Close Proximity (CPX) Round Robin Test 2017

Bert Peeters
M+P, The Netherlands

Fred Reinink
M+P, The Netherlands

WillemJan van Vliet
Rijkswaterstaat, The Netherlands

Summary

Reduction of traffic noise is of great benefit to society. Therefore, silent tyres and silent pavements have been developed and are continuously improved. To measure the performance of silent pavements, measurements of tyre/road noise generated on different pavements are necessary. The Close Proximity (CPX) method, standardized in ISO 11819-2, is widely used as a measurement method for tyre/road noise.

In spring 2017 a Close Proximity round robin test (RRT) was conducted in the Netherlands. In total 9 CPX-systems participated in this test. This included CPX-systems from Austria, Belgium, Germany and the Netherlands.

In the paper the results of this CPX RRT are presented. The goal of the RRT was to look at the reliability of the measurement results in practice, and to see if the differences between CPX levels measured by different parties and measurement systems are within acceptable margins. Measurements and analysis have been performed according to the Dutch "Protocol for admission and round robin test of CPX devices". The paper explains the RRT protocol and the results, including repeatability and reproducibility. In addition, attention will be paid to the effect of applying a correction for the influence of rubber hardness on the CPX levels.

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1. Introduction

Road traffic noise can be significantly reduced by the application of noise reducing pavements. These pavements are a cost-effective solution to reduce traffic noise [1] and much less invasive for the surroundings, compared to noise barriers. Measurement results show that the tyre/road noise varies 12 dB for normal tyres on normal asphalt surfaces (surface dressings to fine-graded porous asphalt) [2]. More extreme surfaces, such as cobble stones or damaged surfaces, exceed this range.

For a successful application of noise reducing pavements, it is important to have a reliable measurement method, such as the CPX method, to assess their noise reduction capability. Using accurate noise reduction values, the beneficial effect of the pavements can be expressed in noise assessment methods, such as EU Directive 2015/996 (a.k.a. 'CNOSSOS') [3]. An accurate and reproducible method is also required for conformity-of-production in road infrastructure tenders. New initiatives to support and standardize the use of low-noise and sustainable pavements, such as the road surface label [4], need a reliable rolling noise measurement method. And finally, an accurate method is needed for research work to further develop and optimize these pavements. A main research topic is the development of acoustic performance over time: low-noise surfaces may require timely maintenance or repaving in order to retain their noise reducing capabilities, as was shown for instance in the QUESTIM project (see [5]). The CPX method helps to monitor the acoustic performance over time.

Figure 1: M+P CPX-trailer

The Close Proximity (CPX) method has been developed over the last 20 years. ISO Working Group 33 has been working on standardization of the method, which led to the current ISO11819-2 standard, published in 2017 [6]. For the Close Proximity Method, a measurement trailer is used with microphones close to the tyres. The CPX devices may be designed according to two enclosure options:

- trailer with enclosure lined with sound absorbing material,
- open trailer without enclosure.

Figure 1 shows the CPX-trailer used and built by M+P, which is a trailer with enclosure. As the tyres have a large influence on the measured tyre/road noise also, a separate ISO technical specification has been developed that describes requirements for the measurement tyres [7].

2. Round Robin Test and CPX protocol

2.1. The need for a round robin test

Road administrations and contractors need to check the noise reduction performance of their noise reducing pavements. For this, they must be able to rely on the accuracy and the independence of the measurement system, regardless which party or operator performs the measurements. A round robin test gives the opportunity to compare measurement systems and decide which systems comply with their accuracy requirements.

For the parties performing the measurements, participating in a round robin tests ensures them that their system gives the same noise levels as other systems. For companies working under accreditation, regular participation in a comparison test may even be mandatory.

2.2. Goals

A CPX Round Robin Test (RRT) was organised by the Dutch CROW in cooperation with the National Road Authority, Rijkswaterstaat. The RRT aims to improve the repeatability and reproducibility of CPX measurements for the Dutch market, by rejecting CPX devices which do not meet the requirements of the protocol.

The goal of the RRT was to look at the consistency of the measurement results in practice, and to see if the differences between CPX-levels measured by different parties and measurement systems are within acceptable margins.

