Programme "Applied research" under the Norwegian Financial Mechanisms 2014 - 2021

Contract No. NOR/POLNOR/ELANORE/0001/2019-00

Norway grants

NCBR National Centre for Research and Development

ELANORE Improvement of the EU tyre labelling system for noise and rolling resistance

Technical Report on CPX, CPB and SEL measurements. Discussion on selected noise results for improvement of the test method

Main author:	Truls Berge			
Contact details:	truls.berge@sintef.no		+47 905 72 026	
Co-authors:				
Work Package:	4	Development and evaluation of improved method of tyre/road noise measurements		
Document type and number:	Technical Report TR16-ELANORE-SINTEF-06-(2023)			
Date, version and circulation:	14.08.2023	Draft	Internal	
File name:	TR16-ELANORE-SINTEF-06-(2023) Draft16.06.2023.docx			

GDAŃSK UNIVERSITY OF TECHNOLOGY SINTEF ekkom

CONTENTS

1 INTRODUCTION

The main results from the RRT of CPB measurements on 4 ISO test tracks and on 5 conventional trafficked roads in Norway and Poland have been presented in the Deliverable D2.2 (TR13-ELANORE-SINTEF-04-(2022) [1]). In this report, the CPX measurements on the ISO tracks are also included. CPX measurements on the conventional roads have been presented in the Technical Report TR15-ELANORE-GUT -11-(2022) [2].

In this report, a more detailed study has been performed on some of the results that need to be discussed for the planned proposal for improvement of the labelling procedure. There are some results that may be caused by uncertainties which could "disturb" the analysis and may lead to wrong conclusions. This report presents a more detailed analysis of the relationship between CPX and CPB data, including the SEL measurements made by EKKOM on 3 of the test locations.

The report may also be used as a starting point for a scientific paper, discussing the use of CPX as an additional method to evaluate the performance of an ISO test track and possible implementation of a calibration method to reduce track-to-track variability.

2 CPB AND CPX MEASUREMENTS

In this chapter, an analysis of the CPB results on the ISO test tracks and on the trafficked roads is compared with the CPX results.

2.1 CPB MEASUREMENTS

In table 1 and in figure 1, the results from the ISO test tracks (average of 4 test tracks for 2 of the tyres and 3 test tracks for the 3 others) are compared with the results on the trafficked roads. All values are according to the ECE Reg.117 test conditions.

Table 1. *CPB measurements (Reg.117) on ISO tracks and on trafficked roads. Speed: 80 km/h*

Tyre	ISO	Ma11	SMA8	SMA11	SMA16	EACC
Yokohama	71.4	74.6	75.0	76.5	77.7	76.7
Michelin	73.6	75.2	76.0	77.0	76.5	75.8
Bridgestone	73.3	75.3	76.4	77.0	76.4	76.3
Evergreen	72.9	75.0	75.6	76.9	77.8	77.0
SRTT	75.9	75.5	78.0	78.3	77.4	77.2
Average	73.9	75.1	76.2	77.1	77.2	76.6

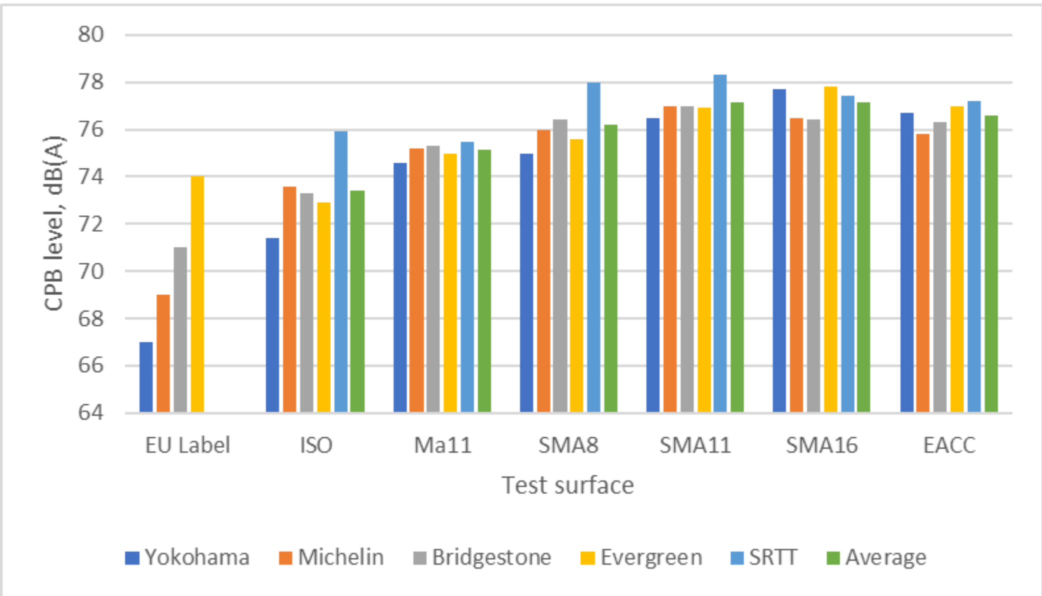


Figure 1. *Ranking of noise levels on ISO test tracks and on trafficked roads at 80 km/h, compared to the EU label values*

From this table and figure, the following conclusions can be made:

- The actual measured levels on the ISO tracks are higher than the EU label values, except for the Evergreen tyre.

- The ranking based on *measured* ISO levels are not in line with the ranking based on EU label values.

- The average noise level on the smooth Ma11 surface is only 2.1 dB lower than the rough SMA16 at 80 km/h. At 50 km/h, this difference was found to be 1.9 dB (see also figure 6).

- The ranking based on *measured* ISO levels does not correlate with the ranking on the rougher surfaces like the SMA16 and EACC.

- The difference between the SMA11 (Polish road) and the rough SMA16 (Norwegian road, exposed to studded tyres) is unexpected small, almost zero. Figure 3 shows a picture of the two surfaces. One would expect a clear difference in noise levels on these two surfaces and the results are not in line with previous investigations in Norway, where SMA11 and SMA16 have been measured [3]. The reason for this should be discussed and analyzed further. One possible reason for this may be the chosen location for the measurements on the SMA16. Figure 2 shows the measurement site, and the location of the 1.2 m and 4 m (SEL) height microphones. The figure shows that there is a soft ground between the driving lane and the pedestrian lane. This is a deviation from the requirements given in the SPB standard. The soft ground could add an extra attenuation of the sound propagating from the tyre/road source and therefore be the main reason for the unexpected small difference between levels measured on the SMA11 (in Poland) and this SMA16.

Figure 2. *Measurement location at Sørum, SMA16*

The CPX measurements showed a clear difference, as shown in figure 5. This indicates that the choice of measurement method has an impact.

Figure 3. *Picture of the SMA11 road surface (left) and the SMA16 road surface (right)*

If the labelled noise values had been in line with the measured ISO levels, it would be interesting to make a linear regression analysis between these ISO levels and the measured levels on the different trafficked roads. This analysis is shown below.

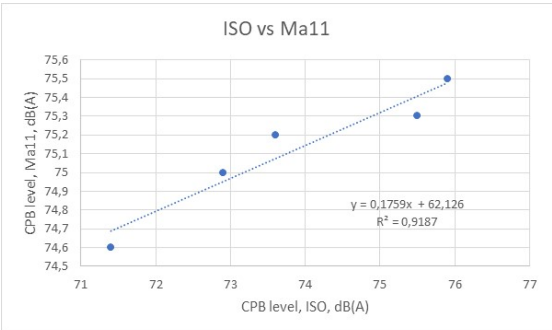


Figure 4a. *Linear regression between ISO and Ma11*

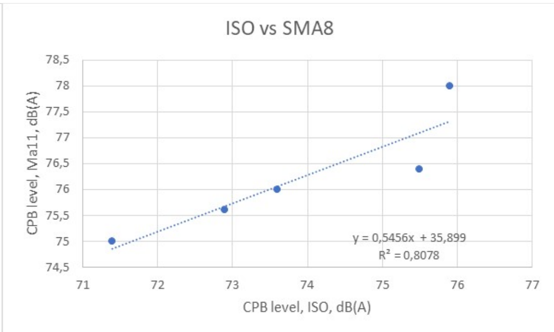


Figure 4b. *Linear regression between ISO and SMA8*

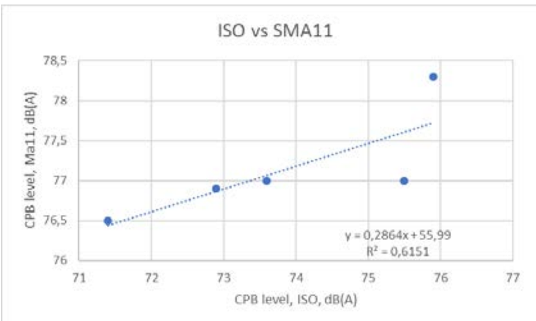


Figure 4c. *Linear regression between ISO and SMA11*

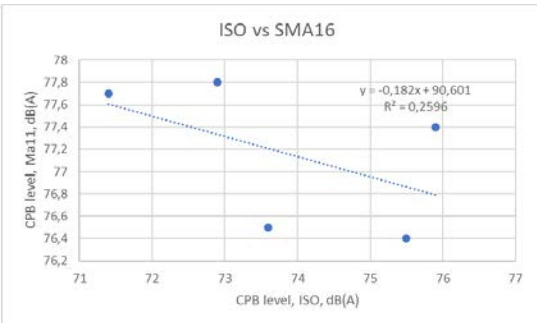


Figure 4d. *Linear regression between ISO and SMA16*

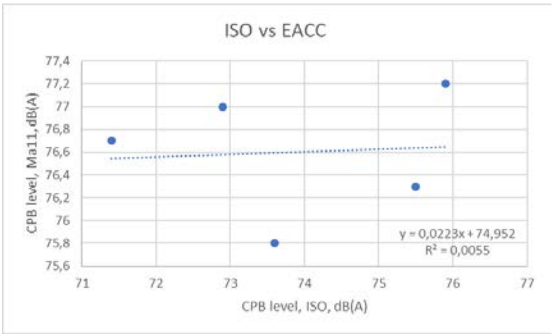


Figure 4e. *Linear regression between ISO and EACC*

This analysis shows a good correlation between the *measured* levels on the ISO tracks and the smooth surfaces like Ma11 and SMA8 with R^2= 0.8-0.9. The slope is highest for the SMA8 (0.55) which indicates that 1 dB reduction on the ISO track will give about 0.5 dB reduction on this kind of surface. On the rough surfaces, SMA16 and EACC there is no good correlation with the ISO levels at all.

But, since we found a mismatch between the EU label values and the measured levels on the ISO tracks, the effect of using low noise tyres based on the label values will not have any effect (or at least only a minor effect) to reduce tyre/road noise on normal roads, except perhaps on very smooth surfaces. This is a big challenge for selecting an improved noise labelling procedure.

2.2 CPX MEASUREMENTS

Since CPX measurements have been made on all 4 ISO test tracks and on the 5 trafficked roads with the same 5 tyres as used for the CPB measurements, it is possible to compare the ranking of tyres and road surfaces based on the CPX standard. However, for the CPB measurements, a set of 4 identical tyres was used, while just one of them was mounted on the GUT CPX trailer. The tyres used for CPX tests are described in chapter 4 and in [1].

Table 2 and figure 5 show the CPX results at a speed of 80 km/h.

