specific pavement of the SPB value based on the CPX result. The extended uncertainty at 95% confidence interval is about double that figure, i.e. in the order of 2 dB.

4.2 Frequency range and spectral distribution

A correct C_{road} implies that not only the total A-weighted effect is correctly taken into account, but also that the spectral distribution follows the SPB result. This is investigated by comparing the 1/3rd octave spectra from SPB and CPX measurements, after correction for the fixed difference between them (see Table 2). Since all data are available in 1/3rd octave bands in total more than 150 data sets for cars and 18 for heavy vehicles are used in the study.

The following steps are taken:

- For each road surface type all available 1/3rd octave band spectra of the SPB and CPX measurements are averaged for vehicle speeds of 50 or for 80 km/h;
- The CPX-levels are corrected with the average difference to the SPB levels. This is -21.6 dB for *CPXP* and -12.6 dB for *CPXH*;
- Both spectra in the range of 315 to 5000 Hz are compared and the difference for each 1/3rd octave band is calculated.

Typical results for cars are presented in Figure 3 and 4 and for heavy vehicles in Figure 5.

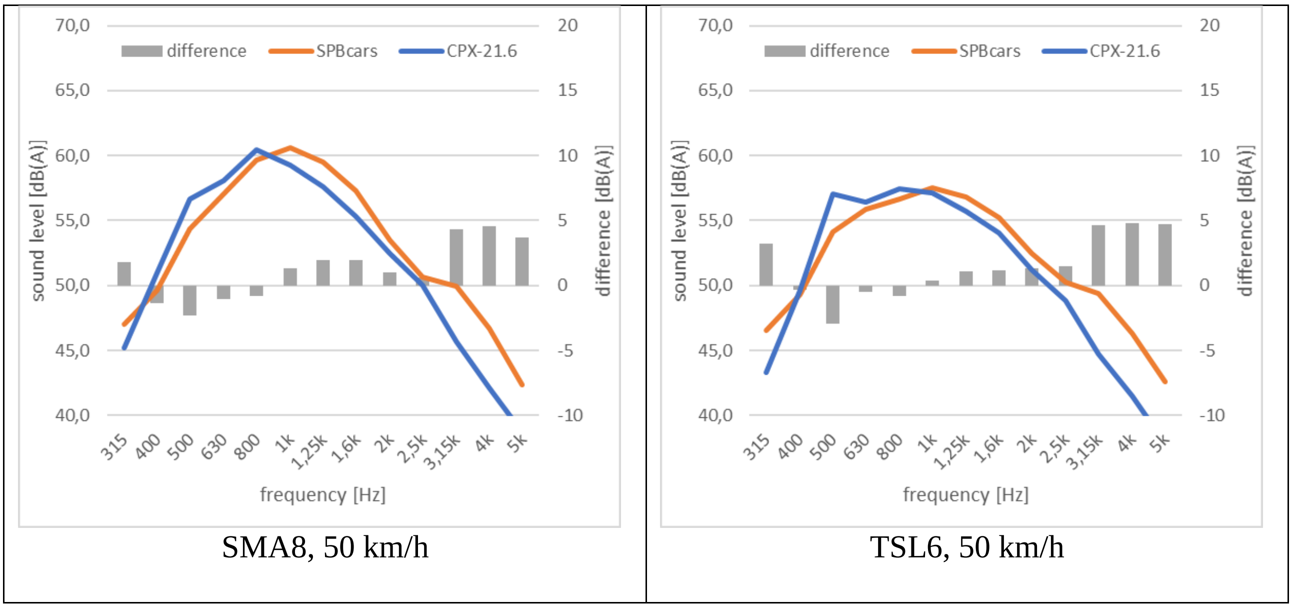


Figure 3: Averaged 1/3rd octave band spectra for CPX- and SPB-measurements at 50 km/h, left SMA8, right TSL6.

