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STATISTICAL ASSESSMENT OF ENVIRONMENTAL NOISE GENERATED BY ROAD TRAFFIC

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Abstract. The necessity to check requirements for sound insulation of new building façades against outdoor noise and for estimating noise pollution of the residential area comprise the assessment of environmental noise taking in situ measurements that are mainly carried out under the standardized method presented in the EU directives and Lithuanian legislation. For these estimations, annual composite daily equivalent sound pressure level L_{den} becomes obligatory. When the value of this descriptor is determined from measurements, it is relevant to reasonably reduce a time interval of the performed measurement. The possibilities of determining the noise level $L_{d,12h}$ of the day (12h) undertaking annual L_{den} assessment making short-term (15÷60 min.) measurements is dealt in this work. In this way, the sensitivity of the set of statistical descriptors to variations in sound pressure levels was investigated. The paper proposes that the obtained instantaneous A-weighted sound pressure levels with F (fast) time weighting histogram of distribution density may be used for characterizing noise pollution in the sites. When traffic noise emitted from arterial town roads with stationary traffic takes a dominating position, the form of these histograms is close to normal distribution density with corresponding statistical parameters: average, standard deviation, asymmetry coefficient and percentiles. The experimental measurements have established that an asymmetry coefficient and an introduced descriptor – the rank of percentile N_{eq} % are the most sensitive to noise variations. The last one is more preferable due to its exclusive relationships with an equivalent level – the corresponding value of this rank of percentile P_{Neq} that coincides with the equivalent level of the measured time interval. It has been found that the introduced descriptor N_{eq} is very sensitive for indicating the dissimilarity of environmental noise (the presence of a casual impulse or high energy noise events). In-situ measurements of the vicinity of roads with intensive traffic in Vilnius City, where stationary urban traffic noise is dominating, indicate that the values of N_{eq} rank obtained during short-term (15÷60 min) intervals in the period from 7:00 to 19:00 are stable and vary from 69% to 74%. When non-stability occurs, a significant increase in the values of this descriptor may be applied as criteria for indicating noise events other than traffic noise and may be used for determining the interval limits of short-term stationary measurement.

Keywords: acoustics, environmental noise, urban traffic noise, statistical analysis, histograms, percentiles, measurements, short-term assessment.

1. Introduction

The origins of environmental noise are in human activities and are especially associated with the process of urbanization and the development of transport (Kaklauskas *et al.* 2009; Shukla *et al*. 2009; Akgüngör, Demirel 2008; Daunoras *et al*. 2008; Jović, Đorić 2010). One of the main sources of environmental noise in cities is related to road traffic. Road transport noise is a dominant source accounting for the nine tenths of the proportion of the EU's population exposed to the levels of noise over 65 dB(A). The same situation can be observed in the towns of Lithuania (Zavadskas *et al.* 2008; Kaklauskas *et al.* 2009).

There are a few basic approaches for reducing environmental noise exposure:

- reducing noise at the source – from machines, engines, tyres and surface;
- reducing speeds and traffic volume as well using special equipment (Baltrėnas *et al.* 2007b; Vaiškūnaitė *et al.* 2009; Vaišis, Januševičius 2009);
- limiting the transmission of noise by placing sound barriers between the source and people affected (Baltrėnas *et al.* 2007a; Vaišis, Januševičius 2009);

– reducing noise at the reception point, such as noise insulation of buildings (Grubliauskas, Butkus 2009).

To implement the diversity of these methods, the policy decisions are in use and include the development of emission standards for individual sources, immission standards based on noise quality criteria, land use planning, infrastructure measures, economic instruments, environmental noise researches, operational procedures as well as education and information actions (Paslawski 2009).

Taking into account the above proposed approach, *emission limit* values are applicable to individual sources (Baltrėnas *et al.* 2007b; Jaskelevičius, Užpelkienė 2008) and additionally may include type approval procedures to ensure that new products are at the time of manufacture complying with noise limits. *Immission standards* are based on noise quality criteria or guideline values for noise exposure to be applied to specific locations and are generally built into planning procedures (Kaklauskas *et al.* 2009; Baltrėnas, Puzinas 2009).

Land use planning procedures (Kaklauskas *et al.* 2009; Burinskienė *et al.* 2009, Jakimavičius, Burinskienė 2009, 2010; Daunoras *et al.* 2008; Szűcs 2009; Tanczos, Torok 2008; Griškevičiūtė-Gečienė 2010) are one of the means of putting immission regulations into practice. The separation of dwellings and other noise sensitive buildings from noise sources is a key tool for ensuring noise abatement. In particular applications, noise abatement through land use planning can include restricting the use of the land that is already subject to high levels of noise that is one of considerations to be dealt with in environmental statements for developments requiring the assessment of environmental impact.

Available measures to protect against high noise levels include noise walls (Baltrėnas *et al.* 2007a; Vaišis, Januševičius 2009), tunnels, cuttings, noise attenuation dams. Additional possibilities give *operational* measures like speed limits (Vaišis, Januševičius 2009) on sensitive road and rail sections and the types of *economic* measures (Paslawski 2009) that are available and could be used for noise abatement policy, including taxes and charges on noise emissions.

