



ADVANCING IN-SITU NOISE BARRIER TESTING: INSIGHTS FROM INTERNATIONAL INTER-LABORATORY STUDIES

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Abstract

Noise barriers are among the most common noise abatement measures for road and rail infrastructure. To be most effective, they must provide both airborne sound insulation and sound absorption. These properties can be measured either in a reverberant room under diffuse sound field conditions or using so-called in-situ methods under direct sound field conditions. The main advantage of in-situ methods is the ability to perform acceptance testing after installation. The in-situ method for measuring sound absorption is specified in EN 1793-5 (road) and EN 16272-5 (rail), while airborne sound insulation is assessed according to EN 1793-6 (road) and EN 16272-6 (rail). As relatively new approaches, it is crucial to examine the measurement uncertainty of these in-situ methods – both in terms of the ability of institutes to apply them correctly and to provide reliable uncertainty estimates. At AIT Austrian Institute of Technology, two inter-laboratory tests were conducted in 2018 and 2023 with international institutes on Austrian noise barriers in a dedicated test bed. In addition to analyzing the standard deviation of repeatability and reproducibility, the influence of different analysis routines on measurement uncertainty was also investigated. These findings provide critical insights for improving confidence in in-situ testing and advancing standardized noise control practices.

Keywords: measurement method, measurement uncertainty, sound absorption, airborne sound insulation, conformity assessment

1 Introduction

Noise reducing devices (i.e. noise barriers) are an integral part of active noise abatement measurements for road and rail traffic noise. To assess the acoustic properties two series of standards exist, which describe measurement methods depending on the application. The direct sound field methods for sound absorption are described in EN 1793-5:2025 for road traffic noise and in EN 16272-5:2024 for rail traffic noise. The measured quantity is the third-octave band sound reflection index RI , which is the ratio between reflected and incident sound energy. For the airborne sound insulation as described in EN 1793-6:2025 (road) and EN 16272-6:2024 (rail) respectively the measured quantity is the third-octave band airborne sound insulation index SI . For an easy comparison between products single-number ratings are derived from the third-octave band values, by averaging with spectral weights, also called traffic noise spectrum. The road traffic noise spectrum according to EN 1793-3:2025 has the highest weight at the 1 kHz third-octave band, whereas the rail traffic noise spectrum in EN 16272-3-2:2024 is most sensitive for the third-octave bands from 1.25 kHz to 2.5 kHz. The direct sound field methods were developed in the QUIESST project, in which also a round-robin test was performed to determine the measurement uncertainty of the newly developed methods [1].

The determined values are now given as estimates in the respective standards. Guidorzi et al. [2] studied the repeatability of the measurement methods and found a significantly lower standard deviation of repeatability for both methods.

2 Methods

In this study two inter-laboratory tests (ILT) with a total of 16 participants are presented, which were organized by AIT Austrian Institute of Technology GmbH.

2.1 Inter-laboratory tests

The first inter-laboratory test (ILT #1) was performed in 2018, where nine laboratories including AIT participated. The second inter-laboratory test (ILT #2) was held in 2023, where eleven laboratories including AIT participated. Four laboratories participated in both ILTs. Table 1 gives an overview of the measured samples. To test the repeatability of the results, each laboratory was asked to perform two rounds of measurements. All measurements of each test were performed within one month on the same samples within a laboratory hall, which ensures reproducible conditions. Additionally, in each ILT, the impulse responses of a virtual sample for each method were provided by AIT and analyzed by each laboratory. The measurements for R5 in the first ILT were optional and not performed by all laboratories. Although the tests were performed in 2018 and 2023, the results are valid for the current versions of the respective standards.

