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EFFECT OF TRAFFIC NOISE STATISTICAL DISTRIBUTION ON $L_{\mathrm{Aeq},T}$ MEASUREMENT UNCERTAINTY

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The study of traffic noise at roads and highways are performed in accordance with reference methodologies adopted as implementation to the Law on Environment Protection. The choice of applicable methodology should be based on measurement quality analysis for each particular case. While estimating the measurement uncertainty it is assumed that results are subject of normal distribution. Such solution raises some doubts or even reservations. Therefore, in the present paper the real statistical distribution of road level noise is examined while a probe of its influence on value of uncertainty of executed measurements is undertaken.

Key words: uncertainly of acoustical measurement, traffic noise.

1. Introduction

In the last 20 years in Poland the dominant factor affecting the acoustic climate of the environment is the traffic noise. This phenomenon is directly related to the rapid transportation development in the country, manifesting itself by noticeable increase of the road traffic. More than threefold increase in the number of registered motor vehicles has been observed in relation to the end of 1980-ties. The annoyance of the transportation routes is mainly determined by the traffic intensity, structure of the vehicle stream and average vehicle velocity, the type and technical condition of the road surface and finally by the distance of the nearest buildings from the road edge. Technical condition of the vehicles is also of considerable importance. Therefore an essential task is the introduction of regular monitoring in all the areas exposed to noise and inhabited by human population. The main objective of the monitoring should be the collection of information related to the acoustic climate, formulation of reports and conclusions, and preparation of maps for the most exposed areas.

The studies of traffic noise have proceeded according to the so-called reference methodologies [2], being the executive regulations for the Environment Protection Act. The choice of proper methodology for each case should be based on the analysis of measurement quality, in particular the analysis of the measurement uncertainty and the costs of its evaluation. During determination of the type-A uncertainty it is often assumed that the examined results exhibit normal distribution or in the less-numerous cases t-Student distribution. Such an approach raises multiple doubts or even criticism. Therefore in the present paper the real statistical distributions of the registered 24-h traffic noise levels have been studied and an attempt has been made to evaluate their effect on the uncertainty values for the analyzed measurements.

2. Theoretical assumptions

Periodic measurements of environmental noise levels, leading to estimation of equivalent level values (1) for the sounds originating from the road traffic, may be carried out using one of three methods [11]:

a) indirect method – measurements of individual acoustic events,

b) direct noise measurements with a specified sampling scheme,

c) direct, continuous measurements in a specified time period.

According to [11] all these methods in their basic intentions lead to estimation of the equivalent sound level value, with the accompanying uncertainty estimation for a given measurement point (1). However in their contents the methods do not specify the procedure for estimation of the uncertainty values $\Delta L_{\mathrm{Aeq},\,T}$.

$$L_{\mathrm{Aeq},\,T} \pm \Delta L_{\mathrm{Aeq},\,T}\,. \tag{1}$$

Let's remind the fact that the measurement uncertainty is defined as a risk of obtaining an erroneous result from a given measurement (measurements), which characterizes the spread of possible values, within which the measured value can be located with a satisfactory probability. The measurement uncertainty is usually composed of many contributions, divided into two groups:

type A – estimation of standard uncertainties by type-A method, i.e. the uncertainty calculation by means of statistical analysis for a series of individual measurement results,

type B – calculation of the uncertainty by means of methods other than the analysis of a series of results, e.g. following from some experimental characteristics of the measurement. Estimating the compound standard uncertainty of the measurement – $u(Y)$, one should take into account all the contributions $u_i(Y)$ affecting the measurement result, calculated by type-A and type-B methods respectively, and get the final result according to Eq. (2).

$$u(Y) = \sqrt{\sum_{i=1}^{m} u_i^2(Y)}. \tag{2}$$

The condition for application of the above-mentioned formula is the fulfillment of the assumption of mutual independence and normal distribution $N[\mu(Y)\,\sigma(Y)]$ for individual measurement errors X_1, X_2, $\ldots$, X_m. If the assumption of mutual independence of random variables is not fulfilled then one has to use the formula taking into account the correlation between the pairs of correlated variables [1]. The authors intentionally skip the description of such a case, because to their best knowledge it does not occur in the discussed problem. Finally for calculation of the total extended uncertainty $U(Y)$ formula shown in Eq. (3) is used.

$$U(Y) = k \cdot u(Y), \tag{3}$$

where the values of extension coefficient k is assumed as $k = 2$ for the confidence level $P = 1 - \alpha = 0.95$, and $k = 3$ for $P = 1 - \alpha = 0.99$.

