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Close Proximity (CPX) Round Robin test: Comparison of results from four different CPX trailers measuring noise properties of 10 Swedish road surfaces

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ABSTRACT

The publication in 2017 of ISO documents 11819-2 (CPX method) and 11819-3 (reference tyres) has made it possible to conduct measurements of noise properties of road surfaces in a standard and reproducible way. However, it is still not well-known what differences one may expect between different CPX equipment. A comparison of CPX trailers in the Netherlands in 2017 gave very positive results, but only two road surfaces were used, and all measurements were made close in time. In practical measurements, more variations in CPX equipment occurs and measurements on a certain test surface cannot take place on a certain day or even week. This study used four CPX trailers, of different designs, and the measurements were made over a time period of 90 days; something that may well happen whenever an authority or organization orders a CPX measurement. In this paper the test equipment and tested road surfaces are described, and the first measurement results are presented.

Keywords: Round Robin, CPX method, Variability

I-INCE Classification of Subject Number: 72

1. INTRODUCTION

Some transport or road administrations are planning to require and apply low-noise pavements based on functional requirements. Also, in the European Committee for Standardization (CEN) there is work in progress with the aim to produce a classification procedure for noise properties of European pavements. Limits applied to such noise properties are subject of political pressure from certain organizations and companies in the ECE-WP29-GRBP in Geneva.

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There is hardly any doubt that such pavement classification will be established within the near future. However, for such a system to be meaningful, it is necessary to know the limitations posed by measurement equipment and methods.

For efficient regulations or requirements in the Scandinavian countries (Sweden, Denmark and Norway), we need to establish how the application of such system(s) can be made here, based on the road surfaces and test equipment that we have access to.

The publication in 2017 of ISO documents 11819-2, the CPX method [1], and 11819-3, reference tyres [2], made it possible to conduct measurements of noise properties of road surfaces in a standard and reproducible way, and many measuring companies or organizations already implement this system. However, the uncertainties are still unclear, and especially it is still not well-known what noise level differences one may expect when using different CPX equipment. When setting functional requirements, it is crucial to have an idea of the expected uncertainties in measurement results.

2. PURPOSE AND LIMITATIONS

The purpose of this experimental study was to determine estimated uncertainties related to CPX measurements according to ISO 11819-2 and ISO/TS 11819-3 on typical Scandinavian pavements and using the diverse CPX equipment available in Scandinavia. This is of utmost importance when setting limits to noise-reducing pavements and when evaluating the performance of those. These uncertainties shall apply not only to ideal cases, such as when all equipment are conducting measurements at the same time on homogeneous and new pavement surfaces within a tight temperature range.

In this case, not only were the CPX trailers of fundamentally very different constructions from different countries; also, measurements were conducted with a spread in time of up to 3 months and were made on pavements which already had been exposed to traffic that had created some moderate rutting. Another irregularity was that the participants measured quite different lengths of the test sections. Furthermore, air temperatures varied between +10 and +30 °C.

3. EARLIER STUDIES

A few earlier studies, so called Round Robin Tests (RRT) are worth mentioning. In 2012 an RRT was presented in the Netherlands [3]. Then 7 CPX trailers did measurements on 5 roads and the deviations were from 0.80 to 2.1 dB(A) between the trailers, depending on pavement, tyre and speed.

In a more limited RRT, three CPX trailers used in Scandinavia were compared in 2009 on 7 pavement surfaces [4]. Differences were then within 1.5 dB(A). It must be emphasized that these tests were made based on early drafts of the ISO standards, which were much less elaborated than the published ones.

More interesting is to look at studies made after the final standards were published. A comparison of CPX trailers was made in the Netherlands in 2017 [5]. Ten trailers were tested on two pavement surfaces, and all measurements were made close in time. The results showed differences of up to 2.0 dB(A) between trailers.

The same year, a French RRT was made. That one used mainly the version of the CPX method where measurements were made on-board the powered test car since this is preferred in France [6]. The RRT was conducted on 8 surfaces on a test track in Nantes. The CPX equipment consisted of 6 SPV systems (SPV = self-powered vehicles) and one

trailer (M+P). A total of 10 test tyres were used, but only the trailer and one of the SPV:s used the P1 reference tyre. The results were complicated but generally rather depressing: with differences up to 9 dB(A) recorded; mostly explained by non-conformance with the actual standards.

4. GENERAL OUTLINE OF THIS EXPERIMENTAL STUDY

The four CPX trailers that either are based in Scandinavia (DRD, SINTEF and Tyréns) or used in Scandinavia (TUG); see description below, were invited to take part, funded by VTI. Also, a device of the SPV type was invited but (the owner) Skanska declined. Ten different road pavement test sections in the regions including Linköping, Örebro and Jönköping were selected, based on the different constructions, conditions and covering a wide range of textures. Two of these were porous pavements while 8 were dense. Two had steel slag as aggregate and max aggregate sizes of 8, 11 and 16 mm were included. Some were new or in rather new condition and a few were old and had prominent ruts in the wheel tracks. Both reference tyres, P1 and H1, were used (see below).

