Sustainable Road Surfaces
for Traffic Noise Control

EUROPEAN COMMISSION
DG TREN - GROWTH
CONTRACT N° GRD2-2000-31801-SI2.335701

SILVIA PROJECT REPORT

A Former LCPC Experimental Campaign about Repeatability and Reproducibility of SPB and CPB Measurement Methods

F. Anfosso-Lédée, LCPC

SILVIA-LCPC-002-00-WP2-170403

CONTENTS

1 CONTEXT

In France in 1994, a round robin test of pass-by measurements (Controlled Pass-By and Statistical Pass-By) demonstrated an acceptable value for the repeatability of the methods around 1 dB(A), but a poor value for the reproducibility (between 2.5 and 5 dB(A)). Consequently, it was decided to improve the procedures. This was the purpose of the first experimentation. The second one was a real round robin test aimed at evaluating the limits of repeatability and reproducibility of both methods.

Note that the aim was to qualify CPB (Controlled Pass-By) and SPB (Statistical Pass-By) measurement methods, in the form they were described in the French Standard AFNOR S 31119 at this time. The first part of the standard deals with CPB measurements, the second part with SPB measurements. This second part is close to ISO 11819-1. A comprehensive comparison between AFNOR S 31119-2 and ISO 11819-1 has been made later on [Doisy 2000]. It shows that the differences in measuring conditions are not significant. However, differences in reference speeds, vehicle categories, and definition of a global indicator may bring significant discrepancies in the final results.

2 1st EXPERIMENTATION : VALIDATION OF THE METHODS

The objective was to mitigate the variability observed when different operators performed the measurement procedure for qualifying road surface acoustic properties.

This experiment was performed in 1995 under the responsibility of LCPC, and gathered 8 (independent) laboratories: LCPC and 7 Public Works Regional Laboratories (Angers, Blois, Clermont-Ferrand, Est Parisien, Lille, Lyon, Strasbourg).

2.1. General Features

- CPB tests were performed on the LCPC Test track in Nantes, on an Asphalt Concrete 0/10 section.
- SPB tests were performed on a main road between Nantes and Rennes (RN 137), on an Asphalt Concrete 0/14 section.

Measurements were repeated by each team at exactly the same location.

2.2. Test Programme

2.2.1. Validation of analysis procedure

The pass-by noise of a controlled vehicle at different speeds on the test track was recorded on a magnetic tape. This tape was then successively analysed by each laboratory with its own equipment. A maximum discrepancy of 0.2 dB(A) was observed on the results, for each speed (maximum variation between –0.1 dB(A) and +0.1 dB(A) around the mean value). This is the order of reliability of numerical acquisition cards used by the teams.

2.2.2. Validation of CPB procedure

Different steps have been followed :
1 – check of each of the 8 speedometers reliability, by comparison with a sophisticated laser beam device,
2 – one vehicle, one driver, and one speedometer identical for all teams. Only the acoustic acquisition system was different for each team,
3 – one vehicle, one driver identical for all teams. The acoustic + speed acquisition systems were different for each team,

4 – one vehicle identical for all teams. The driver and the measurement system were different for each team,
5 – independent measurements according to the standard, i.e. 2 different vehicle with 2 different sets of tyres each (each team having its own vehicles and tyres),
6 – selection of “optimised” vehicles and tyres configurations (2 vehicles and 2 sets of tyres each),
7 – independent measurements (idem 5 -) with the selected configuration (4 pairs of vehicle/tyres)

The analysis were performed on site, right at the end of each measurement.

2.2.3. Validation of SPB procedure

2 sets of measurements have been performed in 2 weeks :

Week 1 : a simultaneous recording of the noise generated by the same vehicles (heavy and light) in the traffic flow by each of the 8 teams (separate acoustic lines but a unique speedometer), separate analysis. Each of the operators were free to decide whether the selection criteria were valid or not (4 seconds between 2 vehicles, 10 dB emergence).

Week 2 : at the same location, only light vehicles pass-by have been recorded. The 4 vehicle / tyre configurations selected from CPB tests were inserted in the traffic flow. The aim was to investigate first the feasibility of CPB measurements without closing the lane, second to compare CPB with SPB for light vehicles, and finally to have an estimation of the repeatability of SPB for light vehicles.