Table 1 Overview of the samples used in the two ILTs for sound absorption (R1-R10) and airborne sound insulation (D1-D9)

ILT #	Sample		Composition	
1	R1	D1	Aluminum cassettes with perforated plate and absorber	
	R2	D2	Aluminum cassettes with perforated plate and absorber	
	R3	D3	Concrete elements with wood-fibre absorber	
	R4		Concrete elements with wood-fibre absorber	
	R5		Aluminum cassettes with unperforated metal plate	
	D4		Post between D1 and D2	
	R6	D5	Same sample as R2/D2 from ILT #1	
	R7	D6	Elements with loam core, reed filling and wooden frame	
2	R8	D7	Timber elements with wood-fibre absorber	
	R9		Timber elements with wood-fibre absorber	
	R10		Same sample as R5 from ILT #1	
		D8		Post between D5 and D6
		D9		Post between D6 and D7

2.2 Analysis of reported values

ISO 5725-2:2022 describes a method for the determination of repeatability and reproducibility of a standard measurement method. Following these guidelines, the following analysis steps were performed:

- collate reported results and check for obviously erroneous data
- cochrane test to check for outliers regarding within-laboratory variances

- grubbs test for outliers regarding between-laboratory variances
- Calculate general mean \hat{m}_j for each sample j .
- Calculate standard deviations for each sample: standard deviation of repeatability s_{rj} , between-laboratory standard deviation s_{Lj} and standard deviation of reproducibility s_{Rj} , whereas $s_{Rj}^2 = s_{rj}^2 + s_{Lj}^2$.

If no functional relationship between the general mean \hat{m}_j for each sample and the corresponding standard deviation can be found, then the respective standard deviation (repeatability, reproducibility, between-laboratory) is calculated as the mean over the standard deviations of all samples. In appendix B of ISO/IEC 17043:2023 statistical methods for proficiency tests are given. In this study the z-score is calculated $z = (x_{ij} - \hat{m}_j) / s_{Rj}$ as with s_{Rj} as the best estimate of the standard deviation of reproducibility, which is given in the respective standard. As a z-score ≤ 2 is considered an acceptable result, a maximum difference between a measurement result x_{ij} of laboratory i for sample j to the mean of 2 s_{Rj} is considered acceptable.

3 Results and discussion

3.1 Sound absorption

Figure 1 shows the single-number ratings for sound absorption under direct sound field conditions according to EN 1793-5 for the road traffic noise spectrum on the left side as well as according to EN 16272-3-2 for the rail traffic noise spectrum on the right side after outlier removal. Each laboratory is assigned a distinct color. The solid lines show the calculated sample means \hat{m}_j , the dashed line is the expanded measurement uncertainty around the sample mean \hat{m}_j calculated from the standard deviation of reproducibility s_{Rj} from the respective standards. The dotted line is the expanded measurement uncertainty $\pm s_{Rj}$ around the sample mean \hat{m}_j calculated from the results of the inter-laboratory tests after outlier removal.

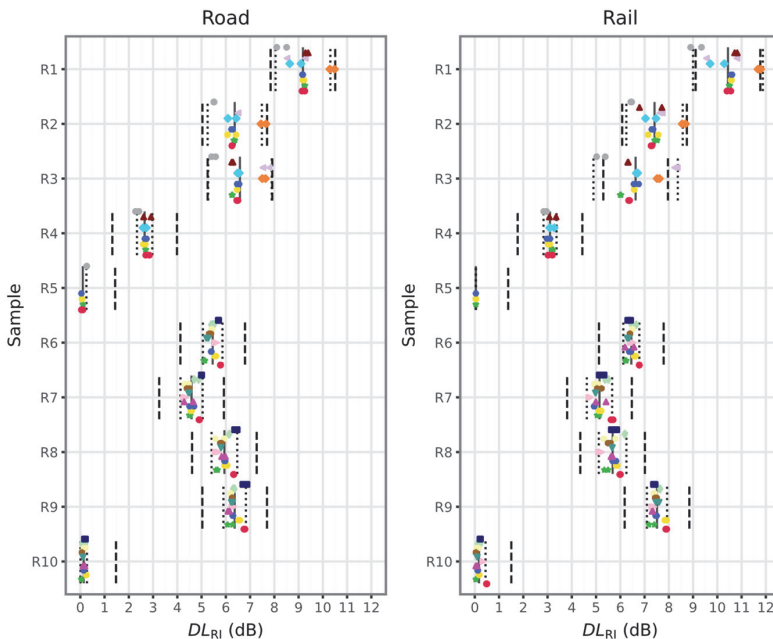


Figure 1 Results of the ILTs for the single-number rating for sound absorption according to EN 1793-5 (road) and EN 16272-3-2 (rail)