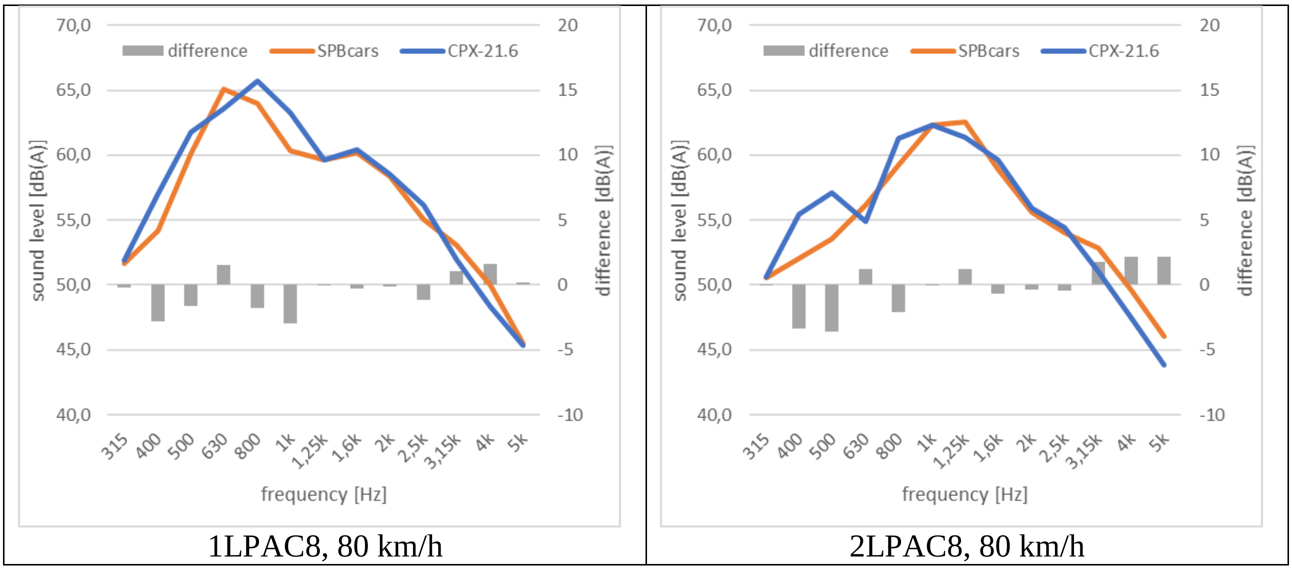
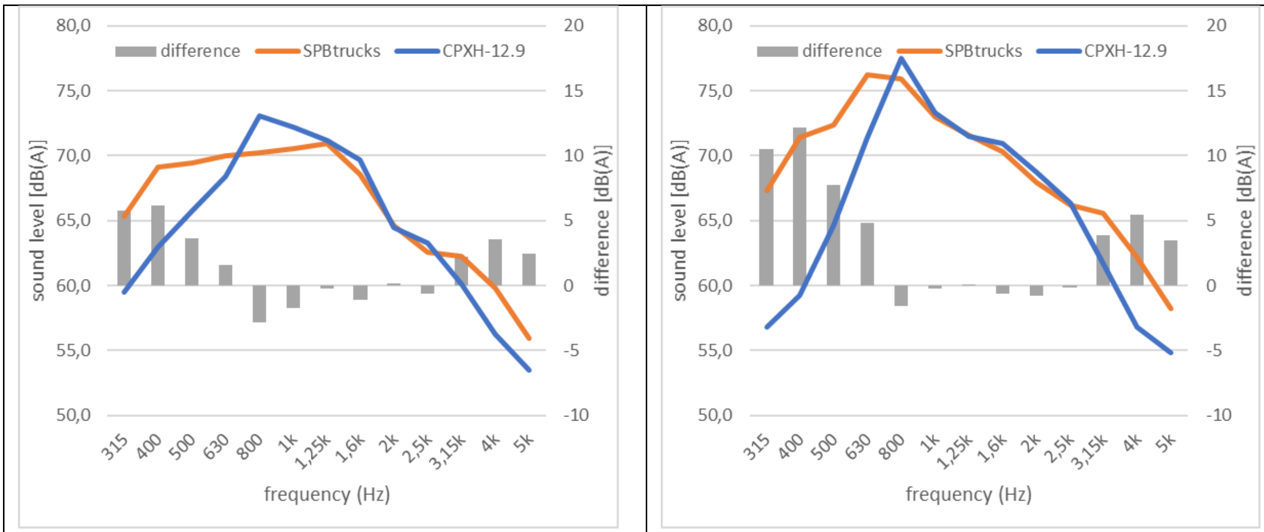


Figure 4: Averaged 1/3rd octave band spectra for CPX- and SPB-measurements at 80 km/h.