The speed was usually 80 km/h, except for 70 or 60 km/h where the posted speed limit was lower. The two two-wheeled trailers made measurements in both wheel tracks, while the two single-wheel trailers ran only in the right wheel track, but in this paper only the right wheel track is analysed. This probably caused a certain systematic difference in exact lateral position within the wheel tracks.

The first measurements were made at the end of June 2018 and the last ones three months later. Air temperatures thus ranged between 10 and 30 °C. A few measurements were made when the surfaces were slightly humid (drying-up after rain), illustrating the case that may happen that a CPX operator does not wait for a fully dry surface.

Consequently, it was never attempted to conduct the measurements in a way to minimize uncertainties. In contrast to earlier RRT:s of CPX equipment, the basic idea behind all this was that measurements would be spread widely in time, temperature, CPX equipment, tyre conditions and road pavement and its condition, in the same way as can be expected when an organization orders CPX measurements one year on a number of roads in Scandinavia.

5. MEASUREMENT PROTOCOL, EQUIPMENT AND METHODS

5.1 Measurement Protocol

Each participant received information regarding the location of the 10 test sites, with a corresponding site designation, nominal test speed(s), lines and directions to be evaluated. The pavement type was also described for each test site. GPS coordinates for the start and finish positions were also provided for 6 of the test sections; the other 4 were defined carefully by visual cues. However, it appeared afterwards that 3 of the participants used visual cues also on the 6 first pavements (which was not the intention), and this resulted in those trailers measuring longer sections than intended.

It was assumed that all equipment was prepared in conformity with ISO 11819-2 and ISO/TS 11819-3. Some of the participants did not have both reference tyres, in which case some tyres were shared, and some were provided by VTI (see Section 6.4).

The participants were requested to perform at least three acceptable runs (according to ISO 11819-2 [1]) for each test section, reference tyre, direction and nominal speed.

The data was to be processed according to ISO 11819-2 [1] (the CPX method), ISO 11819-3 [2] (reference tyres), and ISO 13471-1 [7] (temperature corrections). The correction for the tyre rubber hardness, however, was performed according to an amendment to ISO/TS 11819-3, that was decided on at an ISO meeting [8].

The data to be reported included the CPX averaged levels for the two microphones over the full length of each test site (in 20 m long sections), and average third-octave frequency spectra for the entire test section over at least 250 Hz – 5 kHz. Time histories; i.e. CPX level versus time (or distance), were also to be reported.

The resulting data was then sent to VTI where the authors checked if all the necessary corrections were made in conformity with the standards and reprocessed the data when needed or when it was not entirely processed in accordance to the standards (which happened in some cases).

Rubber hardness measurements were to be performed both by the participants and by VTI for each reference tyre used in this Round Robin programme. After the results were compiled, the most relevant results were sent to all participants and they had the opportunity to send comments.

5.2 CPX Trailers

A total of four different CPX measurement trailers took part in this RRT and are shown in Figure 1. Two of them have an open trailer design, which means that they do not have an enclosure: the trailer from the Swedish consultant company Tyréns and the trailer from the Danish Road Directorate (DRD). The other two trailers have an enclosed design, which means they have an enclosure: the Norwegian trailer from SINTEF and the Polish trailer from Gdansk University of Technology (TUG).