Scientific research on environmental noise and methods for noise abatement are vitally supporting and often initiate improvements in the state of art of noise reduction. In such way, noise mapping becomes an effective and relatively inexpensive method for assessing data on noise and serving as the basic planning tool. Such maps present the ranges of noise exposure for a particular area in, for example, 5 dB(A) steps using different colors. They make it easy to recognize noise exposure and thereby identify the areas where an action is required and other quiet areas where exposure should not increase. Noise mapping is mainly based on calculations, but may be accomplished by measurements (Vaišis *et al.* 2008). In the last case, information about transport flows (Jakimavičius, Burinskienė 2009) must be available. Thus, such investigations into traffic flows in urban sites (Gražulevičienė, Bendokienė 2009; Bazaras *et al.* 2008; Golmohammadi *et al.* 2009) allow predicting variety in environmental noise.

To describe environmental noise pollution, an annual average noise descriptor L_{den} (DIRECTIVE 2002/49/EC) is used. The simplest way is calculating it considering traffic intensity presented in noise maps. However, there are cases when this descriptor may be evaluated by measurements only, e.g. when noise maps for an interested site are not available and there is a need (in a few days) to determine the requirements for facades of new constructed buildings. On the other hand, when the map of site noise pollution is determined by measurements, the whole 24-hours are often replaced by short duration (1÷60 min) measurements (Gaja *et al.* 2003; Morillas *et al.* 2002; Sommerhoff *et al.* 2004; Li *et al.* 2002; Tang, Tong 2004; Vaišis, Januševičius 2008) in a representative time interval of the day. Unfortunately, reliable methods for such short-term evaluation of the annual L_{den} value are not developed yet. The application of statistical methods for environmental noise measurements to assess long-term equivalent levels may be one of the ways to reach this aim. Perhaps, for some types of sites with corresponding environmental noise properties and specific weather conditions, it is possible to develop the technique of short-term measurement L_{den}. Thus, (Gaja *et al.* 2003) statistically shows the possibilities of reducing the number of measurement days to assess annual L_{den}. In other works (Morillas *et al.* 2002; Sommerhoff *et al.* 2004; Li *et al.* 2002; Tang, Tong 2004; Zannin *et al.* 2002), measurement sites are assigned to the specific type of sites for the purpose to statistically determine similarity in results. In (Morillas *et al.* 2002), such sites include the categories of roads (arterial roads, two-way roads, one-way roads), in (Sommerhoff *et al.* 2004) – the sites where 'road traffic is their principal noise generation source' showing that a 24 h interval in such sites comprise a stable noise part (14÷15 hours per day), a long (5÷7 hours) conversion noise part from a stable day to stable night, a short (1÷3 hours) stable night part and a very short conversion part (1÷2 hours) from night to day. Graphically, typical daily variations in $L_{A,eq,1s}$ are shown in Fig. 1.

In (Li *et al.* 2002), measurement data were grouped taking into account the main roads of the town; in (Tang, Tong 2004), site conditions are considered due to differ-

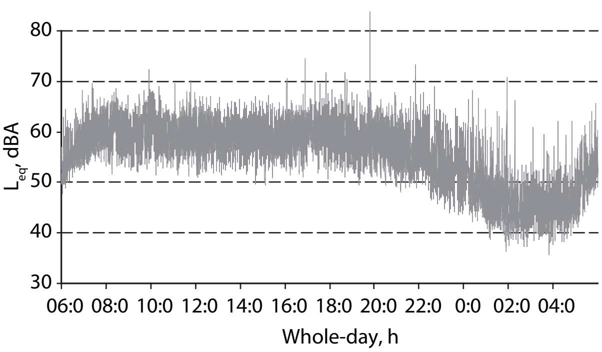


Fig. 1. An example of typical daily $L_{Aeq,1s}$ distribution

ences in road construction and area usage including road gradient and reflecting surfaces; in (Zannin *et al.* 2002) – resulting data are grouped considering urban zones such as residential, mixed, services, downtown and industrial. In these investigations (except Zannin *et al.* 2002) along with $L_{A,eq}$ statistical descriptor like $L_{A,N}$ – N, percent exceedance level (LST ISO 1996-1:2005) is used because sometimes equivalent level is not allowed for describing environmental noise variations, e.g. $L_{A,90}$, $L_{A,95}$ descriptors are often used for background noise estimation; $L_{A,1}$ or $L_{A,5}$ – for max levels estimation and $L_{A,10}$ is sometimes used instead of $L_{A,eq}$.

A good correlation between $L_{A,10}$ and $L_{A,eq}$ is found in (Morillas *et al.* 2002; Tang, Tong 2004; Golmohammadi *et al.* 2009). Nevertheless, the analysis of the results presented in (Gaja *et al.* 2003; Morillas *et al.* 2002; Sommerhoff *et al.* 2004; Li *et al.* 2002; Tang, Tong 2004) shows that $L_{A,10}$ values have a 1÷4 dB exceeding variation in $L_{A,eq}$ depending on the site of measurement. In (Alberola *et al.* 2005), variations in urban road traffic noise usually make 2÷3 dB.

On the other hand, in researches by (Gaja *et al.* 2003; Morillas *et al.* 2002; Sommerhoff *et al.* 2004; Li *et al.* 2002; Tang, Tong 2004; Zannin *et al.* 2002; Alberola *et al.* 2005) the distributions of short-term (from 1 min to 1 h) $L_{A,eq}$ are studied statistically.

Note that such random process as urban traffic noise is formed by the composition of a large amount of similar noise sources and seems to be close to the normal distribution density of probabilities. Similarly to these approaches, the interpretation of environmental noise was followed in (Farrelly, Brambilla 2003) where confidence intervals for $L_{A,eq,T}$ and $L_{A,N}$ were estimated to achieve better accuracy determining the parameters of environmental noise. Along with normal distribution density (Foxon, Pearson 1968; Don, Rees 1985) for describing environmental or urban traffic noise, comparable distributions such as chi-square (Kurze 1971) are used.

