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UNCERTAINTIES FOR MEASURED AND MODELLED ENVIRONMENTAL NOISE PARAMETERS FROM INTERLABORATORY COMPARISON

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ABSTRACT

In this paper the results of interlaboratory comparison (ILC) in the field of environmental noise parameters measurements according to ISO 1996-2:2017 without (41 labs) and with meteorological conditions at 10 m together with modelling results according to ISO 9613-2:1997 (10 labs) and EU-CNOSSOS method (7 labs) are presented. The two measurement situations are considered, simulated industrial site with loudspeaker inside the building and local road. The industrial site noise parameters are measured at two positions (25m in free field and at 50 m in front of reflection surface). Traffic noise levels are measured in the free field at 100 m distance. The environmental noise levels are obtained under the different influence of residual noise from nearby highway and local activities during the day period. The measurement results for A-weighted equivalent sound pressure levels ($L_{Ae,eq}$), A-weighted spectrum for industrial noise site and in addition sound exposure levels (L_{AE}) for each individual pass-by of vehicles with their standard deviations and measurement uncertainties for each traffic category are shown with determined meteorological conditions. The measurement results at reference points are later used in modelling the industrial noise source and local road at other defined positions with results of modelling expressed in terms of sound power and sound descriptors with reported and calculated measurement uncertainties for complete ILC.

Keywords: *interlaboratory comparisons, environmental noise parameters measurement and modelling, industrial site and local road, measurement and modelling uncertainties, meteorological conditions.*

1. INTRODUCTION

The accreditation procedure according to ISO 17025:2017 for laboratories that are doing acoustic measurements (in the field of environmental noise, is a tedious task due to different approaches of different labs to the same problem (sound source) [1]. Quality control is the main motive for individual laboratories to cooperate within the ILC, but this can be used to make detailed analyses of all individual results of laboratories included in environmental noise parameter measurements and modelling. All these laboratories certify the environmental noise parameters from different noise sources (industrial and small workshop sites, road, rail, and air traffic). The motivation for this organization was the change of the standard ISO 1996-2:2017[2] to see how the different laboratories approach to the same problem.

1.1 Measuring scheme

Croatian Acoustical Society organized in ILC with 44 registered participants in the field of stable industrial source measurement at two different positions (first where Eq. 11 from ISO 1996-2:2017 standard is fulfilled and second where it is not fulfilled) [3]. The results are acquired

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from 41 of 44 labs for a stable industrial source installed in the house with one opened window and from 11 of 15 labs when local road traffic noise parameters are measured. The stable industrial pink noise source with 10 kHz tone was installed in the room in one house simulating industrial source according to the Figure 1.

Results for residual noise and when the source is turned on are shown, with experimental measurement uncertainties which are compared with reported uncertainties from labs obtained by repeating measurements in short intervals. The measurement situation is shown in Figure 1.

Figure 1. Measurement situation for stable source and local road with location of sources and imission points).

In this report, only the main measured values are considered measured $L'_{A,eq}$ at two different positions between houses when the source is turned off and on, rated $L_{RA,eq}$ when the source is turned on, and A-weighted spectral values when the source is turned off and on.

When local traffic road is considered the results are acquired from 20 labs for A-weighted equivalent sound pressure level and from 16 labs for L_{AE}, $L_{A,max}$ for each vehicle category type because local road traffic was not so dense and it was possible to distinguish individual vehicle categories and study the statistics.

In addition, the meteorological conditions measured from labs and organizers at 10 m should be related to measured noise samples from the source when the noise levels are measured at position 2 (eq. 11). standard [2] is not satisfied). The measurement uncertainty for all parameters (with excluded outliers) is calculated in the form of standard deviations and experimental measurement uncertainty (depending on the number of samples).

1.2 Modelling scheme

The results of measurements at two positions from stable source and one position from local road source are used in modelling the environmental noise levels at other positions. The calculation models for stable industrial source were ISO 9613-2:1997 [3] and EU-CNOSSOS [4] and for local road observed as line source was NMPB 2008 [5] and EU CNOSSOS. The modelling scheme is shown in Figure 2.

Figure 2. Modeling scheme for stable and local road as line source with measurement positions as reference and new objects and additional positions.

