Influence of short-term sampling parameters on the uncertainty of the $L_{den}$ environmental noise indicator

M Mateus, J Dias Carrilho and M Gameiro da Silva

ADAI/LAETA – Department of Mechanical Engineering, Faculty of Science and Technology University of Coimbra – Pólo II, 3030-201 Coimbra, PORTUGAL

E-mail: mario.mateus@adai.pt

Abstract. The present study deals with the influence of the sampling parameters on the uncertainty of noise equivalent level in environmental noise measurements. The study has been carried out through the test of different sampling strategies doing resampling trials over continuous monitoring noise files obtained previously in an urban location in the city of Coimbra, in Portugal. On short term measurements, not only the duration of the sampling episodes but also its number have influence on the uncertainty of the result. This influence is higher for the time periods where sound levels suffer a greater variation, such as during the night period. In this period, in case both parameters (duration and number of sampling episodes) are not carefully selected, the uncertainty level can reach too high values contributing to a loss of precision of the measurements. With the obtained data it was investigated the sampling parameters influence on the long term noise indicator uncertainty, calculated according the Draft 1st CD ISO 1996-2:2012 proposed method. It has been verified that this method allows the possibility of defining a general methodology which enables the setting of the parameters once the precision level is fixed. For the three reference periods defined for environmental noise (day, evening and night), it was possible to derive a two variable power law representing the uncertainty of the determined $L_{eq}$ values as a function of the two sampling parameters: duration of sampling episode and number of episodes.

1. Introduction

The current draft document of the ISO 1996-2 standard [1] proposes two distinct sampling methods for estimating environmental noise indicators: one making use of long-term measurements and the other using short-term measurements. In both sampling methods, a measurement campaign may consist of several measurement episodes distributed throughout the assessment period. The details on how to design an appropriate sampling strategy, i.e., how to choose the number and duration of the measurement episodes, are, however, left unspecified in the standard. In addition, there is no guidance as to how the choice of the sampling strategy might influence the overall uncertainty in the determination of environmental noise indicators.

There is, in the literature, some indication as to what extent a required accuracy might be achieved with a particular sampling strategy [2–5]. Given the variability in propagation conditions and source emission characteristics from site to site, however, the sampling strategy that produces the best results in one particular site might not be adequate for a another site. With this problem in mind, the authors have recently proposed a systematic analysis method for assessing the adequacy of a sampling strategy for any given site [6]. The method is based on the bootstrap method, and it produces an estimate of the uncertainty associated with determining environmental noise levels from short-term sampling measurements, as a function of the duration and the number of measurement episodes. In the present

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1 Corresponding author: Tel.:+351 239 708 580; fax: +351 239 708 589
E-mail address: mario.mateus@adai.pt

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paper, the authors demonstrate the application of this method in quantifying the influence of the sampling strategy on the uncertainty of the long term environmental noise indicator \( L_{den} \).

2. Mathematical formulation

In Ref [7] the expression for calculating the long term environmental noise exposure indicator appears:

\[
L_{den} = 10 \times \log_{10} \left[ \frac{1}{24} \left( 12 \times 10^{\frac{L_d}{10}} + 4 \times 10^{\frac{L_e}{10}} + 8 \times 10^{\frac{L_n}{10}} \right) \right] \tag{1}
\]

The indicators \( L_d, L_e \) and \( L_n \) are the long term noise levels for the reference periods: day; evening; and night. These, in turn, can be obtained during the long term period of assessment, taking into consideration that weather conditions can have a significant influence in the way sound energy propagates from source to receiver. ISO1996-2 deals with this by defining four meteorological classes with respect to the propagation of sound energy: M1 – unfavorable; M2 – neutral; M3 – favorable; and M4 – very favorable. If the a number of sample measurements \( n_{Mi} \) are performed for a particular weather condition \( M_i \), for which the probability of occurrence \( P_{Mi} \) is known or can be estimated, the indicators for each reference period can be estimated from

\[
L_{[d],e,[n]} = 10 \times \log_{10} \left( \sum_{i=1}^{n} p_{Mi} L_{[d],e,[n]} \times 10^{0.1L_{[d],e,[n]}} \right) \tag{2}
\]

