inter.noise 2012
august 19-22
new york city, usa
Quieting the World's Cities

Comparison of CPX systems with Round Robin Test

Fred Reinink [a)]
Gijsjan van Blokland [b)]
M+P Consulting Engineers
PO box 2094, NL-5260 CB Vught

Foort de Roo[c)]
Giljam Derksen[d)]
TNO Technical Sciences
PO box 96864, NL-2509 JG Den Haag

SUMMARY

The CPX method (ISO/CD 11819-2) is regularly used for assessing the acoustic quality of road surface within the frame work of checking with compliance to contract requirements and conformity-of-production. The reproducibility of the test procedure is investigated with a Round Robin test in which 7 operators of CPX systems, coming from Belgium, Denmark, Germany and Netherlands, participated. All systems were constructed as two wheeled trailers, both with and without enclosure.

All systems performed tests with three different tyre sets. One of them was a reference set that was used by all systems. Tests were done on a series of five different road surfaces, comprising of dense, semi open and porous types.

The analysis of the variances observed in the test results (ANOVA) learned that the repeatability of the test procedure (one standard deviation) is about 0.4 dB. The reproducibility of the system without the effect of differences in tyre properties is about 0.6 dB. When the variation in tyre properties is included a standard deviation of 0.8 dB resulted. These test results corroborate the estimated uncertainty given by the ISO/CD 11819-2.

[a)] email: fredreinink@mp.nl
[b)] email: gijsjanvanblokland@mp.nl
[c)] email: foort.deroo@tno.nl
[d)] email: giljam.derksen@tno.nl

INTRODUCTION

The influence of the road surfaces characteristics on the sound emission of road traffic is routinely assessed with the Close Proximity (CPX) method, which measures the sound emission of the tyre-road contact close to the sound radiating tyre.

Experience in the Netherlands and in other European countries has shown that measurements according to the CPX method may suffer from a relatively large measurement uncertainty. This fact causes interpretation problems for road authorities, when comparing test results from different operators of CPX-trailers, even when all trailers are in conformity with the applicable draft text for the ISO standard [1].

In order to quantify the actual measurement uncertainty that occurs for that procedure, the CROW, the Dutch Technology Platform for Transport, Infrastructure and Public Space, and the Dutch road authority RWS have organized a Round Robin Test (RRT) in which seven operators from the Netherlands, Denmark, Germany and Belgium participated. One participant used two systems and two other participants shared the same CPX trailer, but used their own data acquisition system. The test results were analysed and interpreted by TNO. An English report [2] is available through the site of CROW (www.stillerverkeer.nl).

The objective of the Round Robin Test was to determine the reproducibility of the CPX procedure and to identify the sources of the observed spread in measurement results.

1. TEST SET-UP

1.1 General lay-out

The measurements and the data processing were performed according to the 4th Committee Draft (CD) of ISO 11819-2 issued in 2011 [1]. All participants were invited to measure a circuit of about 5 km in which 5 test sections were included. Each section was covered with a different type of road surface and was part of the normal road network. Part 1.3 describes the composition of the test sections.

The uncertainty in the result of a CPX test is determined by three sources:

1. the properties of the measurement system excluding the test tyres
2. the properties of the test tyres
3. the environmental influencing factors

The experimental set-up is designed such that the error sources from 1. and 2. can be determined. The limited available time prevented extensive study of the third influencing factor.

The general scheme of the RRT consisted of repeated measurements of all participants on the series of 5 test sections. In the repetitions the type of test tyre and the measurement speed were varied. One of the test tyres, referred to as SRTT-Reference, was circulated over all participants. Each tyre/speed combination is measured only once, no repetitions were scheduled.

1.2 Description of participating systems

All CPX systems were two wheeled trailers. Two were non-enclosed and five were enclosed types. The two non-enclosed types and four of the five enclosed types were of the same manufacturers. The figure below presents photographs of an enclosed and a non-enclosed CPX-system (see Figure 1).

All systems complied with the 4th CD of 11819-2. For the enclosed systems the influence of the enclosure was determined according to the procedure given in the 4th CD of 11819-2 and all complied with the requirement that the effect shall be less or equal than 3.0 dB. Although the 4th CD of 11819-2 allows different configurations of vehicles and tyres, the CPX RRT was only open to two wheeled CPX trailers with nearly identical track width, ranging from 1.84 m to 1.95 m.