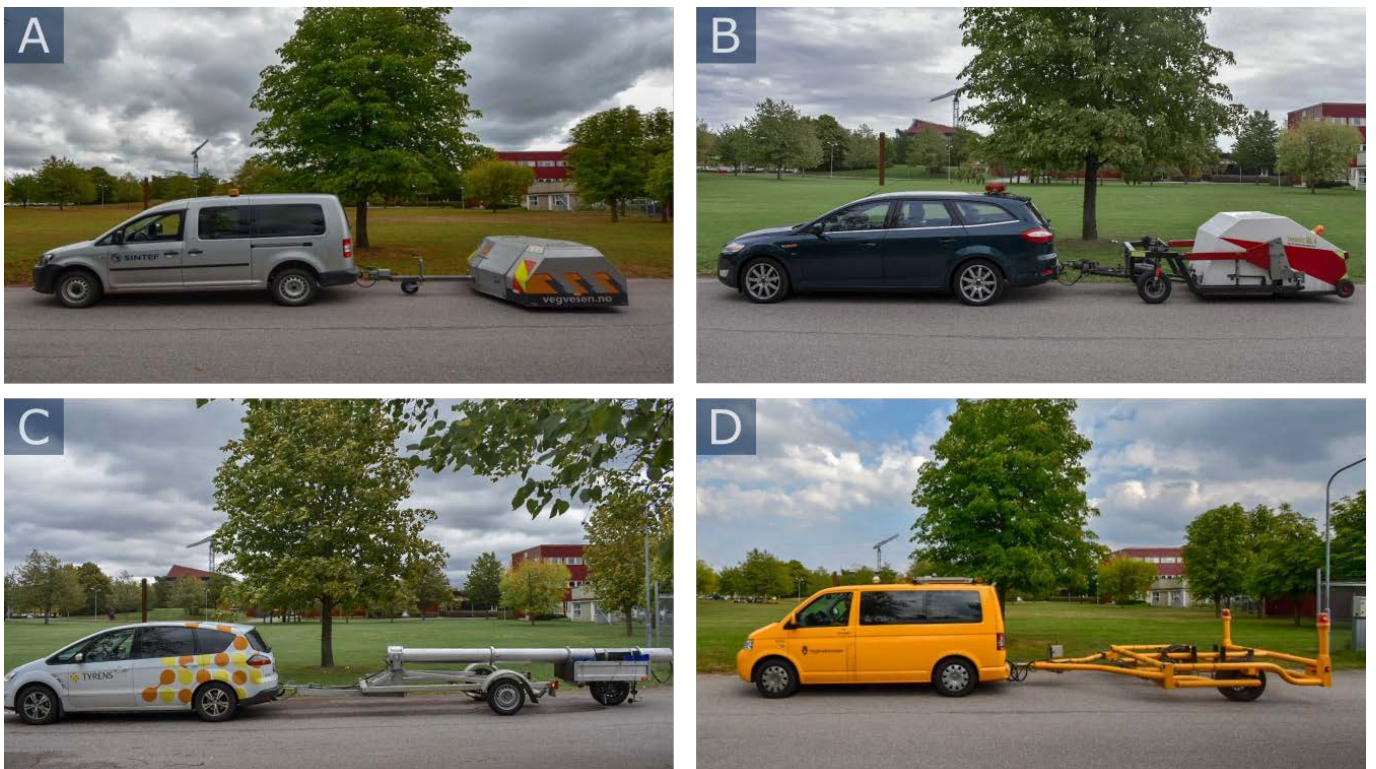


Figure 1. The four CPX trailers that participated in this Round Robin test:
A: SINTEF, B: TUG, C: Tyréns, D: DRD

Note that the CPX trailer from TUG and Tyréns have only one wheel while SINTEF and DRD have two wheels that are measured simultaneously. For this text each CPX trailer arbitrarily received a designation (CPX1, CPX2, CPX3 and CPX4).

The result notations in chapter 7 (CPX1, CPX2, CPX3, CPX4) are not to be confused with the notation in Figure 1 (A, B, C, D). The results are blinded on purpose for the reader as the objective of this specific paper is not to compare a specific measurement device but to examine the method itself. Unblinded results were provided to the participants.

5.3 Test Sites

A total of 10 test sites were selected, including dense and porous surfaces, different stages of wear and at different speeds as shown in Table 1. The maximum aggregate size was either 11 or 16 mm. The test sites are described in Table 1 together with their site id, with which they will be referred to further on in this text. The participants received GPS coordinates for the 6 first sites but CPX2, CPX3 and CPX4 used prominent visual clues instead. This means that they measured somewhat longer sections than CPX1 on those test sections.

Table 1. Test sites, approximative length, tested directions, nominal speeds and the respective MPD value. PAC1 and PAC2 were one year old.

Site id	Pavement type	Road number and location	Length (appr.) [m]	Direction	Test speeds [km/h]	MPD [mm]
DAC1	DAC16	RV47 Jönköping	500-1600	N & S	80	0.49
SMA1	SMA16, old & rough	RV47 Jönköping	500-1400	N & S	80	1.50
SMA2	SMA16, 1 year old	RV47 Jönköping	500-3600	N & S	80	1.13
PAC1	Double-layer PAC, regular	E4 Huskvarna	500-2300	N & S	80	1.74
PAC2	Double-layer PAC, steel slag	E4 Huskvarna	120-200	S	80	1.55
SLG1	SMA8 type, with steel slag	Östra Bangatan, Örebro	370-500	N & S	50, 70	0.72
SMA3	SMA16, 4 years old	Link to E4 from Linköping	220-400	W & E	50, 80	1.13
SMA4	SMA16, 2 months old	RV34 Linköping	290-307	N & S	50, 80	0.94
SMA5	SMA11, 6 years old	Vistvägen, Linköping	225-300	N & S	50, 60	0.49
SMA6	SMA11, 1 year old	Vistvägen, Linköping	300-380	W & E	50, 60	0.96

6.4 Test Tyres

The test tyres were the reference tyres P1 and H1 defined in ISO/TS 11819-3 for the CPX method. The tread patterns of these are shown in Figure 2.