2.3. Experimental results

2.3.1. Validation of CPB

Results with a unique vehicle

In Table 1 below are presented the results for 1 unique vehicle, the same for all the 8 teams (small passenger car Renault Clio with “average” tyres). The reference speed is 90 km/h.

Table 1

		Average L_{Amax} (dB(A))	Max ΔL_{Amax} (dB(A))	Δ[min;max] (dB(A))
2	Identical vehicle + driver + speedometer	75.5	0.6	[-0.3;+0.3]
3	Identical vehicle + driver	75.3	0.7	[-0.4;+0.3]
4	Identical vehicle	75.3	1.1	[-0.3;+0.8]

- as expected, the more external parameters are introduced, the bigger the variation range,
- the influence of the speedometer has low effect. Discrepancies have been observed between the common speedometers and the reference one (laser beam). It can be explained by accuracy of the devices : it is given as 3% for common ones and <1% for laser beam device (less convenient for operational purposes). However, the consequence on the average noise level is very limited,
- the influence of the driver (difference between steps 3 and 4) increases the dispersion of results of about 0.4 dB(A). The average result is however unaffected,
- for a unique vehicle, the maximum allowable discrepancy can be limited to 1 dB(A)

Results with 4 vehicle/tyre configurations

28 different vehicle/tyre configurations were measured at the same location. Subsequently, 4 configurations were selected according to the AFNOR S 31119-1 requirements :

- small car with “noisy” tyres
- small car with “low noise” tyres
- large car with “noisy” tyres
- large car with “low noise” tyres

The average results are presented in Table 2 below.

Table 2

		Average L_{Amax} (dB(A))	Max ΔL_{Amax} (dB(A))	Δ[min;max] (dB(A))
5	Each lab has its own 4 vehicle/tyre configurations	76.8	3.4	[-1.8;+1.6]
7	The same set of 4 vehicle/tyre configuration of all	76.8	1.5	[-0.6;+0.9]

- the free interpretation of the type of vehicle/tyre configuration leads to big variations, up to 3.4 dB(A). That is too important to classify fairly different road surfaces. A detailed analysis of the results shows the major importance of the type of tyre.
- when a unique set of 4 configurations is selected, although the average noise level is unchanged, the discrepancies between laboratories are reduced to 1.5 dB (A). It is not surprising that it is substantially higher than with a unique configuration ;
- by comparing Table 1 and Table 2, it is clear that 4 unique vehicle/tyre configurations give different results than only one : about 1.5 dB(A) on the average noise level in this present case.

2.3.2. Validation of SPB

Results of SPB measurements according to vehicle categories

The average results for the 2 weeks of measurements are presented in Table 3 below. For the given road, the speed reference for the L_{Amax} calculation is 100 km/h. Note that the same vehicles were measured but the choice to select or reject for the analysis was left open to the operator.

Table 3

		Average L_{Amax} (dB(A))	Max ΔL_{Amax} (dB(A))	Δ[min;max] (dB(A))
Week 1	Light Vehicles	79.7	0.3	[-0.2;+0.1]
	Trucks	87.3	0.8	[-0.6;+0.2]
Week 2	Light Vehicles	80.1	0.9	[-0.6;+0.3]

- the discrepancies in the measurements between the 8 laboratories are less than 1 dB(A), when each category of vehicle are separated.
- reproducibility when only light vehicles are considered (between week 1 and 2) is good.

The results of "pseudo CPB" (CPB measurements with the selected 4 vehicle/tyre configurations inserted in the traffic flow) and SPB measurements for light vehicles are compared in Table 4. In CPB measurements, each of the 4 vehicle/tyre configuration is measured at 8 different speeds, ranging from 50 to 110 km/h. The L_{Amax} in Table 4 is related to a reference speed of 100 km/h, by using the following equation :

$$L_{Amax}\ (100\ km/h) = L_{Amax}\ (90\ km/h) + a \log_{10}\ (100 / 90)$$

where ***a*** comes from the regression analysis on the 8 pass-by results.