The Central Limit Theorem [3], being one of the basic theorems of mathematical statistics, states that the resultant distribution of many independent and equivalent random variables X_i converges to a normal distribution, independently of the their individual distributions. Because of the fact that the measurement process is affected by many equivalent and independent random factors, it is usually assumed that the distribution of measurement errors, and what follows, the distribution of final results converges to a normal distribution. In other words even if the individual contributions (partial results used for estimation of the uncertainty value $\Delta L_{\mathrm{Aeq},\,T}$) have been attributed statistical distributions that are not normal, then the distribution of the resultant variable still tends to a normal distribution, provided that there are many contributing components $(n \to \infty)$ and that there are no disproportionate spreads among the contributing variables [1].

3. Research material

The research material used for the present study was the data collected in noise measurements along national roads between June and October of 2005 in Małopolskie, Podkarpackie and Świętokrzyskie voivodships. The measurements have been based on the direct method, using continuous 24-h noise measurements, according to [11, 13]. The measurement sections consisted of two points, located 4 m above the ground level. The reference point (PPH) has been located 10 m, and an additional point (PDH) about 20 m from the road edge. Noise equivalent A-level has been registered continuously for 24 h using the FAST meter time constant. The individual results have been stored with 1 min repetition rate in the memory of the measuring device (as A-level equivalent values for the 1 min period – Lp_1min_i, where $i \in \langle 1,\, 1440 \rangle$). All the data have been collected in a database structure, containing information regarding the noise level, the number and velocity of the passing vehicles and the actual meteorological conditions. For the purpose of the present paper data from 55 measuring reference points (PPH) have been used. Figures 1a and 1b presents the pictures of typical measurement locations.

The equivalent noise level $L_{\mathrm{Aeq},\,T}$, has been determined for each of the monitored sections with division between the day-time period ($T = 16$ hours from 6.00 till 22.00) and the night-time period ($T = 8$ hours from 22.00 till 6.00). For every result uncertainty value $\Delta L_{\mathrm{Aeq},\,T}$ has been estimated, according to the theoretical presumptions. The standard uncertainty (type-A) $u(\overline{X})$ for the data average in one series (for a given

a) b)

Fig. 1. a) GP12 – double lane measurement section near main express-road, in a dispersed inhabitation area; b) SK21 – crossroad measurement section, uninhabited (open) area.

measurement section and time period) has been estimated according to the Eq. (4) below:

$$u(\overline{X}) = \sqrt{\frac{\sum \left(L_{\mathrm{Aeq},\,i} - \overline{L}_{\mathrm{Aeq},\,T}\right)^2}{n(n-1)}}\,, \tag{4}$$

where $\overline{L}_{\mathrm{Aeq},\,T}$ – average value for a measurement series, $L_{\mathrm{Aeq},\,T}$ – results of consecutive measurements in a series, n – number of measurements ($n = 960$ for day-time, $n = 480$ for night-time).

Estimating the standard uncertainty (type-B) the following factors, possibly affecting the measurement result, have been taken into account:

- directivity pattern of the microphone (the noise source moves along a line perpendicular to the measurement section line, changing the location angle with respect to the measurement section from about $85°$ down-to $0°$),
- calibration of the measuring line,
- accuracy class of the measuring device,
- wind speed (not more than 5 m/s),
- measurement background,
- the distance from PPH to the road edge.

Finally the total extended uncertainty $U(Y)$ has been estimated using Eq. (3), and assuming the extension coefficient $k = 2$ for the confidence level $P = 1-\alpha = 0.95$. For all examined 55 measuring points (PPH) the night-time measurement uncertainty does not exceed the value of 1.8 dB, and in the day-time the value of 1 dB [14]. In Table 1 a typical uncertainty budget has been presented for a PPH point in a measurement section.

Additionally, using the average values and standard deviations, the histogram consistency with the normal distribution has been evaluated separately for the day-time and night-time distributions. This has been done using the Lilliefors test and the d Kolmogorov–Smirnov test. If the test probability value is less than the assumed confidence level $(p = 0.05)$, then the hypothesis stating that the examined distribution is consis-

Table 1. Uncertainty budget for a 24 h traffic noise measurement in a PPH point 10 m distance from the road edge.