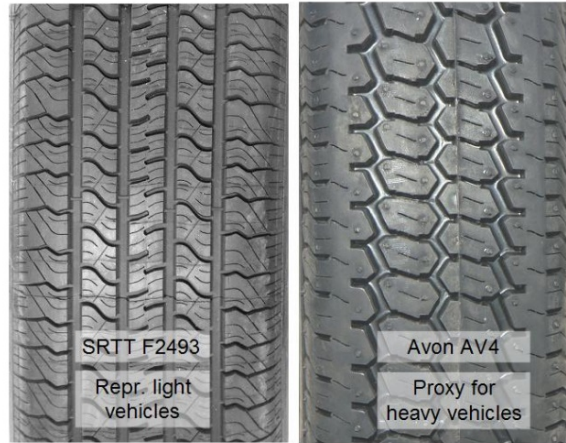


Figure 2. The reference tyres P1 (left) and H1 (right) used for the measurements.

The actual tyre samples used by each participant are listed in Table 2, with the measured rubber hardness values indicated. Since some of the participants did not have one or both tyres, VTI decided to lend tyres to these participants. It meant that in a few cases different participants used the same tyre sample. This is indicated in Table 2.

Table 2. Test tyres used for measurements in the right wheel tracks, with hardness values.

Trailer Id	P1 tyre Id	H1 tyre Id	Shore A hardness	Owned by
CPX1	P1a	H1a	67 (P1), 67 (H1)	CPX1
CPX2	P1b	H1b	64 (P1), 62 (H1)	P1 by CPX2, H1 by VTI
CPX3	P1c	H1b	68 (P1), 61 (H1)	P1 by CPX3, H1 by VTI
CPX4	P1d	H1b	64 (P1), 61 (H1)	VTI

5.5 Measurement Remarks

CPX4 reported that the following test sites were somewhat humid (but not “wet”) during its measurements: SMA3, SMA4, SMA5, SMA6. This participant missed the site PAC2. The device correction term, C_d (according to ISO 11819-2), was not measured for CPX4 and the received data was consequently not corrected with such values. CPX3 missed site SLG1 for tyre P1. Only CPX1 and CPX3 provided GPS coordinates in their results.

6. RESULTS

The actual length that each participant measured at each test section is presented in Table 3. The measured length for each participant was taken as the average length considering all available runs carried out by each participant at each test section. Note that CPX2 did not report measured length nor GPS coordinates and CPX4 missed the test site PAC2; therefore, these results are not available. The participant CPX1, that followed the GPS coordinates, was closer to the expected reference length in almost all the test sections. The test sites that resulted in the lowest deviations between the expected and actual measured lengths were SLG1, SMA3, SMA4, SMA5, SMA6. For these test sites, participants did not deviate from the measured length more than 180 m, or no more than 45 % of the reference length.

Table 3. Comparison of the intended measured length (column "Reference") and the length actually measured by each participant at each test section, in meters.

Site_id	CPX1	CPX2	CPX3	CPX4	Reference
DAC1	500	1600	1185	1360	500
PAC1	2293	1000	995	695	500
PAC2	202	120	200	N.A.	200
SLG1	400	500	370	460	400
SMA1	500	1440	1430	930	500
SMA2	500	3600	1255	1020	500
SMA3	337	220	390	370	400
SMA4	300	300	307	290	300
SMA5	280	260	257	225	300
SMA6	300	320	380	337	300

The CPX levels for each test site, direction and nominal speed were averaged for each participant and the differences to the overall mean CPX level for a given site and nominal speed were calculated. This allows a visualization on how each participant deviates from the mean value measured by all participants at a given site and speed, as shown in Figure 3 for the reference tyre P1. Note that only relative differences between each participant are relevant in this figure, the mean value (zero) only establishes a reference for comparisons. Note that speeds are different, depending on the posted speed and safe driving for the test sections, as shown in Table 1.

The same differences were also calculated for the reference tyre H1 and are shown in Figure 4. Note that if the result for a given CPX participant is not visible it means that its value was near the reference level, *i.e.* zero, on each figure, with the exception of missing data on PAC2 (for both tyres) for CPX4, and SLG1 (for tyre P) for CPX3.

The mean CPX levels were then averaged for all the 10 test sites and are shown in Figure 5 as differences to the mean values for all CPX trailers with a given reference tyre. Note that only relative differences between each participant are relevant in this figure, the mean value (zero) only establishes a reference for comparisons.