Table 2. *CPX measurements on ISO tracks (average of 4 tracks) compared with levels on trafficked roads, Speed: 80 km/h*

Tyre	ISO	Ma11	SMA8	SMA11	SMA16	EACC
Yokohama	91.4	91.3	94.5	97.6	102.2	97.2
Michelin	92.4	92.7	94.7	97.3	100.7	96.5
Bridgestone	92.5	93.1	95.5	97.8	100.6	96.8
Evergreen	92.6	92.5	95.3	98.1	102.6	97.6
SRTT	94.4	94.4	96.0	98.6	102.4	97.9
Average	92.7	92.8	95.2	97.9	101.7	97.2

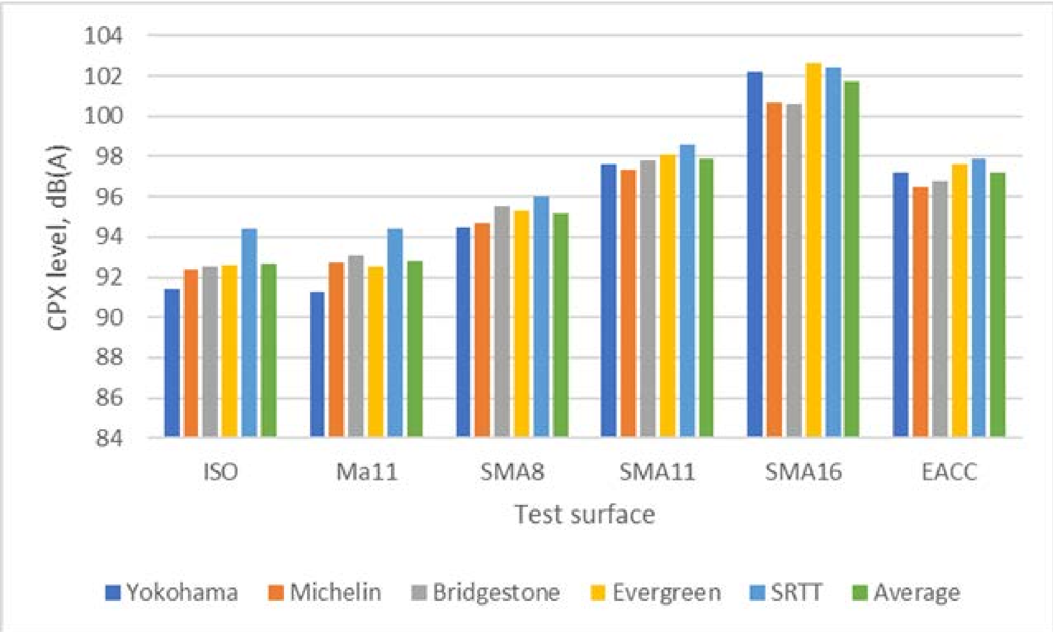


Figure 5. *CPX measurements at 80 km/h on ISO test surface (average of 4 tracks) and on 5 trafficked roads*

From these results, the following conclusions can be made:

- The CPX measurements clearly distinguish between the different noise performance of the different pavement types. As expected, the Ma11 surface (a very smooth surface) gives values close to the ISO surface.
- It seems that a better correlation with ISO can be found for smooth surfaces than for the rougher.

Of special interest is to compare the CPB results for the Ma11 and the SMA16 surfaces with the CPX results. Table 3 shows this comparison.

Table 3. *Comparison of CPB and CPX levels at a speed of 80 km/h*

	CPB			CPX		
Tyre	**Ma11, dB(A)**	**SMA16, dB(A)**	**Difference, dB(A)**	**Ma11, dB(A)**	**SMA16, dB(A)**	**Difference, dB(A)**
Yokohama	74.6	77.7	3.1	91.3	102.2	10.9
Michelin	75.2	76.5	1.3	92.7	100.7	8.0
Bridgestone	75.3	76.4	1.1	93.1	100.6	7.5
Evergreen	75.0	77.8	2.8	92.5	102.6	10.1
SRTT	75.5	77.4	1.9	94.4	102.4	8.0
Average	75.1	77.2	2.04	92.8	101.7	8.9

The table show that the average difference for CPB levels is approximately 2 dB, while the CPX measurements give on average a difference of nearly 9 dB. This is also shown in figure 6, where the difference is shown for both speeds.

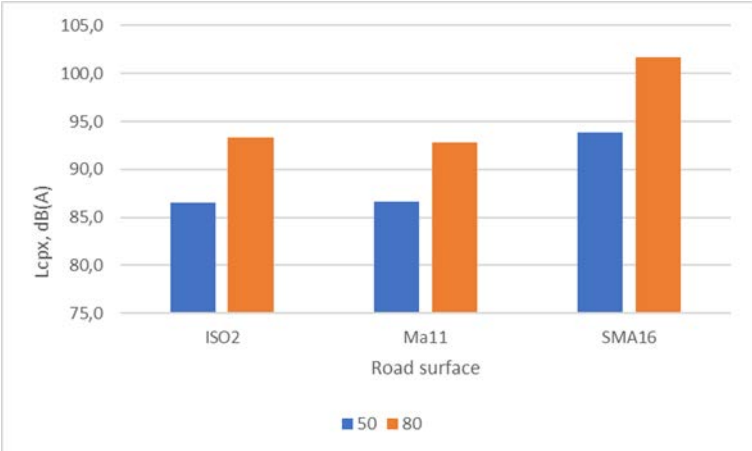


Figure 6. *CPX levels at 50 and 80 km/h on 3 test surfaces*

Why do we find such a big deviation between the two methods?

See chapter 4 for further analysis on this item.

Like for the CPB measurements, a linear regression has been made between the ISO levels and the different road surfaces. This analysis is shown below in figures 7a to 7e.

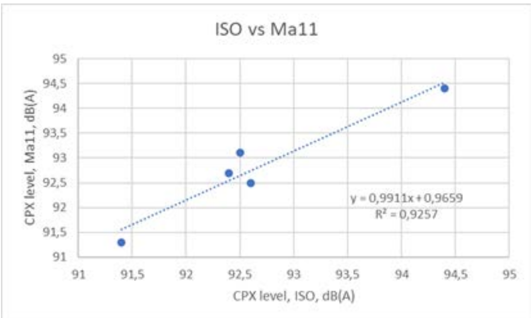


Figure 7a. *Linear regression between ISO and Ma11*

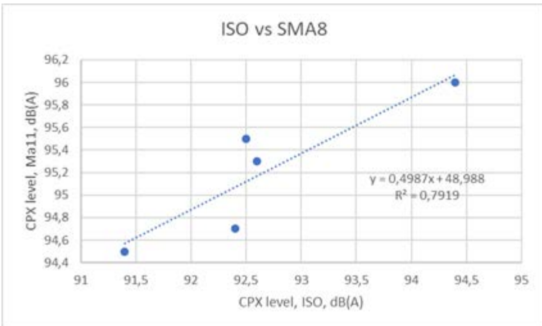


Figure 7b. *Linear regression between ISO and SMA8*

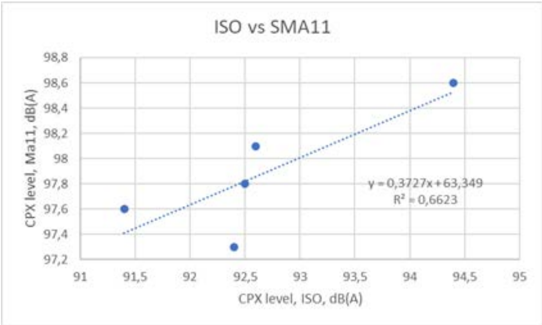


Figure 7c. *Linear regression between ISO and SMA11*

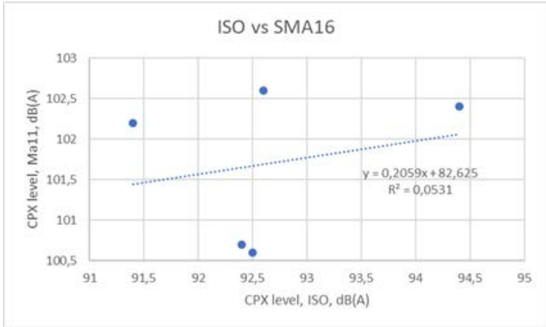


Figure 7d. *Linear regression between ISO and SMA16*

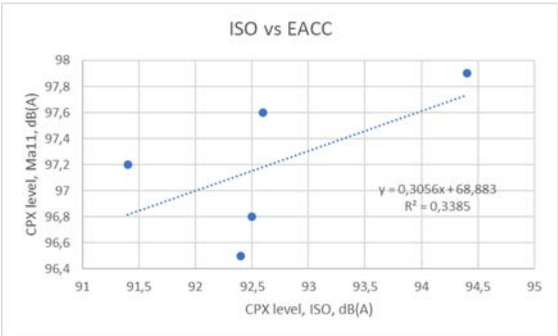


Figure 7e. *Linear regression between ISO and EACC*

The regression analysis shows a higher correlation between ISO levels and levels on the smooth surfaces, like Ma11 and SMA8. Also, for the SMA11 pavement, there is a reasonably good correlation ($R^2 = 0.66$). For the rougher surfaces, like SMA16 and EACC, the relationship between the ISO test surface is very poor. It indicates that *if* the tyres had been labelled according to the *measured* levels on the ISO test tracks, the use of tyres with the lowest noise levels would have no positive effect on reducing tyre/road noise.Even if the regression coefficient R^2 is higher for CPX than for the CPB measurements (figure 4), it is clear that this is linked to the two tyres at the end of the trendlines (Yokohama on the silent side and the SRTT on the noisy side). The three other tyres have noise levels close to each other, especially on the Ma11 surface.

2.3 CPX VS CPB REGRESSION ANALYSIS

Since all 5 tyres have been measured on the ISO test tracks (2 of them on all 4 tracks) and on 5 trafficked roads according to the CPB and the CPX method, it is possible to make a linear regression analysis between the two methods. The analysis is made for both 50 and 80 km/h. Figures 8 and 9 show the results of this analysis.

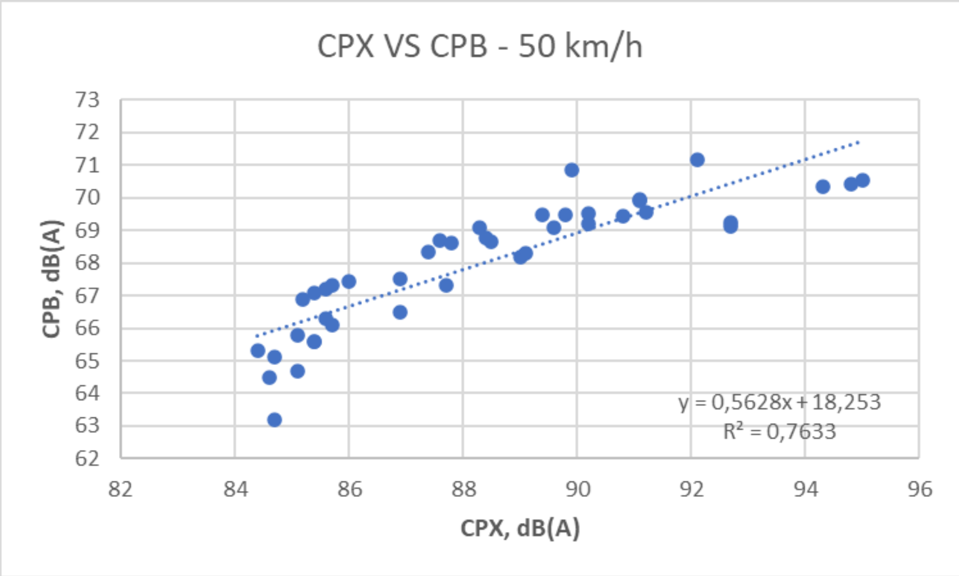


Figure 8. *Regression analysis between CPX and CPB levels at 50 km/h*

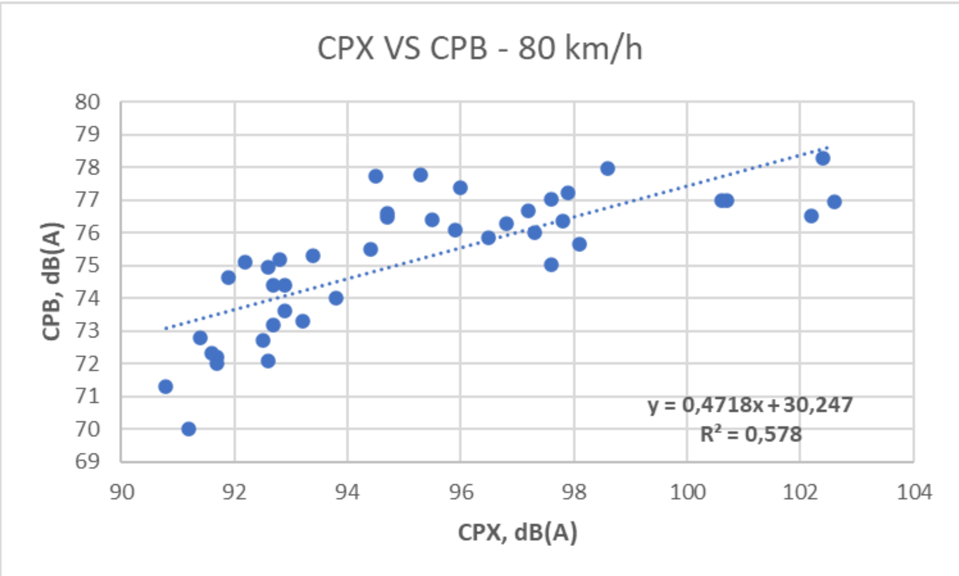


Figure 9. *Regression analysis between CPX and CPB levels at 80 km/h*

The figures show that the correlation is higher for 50 than for 80 km/h.