By the law of propagation of uncertainties, the combined uncertainty of the indicators \( L_{[d],e,[n]} \) is

\[
u(L_{[d],e,[n]}) = \left\{ \sum_{i=1}^{n} \left[ \frac{\partial L_{[d],e,[n]}}{\partial p_{Mi}} \times u(L_{Mi}) \right]^2 + \sum_{i=1}^{n} \left[ \frac{\partial L_{[d],e,[n]}}{\partial P_{Mi}} \times u(P_{Mi}) \right]^2 \right\}^{1/2} \tag{3}
\]

Considering the results presented in (3), it is possible to write the expression for the combined uncertainty of the indicator \( L_{den} \), as follows: Assuming independence between the different variables involved, as in Ref [1], the application of the methodology expressed in the GUM [8], considering also due to sampling component, hereafter denoted by \( u_{samp} \), the following expression is obtained for the uncertainty of sound level \( L_{den} \):

\[
u(L_{den}) = \left\{ \left( \frac{\partial L_{den}}{\partial L_d} \right)^2 u^2(L_d) + u^2_{samp,d} \right\}^{1/2} + \left( \frac{\partial L_{den}}{\partial L_e} \right)^2 u^2(L_e) + u^2_{samp,e} \right\}^{1/2}
\]

\[
u(L_{den}) = \left\{ \left( \frac{\partial L_{den}}{\partial L_n} \right)^2 u^2(L_n) + u^2_{samp,n} \right\}^{1/2} + u^2_{loc} + u^2_{lim} \right\}^{1/2} \tag{4}
\]

were:

- \( \frac{\partial L_{den}}{\partial L_d}, \frac{\partial L_{den}}{\partial L_e} \) and \( \frac{\partial L_{den}}{\partial L_n} \) are the sensitivity coefficients, i.e. they express the change of \( L_{den} \) due to changes in \( L_d, L_e \) and \( L_n \), respectively;
- \( u(L_d), u(L_e) \) and \( u(L_n) \) are the standard uncertainty associated with the measurement performed to characterize the noise in each reference period;
- \( u_{loc} \) is the standard uncertainty associated with the location of the measurement point;
- \( u_{lim} \) is the standard uncertainty associated with the measurement chain;
- \( u_{samp} \) is the standard uncertainty associated with the process of sampling in the period under review.

It is assumed that the components of uncertainty associated with the measuring equipment and the placement of the microphone are constant, i.e., always the same measuring equipment is used and the
sampling is performed on the same site. Regarding the uncertainty due to sampling, it is assumed that it should correspond separately to those resulting from the sampling strategy followed in each period.

Generically, the sensitivity coefficients assume the following expression, were \( w \) is 0 dB, 5 dB or 10 dB, for the day, evening and the night periods, respectively:

\[
\frac{\partial L_{den}}{\partial L_i} = \frac{t_i 10^{-0.1(L_i + w)}}{12 \times 10^{-0.1(L_d)} \times 4 \times 10^{-0.1(L_e + 5)} \times 8 \times 10^{-0.1(L_n + 10)}}
\]  

(5)

In Ref. [6], when implementing a fitting process of the observed experimental data with an analytical function of two variables, it was found that a generic power function expression may be used for the three reference periods, varying only the numeric coefficients. The expression is:

\[
u_{samp} = c_1 \times \Delta T^{\alpha_1} \times N^{-\{\alpha_2 + \alpha_3 \times \ln(\Delta T)\}}
\]  

(6)

where \( \alpha_1, \alpha_2 \) and \( \alpha_3 \) are numerical coefficients found from least squares fitting to locally obtained data.

3. Materials and methods
The site where the study took place is relatively plane with no major obstacles between the source and the adjacent buildings. The dominant noise source is a double lane collecting road following the most recent bridge built over the Mondego river: the Rainha Santa bridge, in Coimbra, a city in the center of Portugal.

Figure 1 shows an aerial photograph of the site, obtained from the web application Google Earth. Superimposed on the photograph is a wind rose centered on the measurement location, showing that the dominant wind direction is from northwest. The most probable velocity is in the range \([1.0 \text{ m/s}; 2.0 \text{ m/s}]\).

The annual average daily traffic is about 37,000 vehicles per day, with approximately 10% of heavy vehicles. The traffic is mostly fluid and decelerating, in the west-east direction, from 70 km/h, over the bridge, to 50 km/h, after the bridge. In the east-west direction, the traffic is also fluid and accelerates from 50 km/h to 70 km/h.