2. MEASUREMENT AND MODELING SITUATION

Measured data have been analyzed in detail and measurement data are used in model calibration.

2.1 Measurement situation

Laboratories have recorded several noise samples in different time intervals (several samples usually 5 with 1 min-15 min duration) at two different positions (free field and in front of reflecting surface) and they averaged the results regarding their duration and found standard deviations as described in [2].

There was a problem with tonality at measurement position S1P1, S1P2 because some laboratories had tonal correction and some not. The problem with 10 kHz tone is large directivity of the source at that frequency so slightly changed position can have significant influence on K_T. In final comparison for $L_{RA,eq}$ the tonal component was removed from labs which reported tonal penalty.

The stability of source is checked by measuring sound pressure level in the room at the same place before and after measurement session of each lab and experimental uncertainty for $L'_{A,eq}$ was u=0,03 dB.

The meteorological data are measured during the intervals when noise is measured at S1P2 (form industrial source) and S2P3(local road with mixed traffic) when equation 11. from standard ISO 1996-2:2017 is not satisfied. Measured meteorological data in noise samples intervals are (wind speed, wind direction, temperature, pressure and humidity at 10 m height or on the height of microphone (for labs which do not have possibilities to measure meteorological conditions at 10m height).

Meteorological parameters have been measured by organizer for each lab which have meteorological station and for all other participants which do not have meteorological station. For some which do not have meteorological station the meteorological data are compared and compared with obtained meteorological windows [2]

2.2 Modelling situation

Laboratories have been measuring noise from the stable source at two predefined positions: first on the border in the middle between houses and second in front of the facade with necessary correction due to position near reflecting surface [2]. One lab (Lab21) has chosen additional measurement positions from stable source in the directions of newly installed objects to account source directivity. Other labs haven't considered plane source directivity (it is not reported) so their results (Lab21) without plane source directivity is taken into comparison. In standard ISO 1996-2:2017 [2] it is explicitly written that for complex sources the directivity of the source in different directions when model is calibrated should be considered.

Laboratories have recorded several noise samples in different time intervals (usually 5 or 10 samples with 1-15 min duration) at two different positions (25 m and 50m) and they averaged the noise samples regarding their duration and standard deviations given in the standard ISO 1996-2:2017 and excel tables. This was done to calibrate the considered acoustic models for stable source and local road. each lab measured the local road traffic noise usually for 60 min in one or two calibration points [7] and sound exposure levels (L_{AE}) for each individual event of interest (light, medium and heavy vehicle pass-by) has been determined.

The laboratories have measured the environmental noise parameters from local road at one predefined position (Pos3 in ILC-1-2019) at 4 m height and some have chosen closer measurement position to the local road (7,5 m from the road or at the position between the predefined measurement position or line sound source ≈50 m). They provided the number of different types of vehicles (light, heavy and medium).

The labs have used the measured equivalent sound pressure level to estimate sound power from the sources and find new equivalent levels at four additionally defined positions.

2.3 Measured and modelled parameters

Measured noise parameters when the source is turned on are:

$L'_{A,eq}$ (dB(A)) and $L_{RA,eq}$ – measured and rated A-weighted equivalent sound pressure level (corrected to free field conditions), corrected due to influence of measurement position and residual noise.

L_{WA} (dBA) - sound power of the sources (unknown but it can be determined from the calibration measurement at predefined positions).

In addition, the sound descriptors $L_{d(ay)}$ for stable sound source and traffic environmental noise parameters during the measurements (usually 1h) are found (from counted number of vehicles). The organizer provided the average number of vehicles for day, evening and night period and participants should determine the equivalent sound pressure levels and sound descriptors L_{day}, $L_{evening}$, L_{night} and L_{den}.

2.4 Statistics

The experimental measurement uncertainty was found using Eqn. (1) when measured quantities are converted to relative numbers and vice versa [2]:

$$u(x_i) = 10 \cdot log_{10}\left(10^{0,1 \cdot L_k} + S(x_i)\right) - L_k \quad (1)$$

where L_k is energy averaged sound pressure level of N_m independent measurements in the meteorological and emission window according to Eqn. 2 [2].

$$L_k = 10 \cdot log_{10}(\frac{1}{N_m} \cdot \sum_{i=1}^{N_m} 10^{0.1 \cdot L_i}) \quad (2)$$

This equation is valid only if each of the independent measurements last equal time. If the independent measurements last non-equal in time, then additional time weighting should be used when calculating averaged value according to the eq. (6).