The average third-octave band frequency spectra were also calculated for each participant and reference tyre as average for all test sites and nominal speeds and shown in Figure 6.

7. DISCUSSION

The observed differences between all CPX participants were 1.5 dB or lower for the sites SLG1, SMA3, SMA4, SMA5, SMA6 and PAC2. Common for these is that the differences in measured lengths are not large. Trailers CPX1 and CPX2 followed each other remarkably well on almost all test sites, the exception being PAC1, where they differed about 1.2 dB(A). CPX3 seems to systematically indicate slightly higher values than the others while CPX4 seems to have a larger variability, sometimes higher and sometimes lower than the other participants.

Tyre P1

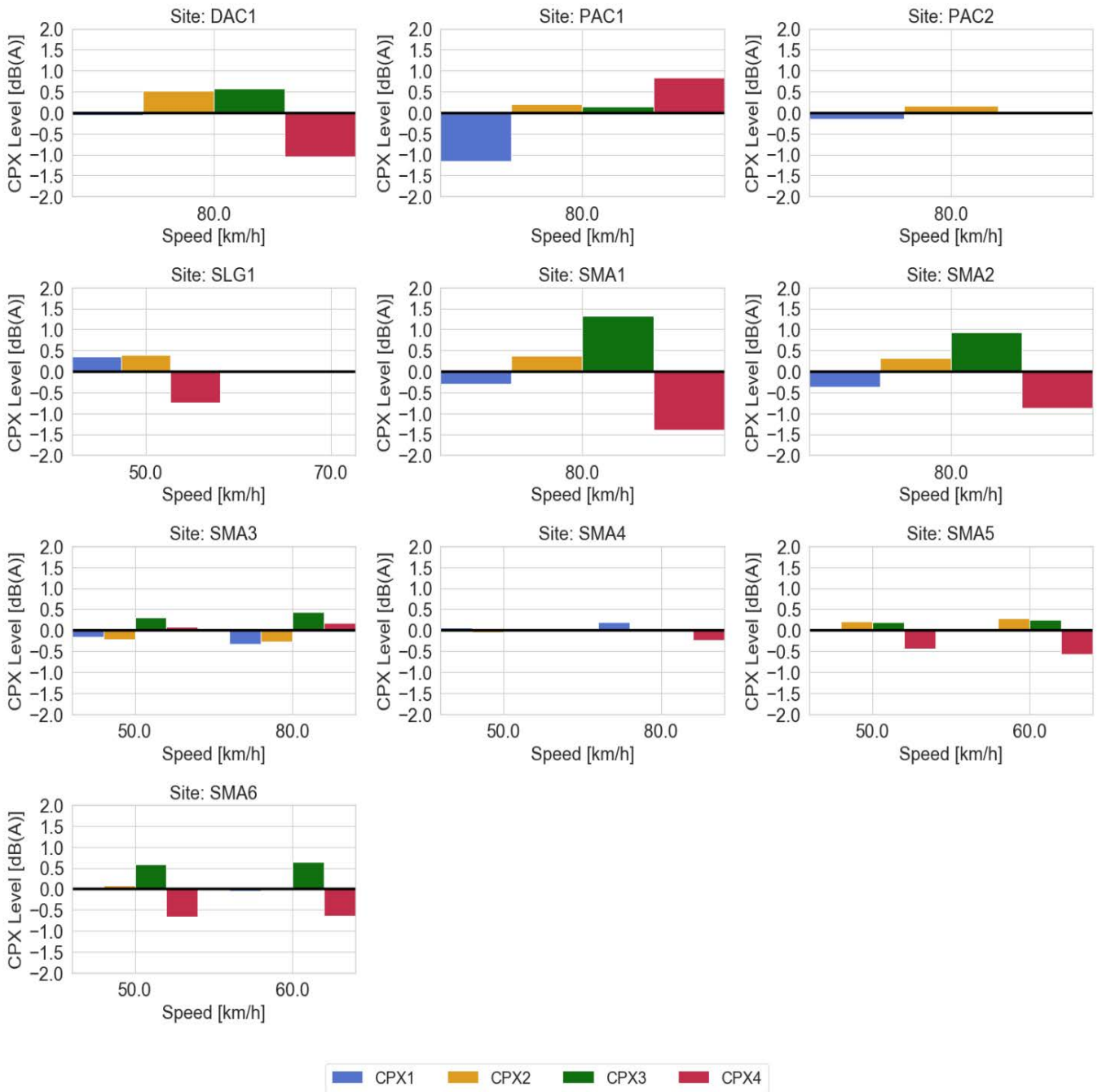


Figure 3. Average CPX noise level difference for each trailer compared to the mean result for all trailers at a given test site and speed, with tyre P1. Sites PAC2 for CPX4 and SLG1 for CPX3 were not measured. If a bar is not visible it means that its value is close to the zero reference level for this figure.