Table 4

	Average L_{Amax} (dB(A))	Max ΔL_{Amax} (dB(A))	Δ[min;max] (dB(A))
SPB Light Vehicles from the traffic flow (approx. 80 vehicles)	80.1	0.9	[-0.6;+0.3]
CPB Light vehicles (4 vehicle/tyre configurations)	79.7	1.1	[-0.6;+0.5]

Finally in Table 5, the global result of SPB measurements, including Light and Heavy vehicle are presented, and compared with "pseudo CPB" measurements of the 4 vehicle/tyre configurations inserted in the traffic flow. The reference speed is also 100 km/h.

Table 5

	Average L_{Amax} (dB(A))	Max ΔL_{Amax} (dB(A))	Δ[min;max] (dB(A))
SPB real traffic flow (80% light veh., 20 trucks)	82.7	0.5	[-0.3;+0.2]
CPB Light vehicles (4 vehicle/tyre configurations)	79.7	1.1	[-0.6;+0.5]

NB : this is not a real test of reproducibility of SPB measurements as the same vehicles in the flow were measured.

3 2nd EXPERIMENTATION : ESTIMATION OF RELIABILITY

The aim was to estimate the reliability (repeatability and reproducibility) of CPB (Controlled Pass-By) and SPB (Statistical Pass-By) measurement methods, with revisions specified by the previous experimentation. The estimation of reliability was made by applying ISO 5725. This experiment was performed in 1996 under the responsibility of the LCPC, and gathered the same 8 independent laboratories.

3.1. Test Programme

- CPB tests were performed on the LCPC Test track in Nantes, on an Asphalt Concrete 0/10 section (AC 0/10) and on a Porous Asphalt Concrete 0/10 section (PAC 0/10).
- SPB tests were performed on a main road between Nantes and Rennes (RN 137), on an Asphalt Concrete 0/14 section (AC 0/14), and on a Porous Asphalt Concrete 0/10 (PAC 0/10).

Measurements were repeated twice, by each team independently at exactly the same location, following the procedure described in AFNOR S 31119.

Model for statistical analysis

The statistical analysis referred to ISO 5725, part 1 and 2 (1994). The statistical model used is described below :
Each measurement result ***y*** can be expressed as the sum of 3 terms :

$$y = m + B + e$$

where ***m*** is the mean value of the test.
The variance of ***B*** is called the ***inter-laboratory variance*** (the square of the standard deviation). It is supposed to be constant over the experimentation.

$$s_L^2 = var(B)$$

e is the random error for each measurement set. Its variance is called the ***intra-laboratory variance***.

$$s_r^2 = var(e)$$

For the estimation of reliability, two indicators are necessary :
- the ***standard deviation for repeatability*** : $s_r = \sqrt{var(e)}$
- the ***standard deviation for reproducibility*** : $s_R = \sqrt{s_L^2 + s_r^2}$

The following limits for repeatability and reproducibility are defined respectively by :

$$r = 2.8\, s_r$$
$$R = 2.8\, s_R$$

3.2. Experimental results

3.2.1 Unprocessed results

Table 6 : CPB and SPB levels measured in dB(A) (referred to a 20°C temperature)
A-Form

	CPB		SPB – LightVehicles		SPB - HeavyTrucks	
Laboratory	AC 0/10	PAC 0/10	AC 0/14	PAC 0/10	AC 0/14	PAC 0/10
Lab 1	76.2	72.3	81.1	75.0	87.8	80.3
	76.1	72.2	80.7	74.7	86.8	79.9
Lab 2	75.7	72.6	81.3	75.4	88.7	81.8
	75.9	72.5	81.5	75.2	88.8	81.8
Lab 3	75.1	71.1	80.8	74.5	87.6	81.2
	75.3	71.4	80.5	75.1	87.6	81.4
Lab 4	75.5	72.0	80.5	75.0	87.6	82.2
	75.6	71.3	81.0	75.3	87.9	82.0
Lab 5	75.3	71.4	81.4	75.7	88.1	80.6
	75.4	-	80.5	-	87.2	-
Lab 6	76.2	73.6	81.0	75.4	88.6	80.8

	76.1	72.6	80.7	76.0	87.3	82.1
Lab 7	75.1 75.1	71.4 71.4	80.6 80.6	75.8 75.4	87.8 87.9	81.6 82.1
Lab 8	75.4 75.2	71.8 72.3	81.0 80.9	75.6 76.0	87.5 87.2	82.0 81.4

3.2.2. Statistical analysis

Calculation of B-Form

B-Form is derived from the average of each cell in A-Form (Table 6)

$$\overline{y_{ij}} = \frac{1}{n_{ij}} \sum_{k=1}^{n_{ij}} y_{ijk}$$

Where n_{ij} is the number of measured results in a laboratory i at a level j, and y_{ijk} is one of these measured results. $n_{ij} = 2$ in the present case.