Historically, yet in 1963, for urban traffic noise studies, Brüel & Kjær applied the level recorder connected to a statistical analyzer to produce the histogram of distribution densities (Brüel & Kjær 1964). When developing a statistical approach and the results mentioned above in this work, the statistical analysis of the histogram of distribution densities and appropriate percentiles as well as relationship between percentiles and an equivalent level will be studied. The standardized $L_{A,N}$ descriptor is related to percentiles $P_{A,R}$, where R is a percentile index (rank) by $L_{A,N} \equiv P_{A,N-100}$ (e.g. $L_{A,10} \equiv P_{A,90}$).

The task is to investigate possible applications of statistical descriptors in order to validate the evaluation of short-term measurements of daytime (12h) noise level L_d which is a component of 24 hour descriptor L_{den}.

2. A System for Sound Pressure Level Acquisition

In our studies, the monitoring system developed by (Jagniatinskis *et al.* 2004; Jagniatinskis *et al.* 2005) was used. This noise monitoring system as input data collect values with a digital sound level meter complying IEC 61672-1:2002 (LST EN 61672-1:2003) Type 1. The sound level meter by choice can apply frequency weighting characteristics designed as A and C. The transferred digital value of the sound pressure level is determined by exponential time average and 125 ms time constant (F). These characteristics are achieved by means of r.m.s. detector of the sound level meter. The digits are indicated with a resolution of 0.1 dB. Dynamic range for data acquisition is 110 dB without commutations.

An interface devise digitizing data at a rate of 100 ms (obtained by the interpolation of data at 125 ms) allows for reading digital data through computer port RS 232. The results of field noise measurements are processed as 4 digits and a comma. The acquired data are stored in PC memory with following post processing applying special designed software. Thus, data on examination are the set of a continuous sequence of instantaneous A weighted sound pressure levels with F (fast) time weightings – $L_{pA,F,\,100\text{ms}}$.

One of the main forms of a statistical presentation of the acquired data is the distribution density of probabilities. Having a large amount of sampling ($L_{pA,F,i}$ $i = 1, 2, \ldots, N$, N – the amount of the registered data in the observation period) distribution density (histogram) can be build in such a way. In further investigations, this set of data $\{L_{pA,F,i}\}$ will be treated and denoted as random quantity $X = \{x_i,\ i = 1,2, ..., N\}$ representing the random process of environmental noise.

The histogram is made by dividing the whole dB range of the acquired data into J intervals (e. g. a width of 1 dB) and calculating the corresponding densities of the histogram (sampling probabilities) p_k:

$$p_k = n_k \,/\, N,$$

where: $N = \sum_{k=1}^{J} n_k$ and n_k – the amount of noise levels falling into k-th interval.

When applying this monitoring system in 2002–2007, the measurements of various environmental sites in the main towns of Lithuania, including Vilnius, Kaunas and Klaipeda were executed (Jagniatinskis, Fiks 2004; Jagniatinskis *et al.* 2005). The measurements were performed in accordance with a standard of ISO 1996-2:2007 (LST ISO 1996-2:2008). The obtained results will show a very large variety of the obtained histograms. Thus, in Figures from 2a to 2d, the examples of the histograms determined from the measured data in some typical environmental sites are presented. Such kinds of histogram shapes (see Fig. 2) show that commonly the true distribution density of environmental noise may be arbitrary, e.g. from close to uniform (equiprobable) to normal or nonsymmetrical densities and depends on the measurement situation. The results presented in Fig. 2 are obtained in the following sites: *a* and *b* – about 100 m from the arterial 4-lane road in day time and night time respectively; *c* – 20 m from the 4-lane road from 13:30 to 14:30; *d* – at night from 22:00 to 06:00 in the 'green' area of the town.

Note that such shapes of the histogram like *d* in Fig. 2 were found in sites near traffic lights for crosswalk.

The site histogram contains much information about noise situation: the shape and parameters of the histogram (width, asymmetry, peaks); all ranks of percentiles can be calculated from the histogram data and equivalent level that will be shown in the next section. Thus, the histogram may be treated as a noise pattern of the studied environment and may be stored for comparing the latest changes in noise situation in this environment. The behavior of the histograms obtained performing measurements at an interval of 1 h in the site with dominant urban traffic noise is shown in Fig. 3.

Fig. 3a clearly indicates that within the time period from 07:00 to 17:00 envelops of 1h histograms (thin lines) have very close forms and the same placement in a dynamic range which tells about the stationarity of environmental noise within this period. Otherwise, within