Fig. 1 - Example of an enclosed and non-enclosed CPX system.

Each participant equipped his trailer with two sets of test tyres. One set consisted of two Standard Reference Test Tyres (SRTT). This tyre is defined in American Standard ATM F2493-06. This tyre is referred to in the 4th CD as reference tyre P1, being representative for passenger car tyres. The other set of two tyres were of the brand AVON, type Supervan AV4, size 195 R14. This tyre is referred to as tyre H1, being representative of heavy vehicle tyres. The photographs below give pictures of the two tyres (see figure 2).

Fig. 2 - Pictures of the two standard tyres used in the CPX Round Robin Test. Left: SRTT, Right: Avon AV4.

In addition an extra set of SRTT-Reference tyres was made available to all participants for using in the test. These set consisted of new tyres that were never used. Since all flanges had identical geometries, the tyre set could be circulated without re-mounting on the rim. The only variation was that the two non-enclosed types had the wheel flanges at the outside of the wheels, so that mounting the reference set without changing the rolling directions implies interchanging left and right position.

1.3 Composition of test sections

The circuit of about 5 km consisted of real roads under trafficked condition . It comprised 5 test sections with varying road surfaces. The table below defines the location, the length and the surface type of each test section.

Table 1 – Specifications of tested road sections.

Section number	**Road number**	**Section length (m)**	**Pavement type**	**Type indication in this paper**
1	N314	1644	2 Layer porous asphalt concrete – grading 2/6 mm	2L- ZOAB 2/6
2	N314	292	Porous asphalt concrete – grading 0/16 mm	ZOAB 0/16
3	N314	416	Low energy porous asphalt concrete – grading 0/16 mm	LEAB ZOAB 0/16
4	N346	ca. 950	Stone Mastic Asphalt – grading 0/11 mm	SMA 0/11
5	N319	ca. 1200	Dense asphalt concrete – grading 0/16 mm	DAB 0/16

1.4 Test program

Each participant performed the CPX test according to the procedures described in the 4th CD of 11819-2. Every circuit of five test sections was measured five times by each participant distributed over the tyres and speeds as follows (see table 2). In addition the measurement with the SRTT at 80 km/h was repeated once.

Table 2 – Test program.

Test speed	**Test tyres**		
	SRTT	AVON AV4	SRTT-Reference
50 km/h	1X	1X	
80 km/h	2X	1X	1X

The measurement procedure and the processing of the data was done according to the 4th CD of ISO 11819-2 issued in 2011. All data were corrected for the temperature on base of the correction formula and coefficient given in the standard. Although the value of the coefficient is now considered too low, its effect on the spread of the data is small since all data were acquired within a narrow temperature range. Air temperature varied between 17 and 22 °C. The exception to the CPX procedure is that repetition, mandatory in the CPX draft, was only done in the case of the SRTT tyre at 80 km/h.

Participant MP03 has repeated the measurements with the SRTT-Reference tyre.

1.5 Additional testing

In addition to the test program, the following components of the measurement systems were evaluated:

1. the sound levels produced by the acoustic calibrators used by the participants
2. the rubber hardness of the tread compound of the test tyres
3. the inflation pressure of the CPX tyres.

1.6 Statistical Analysis

The man aim of the statistical analyses is to estimate the standard deviations during repeatability and reproducibility conditions. The reproducibility is the combination of variations between trailers and measurement error. The values of both quantities are also reported separately. To be in compliance with ISO 3534-1 [3] the following definitions should be used:

- A test item is a road section
- A test result is the average of the CPX values at the left and right tyre
- A laboratory is a trailer.

Due to the lack of repetitions is it is not possible to estimate directly the repeatability for the average of left + right track test results. For that reason the individual left, right values (averages over the whole section) are used in the analyses. With this set-up the variation can be partitioned into the following 3 parts:

- Trailer
- Wheel track
- Interaction trailer*wheel track

An analysis of variances (ANOVA) model with two sources of variation; the trailer and the wheel track, is elaborated. The residual variation of this model estimates the standard deviation of measurement at the left or right side of the trailer. This variation is used to calculate the repeatability of the mean of the left and right wheel track measurement.