The regression coefficients are somewhat weaker than in previous studies, like measurements SINTEF made in Denmark in 2010 [4]. In this project, combined CPB and CPX measurements were made using the same vehicle on different road surfaces. CPX measurements were made with a test vehicle (VW Caddy) with CPX microphones mounted close to the rear right tyre. For each pass-by, the CPX level was measured together with the CPB level at 7.5 m and 1.2

m height. The figure below shows the regression analysis from these measurements. 4 different sets of tyres were used (no SRTT included) for the test.

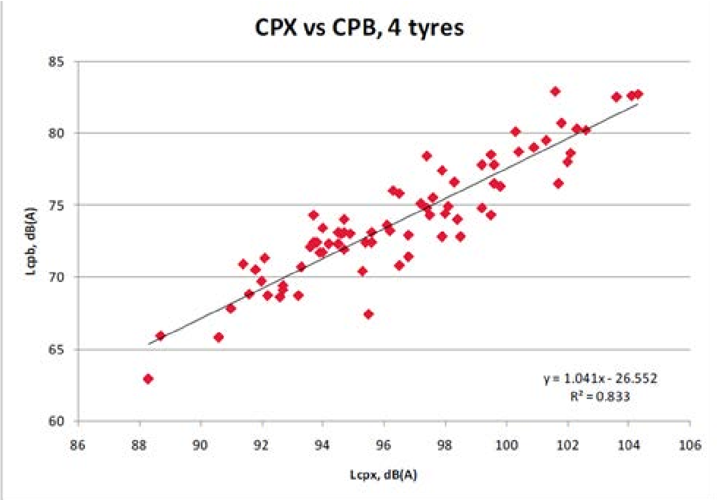


Figure 10. *CPX and CPB measurements made by SINTEF in 2010 on a selection of different Danish roads [4]*

As this figure shows, there is a higher correlation between these measurements, than the ELANORE results. It may be caused by the fact that the ELANORE measurements were conducted with 2 different testing devices; CPX with the GUT trailer and CPB with the Skoda Superb. The ELANORE measurements were also not made simultaneously, which was the case with the measurements in Denmark.

To investigate if some of the trafficked road surfaces had higher influence on the regression, a separate analysis has been made, where first all results on the Ma11 has been removed and secondly, the results on the SMA8. This is only done for 80 km/h.

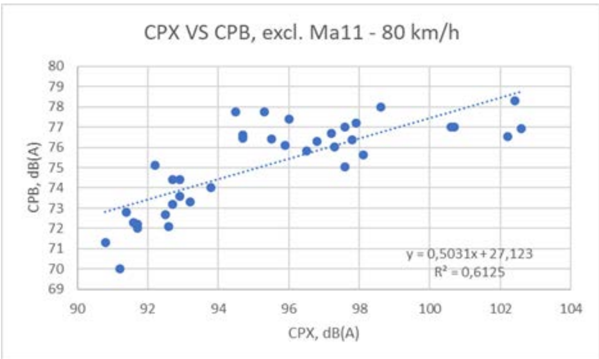


Figure 11a. *Regression analysis without the Ma11 surface*

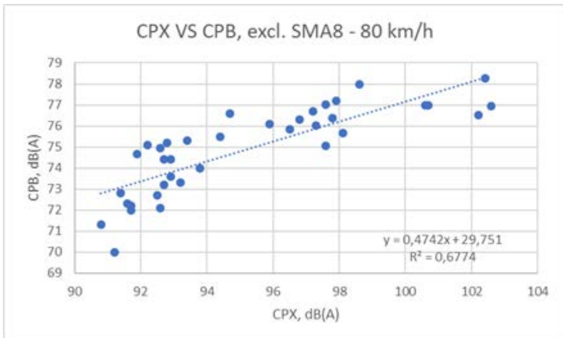


Figure 11b. *Regression analysis without the SMA6 surface*

Both these two examples improve the correlation somewhat, the best when SMA8 has been removed.

As will be shown later (chapter 4), there are some uncertainties about the CPB results on the Ma11 surface, especially for the tyres Yokohama and Michelin. Therefore, the effect of removing these tyres from the analysis is shown below.

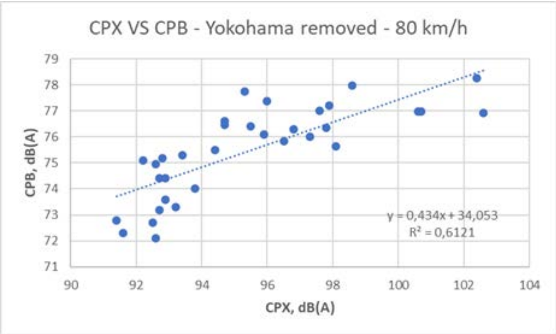


Figure 12a. Regression analysis without the Yokohama tyre

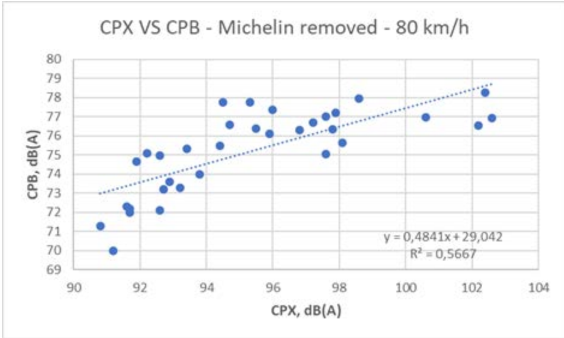


Figure 12b. *Regression analysis without the Michelin tyre*

As these graphs show, only a minor improvement was achieved by removing tyres from the analysis.

From the CPB/CPX measurements made by SINTEF in 2010 [4], the following relationship was found:

$L_{CPX} = L_{CPB} + 22.6$ dB, with a standard deviation of 1.73 dB.

This was found to be close to a French study by LCPC in France [5] which stated that the correction factor was 22.5 dB for dense surfaces.

In the investigation in Denmark, a frequency analysis of the transfer function between CPB and CPX was made for 1/3 octave bands from 315 to 5000 Hz. The figure below shows the results with 95% confidence intervals.

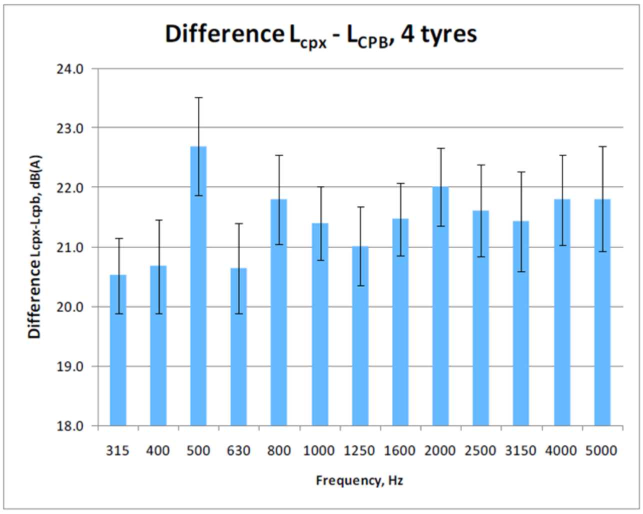


Figure 13. *Difference between CPX and CPB for 1/3 octave bands with9 95% confidence intervals included [4]*

It clearly shows that the difference in noise levels is frequency dependent.

2.4 CPB, CPX AND SEL VALUES

According to a paper published at InterNoise2016 (Hamburg) by G. Licitra et al. [6], any relationship between CPB and CPX levels will be both surface, speed and tyre dependent.

In this paper, CPX and CPB levels are presented for 5 different road pavements. In addition to the standard CPB level (L_{max}) at 7.5 m/1.2 m, SEL values are also included. They were measured at a microphone height of 3 m and over a driving distance of 35 m to ensure to include the whole pass-by event. Note that these CPB measurements were made with a "CPX vehicle" with engine on (cruise-by situation) at each of the speeds (50, 70 and 90 km/h). This author assumes that a "CPX-vehicle" was a motorized car with CPX microphone positioned at one side of the car near one of the rear tyres, similar to the SINTEF measurements in Denmark in 2010.

The figures below show the difference in L_{CPX} levels for 5 different surfaces and a comparison of the L_{max} and SEL values (over a driving length of 35 m). Furthermore, a comparison of the level differences between CPX levels and L_{max} (right) and CPX and SEL (right) for the speeds 50, 70 and 80 km/h is shown.

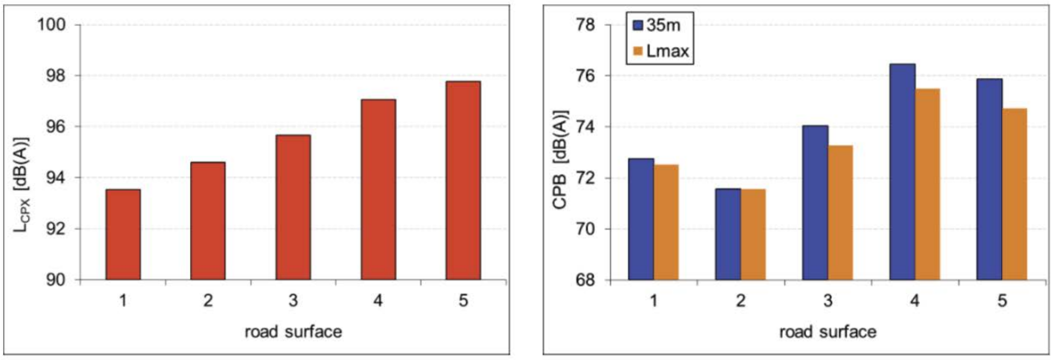


Figure 14. *Comparison between CPX (left) and CPB (right) results [6].*

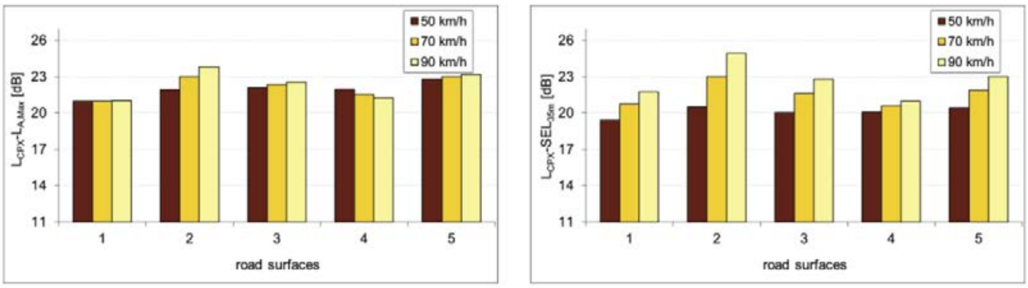


Figure 15. *Difference between CPX and CPB results at varying speed and using both indicators (LAmax to the left and SEL to the right) [6].*

For 3 of the test surfaces in the ELANORE project, we have made similar measurements of L_{cpx}, L_{max} and SEL (at 10 m distance and 4 m height) values. For L_{cpx}, we have only levels at 50 and 80 km/h, so a comparison of these 3 indicators has been done for these two speeds only. SEL measurements were only performed on ISO2, so this is used to represent the ISO surfaces measured in the ELANORE project.

To compare with the results shown in figures 14 and 15, similar calculations have been made for the 3 ELANORE pavement types where we have results for CPX, CPB and SEL values.

Figure 16 shows the average noise difference between CPX and CPB, and CPX and SEL measurements, and figure 17 shows a comparison between CPB (L_{max}) and SEL levels for the two speeds; 50 and 80 km/h.

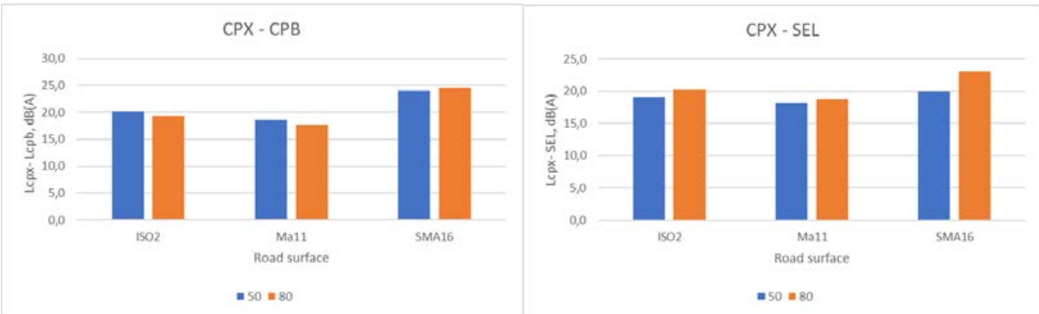


Figure 16. *Noise difference between CPX and CPB (left) and SEL (right) on 3 road surfaces and at 50 and 80 km/h. Average of 5 tyres.*

Figure 17. *Measured noise levels from CPB and SEL at 50 km/h (left) and at 80 km/h (right) on 3 road surfaces. Average of 5 tyres.*

The microphone for SEL measurements is at a distance of 10 m and 4 m height. It means than this microphone is approximately 3.2 m longer away from the car and this should in principle give somewhat lower levels than for CPB. However, the SEL values include the whole pass-by of the car and not only the L_{max} level, which may cause the higher levels. However, it should be noted that on both the Ma11 and SMA16 surface, the SEL values were recorded during the Light Test and not during R117 conditions.