Tyre H1

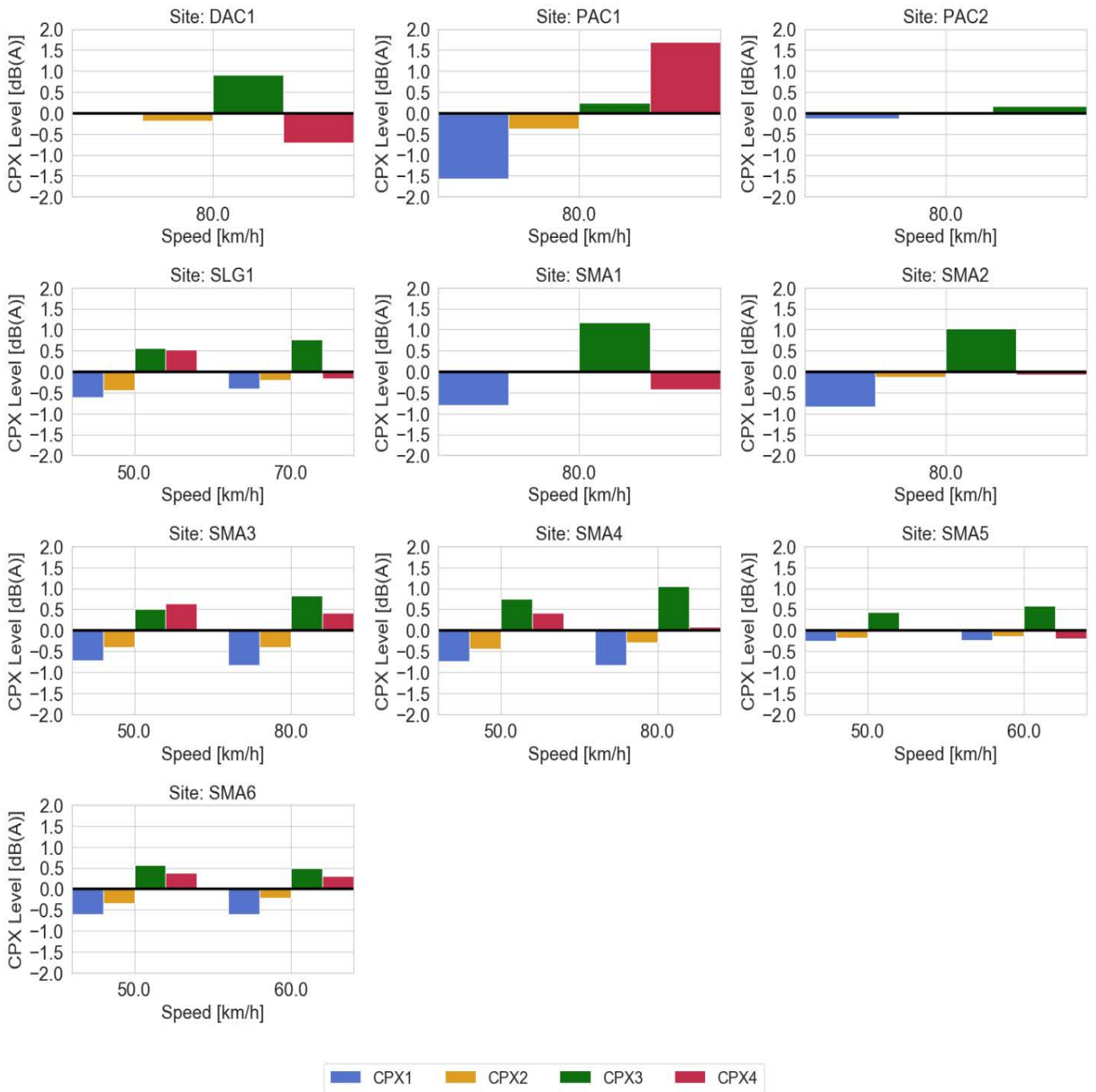


Figure 4. Average CPX noise level difference for each trailer compared to the mean result for all trailers at a given test site and speed, with tyre H1. Site PAC2 for CPX4 was not measured. If a bar is not visible it means that its value is close to the zero reference level for this figure .