This model gives an estimate of the variation between the trailers. By summation of the trailer component and the residual component the reproducibility is obtained which will be found for repeated measurements with different trailers and under different repeating conditions.

For the interpretation of the results the following should be realized:

- The source of variance ‘Trailer’ represents the variation between the CPX values that is due to systematic differences between the trailers. Trailer specific tyre properties of the same tyre type are also part of this source.
- The source of variance ‘residual’ corresponds to the variation that cannot be explained. In this statistical analysis approach the interaction of trailer and wheel-track is part of the residual. This means that the residual is a combination of a number of specific trailer related effects such as differences between the 2 versions of the same type of tyre, measurement errors related to the measurement equipment and variations of the position of the wheel-track in the traffic lane.

2. MEASUREMENT RESULTS

2.1 Variation in length of a section

At an early stage of data analysis it became clear that the properties of the test item (i.e. the road section) can vary significantly for the different "laboratories". Especially the variation reported in the length of the first section was considered a source of additional spread. Figure 3 shows the variation of CPX level of the length of the test section. It is clear that when a smaller part of the section is measured, the resulting CPX value will depend strongly on the location of that smaller segment, especially how much of the initial 500 m is included in the reported data.

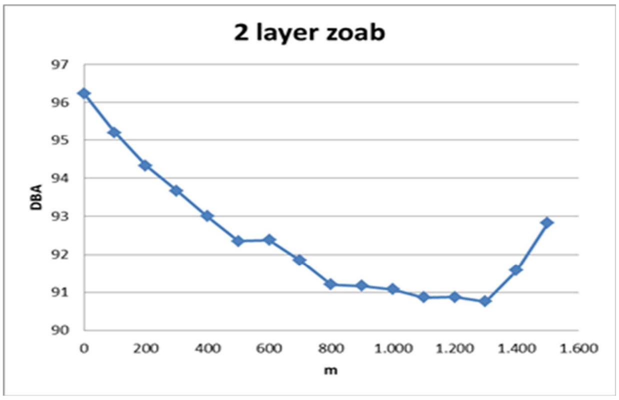
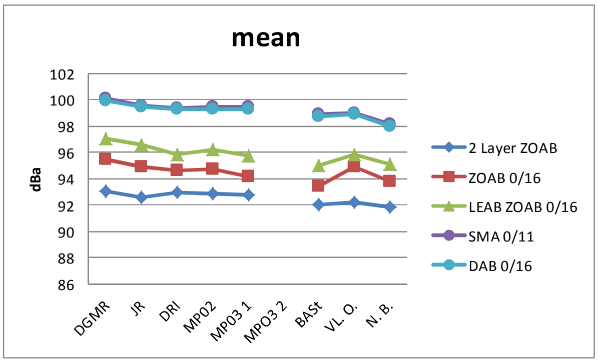


Fig. 3 - Variation of the CPX level over the length of test section 1.

2.2 Results of CPX test

The figure below (figure 4) give the results of the CPX levels at 80 km/h, calculated as the average of the left and right wheel track over the length of the test section measured with the operators own SRTT tyre set. Given are the actual CPX values and the deviation of each individual participant to the average value of that test section.



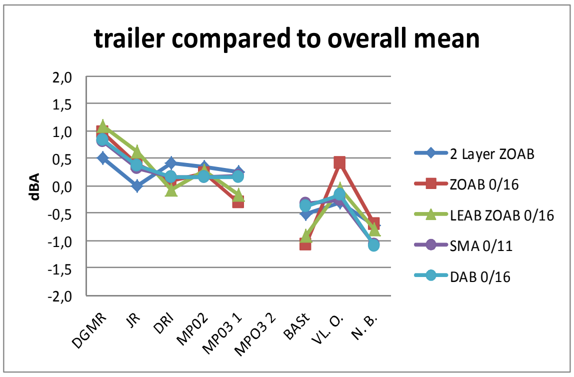


Fig. 4 - Left: CPX levels(average of left and right track) of the 9 combinations over the 5 test sections. Right: deviation of the CPX level from each combination to the average value for that test section. Data for SRTT tyre at 80 km/h.