According to the paper by Licitra et al,[6] one could expect that the relationship between CPX levels and CPB will vary with tyre, pavement type and speed. In tables 4 and 5 , these differences are calculated for the 5 tyres and for 4 ISO test tracks and 5 road surfaces. The tables shows CPX levels minus CPB levels at 50 and 80 km/h.

Table 4. *Difference in dB(A) between CPX and CPB levels at 50 km/h*

Tyre	ISO1	ISO2	ISO3	ISO4	Ma11	SMA8	SMA11	SMA16	EACC
Yokohama	20.1	19.6	21.5	19.3	18.3	19.2	21.4	24.0	20.3
Michelin	19.1	19.3	18.3	18.4	18.6	18.9	21.0	23.6	20.8
Bridgestone	19.8	20.4	-	20.4	19.1	19.9	21.2	23.4	20.5
Evergreen	20.4	19.8	-	19.6	18.4	19.9	21.6	24.5	20.7
SRTT	19.4	20.8	-	19.2	19.6	19.0	20.9	24.5	21.2
Average	19.8	20.0	19.9	19.4	18.8	19.4	21.2	24.0	20.7

Table 5. *Difference in dB(A) between CPX and CPB levels at 80 km/h*

Tyre	ISO1	ISO2	ISO3	ISO4	Ma11	SMA8	SMA11	SMA16	EACC
Yokohama	19.5	19.5	21.2	19.7	17.3	16.8	22.6	25.7	20.5
Michelin	18.6	18.5	19.8	18.3	17.6	18.2	21.3	23.7	20.7
Bridgestone	19.3	19.3	-	19.8	18.1	19.1	21.4	23.6	20.5
Evergreen	20.5	19.9	-	19.5	17.6	17.5	22.5	25.7	20.6
SRTT	17.1	19.8		18.1	18.9	18.6	20.6	24.1	20.7
Average	19.0	19.4	20.5	19.1	17.9	18.1	21.7	24.6	20.6

From these tables, the following conclusions can be made:

- There is a clear connection between the levels differences and type of surface. For the ISO test tracks, the difference between CPX and CPB is in the range of 19-20 dB. For the smooth surfaces , like Ma11 and SMA8, the difference is around 19-20 dB at 50 km/h and 18-19 dB at 80 km/h. For the SMA11, the difference is around 21.5 dB for both speeds and for the SMA16, the difference is 24-24.5 dB. For the EACC, the difference is around 20.5 dB.
- Previous studies concluded a difference of around 22.5 dB for dense surfaces. This seems to fit as an average between SMA11 and SMA16 from the ELANORE results.
- There is no significant difference between 50 and 80 km/h.

- The 5 tyres seem to give the same trend for all tested surfaces.

3 SRTT LEVELS ON ISO TRACKS

In the Deliverable 2.3 (TR14-ELANORE-SINTEF-05 (2022)),[7], the SRTT tyre has been evaluated as a candidate tyre for implementation of a "calibration" procedure to reduce the track-to-track variations existing among ISO tracks today.

In the VDA RRT from 2026 [8], the SRTT tyre was included in the test. Therefore, it is possible to compare the results of the SRTT tyre from both the VDA RRT and the ELANORE RRT.

Table 6 and figure 18 show a comparison between the two RRTs. All ISO tracks noted S01-S15 are from the VDA test and ISO1-ISO4 are ELANORE results. All values according to Reg.117.

Table 6. *Measured levels of the SRTT tyre at different ISO tracks, according to Reg.117. Speed 80 km/h.*

Test track	S01	S02	S04	S05	S06	S07	S10	S11	S13	S14	S15	ISO1	ISO2	ISO4
Noise level	72.5	73.0	73.5	72.2	72.3	72.5	71.2	72.3	73.1	72.2	73.9	75.1	76.1	76.4

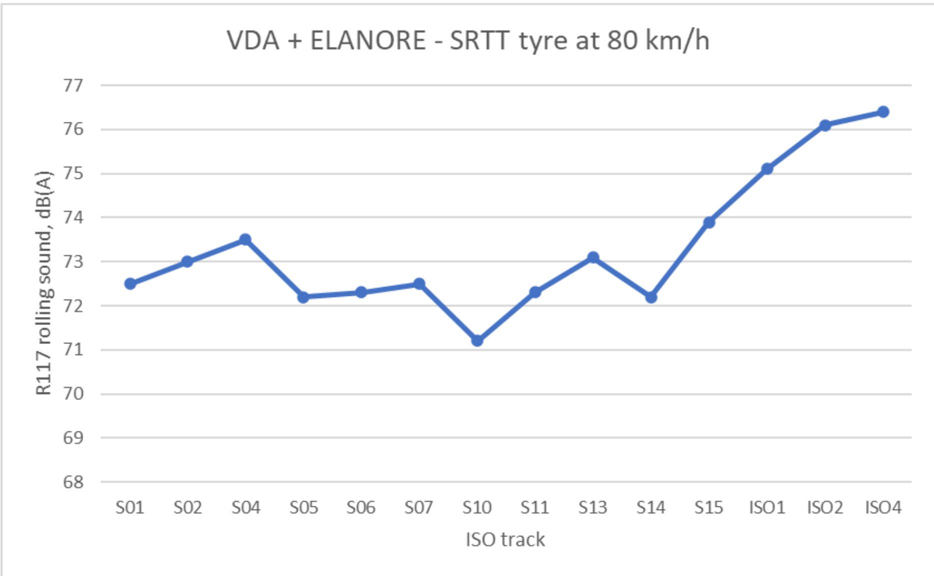


Figure 18. *Measurement of the SRTT tyre on 14 different ISO tracks. S01-S15 are from the VDA RRT and ISO1-ISO4 are from the ELANORE RRT.*

There is a clear difference between the results from the two RRTs for the SRTT tyre. The results from the ELANORE RRT is consistently higher, between 1 to 1.5 dB higher than the ISO test track with the highest level from the VDA tests. This cannot be caused by random errors. The most important differences can be related to:

1. **Test vehicle influence**. The VDA tests were performed with an electric vehicle (VW e-Golf), while the ELANORE tests were made with a petrol driven car (Skoda Superb), where the engine was running during the test, but the gear selector in neutral. In the on-going work within the Informal Working Group on Measurement Uncertainties

(GRBP Geneva), the vehicle influence on the Reg.117 test is estimated to be in the range of 1 dB (peak to peak) [9]. This means that the vehicle influence may explain some of the differences between the two RRTs. An important difference is related to the loading of the two vehicles. For the VDA tests, there is no information about the loading of the car. Since the VDA test results in the main report is given for a cruise-by situation at 50 km/h, it is assumed that the vehicle was not loaded according to the specification in Reg.117 or adjusted the tyre inflation pressure (only loaded with the driver). In the ELANORE tests, the vehicle was loaded according to Reg.117 (530 kg and 200 kPa). The net weight of the e-Golf is 1615 kg, while is quite similar to the Skoda Superb (1635 kg).

1. **Tyre influence**. The shore hardness of test tyre has an influence on the noise. In ISO/TS 11819-3 [10] (Reference tyres P1 and H1 for the CPX standard) the hardness of the SRTT tyre (P1) shall be within 62-73 Shore A. The reference value H_{ref} = 66 Shore A and the correction of a CPX level is given by the formula $C_{HA,t} = \beta_t(H_A - H_{ref})$ For the SRTT tyre, β_t = 0.20. This means that for every unit of Shore A value above 66, the noise level will theoretically increase with 0.2 dB. In the report from the VDA RRT, there is no value given for the SRTT tyre. The 4 SRTT tyres used for our project have been measured to 66 Shore A for all 4 tyres. If the difference in noise levels for the two RRTs shall be related to the difference in Shore A, the SRTT tyres used in the VDA RRT must have a Shore A *lower* than 66. The minimum level is 62. If the VDA tyres had this low level, the maximum influence of the Shore A would be estimated to 0.8 dB. Even if the Shore A was measured to be 66 for all 4 SRTT tyres, we should be aware that we consistently measured higher noise levels on the left side of the vehicle. On average, the difference is around 1.6 dB. If this was caused by the tyres on the left side were noisier than the right side, one could have confirmed this by measuring the pass-by noise while the vehicle was running in both directions. However, this was not feasible due to the set-up of the instrumentation. But, since this was consistent for all 3 ISO tracks, one can assume that the differences in tyre noise performance may contribute to the differences between the two RRTs.
2. **Temperature influence**. The CPB measurements in Reg.117 shall be corrected for road surface temperature. All values given in table 7 are therefore corrected to the reference temperature of + 20°C. In the ELANORE project, the road surface temperature on the 3 ISO tracks was 39 °C on ISO1, 23-25°C on ISO2 and 31-32°C on ISO4. This means an *increase* in the noise level from 0.1 to 0.6 dB, when correcting to the reference temperature. In the VDA RRT there is no specific value of the road surface temperature given for the different ISO test tracks, only that the surface temperature was in the range of +10°C to + 40°C. If the majority of the measurements were done equal to or close to + 10°C it would give a value for the SRTT tyre for the VDA test of 0.7 - 1.2 dB lower than ELANORE results, depending on the ISO test track. However, it is unlikely that most of the SRTT measurements in the VDA RRT were made at this end of the

range. Therefore, it is assumed that any differences related to the temperature correction are not the main reason for the noise differences shown in figure 17.

The most likely influence of the differences between SRTT levels from the VDA test and the ELANORE tests is, in my opinion, related to the *vehicle influence,* especially linked to differences in loading of the vehicle.

Noise differences of the tyres on the left and right side of the vehicle may also contribute to the uncertainties. However, it may not be linked to variations in Shore A. And as shown in Chapter 4, the noise difference between the two channels is not significant for the other 4 tyre sets, and therefore it cannot be related to any differences related to which side of the vehicle the noise levels are measured (vehicle related and not tyre related). If the 4 SRTT tyres also are measured on the GUT drum, this may reveal any noise differences between the tyres. The surface temperature should only give minor influence, especially since we do not have exact values available from the VDA test. In addition, the values from ELANORE are consistently *higher* than from VDA, and this also indicated that the tests being performed with different vehicles and SRTT tyres may be the most important. The ELANORE consortium has discussed these differences for the SRTT tyre. The main conclusion is that the SRTT tyre is in fact non-symmetric, as shown in figure 19. The tyre has also been equipped with an arrow, showing the direction of rotation when mounting the tyre on the rim. According to GUT, the tread pattern is such that it is likely that the noise level on the left side of the tyre (right side on the picture) is higher than the right side.

Figure 19. *Tread pattern of the SRTT tyre*

In figure 20, only the SRTT levels form the right side (ChA) is used as it is the side with the lowest levels, in average about 1.6 dB.

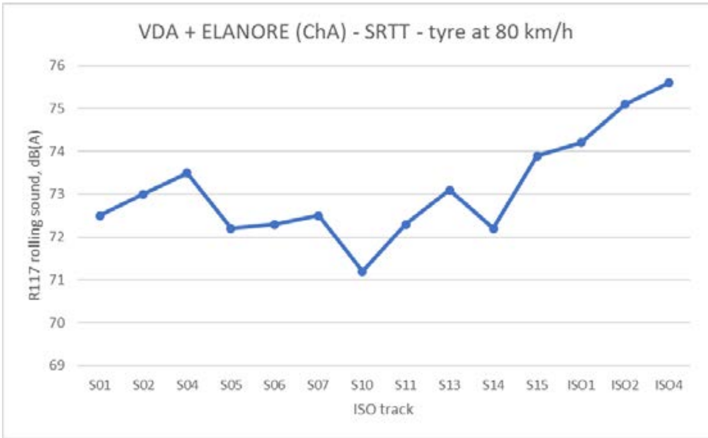


Figure 20. *Measurement of the SRTT tyre on 14 different ISO tracks. S01-S15 are from the VDA RRT and ISO1-ISO4 are from the ELANORE RRT (ChA right side only).*

With only the levels from the right side (ChA) of the test vehicle, the level on ISO1 is quite close to the level on the ISO surface from the VDA test with highest noise level (S15). However, this graph still show a consistent higher noise levels on the ELANORE ISO tracks.