The repeatability and reproducibility are determined from the CPX-RRT results, but only to assess the compliance of the CPX devices with the protocol. It was not the goal of this CPX-RRT to determine the repeatability and reproducibility of the CPX ISO-standard in general.

2.3. Round Robin Test

The RRT was conducted in May 2017 in the Netherlands. In total 9 CPX systems participated in this test (see Figure 2). This included CPX-systems from Austria, Belgium, Germany and the Netherlands. All systems are two-wheeled trailers. Eight CPX-trailers had an enclosure, one CPX-trailer had no enclosure.

In the same week as the CPX-RRT, CROW also organised a round robin test for the related Statistical Pass-By (SPB) method, ISO 11819-1. The results of this SPB-RRT are not presented in this paper.

2.4. CPX RRT protocol

The measurements and analysis have been performed according to the Dutch “CROW Protocol for admission and round robin test of CPX devices”

Figure 2: Overview of the 9 CPX-systems participating in the Round Robin Test 2017

[10]. The protocol describes the admission requirements for systems wanting to participate in the RRT, it gives requirements for the road sections, it described how to conduct the measurements and it defines the accuracy characterisation used to assess the outcome. The protocol mainly aims at a round robin test with several parties, which CROW plans to organise every 2 years, but it also describes the possibility to do a pairwise RRT, comparing a new system to a previously certificated system.

The protocol refers to the DIS-version of the ISO standard [9], since the final version was not yet available when the protocol was written and published.

2.5. Test admission

To be admitted for the CPX-RRT each applicant CPX system has to be certified and calibrated according to the requirements of the ISO/DIS 11819-2. The trailer design has been limited to two-wheeled trailers, with test wheels in the left and right wheel track, 1.90 ± 0.10 m between the centre lines of the wheels.

For all devices, the frequency-dependent device correction term *Cdf* has to be determined according to the method described in the ISO/DIS. With this correction term, the measurement results are corrected for the influence of the trailer itself. The instruments used for the measurement of the driving speed shall have a maximum permissible error of ± 1% of the indicated value.

2.6. Tyres and rubber hardness

For the CPX-RRT, measurements are to be performed with the Standard Reference Test Tyre (SRTT), as specified in the ASTM F2493-14. The Shore hardness of these test tyres needs to be measured no more than 3 months before the test, following the ISO/TS 11819-3 procedure [7]. Calibration information of the Shore hardness tester used must be provided and no more than 24 months old.

The current protocol does not include an actual correction of the measured levels for the tyre rubber hardness, since this correction has been introduced in the 2017 ISO standard [6], after the protocol was published. The influence of the rubber hardness has been investigated in the project, however, see paragraph 6 below.

3. Measurements

3.1. Test sections

According to the protocol the measurements should be performed on an open and dense road surface with at least 1000 m length each. The sections need to be (acoustically) homogeneous, such that the standard deviation of the sound levels over the road section is no more than 0.5 dB(A).

For the 2017 RRT, two test sections were selected:

- the N348 / N314 near Zutphen, paved with double layered porous asphalt concrete (DLPAC);
- the N348 near Brummen, paved with stone mastic asphalt, type SMA-NL 11B (11 mm max. stone size), see Figure 3.

Figure 3: The N348 near Brummen

The acoustic homogeneity was checked before the test using CPX measurements by M+P and was found to be good: standard deviations were found to be 0.1 to 0.3 dB.

3.2. Test conditions

The CPX round robin test was conducted on May 17th, 2017, between 10:00 and 16:00. It was a sunny day with a maximum air temperature of 29 °C and a maximum road surface of 45 °C, which is within the ISO/DIS requirements.

All participants performed measurements on all road sections. Instead of the four measurement runs on each road section, as prescribed in the protocol, all participants have performed six measurement runs.

Measurements have been performed at a target driving speed of 80 km/h.