The graphs of figure 4 show that the mean CPX values of the different operators, each using their own tyre set, lies within a range of 2.0 dB. Figure 4 also shows that the spread is partly explained by the operator. Some operators report relative low levels, while other operators have often higher than average values. This operator dependence can be caused by the deviating properties of the tyre set. Figure 5 presents the results of the same test, but in this case the tyre set consisted of the reference SRTT tyre set which was then used by all participants. The repeated measurements of operator MP03 are presented as a separate contribution, indexed with MP03-2.

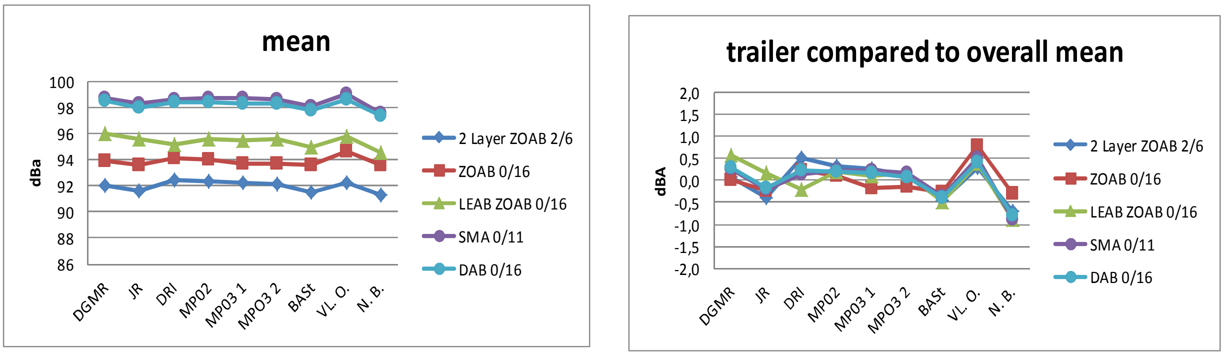


Fig. 5 - Left: averaged CPX levels of the 9 combinations over the 5 test sections. Right: deviation of the CPX level from each combination to the average value for that tyest section. Data for SRTT reference value at 80 km/h..

Comparison of the graphs in figure 5 and 6 illustrates the effect that variation in the properties of the applied tyre set has on the overall spread in results. Replacing the population of operators own SRTT tyres by a single reference tyre set directly reduces the variation between the different systems significantly. The usage of a single tyre set does not eliminate all of the operators influence. Also in figure 6 operators can be identified that are often reporting higher than average CPX values and operators that are at the low side.

Figure 6 illustrates the performance of the operators with all tested tyre/speed combinations. Presented is the result for ZOAB 0/16.

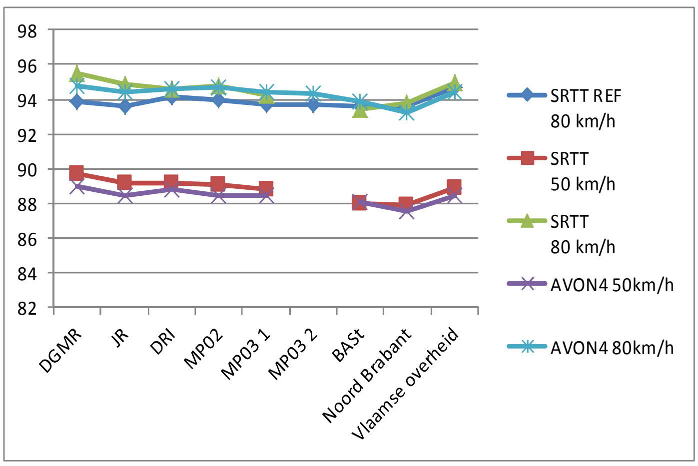


Fig. 6 - Results for all tyre/speed combinations on ZOAB 0/16 (n.b. the last two operators are interchanged compared to figure 4 and 5).

2.3 Results of statistical analysis

The results of the analysis of the variance for each tyre/speed combination are given in Table 3.

Table 3– Results of the analysis of the variance. RMS averaged overall standard deviations for 100 m average values obtained by averaging the results of left and right tyre measurements, according to sources of variance per tyre type and speed [Values in dB].