4 FREQUENCY ANALYSIS

In chapter 2.2, table 3, we see that the difference in CPB noise levels between the Ma11 and SMA16 was much less than when using the CPX method. To investigate possible reasons for this, a frequency analysis has been performed. One major reason for doing this, was the fact that during the CPB measurements on Ma11, it was quite windy. On average, the wind speed was around the allowed maximum of 5 m/s, but there were gusts of wind quite often with a speed in the range of 7-10 m/s. A frequency analysis could reveal any influence of these gusts of wind. Without recording any wind speed or direction, as far as I remember, the wind direction was crosswind to the driving direction, with the wind blowing in opposite direction of the sound (or in the same direction??). Looking on the photos, wind was blowing with 180-135 deg. to the driving direction, partly in the same direction as sound propagation.

For each of the tyres, the frequency spectra I 1/3rd octave bands from 200 Hz to 10 000 Hz. All values are A-weighted and based on the R117 measurement conditions at a speed of 80 km/h.

In addition to Ma11 and SMA16, the spectra on ISO4 are also included in the analysis.

In table 6, the measured average difference between CPX and CPB levels is shown for each pavement type. The noise differences for the 3 pavements used for this analysis in table 6, have been used as a correction factor for the CPX spectra to compare with CPB spectra at 7.5 m. Figure 13 from the Danish roads shows that there may be an individual correction factor for each 1/3 octave band, but a generic correction factor, as given in table 6 has been used for this comparison. This should be accurate enough to show any unexpected behaviour of the tyres and pavement types.

4.1 YOKOHAMA – SUMMER TYRE

For CPX measurements, tyre T1254 was used for measurements. For CPB, the spectra are average of all 4 tyres.

Figure 21a and 21b show the spectra for CPB and CPX measurements.

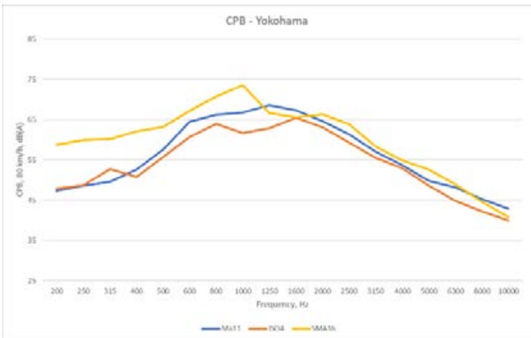


__Figure 21a.__ 1/3rd octave band levels for CPB

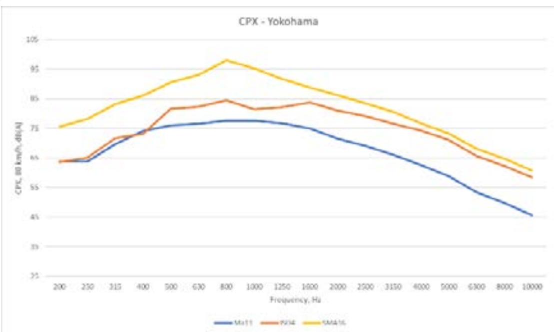


__Figure 21b.__ 1/3rd octave bands for CPX.

The spectra show, as expected, higher levels on the SMA16 surface, especially in the lower frequency range, below 800 Hz (CPB). What is more interesting, is the shift between ISO4 and Ma11 from CPB to CPX. For the CPX measurements, the Ma11 the levels above 400 Hz is well below the levels on the ISO4.

This is also illustrated in figure 22a to 22c. In these figures, the CPX levels are "corrected" according to the values given in table 6. The correction for Ma11 is -17.3 dB, for ISO4, -19.7 dB and -25.7 dB for SMA16.

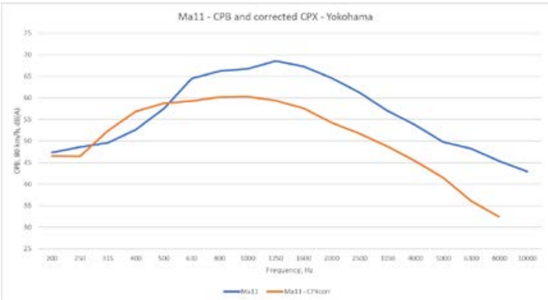


Figure 22a. *Ma11 - CPX levels corrected*

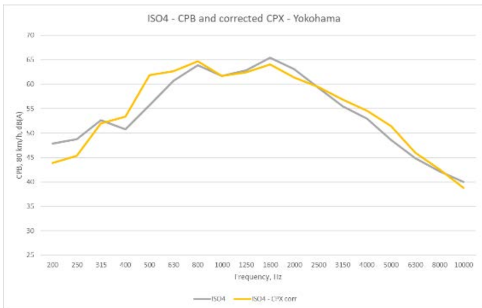


Figure 22b. *ISO4 – CPX levels corrected*

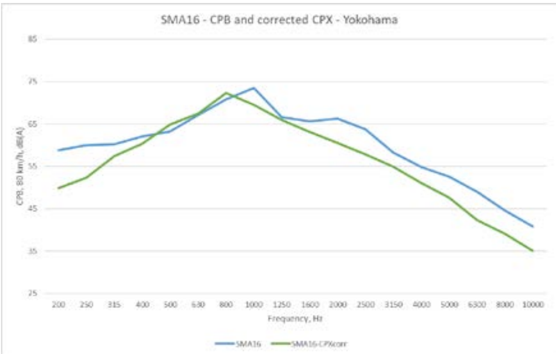


Figure 22c. *SMA16 – CPX levels corrected*

Both figures 22b and 22c show that the spectra are quite similar after the "correction". However, on the Ma11, the spectra from CPB measurements are clearly higher than CPX levels, for frequencies above 500 Hz. Is this due to the "generic" correction factor, or could it be that we now see a clear influence of the windy conditions during the CPB measurements?

4.2 MICHELIN – ALL SEASON TYRE

For CPX measurements, tyre T1259 was used for measurements. For CPB, the spectra are average of all 4 tyres. Figure 23a and 23b show the spectra for CPB and CPX measurements.

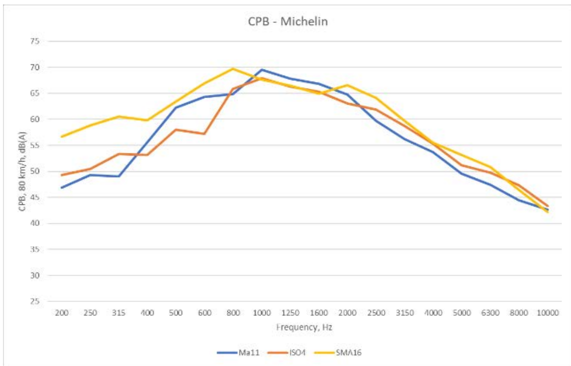


Figure 23a. *1/3rd octave band levels for CPB*

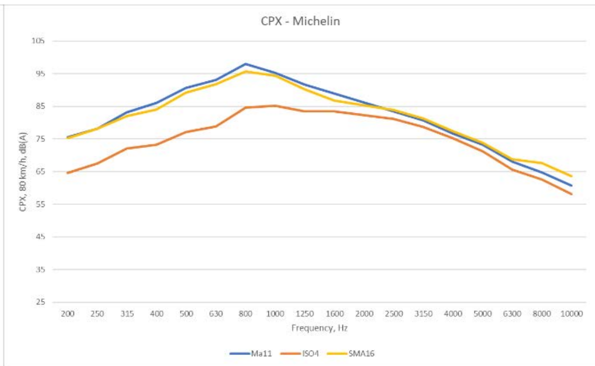


Figure 23b. *1/3rd octave bands for CPX*

Figures 24a to 24c show the corrected CPX values compared to CPB spectra. The correction for Ma11 is -17.6 dB, for ISO4, -18.3 dB and -23.7 dB for SMA16.

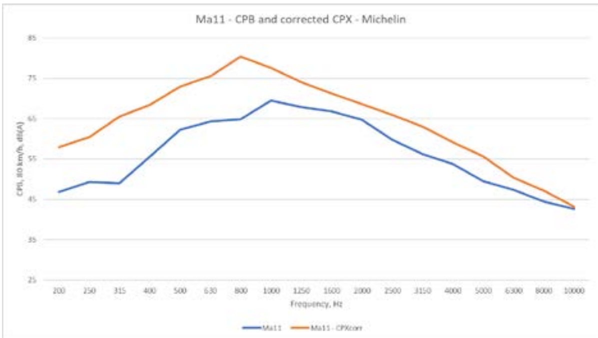


Figure 24a. *Ma11 - CPX levels corrected*

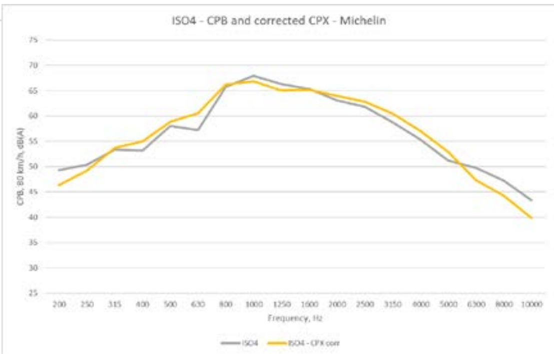


Figure 24b. *ISO4 – CPX levels corrected*

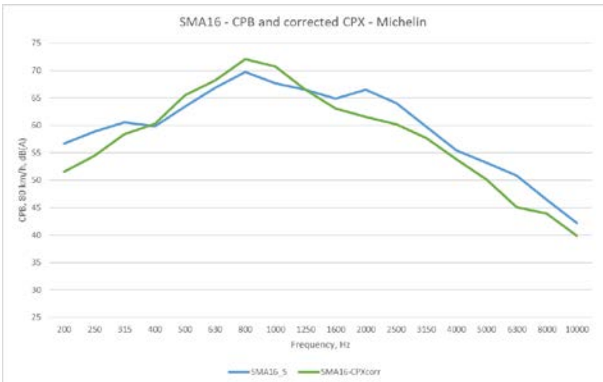
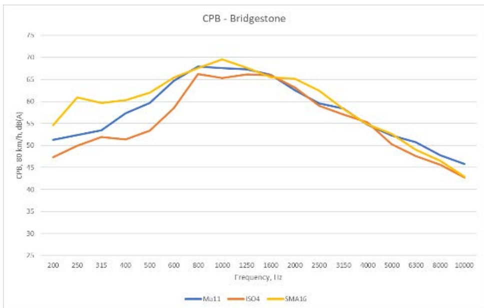


Figure 24c. *SMA16 – CPX levels corrected*

Also, for this tyre, there are no significant differences between CPB and corrected CPX levels for ISO4 and SMA16. However, Figure 23b shows that the spectra for CPB and CPX on the Ma11 is approximately identical. The consequence of this is that when the correction factor of -17.6 is applied on the CPX data, the CPX levels are much higher than CPB, which was the opposite situation for the Yokohama tyre. May be the soft ground between the driving lane and the microphone is the main cause for this deviation.

4.3 BRIDGESTONE – WINTER TYRE

For CPX measurements, tyre T1264 was used for measurements. For CPB, the spectra are average of all 4 tyres. Figure 25a and 25b show the spectra for CPB and CPX measurements.



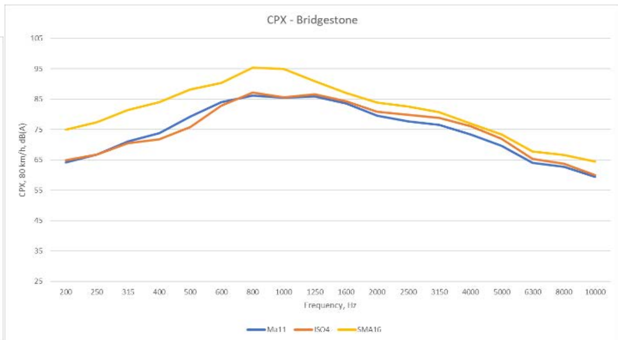
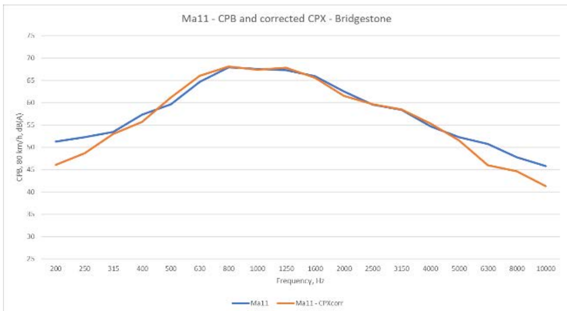


Figure 25a. *1/3rd octave band levels for CPB* ***Figure 25b.*** *1/3rd octave bands for CPX*

Figures 26a to 26c show the corrected CPX values compared to CPB spectra. The correction for Ma11 is -18.1 dB, for ISO4, -19.8 dB and -23.6 dB for SMA16.