For the road rating all samples show an acceptable z-score. In both ILTs some laboratories show increased deviations, but overall the agreement between the laboratories is much higher in the second ILT (samples R6-R10). The results for the rail rating show higher deviations: For samples R1 to R3 in the first ILT not all laboratories reached an acceptable z-score, as the reported values are further away than two standard deviations of reproducibility s_{Rj} from the sample mean \hat{m}_j . In figure 2 the calculated standard deviations for repeatability s_{Tj} and reproducibility s_{Rj} are shown, which were calculated for each sample for the single-number ratings of sound absorption for the road and rail traffic noise spectrum. According to ISO 5725-2 a dependence of the standard deviations on the mean \hat{m}_j should be examined. As samples R5 and R10 are not the necessarily typical application of the standards and are limited to a lower bound of 0.04 dB, these samples are excluded from further calculations. For the other samples, no apparent relationship could be found. Therefore, estimates of the standard deviations are calculated as mean of the standard deviations of the samples (s_{Tj} , s_{Rj}) excluding R5 and R10. The solid lines depict the respective standard deviation from the standard. The dotted lines show the mean standard deviations only for the samples from the first inter-laboratory test, whereas the dashed lines are calculated from the samples from the second ILT. The dash-dotted line uses the samples of both ILTs. These standard deviations are also listed in table 2 together with the between-laboratory standard deviation.

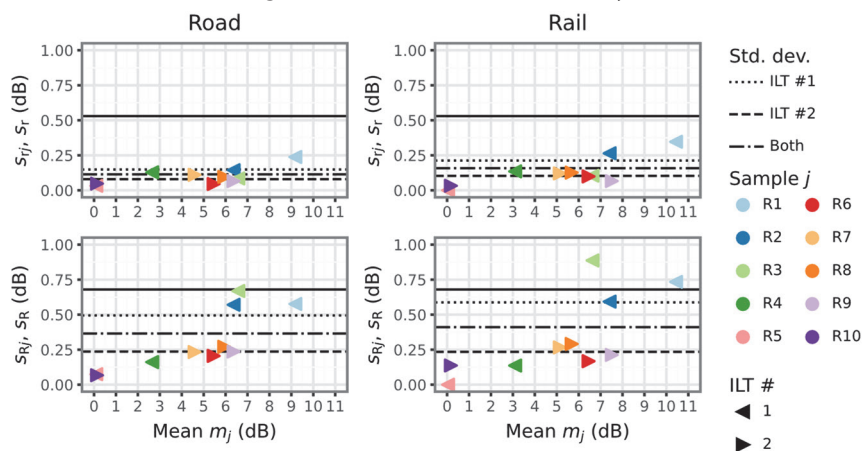


Figure 2 Standard deviation for repeatability s_T (top row) and reproducibility s_R (bottom row) calculated for each sample (colored markers) from the ILTs for the single-number ratings of sound absorption for road (left) and rail (right) traffic noise spectrum

All calculated standard deviations for repeatability and reproducibility are lower than the values from the standards. Also, the most contributing factor shifts from the repeatability variance to the between-laboratory variance. In the first ILT the standard deviations for between-laboratory variance is higher than respective values from the standard. Nevertheless, for the second ILT also the between-laboratory variance is significantly less, which shows a much better agreement between the laboratories. Especially for the first ILT, the standard deviations are higher for the rail traffic noise spectrum. This may be caused by a higher sensitivity of the spectrum for higher frequencies.