In the estimation of SPB_{cars} based on CPXP spectrum, differences in the 1/3rd octave bands up to 5 dB are found. For the mid frequency range the deviations are maximal 2 dB. As expected, the smallest differences are found at the frequencies with the highest sound levels since the conversion factor between CPX and SPB is defined on base of the overall levels in which the sound levels in the mid frequency range dominate.



2LPAC8, 80 km/h | TSL6, 80 km/h

Figure 5: Averaged 1/3rd octave band spectra for CPX- and SPB-measurements at 80 km/h, left two layered porous asphalt, right thin surface layers.

In the comparison of the 1/3rd octave band spectra of *CPXH* and SPB_{trucks} significant differences up to 12 dB are found for the lower frequency range (315-630 Hz). We furthermore notice that the deviations found for 2LPAC8 differ considerably from the deviations found for TSL6.
This raises doubts with regard to the feasibility of determination of the C_{road} coefficients based on *CPXH* data.

5. Conclusions and recommendations

With respect to the relation of the overall SPB and CPX values, one can conclude that:

- Overall CPX-levels can be used for Conformity of Production testing of road surfaces. The standard uncertainty in the prediction of the SPB value based on the CPX result for a specific pavement is 0.90 dB for passenger cars and 0.97 dB for heavy vehicles.
- Most of the available data in the SPB CPX relation analysis concerns measurement results of low noise pavements. It means that this relation is especially representative for this kind of road surface types. The validity of the relation for the traditional road surfaces like dense asphalt concrete, concrete pavement, SMA 0/16, etc. is not investigated. But for such surfaces, noise requirements are not often implied.
- The SPB CPX relation is useable for estimating SPB values of passenger cars when the measured *CPXP* is between 84 and 98 dB. For the prediction of SPB_{trucks} values the measured *CPXH* has to be in a range of 90 to 100 dB and determined at 80 km/h. Other speeds of heavy vehicle results are not taken into account in the relationship.

About the main issue of this study, how well can CPX replace SPB to evaluate noise reducing performance, one can conclude that:

- Acoustic road characterisation in 1/1 or 1/3rd octave band levels by using the CPX-method is not (yet) recommended. In the frequency range 315- 630 Hz the relation between SPB- and CPX-results exhibit significant deviations that do result in unreliable calculation of the sound propagation and screening due to heavy vehicle emission. Even larger errors are to be expected when predicting indoor levels.
- For the lower 1/1 octave bands (with centre frequencies 63 Hz, 125 Hz, 250 Hz and 500 Hz) the C_{road} values cannot be determined with high accuracy by using the CPX-method.

First because of the physical restrictions of the CPX-method by measuring sound levels at low frequencies (63, 125 and 250 Hz). Second because of the above-mentioned deviations found for heavy vehicles in the 500 Hz octave band.
- Naturally the research on noise production of vehicles on road surfaces focuses on the low noise pavements. In most data sets the low noise pavements are overrepresented. To study the effects of the noise reducing effects (C_{road}) in future it is desirable that also the amount of available SPB and CPX data on the reference surface increases. This will improve the understanding about the observed differences and deviations between spectral results of SPB and CPX measurements. In further research this can possibly contributes to a model that estimates the spectral SPB-values in a better way.
- The dependency of CPX sound levels to the speed is not investigated. The speed index $ß_{(m=1,2)}$ is one of the necessary parameters that is required for the C_{road} definition. Research to the speed dependency of CPX and SPB sound levels is recommended in future.

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