Analysis and comparison of methods, CPX and SPB, for measuring noise properties of road surfaces

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ABSTRACT
The objective of the EU financed project ROSANNE is to advance harmonization of measuring rolling resistance, skid resistance and noise emission of road pavements and prepare for standardization. As a part of ROSANNE the relationship between acoustic properties of road surfaces, as measured using the CPX and SPB methods, has been studied. The data are from five parties from five different countries, measured with different equipment and on different types of pavement. The data have been analysed in two groups; CPX and SPB performed at the same reference speed, and CPX measured at 80 km/h while SPB was measured at 110-120 km/h, respectively. The relationship found for passenger cars between the CPX and SPB noise levels measured at 1.2 m height at the same reference speed is $L_{SPB} = 0.95 \cdot L_{CPX} - 15.6$ dB, and for multi-axle trucks $L_{SPBH80} = 0.65 \cdot L_{CPXH80} + 24.0$ dB. The relationship for when measurements are made at different reference speeds is less clear. SPB measurements are performed at other heights than 1.2 m, and the influence of increasing the measurement height was studied. For dense surfaces the average noise level seems to decrease by 0.5 dB per meter the microphone height is increased, whereas the SPB noise levels are almost independent of height at porous asphalt.

Keywords: Road traffic noise: 52.3

1. INTRODUCTION

This paper is a summary of the ROSANNE report on the “Analysis and comparison of existing noise measurement methods for noise properties of road surfaces”, deliverable D2.3 (1). The objective of the EU financed project ROSANNE is to advance harmonization of measuring rolling resistance, skid resistance and noise emission of road pavements and to prepare for standardization.

The aim of the part of ROSANNE here was to study the relationships between measurements of the acoustic properties of road surfaces using different methods, particularly the Statistical Pass-by method (SPB) defined in ISO 11819-1 (2) and the Close-Proximity method (CPX) defined in ISO/DIS 11819-2 (3). The relations between measurement results have been studied for both passenger cars and heavy vehicles, based on data from European institutes and companies.

2. Data

2.1 Data Received

Data for the project were delivered to the Danish Road Directorate from the following seven institutes and companies: Austrian Institute of Technology (AIT), Austria; Federal Highway Research Institute (BASt), Germany; Belgian Road Research Centre (BRRC), Belgium; Danish Road Directorate (DRD), Denmark; French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), France; Transport Research Laboratory (TRL), UK; SINTEF, Norway.

The received data were results from simultaneous SPB- and CPX-measurements. The SPB data consisted of passenger car, dual-axle or multi-axle truck noise levels. Only CPX measurements performed with Uniroyal Tiger Paw (ASTM SRTT F2493-08) denoted P1 and Avon AV4 Supervan, denoted H1 were used to establish the SPB-CPX relation. Various combinations of reference speeds were seen, e.g. in some cases both CPX and SPB noise levels had been recorded at 80 km/h and 110 km/h, in others CPX had been recorded at 80 km/h, SPB at 120 km/h etc. Further, results of statistical analyses of SPB regression line slopes from a French National database were received.

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2.2 Data analysis

The first step in the adaptation of data for the compilation was “pre-processing” by adjusting for differences in temperature correction and differences in reference speeds. In the next step data were grouped according to pavement type. Some of the received data had been temperature corrected using various temperature coefficients. These were “un-corrected” and all data were normalised to 20°C air temperature applying the temperature coefficients given in Table 1.

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>Temperature coefficient, [dB/°C]</th>
<th>Speed coefficient, [·]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cars</td>
<td>Heavy</td>
</tr>
<tr>
<td>Dense asphalt</td>
<td>-0,10</td>
<td>-0,05</td>
</tr>
<tr>
<td>Cement concrete</td>
<td>-0,07</td>
<td>-0,035</td>
</tr>
<tr>
<td>Semi porous asphalt</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Porous asphalt</td>
<td>-0,05</td>
<td>-0,025</td>
</tr>
</tbody>
</table>

SPB data are determined by means of linear regression of the pass-by noise level on the logarithm of the vehicle speed as in Eq. 1, where \( a \) [dB] is the intercept, \( b \) [-] is the speed coefficient, \( v \) is the average speed of the passing vehicles and \( v_{ref} \) is the reference speed.

\[
L_{veh} = a + b \log_{10} \left( \frac{v}{v_{ref}} \right) \tag{1}
\]

In cases where CPX and SPB noise levels had been measured at the same reference speed there was no need for speed correction. Data from sites where the measurements had been made at different reference speeds in some cases could be corrected to the same reference speed based on the regression line slopes of the results themselves. For data where the speed range of validity did not allow such normalisation, relationships are first given between CPXP_{s0} and SPB (120 km/h). After discussions with ROSANNE partners it was decided to also correct these latter SPB results to 80 km/h.