4. Analysis

4.1. Definitions

The CPX measurement results are assessed based on trueness and precision. These concepts are illustrated in Figure 4. ‘Trueness’ (α) is a measure of the systematic error of a measurement result, with respect to the actual, ‘true’ value. ‘Precision’ (β) is a measure of the magnitude of random errors and is a combination of repeatability and reproducibility. ‘Repeatability’ is the variation between repeated measurements on the same specimen, by the same operator using the same equipment under the same conditions within a short period of time. ‘Reproducibility’ is the variation that occurs between repeated measurements on the same specimen, by different operators using different equipment under possibly differing conditions within a longer period of time.

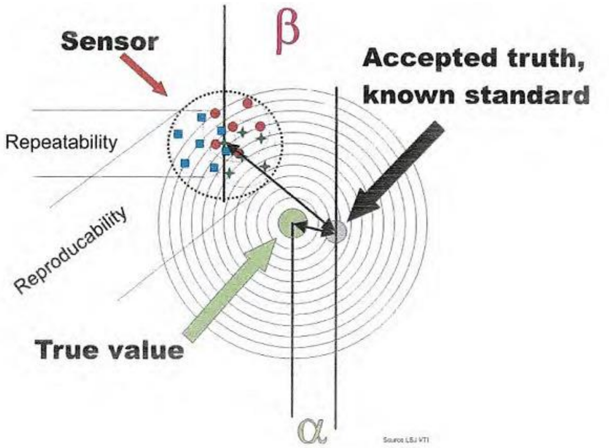

Figure 4: Schematic illustration of trueness, precision, repeatability and reproducability (from [10])

4.2. Analysis of measurement data

The CPX measurement results are analysed to determine the compliance for each measurement system. Measurement data are analysed in a slightly different manner than the formal ISO11819-2:2017 procedure:

- data are analysed using average sound pressure levels (SPL) and standard deviations per 100 m section, instead of 20 m;
- the SPL values are analysed per individual measurement run, instead of averaging over two runs;
- measurement results, for the assessment of compliance, are not corrected for rubber hardness of the tyres. The influence of rubber hardness is investigated separately, however, to investigate improvements for future RRT’s.

4.3. Analysis of trueness

Real ‘trueness’ cannot be determined for CPX measurements, as the ‘true’ value is unknown. Therefore, the group average is used as the ‘accepted’ reference value, but outliers are removed.

The analysis of trueness is performed for each of both road sections (DLPAC and SMA) separately.

First, the group average reference value is determined for each 100 m segment:

1. Collect the sound pressure levels (SPL) for every run, for each participant.
2. For each participant, determine (a) the average SPL and (b) the standard deviation over all runs, for each 100 m segment.
3. Determine the overall average of the SPL values over all runs for all participants together (the reference group). This is the *reference value* for each 100 m segment.
4. For each participant, determine the difference between the participant’s average (2a) and the reference value (3), for each 100 m segment.
5. Remove outliers: if there are more than three participants, check for each 100 m segment whether all differences from step 4 are smaller than 1.0 dB(A). If not, remove the participant with the largest difference from the reference group for that 100 m segment. Then, repeat steps 3 and 4.

The result of these five steps is the final reference value (the accepted ‘true’ value) for each 100 m segment. Then, it is determined if each participant fulfils the trueness requirements:

- For each participant, determine the difference between the participant’s average SPL value for each 100 m segment and the reference value, per measurement run.
- For each participant, calculate the average and of the SPL differences over all 100 m segments and all runs found in the first step. This value is called ‘A’.
- For each participant, calculate the standard deviation of the SPL differences over all 100 m segments and all runs found in the first step. This value is called ‘B’.
- Check the following requirements:
  - the absolute value of ‘A’ shall be less than 1.0 dB(A);
  - the value of ‘B’ shall be less than 1.3 dB(A).

The average deviations from the reference values ('A') constitute the systematic error (bias) of that individual device: a large positive, or negative, bias indicated that the individual measurement system produces generally higher, of lower, values than the rest. The random error value ('B') represents the ability of the individual device to reproduce the actual ('true') variations of the road surface within the selected measurement section. If the individual device accurately reproduces the differences between the more noisy and more silent parts of the road section, it will have a small 'B' value.