2.5 Detection of outliers

Cochran's test is used to check if there are cell standard deviations of several (n≥5) independent measurements exceptionally large and would inflate the estimate of the repeatability standard deviation if retained.

Grubb's test is used to check if there are means in laboratory results that are exceptionally high or low and would inflate the estimate of the reproducibility standard deviation if retained.

3. RESULTS

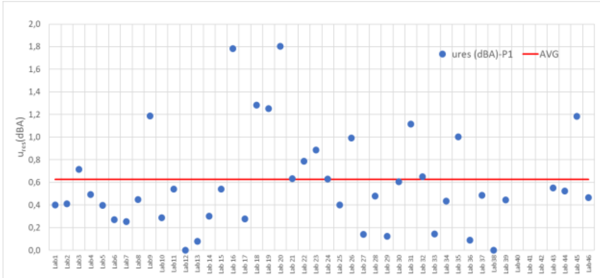
The results section is divided in sections for stable source (residual noise and when the source is turned on), meteorological conditions, A-weighted sound pressure levels for local road, sound exposure levels for each category and modelling results for descriptors with experimental uncertainty.

3.1 Measurement results for stable source

Results in this report are shown only for A-weighted values when the source is turned off and on for two different positions.

3.1.1 Residual noise measurement results

The experimental measurement uncertainties for each lab (by using Eq. 2) are shown in Figure 3 together with reported A-weighted spectrum).



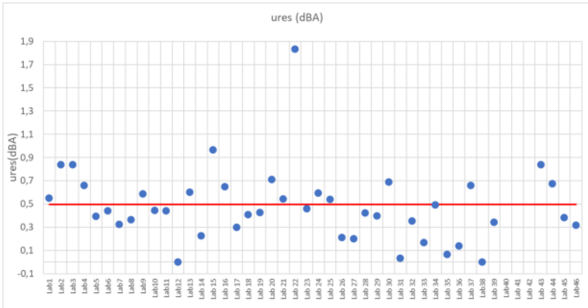


Figure 3. Experimental measurement uncertainties for residual noise measurement results at two different positions (25 m in free field and 50 m (in front of the reflecting surface) and A-weighted spectrum.

It is evident that there is no significant difference between experimental measurement uncertainties for two different positions (u (L_{res}) at S1 and 2 even P1 is in free field and P2 in front of reflecting plane). Some labs haven't shown the A-weighted spectrum (determination of possible tonal penalty was problematic in that case)

3.1.2 Stable source measurement results

The same parameters are observed when the source is turned on. Some labs corrected the level and added tonal penalty in each sample and some have done averaging for all samples and correction for all samples. The results for rating levels are shown in Figure 4 at two different positions.