Source of variance	**SRTT Ref 80 km/h**	**SRTT 50 km/h**	**SRTT 80 km/h**	**Avon AV4 50 km/h**	**Avon AV4 80 km/h**
Trailer	0,41	0,58	0,58	0,54	0,62
Residual	0,38	0,56	0,52	0,63	0,84
Total	**0,56**	**0,81**	**0,78**	**0,83**	**1,05**

This table clearly shows that the standard deviation connected to the type of trailer is lowest for the situation with the reference tyre. This is expected since the tyre as source of variation is removed when every system measures with the same tyre. The resulting trailer influence is then 0.41 dB which fits to the spread found in figure 5 of about 1,5 dB peak-peak. The residual spread of 0.38 dB is to be interpreted as the repeatability of the CPX method.

The difference between the data in the second column and in the third and fourth column reflects the increase of "trailer" effect caused by the variation in tyre properties of the SRTT tyres linked to each trailer. One would expect though that the repeatability would not differ from the situation with the SRTT reference tyre. The increase of the residual spread can be understood from the interaction of the different SRTT tyres with the type of road surface. Such behavior can already be observed in figure 4 which shows that the ranking of trailer results is not the same for every surface.

The total standard deviation increases from less than 0.6 dB to about 0.8 dB. The values for the AVON AV4 tyre are even larger, indicating a wider variation in properties of this tyre type.

3. DISCUSSION AND CONCLUSION

3.1 Results of statistical analysis

The Round Robin Test has proven to be a valuable tool for determining the uncertainty of the present CPX measurement method, described in the 4th CD of ISO 11819-2. The only limitation in the chosen experimental set-up is that all measurements are performed under more or less the same environmental conditions and therefor the effect of temperature, wetness etc. is not included in the overall analysis. These influencing factors would have a negative effect on the reported uncertainty. However, using repetition of the CPX measurements, as is mandatory in the 4th CD is expected to reduce the measurement uncertainty of the final test result.

It is estimated that both effects are about of the same magnitude, indicating that the overall uncertainty of the CPX method (excluding tyre effect) is slightly less than 0.6 dB. This estimated standard deviation for the situation with the SRTT reference tyre is very close to the value for a standard uncertainty of 0.5 dB in the 4th CD of 11819-2 that was derived from an analysis of error sources following the procedure of the GUM (Guide to the expression of Uncertainties in Measurements) [4].

3.2 Effect of tyre properties

The spread in properties of the test tyres forms a relevant influencing effect on the total uncertainty. The technical data of the AVON AV4 tyre are not yet open to third parties. The data of the SRTT tyre are defined in the American Standard ATM F2493-06.

3.3 Effect of shore hardness

The Shore hardness range required in the standard defining the SRTT is 64 ±2. The measured value of the reference SRTT tyre was about 60 and those for the other SRTT tyres ranged from 62 to 70. The values for the AVON AV4 tyres ranged from 60 to 69. Rubber hardness is known to have an influence on the rolling noise and furthermore this effect depends on the type of road surface. The magnitude of the effect of the observed hardness range is in the order of 1 dB. This partially explains the increased standard deviation in the 3rd to 6th column of Table 3. The road surface dependence explains why the tyre effect is distributed over the “trailer” and “residual”.

3.4 Effect of data acquisition system

The operators DGMR and JR shared the same trailer/tyre combination. Still their results are 0.4 to 0.5 dB different. This difference is partly explained by the repeatability, partly by the differences in data acquisition and processing. The systematic nature of the difference points into a higher influence of the acquisition and processing system. The nature of it cannot be understood from the available information.

3.5 Recommendations for improved CPX testing

- Repetition of measurements is essential. It may reduce the repeatability of 0.38 dB by a factor of 0.7 leading to an improvement of reproducibility without tyre effect from 0.6 to 0.5 dB. The expended uncertainty with 95% coverage is then about ±1.0 dB.
- The properties of the test tyres are not part of the 4th ISO/CD 11819-2. They are however an important part of the total measuring chain as is illustrated by the results in table 3 and it is essential that the properties of the test tyres are controlled, either by an additional part 3 of the ISO 11819 series, or by a quality controlled production of specific batches of tyres.
- The observed effect of the data acquisition and processing system learns that improvements are possible. Further investigation is necessary to understand the cause and possible measures.

5 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions from the participants to the Dutch 2011 CPX Round Robin Test, the organizations JR, DGMR, M+P, BASt, Flemish Road Administration, DRI and the province of Noord-Brabant. Further the authors acknowledge CROW and RWS for the organizational and financial support of this project.

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