Table 7 : B-Form in dB(A)

	CPB		SPB – LightVehicles		SPB - HeavyTrucks	
Laboratory	AC 0/10	PAC 0/10	AC 0/14	PAC 0/10	AC 0/14	PAC 0/10
Lab 1	76.15	72.25	80.90	74.85	87.30	80.10*
Lab 2	75.80	72.55	81.40	75.30	88.75	81.80
Lab 3	75.20	71.25	80.65	74.80	87.60	81.30
Lab 4	75.55	71.65	80.75	75.15	87.75	82.10
Lab 5	75.35	-	80.95	-	87.65	-
Lab 6	76.15	73.10	80.85	75.70	87.95	81.45
Lab 7	75.10	71.40	80.60	75.60	87.85	81.85
Lab 8	75.30	72.05	80.95	75.80	87.35	81.70
Total Avg	*75.58*	*71.99*	*80.88*	*75.34*	*87.78*	*81.41*

Calculation of C-Form

This following step consists in evaluating the dispersion inside cells, by a calculation of standard deviation :

$$s_{ij} = \sqrt{\frac{1}{n_{ij}-1} \sum_{k=1}^{n_{ij}} \left(y_{ijk} - \overline{y_{ij}}\right)^2}$$

Table 8 : C-Form in dB(A)

	CPB		SPB – LightVehicles		SPB - HeavyTrucks	
Laboratory	AC 0/10	PAC 0/10	AC 0/14	PAC 0/10	AC 0/14	PAC 0/10
Lab 1	0.07	0.07	0.28	0.21	0.71	0.28
Lab 2	0.14	0.07	0.14	0.14	0.07	0.00
Lab 3	0.14	0.21	0.21	0.42	0.00	0.14
Lab 4	0.07	0.49	0.35	0.21	0.21	0.14
Lab 5	0.07	-	0.64	-	0.64	-
Lab 6	0.07	0.71	0.21	0.42	0.92	0.92
Lab 7	0.00	0.00	0.00	0.28	0.07	0.35

Lab 8	0.14	0.35	0.07	0.28	0.21	0.42

Application of Cochran Test for intra-laboratory variability

This test consists in calculating a statistical indicator C_{stat} from C-Form and comparing it to tabulated critical values $C_{cr}(1\%)$ and $C_{cr}(5\%)$. If C_{stat} is lower or equal to $C_{cr}(5\%)$, than the tested population is accepted as correct (no aberrant value).

$$C_{stat} = \frac{S_{max}^2}{\sum_{i=1}^{p} S_i^2}$$

where ***p*** is the number of laboratories involved.
The results of the present test gives :

Table 9 : Cochran Test statistical indicators

	CPB		SPB – LightVehicles		SPB - HeavyTrucks	
	AC 0/10	PAC 0/10	AC 0/14	PAC 0/10	AC 0/14	PAC 0/10
C_{stat}	0.2500	0.541	0.559	0.286	0.457	0.665
p	8	7	8	7	8	7
$C_{cr}(5\%)$	0.680	0.727	0.680	0.727	0.680	0.727
Aberrant value ?	no	no	no	no	no	no

No aberrant value was detected in the experimental set according to the Cochran Test.

Application of Grubbs Test for inter-laboratory variability

This test is applied on B-Form values, for each level independently. It consists in calculating statistical indicators G_{min} for minimum value and G_{max} for maximum value, and comparing them to tabulated critical values $G_{cr}(1\%)$ and $G_{cr}(5\%)$ (details for the calculation of G_{min} and G_{max} and the procedure for comparison with G_{cr} can be found in ISO 5725-2).