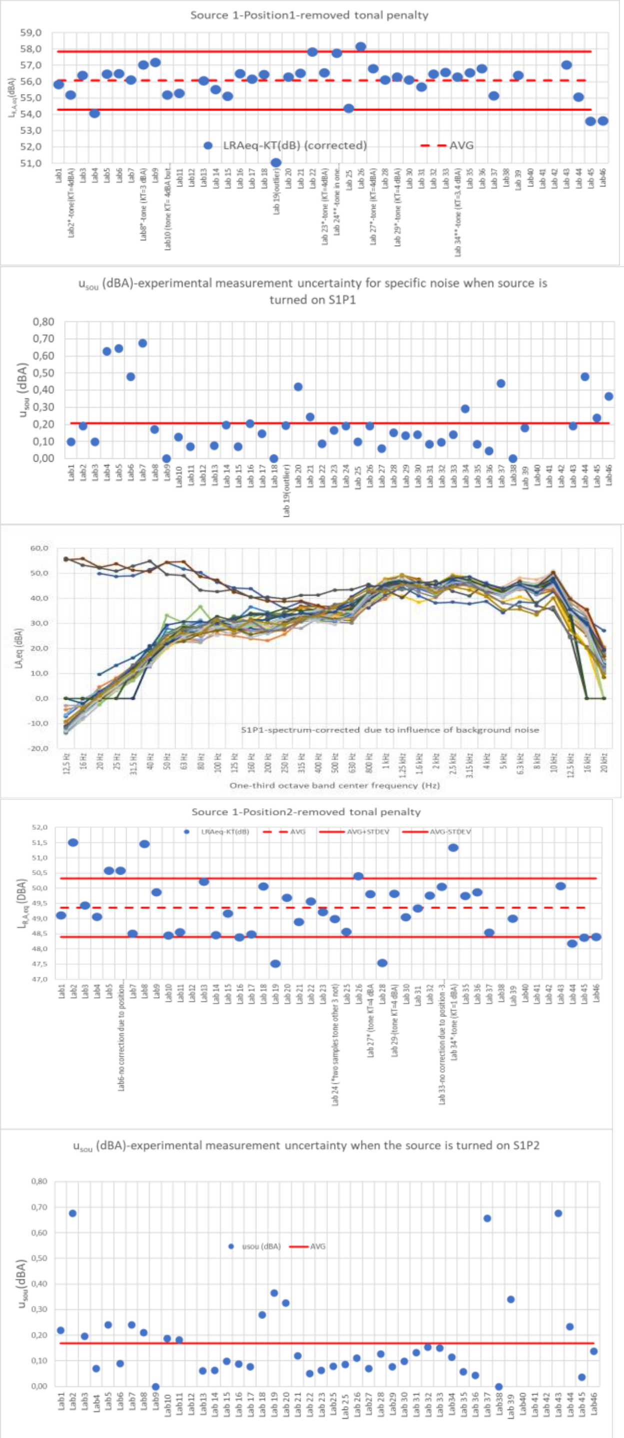


Figure 4. Measurement results for $L_{R,eq}$ at two different positions (25m free field and 50 m in front of the reflecting plane) with experimental measurement uncertainties.

It is interesting that average value of experimental measurement uncertainty (u_{sou}) at position 2 is almost equal than at position 1 due to directivity of plane source in near field at higher frequencies because the tone is inserted in the signal (10 kHz). Some labs reported tonal penalty at 10 kHz depending on their location at position 1 (in front of the plane source or little beside) due to source directivity at 10 kHz frequency. The majority of labs haven't reported tonal penalty so the tonal penalty was removed and rating levels (corrected due to residual noise are shown).

All the measured parameters should have been corrected due at P2 to influence of reflection (-3 dB) The labs provided residual noise and spectrum spectrum data without correction due to position (just corrected due to influence of background noise in agreement with organizer). This was done by organizer to obtain comparable results.

In A-weighted spectrum the tone at source 1 measurement position 1 is visible and also some labs reported the Z(ero)-weighted spectrum due to restriction in their instruments (A-weighting is not done in instrument and additional calculations should be done in software). The results for parameters (averaged values) with standard deviations and overall experimental measurement uncertainty are shown in Table 2.

Table 2. Ovarall results from labs without outliers for measured parameters.

Parameter	AVG (dB)	STDEV (dB)	Number of participants	u (dBA)
$L'_{A,eq}$-Residual noise -S1P1	43,6	2,1	41	0,3
$L'_{A,eq}$-Residual noise -S1P2	44,4	2,3	41	0,4
$L_{RA,eq}$- Source noise- S1P1	56,1	0,9	41	0,1
$L_{RA,eq}$-Source noise S1P2	49,4	1,1	41	0,2

3.1.3 Meteorological conditions during measurements of stable source at S1P" position

The laboratories put their meteorological station near to organizer and meteorological windows obtained by organizers and the results for meteorological windows are shown in Table 2. The majority of labs don't have meteorological station because they measure the noise levels at short distances so the organizer determined meteorological windows for them in accordance to Table 4 and ANNEX A from ISO 1996-2:2017. The participants measured the noise levels during day period between 8:00-19:00. Each lab come at different day and time period to have different influence of residual noise.

Table 2. Compared meteorological windows from participants and organizer during measurement interval when measurements are done at S1P2 position.