4.4. Analysis of precision

The analysis of the precision is also performed for each of both road sections separately, following these steps:

- For each participant and for each 100 m segment, determine the standard deviation of the SPL values over all runs.
- For each participant, determine the root mean square of the standard deviations over all 100 m segments. This value is called 'C'.
- Check the requirement: the value of 'C' shall be less than 0.5 dB(A).

4.5. Illustrating example

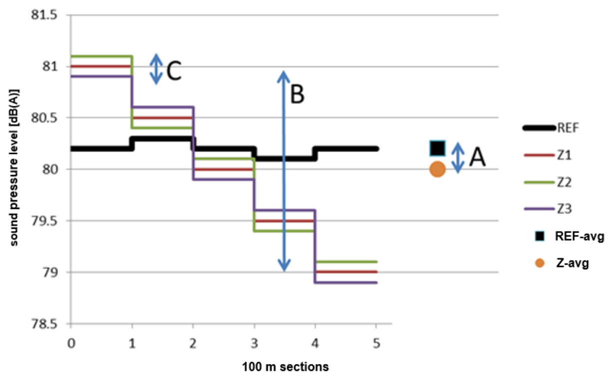

Figure 5: Explanation of analysis parameters 'A', 'B' and 'C' in the CPX-RRT

To explain the analysis parameters 'A', 'B' and 'C' in more detail, an illustrating example is presented in Figure 5. The figure shows the SPL for three runs (Z1, Z2, Z3) measured by one participant, averaged over the 100 m segments. The black line shows the group average reference value per 100 m segment.

This particular participant has a small 'A' value: his average SPL over the entire measurement section and all runs (Z-avg) is only -0.2 dB(A) from the average reference value (REF-avg). The participant has a large 'B' value: his measurement system shows much larger variations in the road surface than the group average. The 'C' value is small, so the repeatability of his measurement system is good. This indicates that the large 'B' value is not an accidental coincidence. This example participant would not comply with the requirements.

5. Results

5.1. CPX-RRT 2017 results

The CPX-RRT results for all 9 participants are shown in Table I. The participants are labelled CPX01 to CPX09 in random order.

The first step in the analysis (see 4.3) is the determination of the group average reference value for each 100 m section. The exclusion of outliers resulted in the following:

- CPX01 was excluded from 12 of 12 segments of the SMA road section;
- CPX01 was excluded from 4 of 9 segments of the DLPAC road section;
- CPX02 was excluded from 9 of 9 segments of the DLPAC road section;
- CPX03 was excluded from 1 of 9 segments on the DLPAC road section.

Table I shows the 'A', 'B' and 'C' values resulting from the analysis methods of 4.3 and 4.4. The 'A' values are presented as a non-absolute (+/-) value, to indicate whether the system produces, on average, higher or lower values than the reference. The 'A' values are also presented in Figure 6.

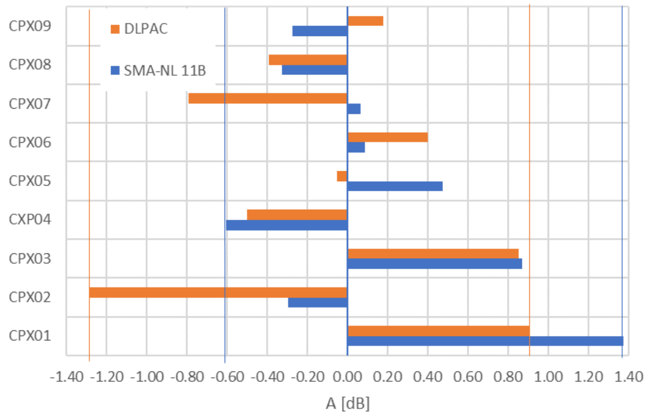

Figure 6: 'A' values for each participant, for the DLPAC and SMA road sections; vertical lines show the min/max

The bold values in Table I do not meet the CPX-RRT requirements: the CPX01 and CPX02 systems do not fulfil the requirements for systematic errors

('A' value). In total, the 9 systems show systematic errors ranging from -0.61 to +1.37 dB(A) on SMA and -1.29 to +0.91 dB(A) on DLPAC.