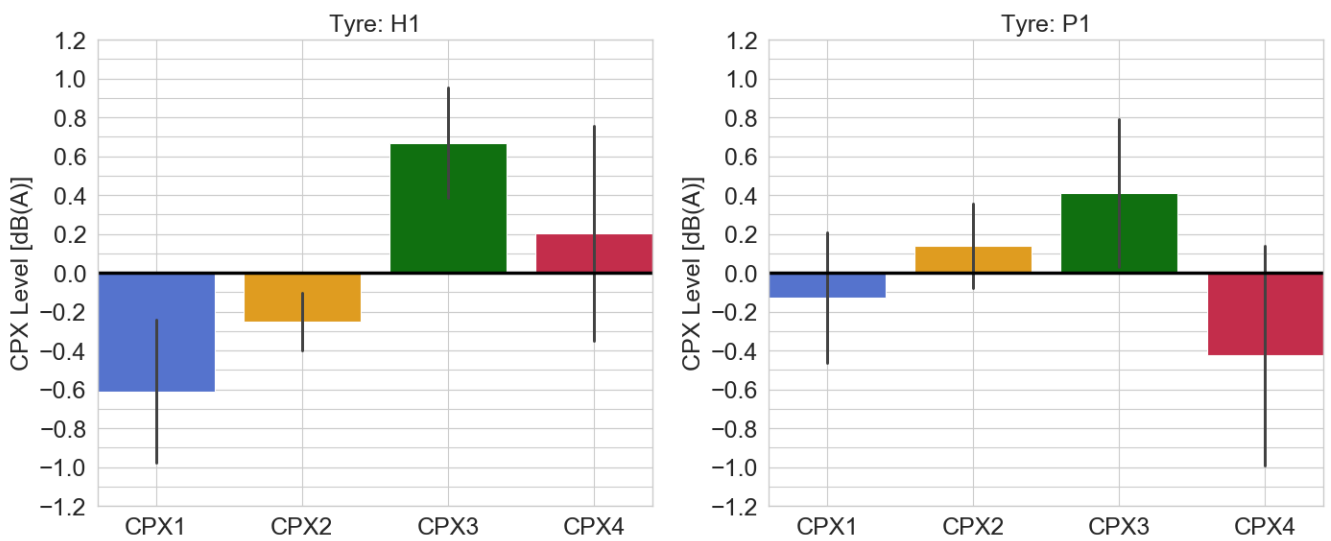


Figure 5. Average noise level difference for each trailer compared with the difference to the mean of all the trailers (mean value for all test sites and speeds). The standard deviation (over all conditions) is also shown for each measurement trailer.

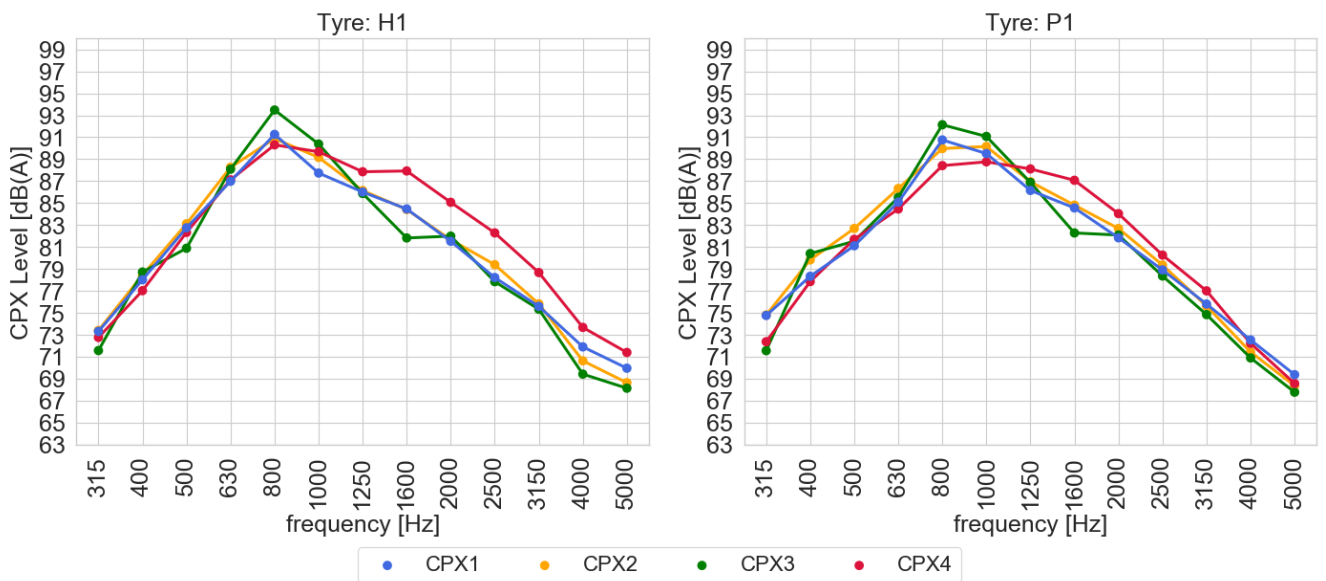


Figure 6. Average frequency spectra for each participant, expressed as mean for all test sites and speeds