Lab	Org-Window-Table 4.	Org-Window-Annex-A	Participant-Window-Table 4.	Participant Window-Annex-A
1	M1	M1		
2	M1	M1	M1	M1
3				
4	M1	M1	M1	M1
5	M1	M1		
6	M1	M1		
7	M1	M1		
8	M2	M3		
9	M1	M2	M1	M2
10	M1	M1	M1	M1
11	M2	M1		
13	M1	M2	M1	M2
14	M1	M2		
15	M1	M1	M1	M1
16				
17	M1	M1	M1	M1
18				
20	M1	M2	M1	M2
21	M1	M1	M1	M1
22	M1	M1		
23	M1	M2	M1	M2
25	M1	M1	M1	M1
27	M1	M1		
28	M1	M2	M1	M2
29	M1	M1		
30	M1	M1	M1	M1
32	M1	M1		
33	M1	M1		
35	M1	M1		
37	M1	M2	M1	M2
45	M1	M3	M1	M3
46	M1	M1	M1	M1

Most participants haven't averaged the meteorological data in intervals when noise samples from the source are obtained or just provided the list of data without determination of meteorological windows. Some stations perform the scalar averaging of wind speed not vectorial.

3.2 Measurement results for local road traffic

The local road noise levels are measured at distance 100 m from the road (open area, soft ground). In addition to $L'_{A,eq}$ and $L_{A,max}$ parameters the sound exposure levels for each vehicle category is determined with their uncertainty and this location. The traffic was not so dense so individual pass-by of different vehicle categories are distinguish according to figure 5 (logging data during measurements) and by the L_{AE} parameters are determined for each lab with experimental measurement uncertainty.

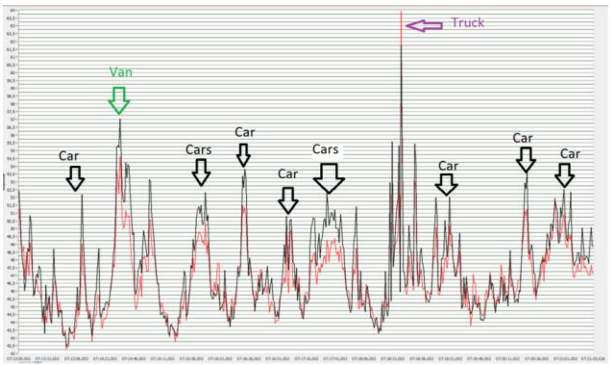


Figure 5. Logging $L_{Aeq,1}$ s data during pass by of vehicles and distinguishing different type of vehicles (S2P3 at 100m and control position at 40 m distance).

The results for measured $L'_{A,eq}$ levels from local road with $L'_{A,95}$ and L_{AE} for each vehicle category are shown in Table 3.

Table 3. Measurement results (overall AVG without outliers) for traffic noise parameters with experimental measurement uncertainties and number of observed vehicles.

Parameter	AVG (dB)	STDEV (dB)	Number of participants	u (dBA)
$L_{RA,eq}$	45,6	2,3	20	0,5
$L'_{A,95}$	38,9	2,8	19	0,6
L_{AE} -L	50,7	3,1	15	0,8
L_{AE} -M	55,4	2,3	16	0,6
L_{AE} -H	60,8	3,2	16	0,8
$L_{A,max}$ -L	48,7	3,8	16	1,0
$L_{A,max}$ -M	50,5	3,6	16	0,9
$L_{A,max}$ -H	558	3,9	16	1,0

*L-light, M-medium, H-heavy

Some labs didn't want to analyze passing-by vehicles as individual events, so they just send the overall measured value. Two labs (17,27) didn't have logging, so they have done the analysis by observing individual pass-byes of different vehicles categories. It is evident that obtained experimental measurement uncertainties for $L_{A,eq}$ are much lower than suggested in ISO 1996-2:2017 (eq. 12 and 13.) under typical meteorological windows during the day period.

3.3 Modeling results

3.3.1 Stable source

The laboratories used measurement results at closer position to calibrate the model (determine sound power of the source) and then used that data to recalculate the noise levels at other locations.

The results for stable source sound power with modelling uncertainty are shown in Table 4.