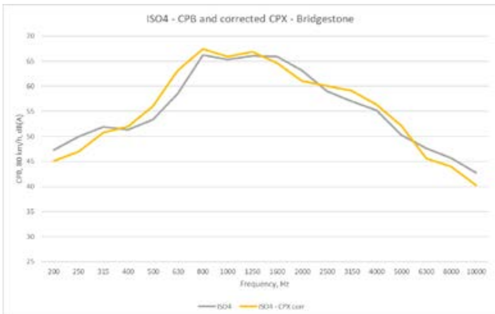


Figure 26a. *Ma11 - CPX levels corrected* ***Figure 26b.*** *ISO4 – CPX levels corrected*

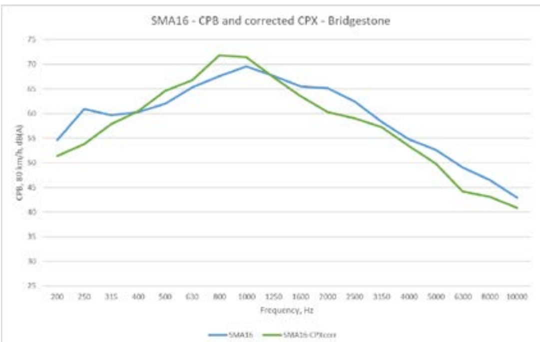


Figure 26c. *SMA16 – CPX levels corrected*

Figures 26a to 26c show that for this tyre, there are no significant differences between the spectra for CPB and CPX measurements.

4.4 EVERGREEN – SUMMER TYRE

For CPX measurements, tyre T1269 was used for measurements. For CPB, the spectra are average of all 4 tyres. Figure 27a and 27b show the spectra for CPB and CPX measurements.

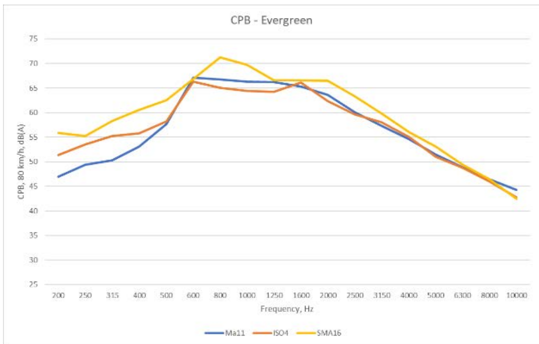


Figure 27a. *1/3rd octave band levels for CPB*

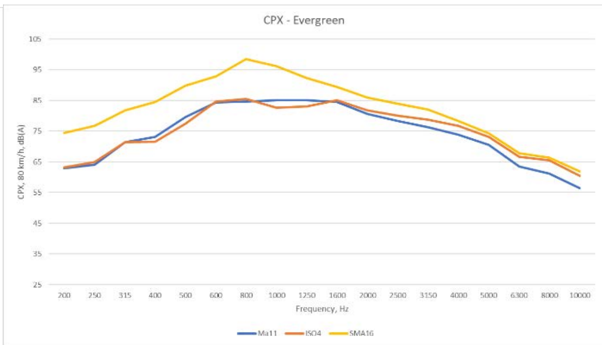


Figure 27b. *1/3rd octave bands for CPX*

Figures 28a to 28c show the corrected CPX values compared to CPB spectra. The correction for Ma11 is -17.6 dB, for ISO4, -19.5 dB and -25.7 dB for SMA16.

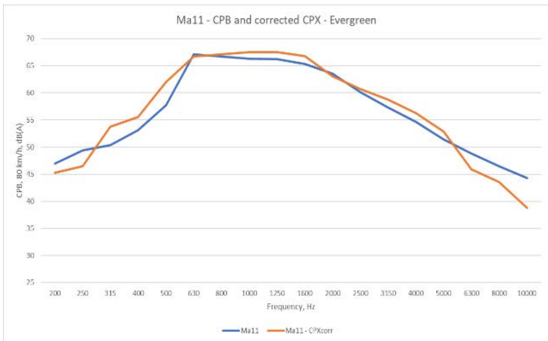


Figure 28a. *Ma11 - CPX levels corrected*

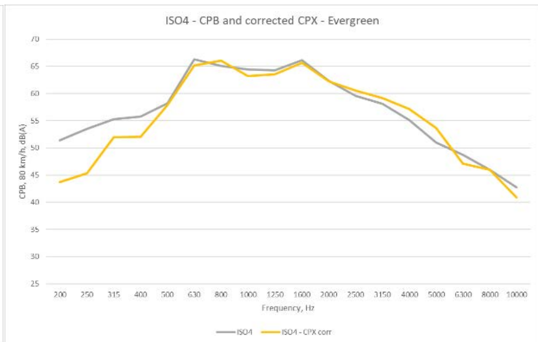


Figure 28b. *ISO4 – CPX levels corrected*

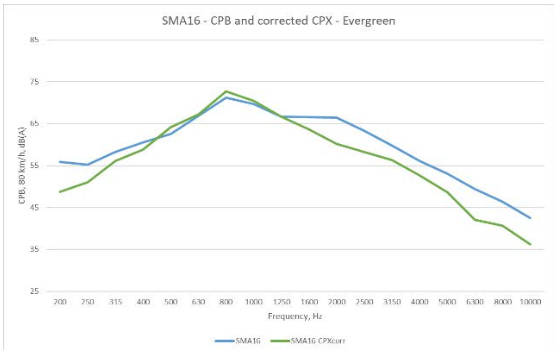


Figure 28c. *SMA16 – CPX levels corrected*

As the case was for the Bridgestone tyre, there are no significant differences between the CPB and the CPX spectra.

4.5 SRTT TYRE

For CPX measurements, tyre T1273 was used for measurements. For CPB, the spectra are average of all 4 tyres. Figures 29a and 29b show the spectra for CPB and CPX measurements.

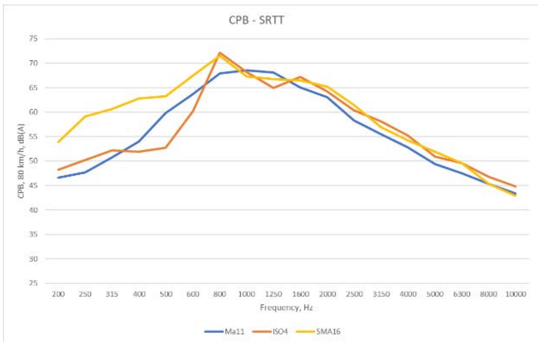


Figure 29a. 1/3rd octave band levels for CPB

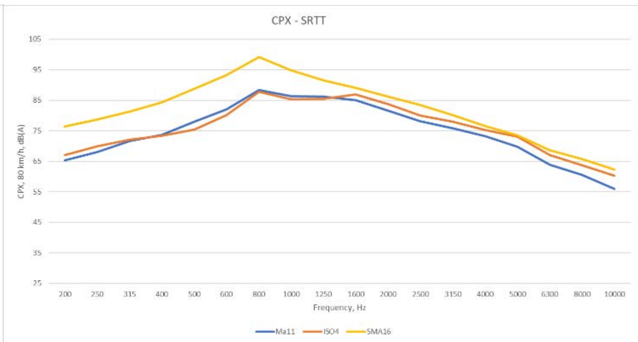


Figure 29b. *1/3rd octave bands for CPX*

Figures 30a to 30c show the corrected CPX values compared to CPB spectra. The correction for Ma11 is -18.9 dB, for ISO4, -18.1 dB and -24.1 dB for SMA16.

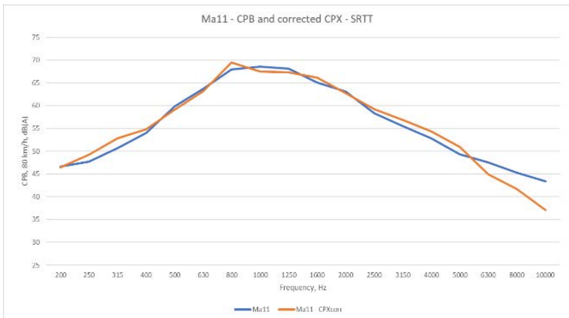


Figure 30a. *Ma11 - CPX levels corrected*

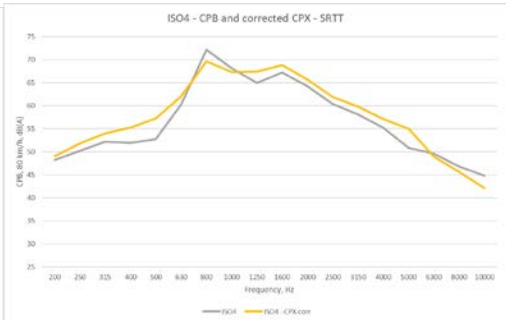


Figure 30b. *ISO4 – CPX levels corrected*

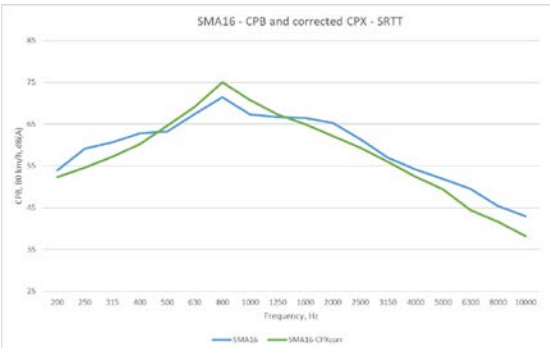


Figure 30c. *SMA16 – CPX levels corrected*

Like for the Bridgestone and Evergreen tyres, there are no significant differences between the CPB and CPX spectra for the SRTT tyre.

If one compare the uncorrected CPX spectra for all these last 3 tyres, they all show the same, that the CPX measurements, give almost the same spectrum for Ma11 and ISO4. This is consistent with the with the overall CPX levels as shown in figure 3. However, the ranking of the CPX levels for Yokohama and Michelin seem to fit with the ranking of the levels for the other 3 tyres, as shown in in figure 3.

As the results for Yokohama and Michelin show, there is obviously some influence on the results that is not clear. As mentioned before, there were some adverse wind conditions during the CPB measurements on Ma11. The CPB measurements of the Yokohama tyre were conducted on July 4th, between hours 19:36 and 20:08, while the measurements on the Michelin were made the same evening, between 20:48 and 21:14. During these time periods, the air temperature during Yokohama measurements, dropped from +17.0°C to 16.1°C for air and road surface temperature dropped from +29°C to 26.3 °C. For the Michelin tyre, the air temperature dropped from + 15.9°C to 14.7°C and road surface temperature from +26.3°C to 22.2°C.

Therefore, the temperature influence cannot be the reason for the uncertainties related to CPB measurements on Ma11 for these two tyres. Since the measurements were performed timewise very close to each other, it is unlikely that any changes in wind direction occurred during this period. It is possible that we need to look for some systematic "errors" to explain these deviations. As far as I can see, this "uncertainty" possibly influences the overall evaluation of the performance of the tyres on the Ma11 pavement.

4.6 INVESTIGATING NOISE DIFFERENCES BETWEEN CPB AND CPX FOR THE LIGHT TEST

As shown in figure 1, and the discussion in the previous chapter there were some concerns about the measurement conditions on the Ma11 for two tyres, Yokohama and Michelin for the Reg.117 tests. The frequency analysis with the "corrected" CPX spectra as shown in figures 22a and 24a confirms this deviation from the other tyres. The special environmental conditions on the Ma11 (ground influence) was of concern as the main reason for these results.

Tests according to the Light Test (LT) conditions were conducted on all surfaces (except for SMA8), both for CPB and CPX for the 5 tyres. However, the LT measurements on the Ma11 pavement were made on the following day of the Reg.117, without the any wind conditions of concern. A new analysis of all the LT results, both for CPB and for CPX has therefore been conducted. Since the LT were not made on all ISO tracks, only the results from ISO4 are used for this analysis.

Tables 7 and 8 show the results of this analysis. The CPB results from the Reg.117 is shown in figure 31 (same results as figure 1, except the average of ISO tracks are replaced by ISO4 results) and the similar results for the Light Test are shown in figure 32. Figure 33 shows the CPX results for the Light Test.