	variability range ± dB	standard uncertainty dB	Extended uncertainty [95%] dB
Type B uncertainty			
microphone calibration	0.3	0.2	
microphone directivity	0.2	0.1	
meter accuracy class	0.3	0.2	
distance from the source	0.2	0.1	
wind speed	0.3	0.2	
Type A uncertainty			
day-time	0.75	0.25	
night-time	2.06	0.69	
Compound uncertainty			
day-time	1.18	0.45	0.9
night-time	1.94	0.78	1.6

tent with a normal distribution should be rejected. Figure 2 presents the day-time noise level distribution for the PPH – SK22_1 point, together with the best fitting normal distribution. Accordingly Fig. 3 presents the night-time noise level histogram for the PPH – GP12b point together with the best fitting normal distribution. These two cases have been shown on purpose. Figure 2 represents the best correlated noise level density distribution, highly similar to the Gauss curve. It can be directly seen and this fact is also confirmed by the confidence level value obtained from the d Kolmogorov–Smirnov

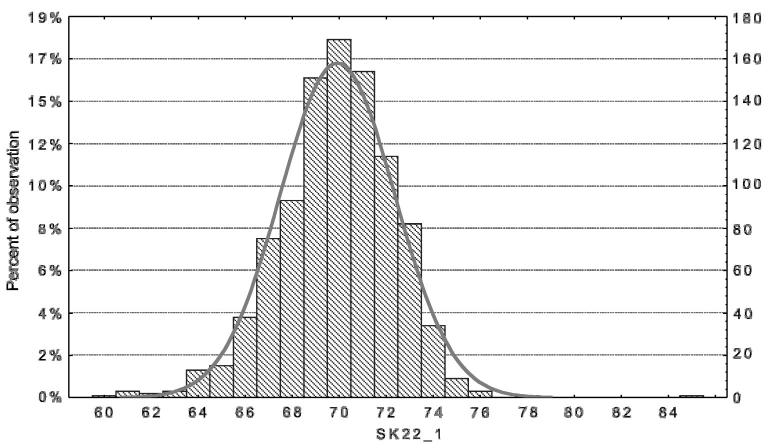

Fig. 2. Histogram of the day-time noise level distribution for PPH SK22_1: d Kolmogorov–Smirnov $p < 0.06$, Lilliefors $p < 0.01$, $N = 960$, Mean $= 70.4$, Stand. dev. $= 2.4$, Max $= 85.5$, Min $= 60$.

test $(p < 0.06)$, which allows the acceptation of the hypothesis stating full consistence with the normal distribution. However the Lillefors test, exhibiting higher discriminative power, shows no correlation between the observed and the expected distribution. Therefore in the final conclusion the zero-hypothesis is rejected.

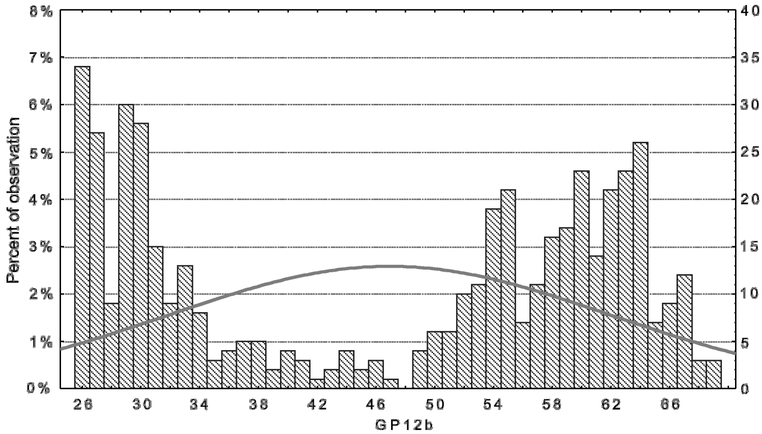

Fig. 3. Histogram of the night-time noise level distribution for PPH GP12b: d Kolmogorov–Smirnov $p < 0.01$, Lilliefors $p < 0.01$, $N = 481$, $\mathrm{Mean} = 47.3$, $\mathrm{Stand.\ dev.} = 14.8$, $\mathrm{Max} = 69.9$, $\mathrm{Min} = 26$.

Within a similar procedure, Fig. 3 presents the distribution that is least similar to the normal distribution curve among all the examined distributions. The histogram shown in Fig. 3 is a typical bimodal distribution. The values of the confidence levels for both tests are shown below Fig. 3.

In the present study it has been shown with the confidence level $p = 0.05$, that no acoustic data obtained from PPH points, both for day-time and night-time measurements, do not exhibit the characteristics of normal distribution. An attempt has been made to fit all the known theoretical distribution to the data obtained from the measurements. It turned out that the statistical distribution of noise levels obtained from 55 measuring points is not consistent with any distribution known in the literature.