Table 4. Overall results and experimental uncertainties for stable industrial source obtained by two modelling methods.

	AVG - ISO 9613-2:1997 (dB)	u(dB)- ISO 9613-2:1997	AVG-EU-CNOSSOS (dB)	u (dB)-EU CNOSSOS
S1-power	88,2	1,2	90,6	1,3
L_d-1	45,4	0,6	46,4	0,4
L_d-2	45,3	0,7	44,1	0,6
L_d-3	51,5	1,5	51,9	1,0
L_d-4	48,6	0,6	48,2	0,6

It is evident that approximately the same modeling uncertainties are obtained for two different methods and when compared with reported modelling uncertainties from labs they are much lower.

3.3.2 Local road source

In this part the two different approaches have been tested. In first laboratories used measurement data at S2P3 position to calculate noise levels at other positions with number of vehicles during measurement and in other approach only the model has been calibrated with the measurement results and organizer provided the number of vehicles (day, evening night period) to calculate sound descriptors.

The results for number of vehicles during measurements, sound power is and descriptors L_d for two positions during day period are shown and Table 5.

Table 5. Modeling uncertainty for different methods of calculation (NMPB-XPS-12 and CNOSSOS EU-8).

	AVG (dB)-NMPB	u(dB)-NMPB-XPS	AVG (dB)-CNOSSOS	u(dB)-CNOSSOS
S2-power	79,9	0,8	77,7	0,6
L_d-1	46,8	0,9	44,3	0,7
L_d-2	43,4	1,0	41,5	0,6
L_d-3	40,8	1,8	38,1	1,6
L_d-4	41,6	1,5	40,0	1,0

The same procedure is repeated for defined number of vehicles during different periods and the results for modelling with different methods are shown in Table 6.

Table 6. Modelling results and uncertainties with given number of vehicles during day (N_{light}=600 /hour , N_{medium}= 48 /hour, N_{heavy}=12 /hour).

	AVG-NMPB	u(dB)-NMPB	AVG-CNOSSOS	u(dB)-CNOSSOS

S2-power	73,9	0,6	79,4	0,6
L_d-1	49,0	0,5	46,1	0,6
L_d-2	45,5	0,6	43,2	0,5
L_d-3	43,3	1,2	40,8	1,2
L_d-4	44,6	0,8	42,0	1,1

It is visible that with the same data the sound descriptors obtained by CNOSSOS method are lower than compared to the NMPB-XPS method. The modelling uncertainty for all results is significantly lower than reported from the participants (stable and local road source sound power u form 2 dBA to 2,5 dBA, sound descriptors from 2 dBA to 3,5 dBA.

3.3.3 Influence of meteorological conditions on modelling results

All laboratories measured noise levels in neutral on unfavorable conditions during day period and have not corrected the modelling results according to favorable or very favorable conditions.

4. CONCLUSION

Few general remarks are noted for stable source, local road source and meteorological conditions. u_{sou} parameter should be always determined closer to the source and not far away due to influence of other conditions (meteorology, measurement location, absorption in air, reflection from ground). Some laboratories have not apply A-correction on their measurement data so it can be problematic to determine tonal correction K_T which is visible in spectrum when the source is turned on. Also, the A-weighted spectrum is not provided when the background noise is considered. Some labs have not use vectoral averaging but scalar averaging and wind velocity are not averaged in correct manner (as vectors in each interval of noise sample observation). There were no possibility to obtain M3 and M4 meteorological windows during day period. The overall experimental measurement uncertainty u was much lower than suggested isn standard ISO 1996-2:2017 according to u_{met}=2 dBA. When plane source is considered, the directivity should be also taken into account (Lab21 has reported the results assuming directivity of plane source and when directivity is not included into account). Other labs haven't reported that they accounted directivity of the source and that they haven't checked the directivity by measuring sound pressure levels in different directions from plane source.

Some participants didn't want to calculate sound exposure levels for each traffic vehicle category so just reported the overall level during measurement with excluded some residual noises. Some labs are not provided modelling uncertainty and spectrum of the source power for comparison. It is observed that sound power of CNOSSOS method is slightly lower compared to the situation when XPS-NMPB2008 method is considered.

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