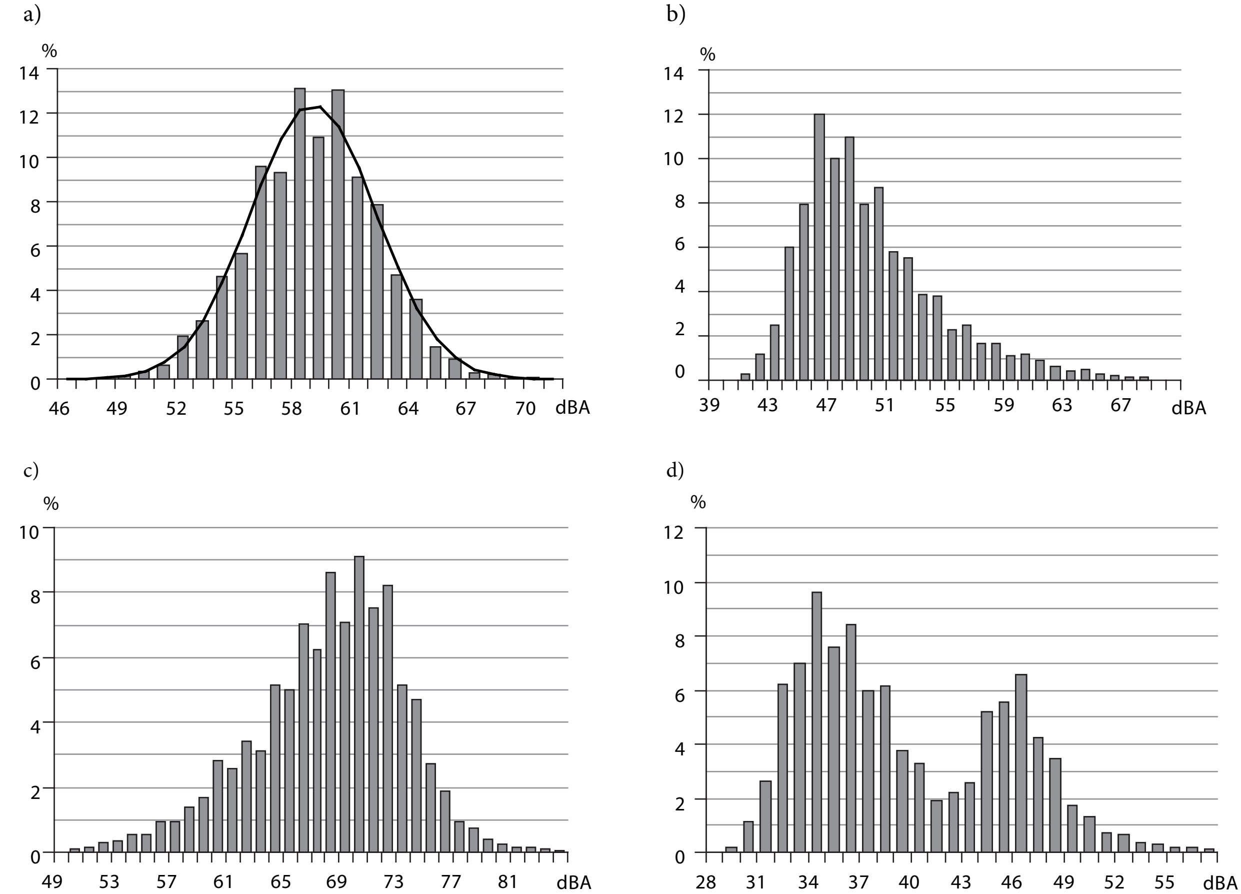


Fig. 2. The examples of the histograms of urban traffic noise: a – at noise stationary time interval (line – approximation to normal distribution); b–d – at non stationary noise time intervals

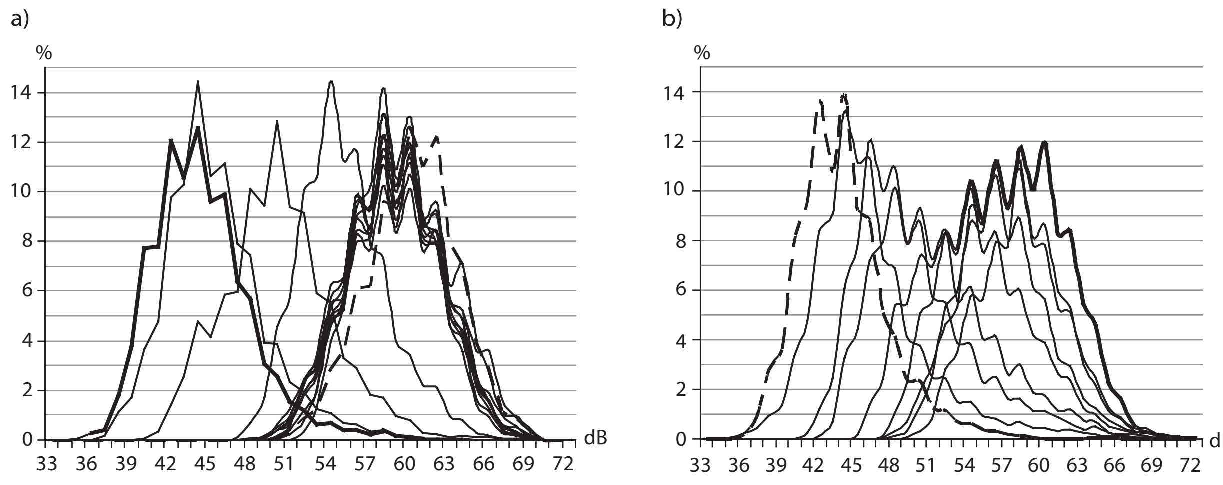


Fig. 3. The envelops of the histograms obtained at an interval of 1h depending on daytime: a – when noise is raised: from 3:00 to 4:00 (bold) to 17:00÷18:00 (dashed); b – when noise is abated: from 18:00 to 19:00 (bold) to 2:00÷3:00 (dashed)

the intermediate period of the whole-day from day to night (from 18:00 to 03:00, see Fig. 3b)) the shape and place of 1h histograms are significantly changed (are shifted from right to left).

The above displayed in-situ results conclude that within a stationary noise period in the site where the noise of road traffic dominates, noise distribution density as a random process is close to normal distribution. For the purpose to statistically represent an equivalent level, appropriate relationship to statistical descriptors must be found.