Table 10 : Grubbs Test statistical indicators

	CPB		SPB – LightVehicles		SPB - HeavyTrucks	
	AC 0/10	PAC 0/10	AC 0/14	PAC 0/10	AC 0/14	PAC 0/10
G_{min}	1.145	1.190	1.135	1.277	1.047	2.080
G_{max}	1.770	1.537	1.949	1.074	2.044	1.388
p	8	7	8	7	8	7
$G_{cr}(5\%)$	2.126	2.02	2.126	2.02	2.126	2.02
$G_{cr}(1\%)$						2.139
Aberrant value ?	no	no	no	no	No	1 isolated val.

According to Grubbs test analysis, there is no aberrant value in the set of measurements. There is only one isolated value mentioned by an asterisk (*) in B-Form.

Calculation of repeatability and reproducibility

In our case where the number of measured results for each laboratory is $\boldsymbol{n_{ij}=2}$, the different variances at each level as defined previously can be written :

- Variance for repeatability :

$$s_{rj}^2 = \frac{1}{2p}\sum_{i=1}^{p}\left(y_{ij1} - y_{ij2}\right)^2$$

- Intra-laboratories variance :

$$s_{Lj}^2 = \frac{1}{p-1}\sum_{i=1}^{p}\left(\overline{y_{ij}} - \overline{\overline{y_j}}\right)^2 - \frac{s_{rj}^2}{2}$$

- Variance for reproducibility :

$$s_{Rj}^2 = s_{rj}^2 + s_{Lj}^2$$

The analysed results are presented in Table 11 below.

Table 11 : Repeatability and reproducibility of the experimental results in dB(A)

	CPB		**SPB – LightVehicles**		**SPB – HeavyTrucks**	
	AC 0/10	**PAC 0/10**	**AC 0/14**	**PAC 0/10**	**AC 0/14**	**PAC 0/10**
s_L^2	0.17	0.37	0.02	0.12	0.09	0.35
s_r^2	0.01	0.13	0.09	0.09	0.23	0.18
s_R^2	0.18	0.50	0.11	0.21	0.32	0.53
r	0.3	1	0.8	0.8	1.3	1.2
R	1.2	2	0.9	1.3	1.6	2

Final limits of repeatability and reproducibility

It would be interesting to look for a functional relationship between the reliability and the average level ***m***. This could indicate if the values of reliability depend on the type of road surface. Of course, the number of measured results in this experiment is too small (only 2) to get such an information.

However, an average value of ***r*** and ***R*** at each level was used for a general estimation of repeatability and reproducibility of the measurement method :

Table 12 : Final estimations of the reliability of the methods in dB(A)

	CPB method	**SPB method**
r in dB(A)	0.7	1
R in dB(A)	1.6	1.5

4 CONCLUSION

Two series of round robin tests were made in order to validate the reliability of CPB and SPB measurement methods. The first experiment resulted principally in an improvement of CPB procedure by defining 4 vehicle/tyre configurations. The second experiment resulted in an estimation of repeatability and reproducibility. Both procedures show a similar reliability : around 1 dB(A) for repeatability, and 1.5 dB(A) for reproducibility.

It is clear that the improvement of the procedures resulted in a greater reliability of the method. But another important factor that contributed to this, very difficult to estimate, is the greater awareness of the operators.

Reference

AFNOR S 31-119, 1993 - Acoustique : Caractérisation in situ des qualités acoustiques des revêtements de chaussées - Mesurages acoustiques au passage.

ISO 11819-1, 1997 – Acoustics : Methods for measuring the influence of road surfaces on traffic noise. Part 1 : The statistical Pass-By method.

S. Doisy – "Comparison of ISO 11819-1 and AFNOR S 31119 for SPB measurements" – 11710199, 2000 [*internal document in French*]

M. Bérengier – "Round robin test for repeatability and reproducibility for the characterisation of tyre-road noise according to AFNOR S 31119", 1995 [*internal document in French*].

B. Dulau - "Reliability of French-German method for the characterisation of road traffic noise sources" – FAER 271126, 1997 [internal document in French]

ISO 5725-1 - Application of statistics. Accuracy (trueness and precision) of measurement methods and results. Part 1 : general principles and definitions , 1994

ISO 5725-2 - Application of statistics. Accuracy (trueness and precision) of measurement methods and results. Part 2 : basic method for the determination for repeatability and reproducibility of a standard measurement method, 1994