The speed corrections for this normalisation were based on analyses made by IFSTTAR of the speed coefficients \( b \) as given in Eq. 1, in a French national database of SPB measurement results. There was no correlation between the speed coefficient and the surface age, the reference speed, the traffic intensity, etc. In all these cases, the analyses resulted in a cloud of uncorrelated data. The average slopes found are given in Table 1.

3. Results obtained on SPB-CPX relation

Section 3.1 deals with the relations between SPB noise levels from light vehicles while Section 3.2 deals with SPB noise levels from heavy vehicles. The first subsection on light vehicles is on results of SPB and CPX measurements made at the same reference speed while the following two subsections deal with the results of such measurements made at different reference speeds.

3.1 Light vehicles

3.1.1 SPB and CPX at same reference speed

This section deals with data for light vehicles measured at nearly the same reference speed. Figure 1 shows the pass-by noise levels from light vehicles at 80 km/h as a function of CPXP_{s0}. There is a reasonably straightforward relation with ±0.5 dB or ±1 dB variation in SPB noise levels for the same CPX noise level, independent of pavement type and the source of measurement results. Approximately 90% of the SPB results lie within the grey lines SPB = CPX - 19.5 dB and SPB = CPX - 21.5 dB shown in Figure 1. Suspicions raised by measurement results shown later in Figure 3, that German SPB noise levels would be higher than Danish SPB noise levels because Germans have larger/heavier cars than Danes, are not supported by the results in Figure 1.

Figure 2 is a compilation of ROSANNE data and earlier DRD data. The figure shows sets of CPX and SPB noise levels measured at the same reference speed, which may have been 50 km/h, 80 km/h or 110 km/h. The ROSANNE data shown in blue, except for three sets of data in orange colour which are considered “outliers”, were all measured at 80 km/h or 110 km/h reference speed. The (older) Danish data shown in grey were measured at the three reference speeds given in the figure legend. Figure 2
shows two trend lines, a blue line for the ROSANNE data (solely the data denoted ROSANNE in the figure contribute to this trend line – outliers do not contribute), and a dashed red line for the grey data points from Danish measurements made in 2010-2011 for other projects. The blue ROSANNE data points which include the new Danish ROSANNE data show a trend for higher SPB noise levels than the older Danish data. The average relationship between these ROSANNE noise levels is \( \text{SPB} = \text{CPX} - 20.5 \text{ dB} \).

Figure 1: Relationship between \( \text{CPXP}_{80} \) and \( \text{L}_{\text{veh}} \) measured at 80 km/h. The legend indicates pavement type and data origin (country).

Figure 2: Relationship between \( \text{CPXP}_{80} \) and \( \text{L}_{\text{veh}} \) measured at the same reference speed (outliers do not contribute to the blue trend line). Grey data points are from Danish measurements in 2010-2011; the dashed red line is the trend line for these data.
3.1.2 SPB at 120 km/h and CPX at 80 km/h reference speed

In many cases, the ROSANNE data contained SPB measurement results at reference speeds differing so much from the reference speed used for CPX measurements that the validity range for the SPB regression lines did not encompass the CPX reference speed. For these cases it was first decided to normalise the SPB measurement results to 120 km/h and to show their relation with CPX noise levels measured at 80 km/h. The results are illustrated in Figure 3. The relationship between SPB and CPX noise levels in this figure is not clear. SPB data from the pavements denoted Porous, most data denoted as Dense, AC (Asphalt Concrete) and some data denoted as SMA (Stone Mastic Asphalt) are within SPB = CPX – 18.0 ± 1 dB. Several data denoted SMA, EACC (Exposed Aggregate Concrete Concrete), PMA (Porous Mastic Asphalt, in German “Gussasphalt”) and Dense deviate by 2 dB or more from SPB = CPX – 18.0 dB. The large group of data from EACC with CPXP\_80 = 96 – 98 dB deviate by 4 – 7 dB, likewise does one of the PMA points and one SMA point.