3. Equivalent Level and Percentile Relationship

This work suggests that the theoretical distribution density of the random process is known as urban traffic noise $p(x)$ and all noise levels of this process lies within the range of $[L_1, L_2]$. Then, with reference to the quantile definition (Kruopis 1993), we obtain that equivalent level L_{Aeq} is related to statistical descriptors by equation:

$$\int_{L_1}^{L_{Aeq}} p(x)\,dx = p_{eq}\,, \tag{1}$$

where: p_{eq} is the probability of falling noise levels into interval $[L_1, L_{Aeq}]$. Therefore, the introduced equivalent rank of percentile N_{eq} is expressed as $N_{eq} = 100\,p_{eq}$, %.

On the other hand, it is clear, that the obtained set of data on sound pressure has a corresponding equivalent sound pressure level as well as distribution density which may be expressed in a histogram form.

Thus, to calculate the integral in (1), L_{Aeq} must also be expressed from $p(x)$ and done in the following way.

By definition (IEC 61672-1:2002), time-averaged (equivalent) A-weighted sound level L_{AeqT} is expressed by the formulae:

$$L_{AeqT} = 10\lg \frac{1}{T}\int_{t_1}^{t_2} \frac{p_A^2}{p_0^2}\,dt, \tag{2}$$

where: $T = t_2 - t_1$, p_A^2 is squared instantaneous A-weighted sound pressure in pascals; and p_0^2 is the square of reference sound pressure.

When the set of sound pressure levels of instantaneous data $L_{pA,F,i}$ (see Section 2) is stored, L_{Aeq} is calculated as the sum of this set:

$$L_{Aeq} = 10\lg\left(\frac{1}{N}\sum_{i=1}^{N} 10^{x_i/10}\right), \tag{3}$$

where x_i is defined in Section 2. Similarly to creating the histogram (see Section 2), all dynamic range of obtained data is divided into J intervals having width Δx (e.g. 1 dB intervals) by regrouping the elements of the sum presented in (3). Having performed further transformations, we obtain that:

$$L_{Aeq} = 10\lg\left(\frac{1}{N}\sum_{k=1}^{J}\sum_{j=1}^{n_k} 10^{(x_{jk}-x_{0k}+x_{0k})/10}\right) =$$

$$10\lg\left(\frac{1}{N}\sum_{k=1}^{J}\left(10^{x_{0k}/10}\sum_{j=1}^{n_k}10^{(x_{jk}-x_{0k})/10}\right)\right),$$

where: x_{jk} is the noise levels of the registered data falling into k-th interval with the centre value of x_{0k}. The last sum, taking into account that all values in k-th interval x_{jk} lie within $[x_{0k} - 0.5;\ x_{0k} + 0.5)$ and are uniformly distributed in this interval, may be transformed applying the Fourier series for exponential functions:

$$\sum_{j=1}^{n_k} 10^{(x_{jk}-x_{0k})/10} =$$

$$\sum_{j=1}^{n_k}\left(1+\frac{\ln 10}{10}(x_{jk}-x_{0k})+\frac{1}{2}\left(\frac{\ln 10}{10}\right)^2 (x_{jk}-x_{0k})^2+\cdots\right) =$$

$$n_k + \frac{\ln 10}{10}\sum_{j=1}^{n_k}(x_{jk}-x_{0k}) + \frac{1}{2}\left(\frac{\ln 10}{10}\right)^2 \times$$

$$\sum_{j=1}^{n_k}(x_{jk}-x_{0k})^2+\cdots \cong n_k.$$

It is valid because the sum in the third row is a mean value of the uniform distribution of difference $x_{jk} - x_{0k}$ equal to zero, and the sum in fourth row is dispersion that determines the error of this estimation. As the dispersion of uniform distribution in our case is equal to $\Delta x^2/12$, this error may be evaluated as equal nearly to 0.002, which is negligible for L_{Aeq} estimation. Finally, for a discrete case, it can be written that:

$$L_{Aeq} = 10\lg\left(\sum_{k=1}^{J}\frac{n_k}{N}10^{x_{0k}/10}\right). \tag{4}$$

In the integral form, applying probability density for the centre of k-th interval $p(x_{0k})$ and considering that $n_k/N = p(x_{k0})\cdot\Delta x$, the formula for an analogous case is presented in the following view:

$$L_{Aeq} == 10\lg\int_{L_1}^{L_2} p(x)10^{x/10}\,dx, \tag{5}$$

where: $p(x)$ is continuous distribution density and $L_2 - L_1$ is the range of the registered noise levels in dB. Thus, equations (1) and (5) can help with determining the rank of percentile N_{eq} the percentile value of which is equal to the equivalent level for a determined time interval. Such rank of percentile introduced in this work is named as an equivalent rank of percentile.

Obviously, for symmetrical distribution densities, the required N_{eq} depends on the width of distribution density only. For example, for normal distribution, such width will be characterized by 6σ covering 99.73% of the whole distribution, where σ is dispersion.

Fig. 4 shows the dependencies of the equivalent rank of percentiles N_{eq} on the widths of normal distribution.