Random errors are generally small: the 'B' values range from 0.11 to 0.27 dB(A). Also, the repeatability of each system is good: the 'C' values range from 0.07 to 0.22 dB(A).

Table I: CPX-RRT results for participant CPX01 to CPX09 in random order, showing values 'A' (systematic error), 'B' (random error) and 'C' (repeatability). Bold values do not fulfil the requirements.

participant	*SMA-NL 11B*		
	A [dB]	*B [dB]*	*C [dB]*
CPX01	**1,37**	0,13	0,12
CPX02	-0,30	0,11	0,11
CPX03	0,87	0,21	0,15
CPX04	-0,61	0,25	0,21
CPX05	0,48	0,14	0,12
CPX06	0,09	0,12	0,12
CPX07	0,07	0,20	0,21
CPX08	-0,33	0,22	0,22
CPX09	-0,27	0,11	0,09
min.	*-0,61*	*0,11*	*0,09*
max.	*1,37*	*0,25*	*0,22*
range	*1,98*	*0,14*	*0,12*
st.dev.	*0,64*	-	-
participant	*DLPAC*		
	A [dB]	*B [dB]*	*C [dB]*
CPX01	0,91	0,17	0,09
CPX02	**-1,29**	0,12	0,08
CPX03	0,85	0,17	0,10
CPX04	-0,50	0,27	0,22
CPX05	-0,05	0,14	0,07
CPX06	0,40	0,15	0,09
CPX07	-0,79	0,16	0,14
CPX08	-0,39	0,12	0,11
CPX09	0,18	0,11	0,10
min.	*-1,29*	*0,11*	*0,07*
max.	*0,91*	*0,27*	*0,22*
range	*2,20*	*0,16*	*0,15*
st.dev.	*0,74*	-	-

5.2. Comparison with CPX-RRT 2011

CROW has organised a CPX round robin test before, in 2011. Five of the nine CPX systems participating in the 2017 RRT also participated in 2011. This allows for a comparison of the RRT results between both editions. For this comparison, the 2011 measurement data have been analysed using the 2017 method (described above).

Figure 7 shows the 'A' values from the 2017 RRT from Table I (blue/orange bars), as well as the average differences from the reference found in 2011 for the five CPX systems that participated back then (grey bars). The 2011 values are an average of DAC, SMA, PAC and DLPAC surfaces. The two round robin tests show remarkable similarities for these five CPX-systems: the average differences all point in the same direction and the 2011 values correspond quite well to the average of the 2017 SMA and DLPAC values. Table II shows the values for the average differences for these five systems: both columns match remarkably well.

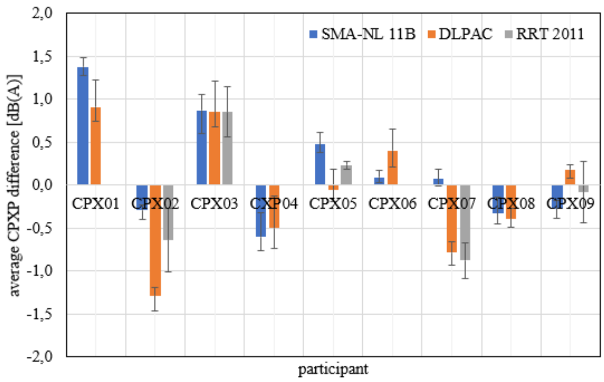

Figure 7: Average differences per participant ('A' values) on SMA and DLPAC, combined with the differences found in the CPX-RRT 2011. Error bars indicate min-max values.

Table II: Average differences found for CPX systems that participated in the 2011 RRT as well as in the 2017 RRT. Values for RRT 2017 are an average of the SMA and DLPAC road sections; values for RRT 2011 are also an average of various open and dense road surface types.

participant	average differences [dB]	
	RRT 2011	RRT 2017
CPX02	-0,64	-0,80
CPX03	0,85	0,86
CPX05	0,23	0,22
CPX07	-0,88	-0,36
CPX09	-0,08	-0,05

6. Influence of tyre rubber hardness

The hardness of the rubber in the tyre tread influences the generated tyre/road noise. Softer rubber will lead to less excitation and more damping of the tyre/road contact interaction forces. Also, the rubber hardness may influence the radiation efficiency of the tyre tread.