The measurement system was built around a National Instruments (NI) data acquisition system and LabVIEW application development platform. The signal from a Brüel & Kjær ½” diameter microphone model 4189, with pre-amplifier model 2671, is converted to digital format by a NI USB-9233 data acquisition board. The microphone was mounted on the exterior of a window, at the third floor level of the Laboratory of Industrial Aerodynamics, of the University of Coimbra. The distance to the road is about 150 m.

![Figure 1. Aerial photograph of the noise assessment site, with a wind rose centered on the measurement location.](image-url)
In order to determine the numerical coefficients in (6), a consecutive 17-day \( L_{eq.5min} \) time series was selected from a continuous 4-year noise monitoring campaign. Figure 3 compares the 17-day daily average levels with the 4-year daily average levels, showing that the 17-day sample is representative of the expected daily noise level variation at the site. The two dotted lines represent an uncertainty band for the 4-year measurements, considering that, in each period during the day, the noise equivalent level has a Gaussian distribution. A coverage factor equal to 2 (95% probability) has been used. Table 1 shows the numerical coefficients obtained from fitting (6) to the 17-day noise sample.

![Figure 3. Comparison between the 17-day daily average levels (solid line) and the 4-year daily average levels (dashed line)](image)

| Coef. | Day   | evening | Night  |
|-------|-------|---------|--------|
| \( c1 \) | 2.5224 | 2.2885  | 4.6034 |
| \( a1 \) | -0.086 | -0.181  | -0.068 |
| \( a2 \) | 0.408  | 0.3695  | 0.4686 |
| \( a3 \) | 0.010  | 0.034   | 0.002  |

4. Results and discussion

In Ref [1] the values of uncertainty accounted as fixed components to the sound level meter and microphone placement measurement, should be respectively, 0.5 dB and 0.4 dB. For the latter component its value must be recorded in the case of noise from road noise sources, and whose impact on the mounting location of the microphone is not grazing incidence.

Accounting for only these two components of uncertainty, in which we consider the remaining components in (4) to be zero, leads to a fixed component of the expanded uncertainty \( U(L_{den}) \) which cannot be less than 1.3 dB.
Following the measurement model assumed in this paper, the accounting of the \( u_{samp} \) component will always be affected by the sensitivity coefficients associated with each period. These coefficients have a strong dependence of the noise levels of each period, as shown in Table 2.

**Table 2.** Sound levels for three different situations, and their respective sensitivity coefficients, used to analyze the influence of sampling in the expanded uncertainty \( U(L_{den}) \).

| Case | \( L_d \) (dB(A)) | \( L_e \) (dB(A)) | \( L_n \) (dB(A)) | \( \frac{\partial L_{den}}{L_d} \) | \( \frac{\partial L_{den}}{L_e} \) | \( \frac{\partial L_{den}}{L_n} \) |
|------|-------------------|-------------------|-------------------|------------------|------------------|------------------|
| A    | 61                | 60                | 50                | 0.423            | 0.354            | 0.224            |
| Ref  | 61                | 60                | 54                | 0.316            | 0.264            | 0.420            |
| B    | 61                | 60                | 58                | 0.193            | 0.162            | 0.645            |

The accounting of the \( u_{samp} \) component, for the three cases considered, the results are presented in Figure 10, providing evidence of the influence of sampling component in the expanded uncertainty \( U(L_{den}) \), also highlighting its dependence on the number of episodes and duration, as well as differences in the level of indicators \( L_d \), \( L_e \) e \( L_n \).

**Figure 10.** Variation range of \( U(L_{den}) \): a) case A; b) case Ref; c) case B.

The influence that the sound level of nighttime have on the results presented for \( U(L_{den}) \), is greater the smaller the difference to the levels of other periods. This feature results from the weight that is given by the respective sensitivity coefficient and also due to the uncertainty of the noise level in this period.
The results presented in these figures refer only to fixed components, not yet part of the uncertainty inherent to the repeatability of the measurements, which will naturally increase further the limits presented.

5. Conclusion
A systematic analysis method, based on the bootstrap method, is proposed by the authors for assessing the quality of sampling strategies for estimating long-term environmental noise indicators at any given site.

The methodology developed allows to determine the best sampling strategy that meets a given requirement regarding measurement uncertainty. Implicitly it follows also that distinct effort should be placed in measurement strategies depending on the contribution that each component has on the final result as well as the precision value associated with it.

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