Fig. 4 displays that the equivalent rank of percentiles for normal density in realistic width ranges from 15 to 35 dB and changes from 60% to 75%. Thus, theoretically, the most suitable rank of percentile which in the best way to represent the equivalent level lies between 65% and 75% depending on the width of distribution density. In this way, it is clear that any rank of percentiles

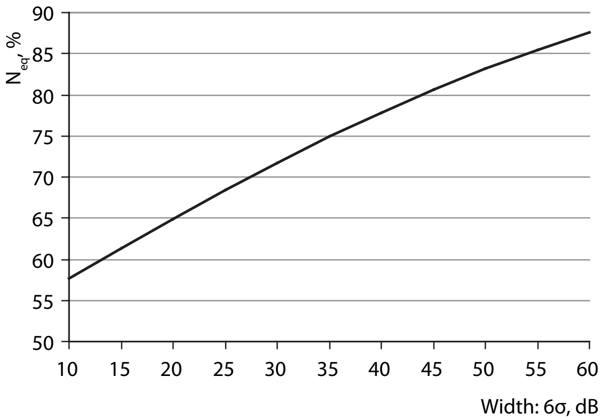


Fig. 4. Dependencies of the equivalent rank of percentiles N_{eq} for normal distribution density on the width of distribution

cannot replace the equivalent level for all sites of measurements. It can be useful as an additional descriptor analyzing environmental noise. The following paragraph displays possible practical applications of the equivalent rank of percentiles based on the results of in situ measurements.

4. Analysis of Data Measurement

First, the analysis of data measurement acquired in various environmental sites in the main towns of Lithuania, including Vilnius, Kaunas, Klaipėda (Jagniatinskis, Fiks 2004; Jagniatinskis *et al.* 2005) shows that the equivalent rank of percentile (the percentile value is coinsident with L_{Aeq} value) in the obtained data largely depend on the properties (noise sources) of the measured place, as shown in Fig. 5.

As can be seen from Fig. 5, N_{eq} values in urban areas are mostly in the range from 70% to 85%; otherwise, in the presence of aircraft transport noise they vary mostly from 80% to 95%. So, the equivalent rank of percentiles may characterize the dissimilarity of the investigated site. In the presence of high energy noise, the value of this descriptor has a tendency to rising.

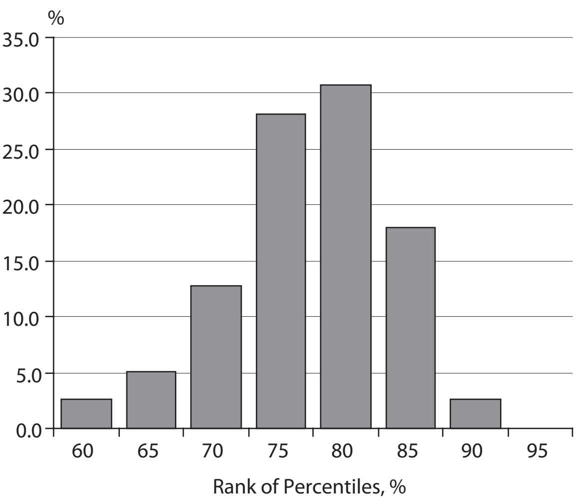
For the purpose of this work, a more detailed analysis of data measurement in one of the sites representing the road in Vilnius centre (Konstitucijos av.) characterized by stable traffic noise during the daytime period is accomplished. G. R. A. S. free field microphone is placed between two roads on the building facade about 70 m from the centre of the six-lane road (two lanes – for buses), 40 m from the centre of the two-lane road, 6 m from the ground surface and 2 m from the building facade (measurement was done to check whether facade sound insulation satisfy the requirements corresponding to the value of environmental noise). The facade surface of the building is placed perpendicularly to the roads. The data were acquired applying the system described in Section 2. This example shows the available kind of information when the acquired data are analyzed applying the histograms of distribution densities and theoretical results of Section 3.

First, the acquired daily measurement data were estimated at an interval of 1 h to examine changes in the histograms of distribution densities (see Fig. 3) and other parameters of distributions like percentiles, standard deviation and asymmetry coefficient. Figures from 6 to 8 show statistics concerning the parameters of distribution densities at measurement intervals of 1 h.

Fig. 6 presents the parameters of histogram distribution densities such as an equivalent level and standard deviation (distribution width) obtained within daily representative measurements at an interval of 1 h. A grey colour in the following figure denotes the period of daytime, black colour – evening time and the white one – night.

Similar but more sensitive behavior in these periods is shown using the ranks of percentile and asymmetry coefficients (see Figs 7 and 8).

a)



b)

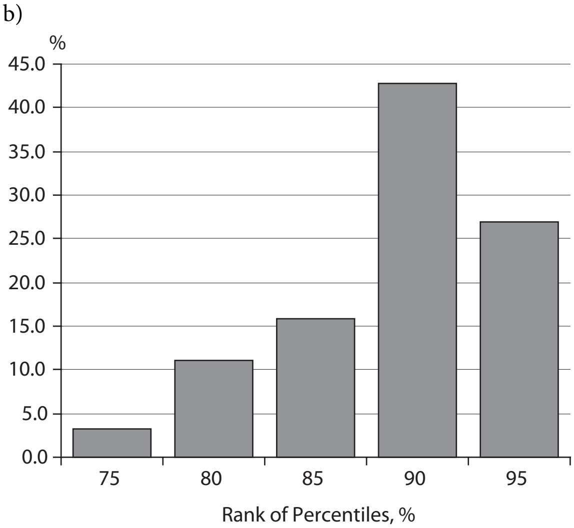


Fig. 5. The distribution of ranking values of the equivalent percentile (%) within the period from 06:00 to 18:00: a – data obtained performing noise measurements in 50 different urban areas typical of road transport; b – data obtained performing all year round measurements on different days of the week in the urban area close to the airport