Table 7. *CPB measurements (Light Test) on ISO4 and on trafficked roads. Speed: 80 km/h*

Tyre	ISO4	Ma11	SMA8	SMA11	SMA16	EACC
Yokohama	71.8	74.6	-	76.6	78.3	76.8
Michelin	74.0	75.0	-	76.9	76.4	75.7
Bridgestone	74.3	75.5	-	77.2	76.8	76.1
Evergreen	73,2	75.1	-	77.4	78.3	77.1
SRTT	76.4	75.6	-	78.4	77.8	77.6
Average	73.9	75.2	-	77.3	77.5	76.7

Table 8. *CPX measurements (Light Test) on ISO4 and on trafficked roads. Speed: 80 km/h*

Tyre	ISO4	Ma11	SMA8	SMA11	SMA16	EACC
Yokohama	91.7	91.3	94.3	96.7	101.1	96.5
Michelin	92.7	92.4	94.9	96.8	100.1	95.9
Bridgestone	93.8	93.3	95.7	97.1	99.5	96.1
Evergreen	92.7	92.5	95.3	97.2	101.7	97.1
SRTT	94.7	93.7	96.1	98.1	101.0	97.2
Average	93.1	92.6	95.3	97.2	100.7	96.6

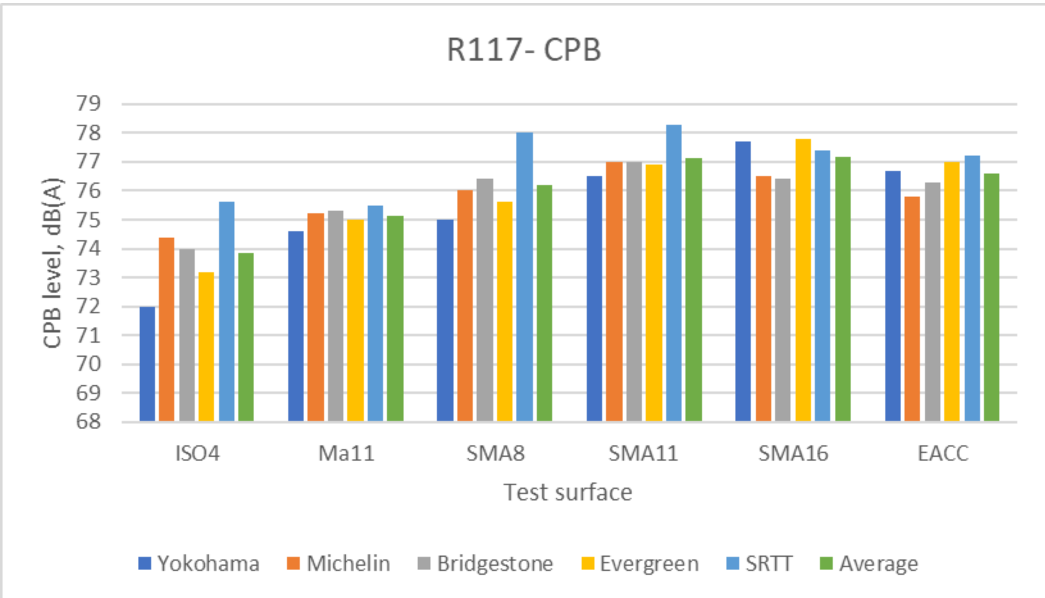


Figure 31. *CPB (Reg.117) on ISO4 and trafficked pavements. Speed: 80 km/h*

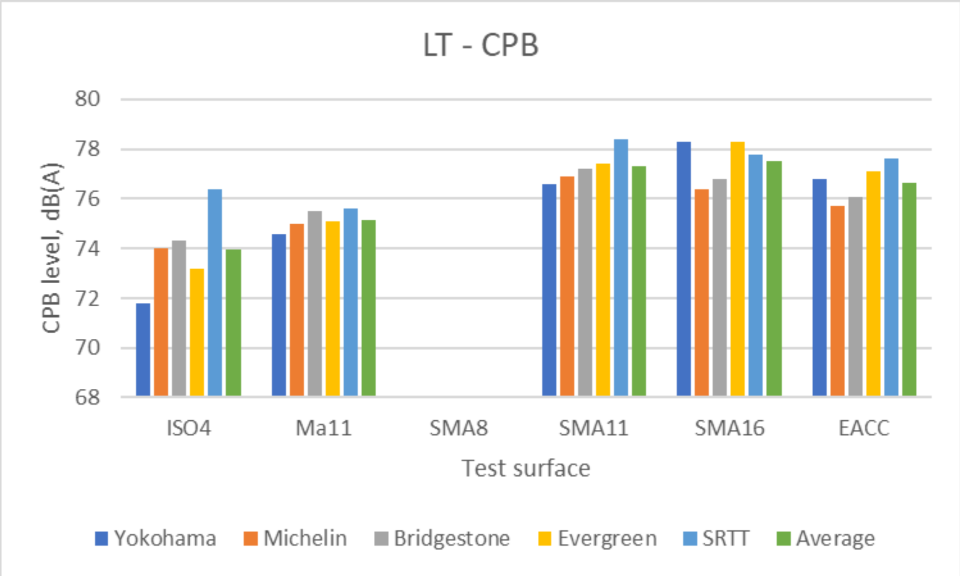


Figure 32. *CPB (LT) on ISO4 and trafficked pavements. Speed: 80 km/h*

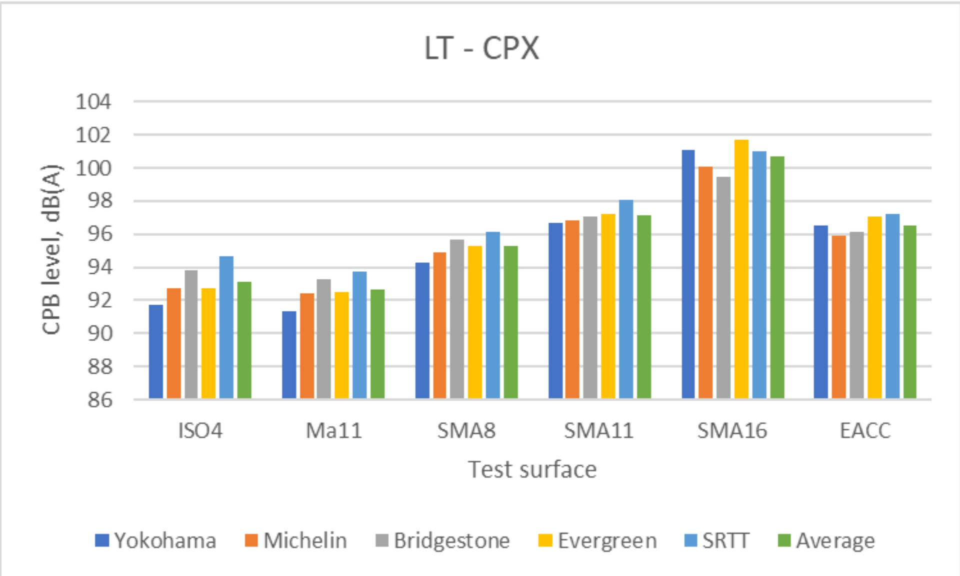


Figure 33. *CPX (LT) on ISO4 and trafficked pavements. Speed: 80 km/h*

These figures show that the LT results is more in line with the CPX results, especially for Ma11, however the differences between the Reg.117 and the LT are small. For the Reg.117 tests, the difference in maximum sound levels on the Ma11 and the SMA16 pavements were in average 2 dB for the CPB test and 9 dB for the CPX test. For the Light Test, these differences were 2.4 and 8 dB.

As shown in figures 22a (Yokohama) and 24a (Michelin), there was not a good agreement with the measured CPB spectra and the "corrected" CPX spectra, based on the Reg.117 data. The same analysis has been done for the LT, as these measurements were done on a different day and without the wind gusts.

Figure 34a shows the CPB spectra for the Yokohama tyre on the 3 pavements, ISO4, Ma11 and SMA16, based on the LT, Figure 34b shows the CPX spectra on these pavements and Figure 34c shows a comparison of the measured CPB spectrum and the "corrected" CPX spectrum, using the same procedure as described in chapter 4.

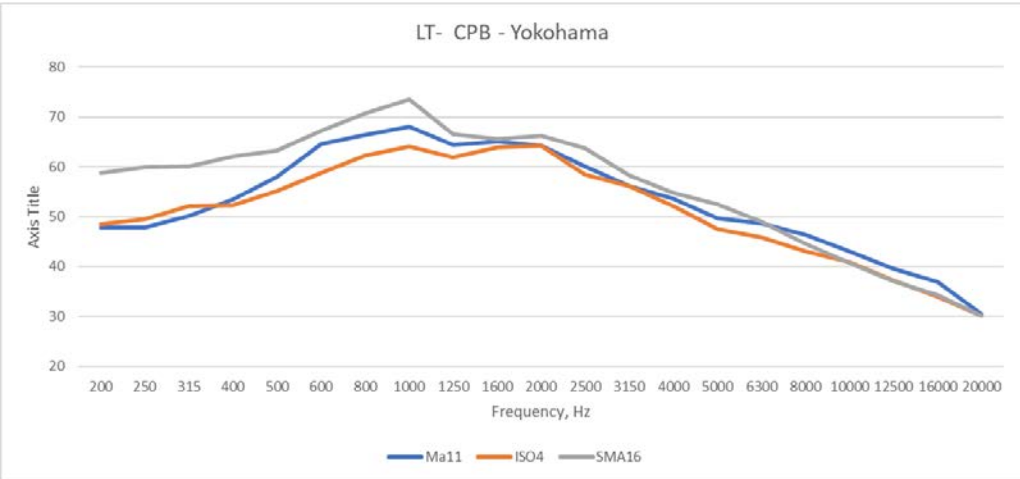


Figure 34a *CPB (LT) spectra for Yokohama tyre on ISO4, Ma11 and SMA16s. Speed: 80 km/h*

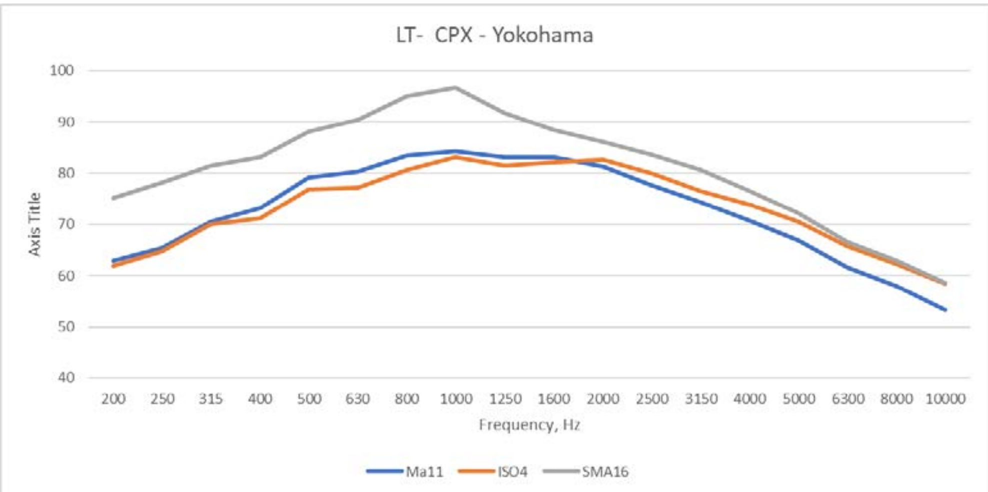


Figure 34b *CPX (LT) spectra for Yokohama tyre on ISO4, Ma11 and SMA16s. Speed: 80 km/h*

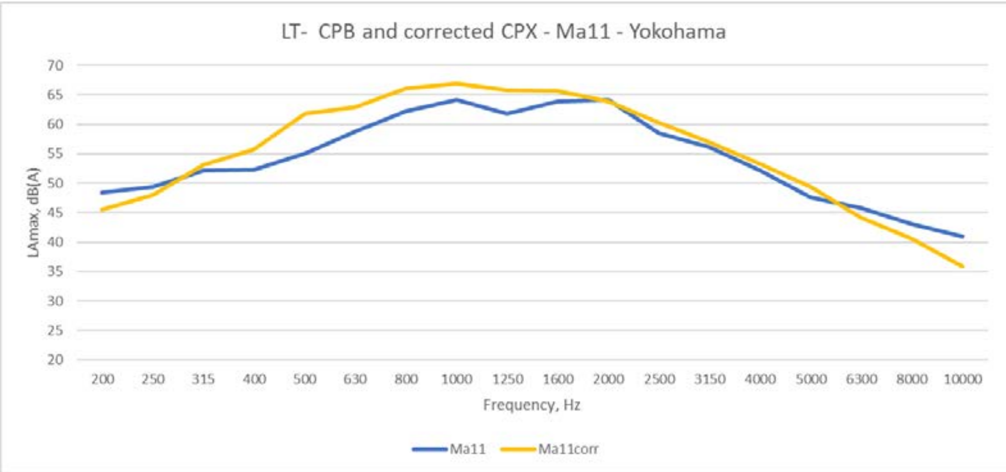


Figure 34c *CPB (LT) spectrum and corrected CPX spectrum for Yokohama tyre on Ma11*

In figures 35a to 35c, the similar analysis has been done for the Michelin tyre.