The porous site PAC1 led to notably higher differences between the participants. It could be that some measurements, especially in this section, started too late or ended too early. As not all participants provided GPS coordinates for their measurements, the authors were not able to verify this. Another plausible possibility is that this pavement changed during the 3 months between CPX 1 did the measurements (which gave low levels) and CPX4 did the same measurements (which gave high levels). During the summer of 2019, the weather was extremely hot (CPX1 made measurements at 30 °C

air temperature while CPX 4 made measurements at 10 °C) which might have caused some bitumen to melt and partially clog the porosity.

This, however, does not mean that porous surfaces generally increase the dispersion of results between participants. This can be verified by inspecting PAC2, where the differences between participants remained within tenths of decibels. PAC2 would not have been so sensitive to temperature as it used unconventional materials.

The reference tyre H1 seems to slightly amplify the differences between participants. This is visible when comparing Figure 3 with Figure 4. CPX3 measured systematically higher than the others for almost all the test sites. This can also be verified by inspecting Figure 5. From the same figure it is visible that CPX3 indeed systematically results in slightly higher values, which the authors assume is related to its obsolete device calibration. Systematic differences can also be seen in Figure 6 where CPX3 registers higher values for the 800 Hz band, dips around 1.6 kHz and around 4 kHz.

Figure 5 also shows that the trailers with enclosures consistently give a more prominent peak at 800 Hz than the open trailers. The reason for this will be studied later.

As CPX4 was not device-calibrated according to ISO 11819-2 [1], this led to an increased variability, which is seen in Figure 5 where the standard deviation for each participant is shown. Additionally, measuring when the surface is not completely dry may have led to increased noise levels for higher frequencies. As CPX4 performed several measurements under such conditions, this probably added up to the dispersion in results. An effect similar to that of wet or humid surfaces [9] can clearly be seen in the average frequency spectra shown in Figure 6 where CPX4 registered higher values especially for frequencies equal to 1.6 kHz or higher. But, as indicated above, a supplementary effect may be due to the lack of device-correction, as there might have been acoustic reflections against the underside of the load package.

It was a disappointment that participants measured different lengths of test sections compared to the intended lengths. Instead of using GPS data, three of the participants used visual clues regarding the start and end of each section. Even this resulted in substantially different lengths in some cases. VTI had supplied some visual clues and some not detailed maps, as a guide, but not intended for setting start and stop of each measurement. Partly, this problem was the fault by VTI as it was not enough stressed how important it was to measure equal lengths and to use the GPS data. Nevertheless, it can be argued that this problem is not uncommon when a stakeholder orders a CPX measurement on a certain road; thus it is part of “real-world” potential problems.

This problem is, of course, a source of differences between the results of the participants. However, since the pavements were visually homogeneous along their lengths, this error should not be substantial. Checks of texture measurements and of CPX time histories for some test sections have verified this subjective impression.

Given the failures of some trailers to comply with all requirements in the standard and to comply with all details in the test programme, the results are surprisingly good. No ISO standard is perfect, and certainly not the three involved here, but the ISO specifications implemented in this project seem to do the job quite well.

8. CONCLUSION

This paper presents the initial results of a Round Robin test with four different CPX participants on ten different test sites, including porous and dense surfaces, having MPD

values between 0.49 mm and 1.74 mm. A more comprehensive analysis is not presented here due to space limitations but will be published by the authors later.

The results indicate that the maximum difference between participants, considering an average for all 10 sites and different test speeds, was about 1.2 dB for the reference tyre H1 and 0.8 dB for tyre P1. The authors consider this to be a satisfactory result, given the differences not only in test sites, but also variations in test temperature and humidity; not to mention different device constructions. Individual results for some test sites were significantly higher, with a maximum for PAC1, which could be related to different start and stop measurement positions, and/or to changes in porosity during the time delay between the first and last measurements.

This compares quite well with the typical uncertainties suggested in ISO 11819-2 [1]. It is noteworthy that the observed differences here could be reduced in future measurements by: (i) device-calibrating CPX4, (ii) recalibrating CPX3, (iii) not measuring under humid or wet conditions, and (iv) that all devices measure the same length of the test sections. All devices should observe GPS coordinates and also report them.

Some general recommendations when delivering or receiving CPX measurement result are: (i) check if the data has been processed according to the technical standards, (ii) check section start and finish points as well as section length, (iii) use a consistent terminology throughout the results, preferably the same as the standards.

9. ACKNOWLEDGMENTS

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