![Figure 3: Relationship between CPXP\_80 noise levels and L\_veh for light vehicles measured at 120 km/h or measured at 110 km/h and converted to 120 km/h](image)

3.1.3 SPB at 120 km/h normalised to 80 km/h and CPX at 80 km/h

Even though normalising SPB results measured at 120 km/h reference speed to 80 km/h is outside the range of validity of the regression line of noise levels against vehicles speed, this normalisation is performed. This is a deliberate violation of the specifications in the measurement standard (2). The results are illustrated in Figure 4. The figure shows the same blue, grey and orange data points as Figure 2. The normalised data are shown in green/orange and they still display large variations with almost half of the data points being more than 2 dB from the average, in both directions.
This section deals with SPB measurement results provided for the ROSANNE project by BASt and DRD. BASt measured simultaneously at 1.2 m, 2.4 m, 3.6 m and 4.8 m height, while DRD measured at 1.2 m, 3 m and 5 m, respectively. Figure 5 shows the SPB noise level at different heights as a function of the noise level at 1.2 m height. BASt data are from SMA/PMA or EACC pavements while DRD data are from SMA, AC, UTLAC, semi-porous asphalt and PERS. The trend lines shown are essentially parallel with slopes around 1.0, so the general effect of increasing the microphone height is decreasing the measured pass-by noise level.

Figure 6 shows the same results in a slightly different way, subdivided in pavement types. For each measurement height the figure shows the reduction in noise level by increasing the microphone height from the 1.2 m height specified in the SPB measurement standard. The spread in differences measured at individual sites is rather large. This variation may be caused by general measurement uncertainty or by frequency spectrum differences due to variations in sound propagation, pavement surface or vehicle speed. The figure illustrates that the decrease in noise level differs for pavement types, where the noise levels at the PA pavements were almost independent of the microphone height.

Figure 7 shows the average differences from Figure 6 and their standard deviations. The trend line for these average differences has a slope of 0.5 dB per meter increase in microphone height and the standard deviations of the differences are between 0.4 dB and 0.8 dB. The differences are shown for the pavement types EACC, SMA and AC respectively. The trend is for noise levels measured at EACC to decrease more than the others when the microphone height is increased from 1.2 m to 2.4 m.
Figure 5: SPB noise levels from cars measured at 2.4, 3, 3.6, 4.8 and 5 m height as a function of the noise level at 1.2 m height.

Figure 6: Differences between SPB noise levels at 1.2 m and SPB at other measurement heights on EACC, SMA, AC and PA pavements.
3.2 Heavy vehicles

3.2.1 SPB relation with CPXH

BASt and SINTEF contributed CPX noise levels measured with reference tyre H1 (Avon AV4), and SPB noise levels from heavy vehicles. BASt only measured noise levels from multi-axle trucks, while SINTEF also measured noise levels from dual-axle heavy vehicles. The results for multi-axle heavy vehicles are illustrated in Figure 8, with both CPX and SPB noise levels given at 80 km/h. There is a trend, although not very clear, for increasing SPB noise level with increasing CPX noise level. The results from porous asphalt deviate from those from other types of pavement. The data from SMA, EACC, PMA and AC have been grouped into dense pavements (blue data points) and the trend line for these data is shown. The determination coefficient $R^2$ is 0.5.

The average difference between pass-by noise levels from multi-axle and dual-axle heavy vehicles was 2.5 dB. This difference is based on results from four British sites, each measured twice, and from 14 Norwegian sites.

Figure 8: Relation between CPXH$_{80}$ noise levels and SPB noise levels for multi-axle heavy vehicles at 80 km/h. The trend line illustrated is for dense pavements SMA, EACC, PMA and AC (blue data points).
3.2.2 SPB relation with CPXP

Parties other than BASf and SINTEF only delivered CPX data measured with reference tyre P1 (SRTT). Figure 9 shows the relation between \( \text{CPXP}_{80} \) and the pass-by noise levels from multi-axle trucks. No clear overall trend is seen in the data, not even in data for each type of pavement. In order to compare how well the two reference tyres represent pass-by noise levels from multi-axle trucks, the data from the same SMA, EACC, PMA and AC sites as Figure 8 have been marked with the same blue signatures and the trend line is shown. The determination coefficient \( R^2 = 0.2 \), and thus the Avon AV4 reference tyre is a better representative of pass-by noise levels from multi-axle trucks than the SRTT, but there is considerable spread in data for individual pavements.

![Figure 9: Relation between CPXP\(_{80}\) noise levels and SPB noise levels from multi-axle heavy vehicles at 80 km/h. The surfaces with blue solid legends are the same as in Figure 8, and the trend line represents these surfaces: SMA, EACC, PMA and AC.]

3.2.3 SPB noise levels at different receiver heights – Heavy vehicles

This section, like Section 3.1.4, deals with data from BASf and from DRD. BASf measured pass-by noise levels at 1.2, 2.4, 3.6 and 4.8 m height while DRD measured at 1.2, 3 and 5 m. height. Figure 10 shows the SPB noise level at different heights as a function of the noise level at 1.2 m height. All trend lines in Figure 10 are roughly parallel with a slope in the order of 1. The range in noise levels in the data from DRD is small, and data from an individual pavement may have heavy influence on the trend line.