Table 2 Standard deviations for sound absorption

	Repeatability		Reproducibility		Between-lab.	
	Road	Rail	Road	Rail	Road	Rail
ILT #1	0.15 dB	0.21 dB	0.49 dB	0.59 dB	0.47 dB	0.55 dB
ILT #2	0.08 dB	0.10 dB	0.24 dB	0.23 dB	0.22 dB	0.21 dB
Both	0.11 dB	0.16 dB	0.37 dB	0.41 dB	0.35 dB	0.38 dB
Standard	0.54 dB	0.54 dB	0.69 dB	0.69 dB	0.43 dB	0.43 dB

3.2 Airborne sound insulation

Figure 3 shows the single-number ratings for airborne sound insulation under direct sound field conditions according to EN 1793-6 for road traffic on the left side as well as according to EN 16272-3-2 for rail traffic on the ride side after outlier removal. The layout of the figure is the same as in figure 1 in section 3.1.

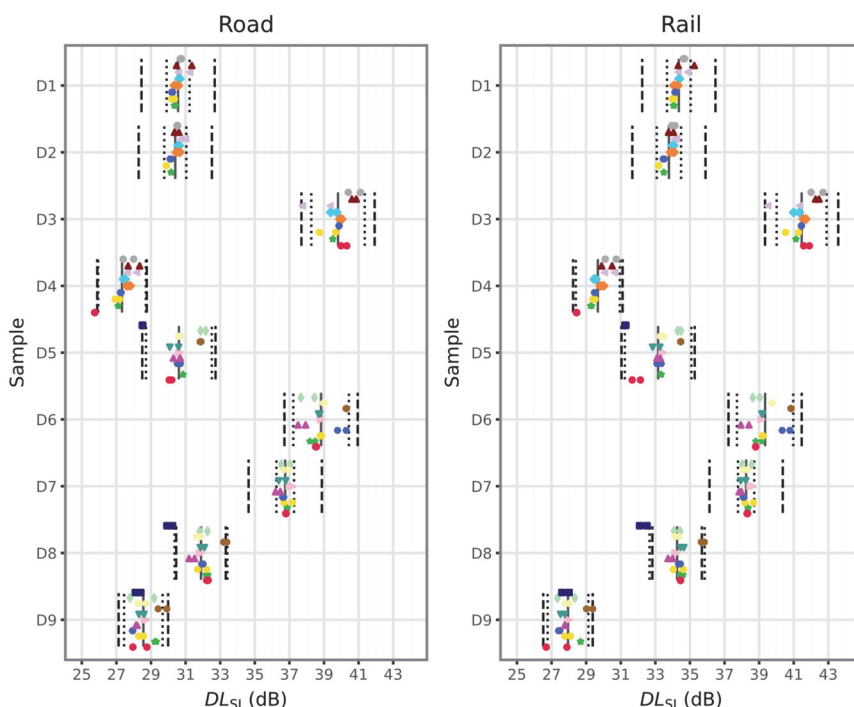


Figure 3 Results of the ILTs for the single-number rating for airborne sound insulation according to EN 1793-6 (road) and EN 16272-3-2 (rail)

Even after outlier removal, some laboratories didn't reach an acceptable z-score rating, especially the two laboratories depicted with red dots and navy-colored squares. The performance of the red laboratory significantly improved between the ILTs. The navy laboratory only participated in the second tests and except for D9 showed significantly lower values than the other laboratories (also for the removed outliers in D6 and D7). For both tests, some samples show smaller deviations than expected from the uncertainty values in the standards, while for others the estimates in the standards appear valid. No significant differences between the road and rail spectrum could be observed.

In figure 4 the calculated standard deviations for repeatability s_{rj} and reproducibility are shown, which were calculated for each sample for the road and rail traffic noise spectrum. The standards report a different standard deviation for the Element (E) and Post (P) measurements. Nevertheless, in the two ILTs no apparent significant differences could be found and due to the limited number of samples, the overall standard deviations are calculated regardless if it is an element or post measurement. Also, no functional dependence of the standard deviations on the sample mean values can be observed and the standard deviations are calculated as mean of the standard deviations of the samples (s_{rj} , s_{Rj}). The layout of figure 4 is the same as in figure 2. The standard deviations are listed in table 3.