In the latest ISO11819-2 [6], a correction to the measured sound power levels is therefore applied, which is defined in the ISO/TS 11819-3 [7]:

$$C_{HA,t} = \beta_t\left(H_A - H_{ref}\right), \qquad (1)$$

where β_t is the rubber hardness coefficient for tyre t, H_A is the Shore A hardness of the tyre, measured according to the described procedure using a Shore A hardness tester (e.g. Figure 8), and H_{ref} is the reference rubber hardness value. The reference hardness value is equal to 66 Shore A and the hardness coefficient is 0.20 dB/Shore A for the SRTT tyre.

Figure 8: Shore A hardness tester.

In the 2017 CPX round robin test, the measured values were not corrected for rubber hardness in the compliance check. However, all participants were asked to measure and report the rubber hardness of their tyre, to allow an investigation of the effect on the noise levels and on the RRT outcome.

The analysis described in 4.3 for the parameter ‘A’ was repeated, but with all sound power levels corrected for the rubber hardness of the measurement tyres. The corrected ‘A’ values are presented in Figure 9. Comparing this figure to Figure 6 shows a significant effect on the outcome:

- Participants CPX01 and CPX02 did *not* meet the trueness requirement (‘A’ < 1.0 dB(A)) before, but they *do* meet the requirements if the hardness correction is applied.
- Participants CPX04 and CPX07 *did* meet the trueness requirement before, but they do *no longer* meet the requirement after the hardness correction is applied.

All participants still fulfilled the requirements for values ‘B’ and ‘C’, after applying the hardness correction.

Regarding all participants together, the application of the rubber hardness correction leads to a smaller min-max range and standard deviation:

- For the SMA road section, the min-max range decreases from 1.98 dB(A) to 1.60 dB(A) and the standard deviation decreases from 0.64 to 0.49 dB(A).
- For the DLPAC road section, the min-max range decreases from 2.20 dB(A) to 1.99 dB(A) and the standard deviation decreases from 0.74 to 0.68 dB(A).

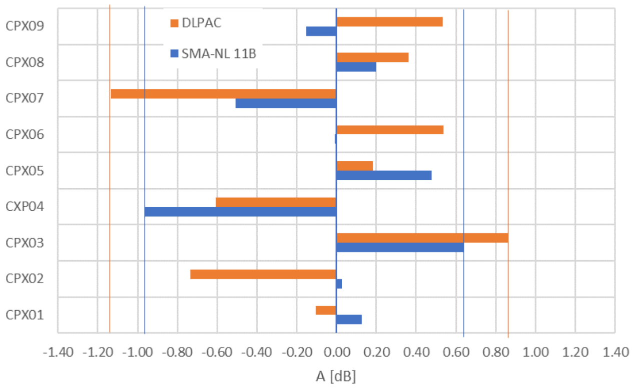

Figure 9: ‘A’ values for each participant after applying the tyre rubber hardness correction, for the DLPAC and SMA road sections; vertical lines show the min/max

7. Conclusions and recommendations

The CPX round robin test conducted in 2017 is considered successful: there was a large number of participants and they were able to perform the measurements efficiently and according to the protocol, within the given time frame.

The analysis of the compliance with the pre-set requirements showed that all participants fulfilled the requirements for random errors (small ‘B’ values) and repeatability (small ‘C’ values). Two participants showed systematic deviations from the group average and did not fulfil the trueness requirement (‘A’ values).

The RRT results for the ‘A’ values shows remarkable similarity with the results of the previous RRT in 2011, for the five participants that were involved in both editions.

The rubber hardness correction was not applied for the compliance checks. There is a significant effect of the rubber hardness on the RRT outcome: participants no longer comply with the requirements after applying the correction, and others do not comply with the requirements if the correction is not applied. If the rubber hardness correction would be applied, the 'A' values of all participants would be closer together. It is recommended for future RRT's, therefore, to include the rubber hardness correction in the analysis, thereby following the latest ISO11819-2 requirements.

Acknowledgement

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