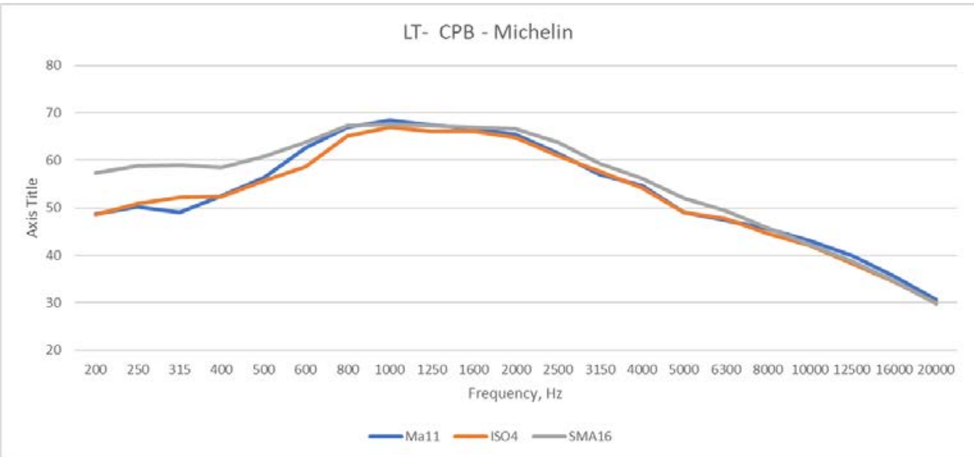


Figure 35a *CPB (LT) spectra for Michelin tyre on ISO4, Ma11 and SMA16s. Speed: 80 km/h*

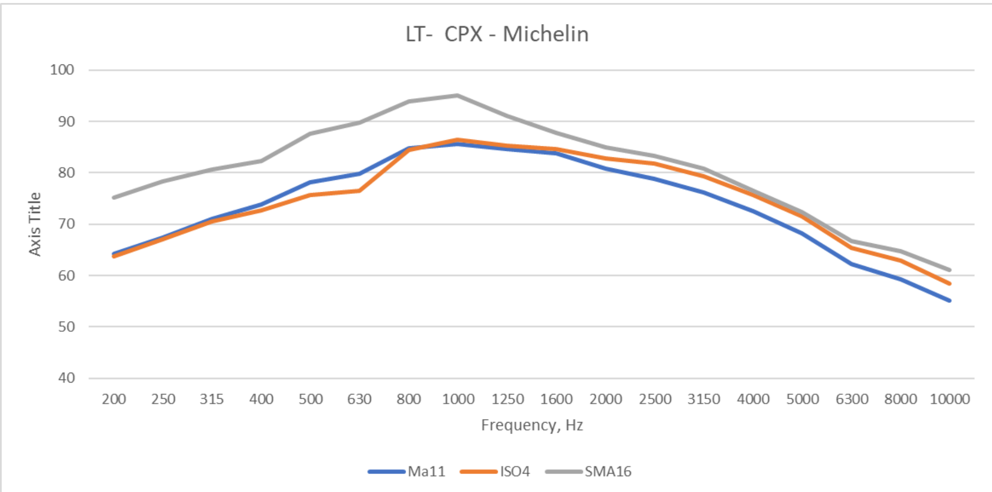


Figure 35b *CPX (LT) spectra for Michelin tyre on ISO4, Ma11 and SMA16s. Speed: 80 km/h*

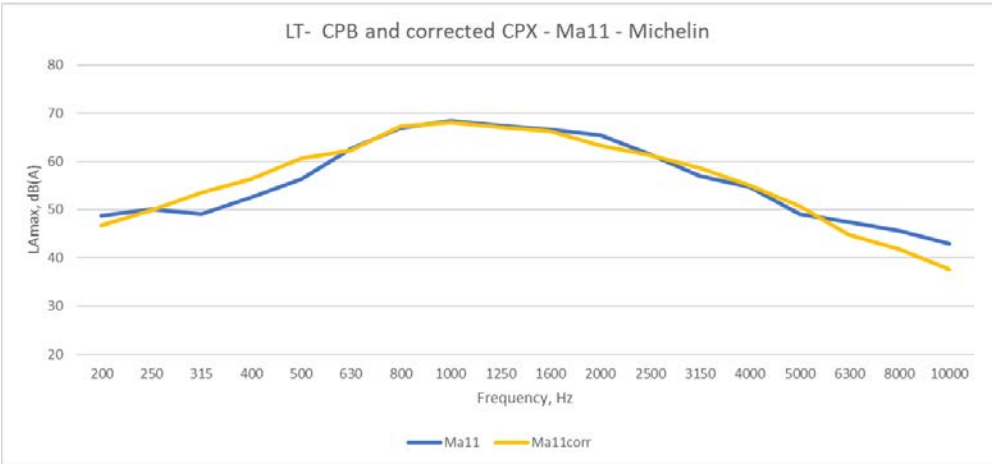


Figure 35c *CPB (LT) spectrum and corrected CPX spectrum for Michelin tyre on Ma11*

Comparing figure 22c and figure 32c (Yokohama) it is obvious that there was some influence of the environmental conditions during the Reg.117 test. When the CPX spectrum is corrected to the CPB distance for the Light Test, the spectra do not differ anymore as they do for the Reg.117 test. The same can be seen when comparing figure 24a and figure 35c for the Michelin tyre. For the Light Test (figure 35c), the spectra is no longer significantly different.

Also, for the other pavements (ISO4 and SMA16), there is no major difference between the CPB and corrected CPX spectra.

The major difference in environmental conditions between the two sets of measurements on these tyres were the windy conditions (gusts of wind). Note that the CPB measurements were made at a distance of 7.5 m from the vehicle and therefore, it is somewhat surprising that the wind could influence the spectra in the way shown above.

However, these differences in spectra was not found for the other 3 tyres.

5 NOISE DIFFERENCES BETWEEN CHA AND CHB – CPB MEASUREMENTS

This relates only to the measurements made on each side of the test vehicle. This was done on all ISO test surfaces, and on two of the Polish pavements; SMA11 and EACC. For all the other pavements, ChA and ChB were measuring on the same left side of the test vehicle.

In the report from the CPB measurements [1], it has been shown that for all tyres, except the SRTT, the difference between right side (ChA) and the left side (ChB) is rather small, within the measurement uncertainty.

However, all measurements (independent of tyre) on the EACC surface show that the levels on this pavement are consistently higher on the *right* side of the vehicle (ChA). Table 9 show the average difference between ChA and ChB for both the R117 and the LT test. Positive values mean that the levels from ChA (right side of the vehicle) were the highest.

Table 9. Average noise differences between ChA and ChB on the EACC pavement

Tyre	R117		LT	
	ChA-ChB, dB(A)	St.dev, dB(A)	ChA-ChB, dB(A)	St.dev, dB(A)
Yokohama	3.88	0.45	4.18	0.53
Michelin	3.81	0.49	3.96	0.57
Bridgestone	4.44	0.56	4.32	0.71
Evergreen	3.51	0.56	4.41	0.42
SRTT	3.13	0.40	3.61	0.71

The differences shown in table 9 cannot be caused by the vehicle not driving off-centre. It is unlikely that this would occur as a "one-sided" event, both for the R117 and the LT test modes. Also, a difference of 3-4 dB is far too high for this to be caused by the driver behaviour. In the analysis of the measurements on this location, the *average* of ChA and ChB has been used to determine the results for all tyres [1], so this unexplained difference has a direct influence on the comparison of the CPB levels of the 5 trafficked roads.

Table 9 shows that the difference levels are smaller for the SRTT than for the others. From previous measurements on the ISO test tracks, we found that the *left* side (ChB) of the vehicle gave around 1-2 dB *higher* levels than the *right* side (ChA). On the EACC location, also the *right* side gives the higher levels. The fact that the SRTT then show lower differences here, must then confirm that the two SRTT tyres on the *left* side do have consistently higher levels than the two on the *right* side. But this difference is not so large that it "compensate" for the unexpected high differences as shown in table 9.

If all 4 SRTT have been measured on the GUT drum, this may explain different noise behaviour, even if the Shore A values are identical. Any noise differences should be linked to the position of the SRTT, when mounted on the test vehicle for CPB measurements.

6 CONCLUSIONS

The main conclusions from this analysis are:

- Neither the CPB nor the CPX measurements on the ISO tracks tested in this project show any good correlation with the EU label values given for the tyres included in the test program. In this report, only 5 tyres are included in the analysis, as only these tyres have been tested according to both methods.
- The CPX method seems to give better correlation with the ***measured*** levels on the ISO test tracks than the CPB.
- The CPX method also seems to rank the noise on different trafficked roads better than the CPB method.
- There is only a small difference in CPB levels on Ma11 compared to SMA16, around 2-3 dB. However, by the CPX method this difference is around 8-9 dB. During the CPX method, one single tyre was mounted on the trailer and the noise level measured close to the tyre (0.5 m). For the CPB measurements, 4 sets of the same tyre type (including the one used in the CPX test) are mounted on the vehicle and the sound level is measured at a distance of 7.5 m. Thus, the CPB method also includes any propagation effects from the source to the receiver. However, this alone cannot explain why the difference between a smooth and a rough surface is much higher when measuring with the CPX trailer, than with the CPB method. This needs to be further investigated.
- A frequency analysis revealed some abnormal results for the Yokohama and Michelin tyre on the Ma11 pavement (in comparison to SMA16 and ISO4) in the Reg.117 test. This was not the case for the other 3 tyres. However, when analyzing the Light Test results on the same surfaces, but measured on a different day, these special deviations for these two tyres were not present. These special results need more investigation.
- The correction value between CPX and CPB was found to be dependent on pavement type, but not so dependent on tyre type. The correction value varied from -17.3 to -25.7 dB. The roughest pavement types (SMA16 and EACC) have the highest correction value.
- The CPB measurements on the EACC pavement showed consistently *higher* levels (in the range of 3.5-4.5 dB) on the *left* side (ChA) than on the *right* side. This seems to be some kind of systematic error and the reason for this has so far not been found.

REFERENCES

[1] Berge, T., Mioduszewski, P., Bohatkiewicz, J., Hałucha, M.: *Deliverable D2.2 – Final report on the noise measurements on ISO reference surface and on conventional pavements*, TR13-ELANORE-SINTEF-04-(2022)

[2] Mioduszewski, P., Berge, T., Woźniak, R.: Technical report from the test program of CPX measurements TR15-ELANORE-GUT (2022)

[3] Berge, T., Haukland, F., Ustad, A.: Environmentally Friendly Roads. Results from noise measurements 2005-2008. SINTEF Report A9721, 2009-01-30 (report can be accessed through first author)

[4] Berge, T.; Noise measurements of passenger car tyres on Norwegian and Danish roads. SINTEF Memo 90E352/90E358, 2015-03-24. (Memo can be accessed through the author)

[5] Anfosso-Ledeé, F.; Modelling the local propagation effects of tire/road noise: propagation filter between CPX and CPB measurements. Proceedings of InterNoise2004, Praha, Czech Republic, August 2004.

[6] Licitra, G. et al.: Relationship between Pass-by results. CPX ones and roadside long-term measures: some considerations. Proceedings of InterNoise2016, Hamburg, Germany, August 2016.

[7] Berge, T., Mioduszewski, P.: Deliverable D2.3 Proposed calibration procedure for ISO test tracks.TR14-ELANORE-SINTEF-04 (2022).

[8] Richartz G., Männel M., Wibmer Ch., Finsterhölzl H.: *Round-Robin-Test Pass-by Noise tracks Europe*, EXCERPT for GRBP Task Force on Measurement Uncertainties, Brussels, 22nd May 2019

VDA (2019): TFMU-01-03 (VDA) 2019-05-20-VDA-Final report RoRoTe Europe-20161103_EN_EXCERPT.pdf (https://wiki.unece.org/display/trans/TF+MU+-+1st+session%2C+Belgium+May+2019)

[9] ETRTO (2019): Tyre noise uncertainties. TFMU-02-02 Rev.1 (https://wiki.unece.org/display/trans/TF+MU+-2nd+session%2C+Belgium+November+2019)

[10] International Organization for Standardization (ISO): *Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 3: Reference tyres,* ISO/TS 11819-3:2017, Geneva, Switzerland, 2017