Figure 11 shows the average difference between the noise level at 1.2 m and the noise level at other measurement heights including the standard deviation. There is a clear trend for lower noise levels with increasing microphone height. The variation in differences measured at individual sites is rather large. This variation may be caused by general measurement uncertainty or by frequency spectrum differences due to different sound propagation condition, pavement surface or vehicle speed. The trend line for these average differences has a slope of 0.6 dB per meter increase in microphone height and the standard deviations of the differences are between 0.3 dB and 0.6 dB.
Figure 10: Relation between SPB noise levels from multi-axle trucks measured at 1.2 m and 2.4, 3, 3.6, 4.8 and 5 m height, respectively.

Figure 11: Average difference and the standard deviation of differences between SPB from multi-axle trucks at 1.2 m and SPB at other measurement heights.

3.3 SPB noise levels at different heights – Summary

The average difference between vehicle pass-by noise levels measured at different heights is about the same for cars and multi-axle trucks. Table 2 summarises the average difference between the noise levels at 1.2 m and the noise level at other measurement heights. The table also gives average differences found in Dutch measurement results in the SUPSIL project (5).
Table 2: Average difference between pass-by noise levels at 1.2 m and other measurement heights. ROSANNE data and Dutch data from 2010.

<table>
<thead>
<tr>
<th>Height [m]</th>
<th>Cars [dB]</th>
<th>Heavy [dB]</th>
<th>Cars [dB]</th>
<th>Heavy [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>2.1</td>
<td>2.2</td>
<td>2.0</td>
<td>1.8</td>
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<tr>
<td>4.8</td>
<td>2.0</td>
<td>2.1</td>
<td></td>
<td></td>
</tr>
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<td>3.6</td>
<td>1.3</td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>2.4</td>
<td>0.7</td>
<td>0.7</td>
<td></td>
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</tbody>
</table>

4. CONCLUSIONS

The objective of the study was to investigate the relationships between measured acoustic properties of road surfaces found using different methods, particularly those in ISO 11819-1 and ISO/DIS 11819-2.

There seems to be a reasonably 1:1 relationship between CPX noise levels measured with tyre P1 (the standard reference test tyre, SRTT), and SPB noise levels from passenger cars, as long as both types of noise level are measured at the same reference speed. The average relationship found in the data collected for ROSANNE at a microphone height of 1.2 m is

Cars: \( L_{\text{AFmax}} = 0.95 \cdot CPXP - 15.6 \text{ dB} \) (2)

This equation yields a 20.5 dB average difference between the two measured quantities, and almost 90% of all data are within ±1 dB around this trend line.

Sets of data where the CPX noise levels had been measured at 80 km/h reference speed while the vehicle pass-by noise levels had been measured at 110 – 120 km/h reference speeds did not show the same clear pattern. The reasons for this are not known. When corrected for the speed difference using the speed coefficients given in Table 1 almost half of these data deviated by ±2 dB or more from the average relation given in Eq. 2.

On dense pavements an average 9.5 dB difference was found between the CPX noise level measured with reference tyre H1 (Avon AV4) and the pass-by noise level from multi-axle heavy trucks measured at 1.2 m height. This implies a 12.0 dB average difference between CPXH80 and \( L_{\text{AFmax}} \) from dual-axle trucks, based on average observed differences between pass-by levels for two-axle and multi-axle trucks. The agreement between the CPX noise levels measured with reference tyre P1 (SRTT) and the pass-by noise levels was not as good. The average relationship between multi-axle truck pass-by noise levels and CPXH80 was:

Multi-axle trucks: \( L_{\text{AFmax,80}} = 0.65 \cdot CPXH_{80} + 24.0 \text{ dB} \) (3)

When higher SPB microphone positions are used the average noise level decreases by approximately 0.5 dB per meter the microphone height is increased. There was a trend for a larger change in noise level when increasing the height from 1.2 m to 2.4 m on EACC than on SMA. The reasons for this are not known. Dutch SPB data collected at different heights indicates a need to distinguish between different types of pavement (thin noise reducing asphalt layers, single layer or two-layer porous asphalt), see (1, 5).

The comparison of pavements, and hence their classification, may depend on the microphone height used for pass-by noise measurements. It is therefore essential that such measurements for pavement noise classification purposes are taken at a height which is representative of the noise exposure of people living/working close to the road.
ACKNOWLEDGEMENTS

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REFERENCES