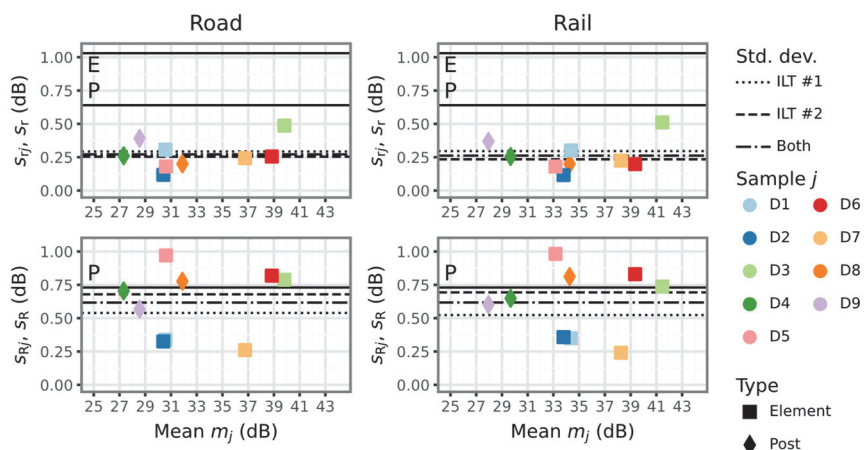


Figure 4 Standard deviation for repeatability s_{rj} (top row) and reproducibility s_{Rj} (bottom row) calculated for each sample from the ILTs for the single-number ratings of airborne sound insulation for road (left) and rail (right) traffic noise spectrum

The repeatability was very similar in both ILTs and much better than the estimates in the standards. However, the standard deviation of reproducibility didn't increase in the same amount, as the observed between-laboratory standard deviation is higher than the measurement uncertainties given in the standards suggest. Also, the repeatability of the laboratories improved a little from the first to the second ILT. Nevertheless, the laboratory variance significantly increased, thus resulting in a higher standard deviation of reproducibility (0.68 dB instead of 0.54 dB for road traffic noise for the two ILTs).

Table 3 Standard deviations for airborne sound insulation

	Repeatability		Reproducibility		Between-lab.	
	Road	Rail	Road	Rail	Road	Rail
ILT #1	0.29 dB	0.30 dB	0.54 dB	0.52 dB	0.45 dB	0.43 dB
ILT #2	0.25 dB	0.23 dB	0.68 dB	0.69 dB	0.63 dB	0.65 dB
Both	0.27 dB	0.26 dB	0.62 dB	0.62 dB	0.55 dB	0.56 dB
Standard E.	1.03 dB	1.03 dB	1.08 dB	1.08 dB	0.32 dB	0.32 dB
Standard P.	0.64 dB	0.64 dB	0.73 dB	0.73 dB	0.35 dB	0.35 dB

3.3 Virtual sample

Table 4 shows the calculated standard deviation of the single-number ratings after the manual removal of outliers, which were caused by data import errors. The deviations are caused by different applications or implementations of pre-defined algorithms and might also influence the measurement uncertainty of the methods.

Table 4 Standard deviation for the single-number ratings of the virtual sample

	Sound Absorption		Airborne Sound Insulation	
	Road	Rail	Road	Rail
ILT #1	0.09 dB	0.06 dB	0.05 dB	0.02 dB
ILT #2	0.05 dB	0.06 dB	0.02 dB	0.05 dB

4 Conclusion

Two ILTs on methods for measuring sound absorption and airborne sound insulation under direct sound field conditions of noise barriers were performed. In this study, the results were published for the application for road and rail infrastructure. In comparison to the estimates of the measurement uncertainty in the standards, the observed repeatability is much better. In both ILTs, the standard deviation of reproducibility is also generally lower. Significant differences between the road and rail spectrum could not be found, except for sound absorption in the first ILT. Nevertheless, analysis of measurement results should consider the different noise spectrum weighting, as the calculated standard deviations are close but not necessarily identical. Further ILTs are recommended to create a good data basis for improving the estimates of measurement uncertainty in the standards.

Acknowledgments

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References

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ADVANCES IN RAIL INFRASTRUCTURE CONDITION MONITORING