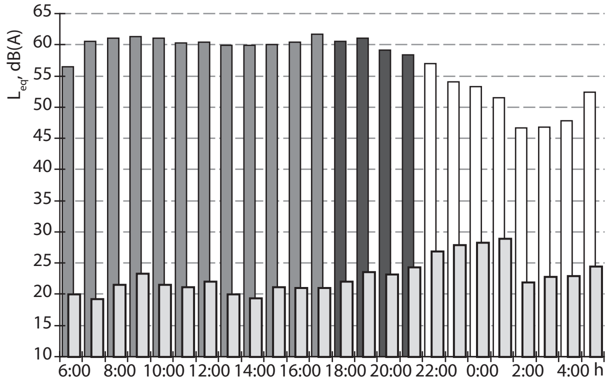


Fig. 6. $L_{Aeq,1h}$ (black-white bars) and the corresponding widths of histogram distribution densities (texture bars) at an interval of 1 h during daily measurements

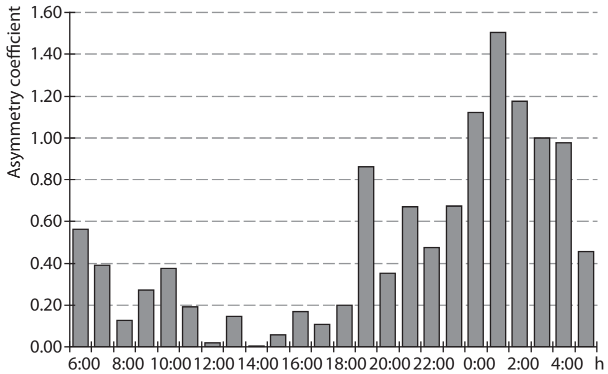


Fig. 7. Asymmetry coefficients of histogram distribution densities partitioned into the intervals of 1 h

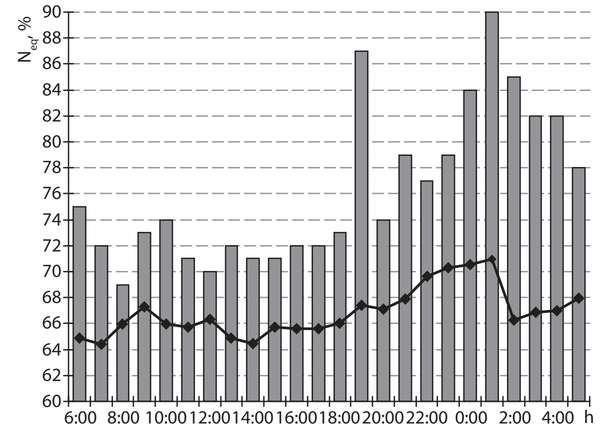


Fig. 8. The equivalent ranks of percentiles at an interval of 1 h: bars are calculated directly from the histogram, lines are calculated considering the curve presented in Fig. 4

Fig. 6 displays that a stable noise period is from 7:00 to 21:00 and distribution width (low bars) rise from 20 dB to 30 dB in the intermediate period from 21:00 to 01:00.

The measurement results have determined that the equivalent rank of percentiles $N_{eq,mes}$ that corresponds to real distributions (see Fig. 3) and is related to the measured equivalent level depends on the real noise situation in the investigated site and correspondingly varies as shown in Fig. 8 (also see Fig. 5).

On the other hand, this rank is naturally rises when the width of the measured distribution (histogram) is increased (see Fig. 4). This fact must be taken into account by subtracting the value of the equivalent rank of percentile from rank $N_{eq,mes}$ which corresponds to the width of normal distribution $N_{eq,norm}$ (line on Fig. 8). As mentioned above, this distribution in an ideal case (in case there are same infinitive independent sound souses) naturally represents urban traffic noise. The value of $N_{eq,norm}$ is calculated from the obtained curve presented in Fig. 4 when width is estimated at 6σ where σ – is a standard deviation from the measured and stored sound pressure levels within the determined time period.

Therefore, it is tenable to assume that difference between $N_{eq,mes}$ and $N_{eq,norm}$ can represent the measure or criteria by which the presence of undesirable noises in urban traffic noise can be detected. When applying these criteria, the availability of measuring a short-term interval can be determined. Check this assumption experimentally.

Fig. 9 presents the values of criteria ($N_{eq,mes}$ – $N_{eq,norm}$) at an interval of 1 h following the above described case.

Fig. 9 clearly indicates that criteria values exceed $N_{eq,norm}$ values only up to 8% in the stable noise period from 7:00 to 20:00 (white bars in Fig. 9) except from the value at 19:00 (textured bar). In the intermediate noise periods, criteria values appear from 21:00 to 04:00 (noise decreases to night level) and from 05:00 to 06:00 (noise reaches day level) and are commonly are higher than 10% (grey bars in Fig. 9). Considering the period from 21:00 to 06:00, such large values of the suggested criteria may be explained by the fact that noise at this time is produced by the superposition of two independent random processes – urban residual night noise and low intensity traffic noise, which can be treated as a contribution of high energy single-events in residual noise.

The most typical histograms of this experimental site are shown in Fig. 2a indicating stationary noise periods and Fig. 2b showing intermediate noise periods.