An extra study has been proposed in order to examine the difference (distance) between the expected value (mean value of the series of samples), being the maximum of the normal distribution density function, and the actual maximum of the examined histogram (the argument value for which the maximum event frequency is observed in the real histogram), according to Eq. (5).

$$\Delta L_1 = \left| \overline{L}_{\mathrm{Aeq},\,T} - \max(f(L_{\mathrm{Aeq},\,T})) \right| , \tag{5}$$

where $f(L_{\mathrm{Aeq},\,T})$ – probability density function for the random variable $L_{\mathrm{Aeq},\,T}$.

Then, the ΔL_1 value for each measurement series has been compared with the calculated σ (standard deviation) for the respective series, according to (6)

$$\Delta L_2 = \sqrt{\frac{\sum (L_{\mathrm{Aeq},\,i} - \overline{L}_{\mathrm{Aeq},\,T})^2}{(n-1)}} - \Delta L_1 \, . \tag{6}$$

For the 55 examined points only in 4 cases the ΔL_2 value have been found to be less than zero. It occurred only for night-time measurements with the bimodal histogram characteristics. The negative ΔL_2 value contains the information that the measured value (in the present case the noise level) is not contained in the $\mu \pm \sigma$ interval. Therefore in such a case the application of standard deviation for estimation of type-A standard uncertainty value may induce serious reservations.

An additional hypothesis has been also tested: is it true, in consistence with our intuition, that with increasing traffic intensity (provided that its smoothness is preserved) the traffic noise distributions become closer to "normal" ? In order to test this hypothesis all measuring points have been divided into four subgroups:

- for night-time data – "*up to 1000*", "*up to 2000*", "*up to 3000*", "*above 3000*";
- for day-time data – "*up to 10000*", "*up to 20000*", "*up to 30000*", "*above 30000*".

Then, applying the variance analysis, it has been checked whether for confidence level $p = 0.05$ there are statistically significant dependencies between the traffic intensity and the deviation from "normality" of the observed histogram, and whether any such dependencies could affect the uncertainty value estimated according to formulas from Sec. 2. It has been found that such a regularity is true in consistency with the proposed hypothesis. Typical results of such analysis have been shown in Fig. 4 for the night-time data (for all 55 measurement sections) and Fig. 5 for the day-time data.

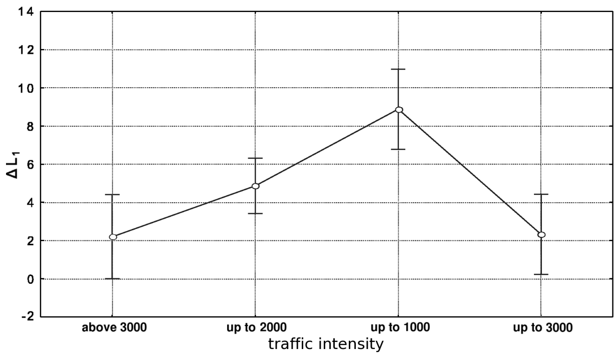

Fig. 4. Results of variance analysis for night-time data ΔL_1 as a function of traffic intensity.

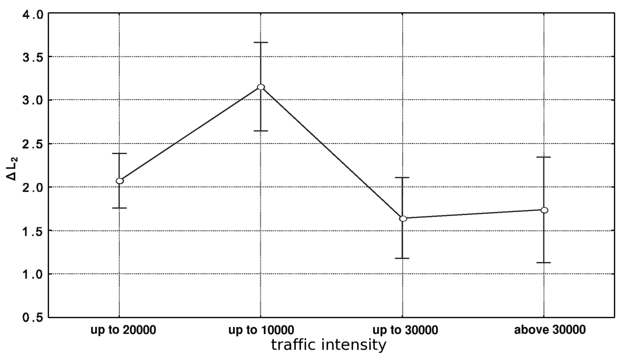

Fig. 5. Results of variance analysis for day-time data ΔL_2 as a function of traffic intensity.

4. Conclusions

In the present paper the authors have examined real statistical distributions of 24-h noise levels registered in 55 reference points. The measurements and analysis have shown that for the confidence level $p = 0.05$ none of the acoustic data series obtained from the PPH points, neither for day-time nor night-time, exhibits characteristics of the normal distribution. Additionally it has been found that the measured distributions are not related to any statistical distribution known in the literature.

On the basis of the completed variance analysis it has been found that both for night-time and day-time data the observed distributions tend to Gauss distributions with the increasing traffic intensity observed in a given measurement section. It has been also found that for the studies of 24 h levels of traffic noise the estimated value of extended uncertainty $U(Y)$ is correct, in spite of the fact that the assumption concerning the normality of the density distributions for the individual random variables is not fulfilled (see Fig. 5), with some restrictions concerning the bimodal distributions.

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