Note that ranks $N_{eq,mes}$ are very stable within the day (vary from 69% to 74%) and significantly changes

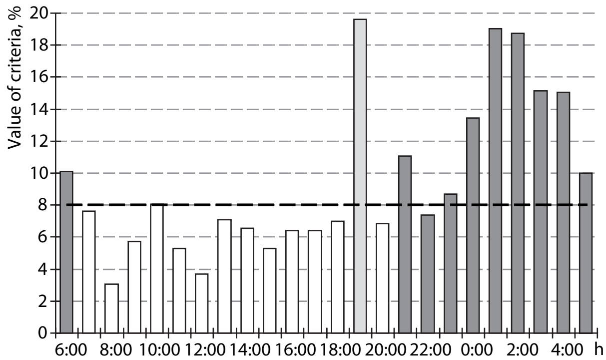


Fig. 9. Criteria values ($N_{eq,mes}$ – $N_{eq,norm}$) at the intervals of 1 h during the day

in non-stable noise periods (vary from 77% to 90%). Corresponding to the appropriate widths of histograms, 'theoretical' $N_{eq,norm}$ values (see Fig. 4) range from 64% to 67%.

The above mentioned exception time is from 19:00 to 20:00 and belongs to the stable noise period (see Fig. 6). Therefore, criteria (and $N_{eq,mes}$) take a very high value (see Fig. 8 and 9) which is due to only one high energy single-event of 15 s the occurrence in this interval of which is presented in Fig. 10.

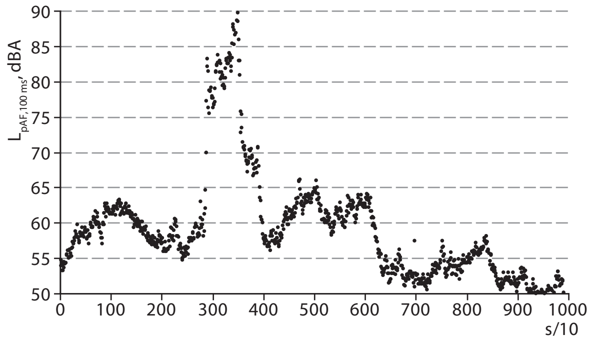


Fig. 10. A fragment of registered data on a high-energy impulse in the background of urban traffic noise

It seems to be clear that impulse characteristics presented in Fig. 10 cannot be produced by urban traffic as this is a casual noise event and for L_{DEN} estimations must be eliminated. The elimination procedure in the presented studies is very simple: in the resulting histogram of noise distribution densities, it is enough to make zero values corresponding to limit noise levels 15 dB or more of which exceeded the equivalent level (it was suggested that in the investigated environment, urban traffic noise only will be taken into account). In our case, this limit level is about 75 dB and the eliminated amount of values in the histogram makes about 0.23% of the registered amount of data at an interval of 1 h. Changes in the values of the parameters of distribution density after producing the elimination procedure are presented in Table 1.

Thus, as can be seen in Table 1, the equivalent rank of percentiles $N_{eq,mes}$ and asymmetry coefficient are most sensitive for impulse events and may be used for characterizing the impulsiveness of environmental noise. However, N_{eq} parameter is more representative and preferable due to relationship to the value of L_{Aeq}.

Finally, Table 2 shows how L_{eq} level varies in short-term measurement intervals of 1 h, 0.5 h and 15 min within the day from 7:00 to 18:00.

Data presented in Table 2 show a real possibility of using shot-term measurement for assessing day's (12h) L_{eq} level with standard deviation of ±1 dB.

Table 2. Variation in L_{Aeq} level (dBA) at the intervals of short-term measurement around real $L_{Aeq,day}$ of 60.6 ≈ 61 dBA

Parameter	$L_{Aeq,1h}$	$L_{Aeq,30min}$	$L_{Aeq,15min}$
mean	60.6	60.6	60.5
standard deviation	0.6	0.7	0.8
interval	60÷61.7	59.6÷62.1	59.4÷62.5

5. Conclusions

1. Noise measurements of road traffic performed in the main Lithuanian cities show that the obtained results of daily measurements comprise four periods, including a period of stable noise (14÷15 hours per day), a relatively long period (5÷7 hours) covering the length of time from stable noise generated during the day to that at night, a short period (1÷3 hours) of stable noise at night and a very short period of (1÷2 hours) stable noise starting at night and lasting till the day starts. A statistical analysis of the obtained data has provided a possibility of establishing noise level during the day (12 h) necessary for evaluating the annual noise index $L_{d,12h}$, performing short-term (15÷60 min) measurements.
2. The paper presents the results showing a statistical evaluation of environmental noise generated by road traffic showing the possibilities of calculating the equivalent sound pressure level from the obtained statistical distribution density (histogram) of the set of the acquired sound pressure levels.
3. The article also shows the usefulness of road traffic noise distribution density (histogram) introducing a new statistical descriptor, the equivalent rank of percentiles N_{eq}. This new characteristic defines a percentile the value of which coincides with that of the equivalent sound pressure level within the same time interval.
4. Assuming the normal distribution of data on environmental noise, the conducted research has disclosed dependences of the introduced statistical descriptor on the width of this distribution. The analysis of the results of in-situ measurement show that the equivalent rank of percentiles N_{eq} is sensitive (speedily increase) to relatively high energy sounds sources, available in the studied environments with dominant road traffic noise.
5. In-situ measurements of the vicinity of roads with intensive traffic in Vilnius city where stationary urban traffic is the major noise source indicate that the described statistical criteria allows validating short-term measurements results as the estimation of day time interval level L_d with a standard deviation of ±1 dB.

Table 1. The values of the parameters of distribution densities changing after eliminating the noise event presented in Fig. 10

Parameter	$L_{Aeq,1h}$, dBA	Equivalent rank N_{eq} %	Standard deviation s, dB	Mean value, dB	Asymmetry coefficient
before elimination	61.1	87	3.92	57.42	0.86
after elimination	59.2	74	3.75	57.36	0.40

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