ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 134 (2016) 301 – 308
Procedia Engineering
www.elsevier.com/locate/procedia

9th International Scientific Conference Transbaltica 2015

Annual Assessment of Transport Noise Using Representative Time Measurements

Aleksandras Jagniatinskis[a]*, Boris Fiks[a], Oleksandr Zaporozhets[b]

[a]Vilnius Gediminas Technical University, Linkmenų g. 28, LT-08217 Vilnius, Lithuania
[b]National Aviation University, Kosmonavta Komarova Ave 1, 03680 Kyiv, Ukraine

Abstract

By the World Health Organization (WHO) data reported in Burden of disease from environmental noise "one in three individuals is annoyed during the daytime and one in five has disturbed sleep at night because of traffic noise". By these data the odds of incidence of disease rise to about 10% when LAeq, day noise level increase from 55–60 dB to 65–70 dB. The main descriptor for evaluation of the environmental noise impact in the leaving areas by EU Directives is composite annual day-evening-night level Lden and sometimes annual Lnight level is used. These descriptors are mandatory used in noise mapping, mainly calculated with appropriate methods. The problems arise in cases, when these annual values must be evaluated from short time measurements. The replacement of full year measurement by choosing a shorter time interval is suggested in this work using the conception of representative time interval. The time interval is understood as a representative when selected sampling interval contains an appropriate amount of transportation noise events (passing bys or flying bys) and that allows to estimate annual noise descriptors with required accuracy. In paper the particularities for representative sample definition for cases of road, aircraft and rail transport are analyzed. It is shown, that statistical distribution of measured sound exposure levels of transportation noise events may serve as a basis for representative sample determination and may be used for annual noise assessment of aircraft flying bys, rail transport passing bys and road vehicle passing bys in suburban type of roads. As an example in Lithuanian traffic conditions it is shown, that the usage of consecutive seven days (one week) measurements under normal weather conditions is applicable as a representative time interval for annual urban traffic noise assessment.

Peer-review under responsibility of the organizing committee of Transbaltica 2015

Keywords: transport noise; annual assessment; measurements; representative sample.

* Corresponding author
E-mail address: akustika@vgtu.lt

Peer-review under responsibility of the organizing committee of Transbaltica 2015
doi:10.1016/j.proeng.2016.01.011

1. Introduction

By the World Health Organization (WHO) data reported in *Burden of disease from environmental noise* (WHO 2011) the transportation noise is one of the main factors that influence the overall noise level in leaving areas. So e.g., when day noise level $L_{\mathrm{Aeq,day}}$ increase by 10 dB from 55–60 dB to 65–70 dB the odds of incidence of disease rise to about 10%. For noise impact estimation on human beings in EU (Committee of the regions 2012) the annual composite day-evening-night level L_{den} is introduced as a mandatory noise descriptor, for noise mapping. The annual night level L_{night} is also especially attended to assess the noise impact at night time periods (WHO 2009). By WHO estimations made in the report WHO 2009, *Night Noise Guidelines for Europe* more than 30% of population is exposed to levels exceeding 55 dBA at night, whereas the sleep disturbance is caused by traffic noise with outdoors levels starting from 40 dBA of $L_{\mathrm{Aeq,night}}$. These two annual descriptors are used as obligatory for noise mapping and also for zoning and land use planning applications. Additionally to the above mentioned annual descriptors, the annual maximal level is used for noise impact analysis, especially for night time. In various combinations with other descriptors, these annual descriptors are often used to estimate the annoyance response of communities to the overall steady sound situation. The values of various descriptors used in the above mentioned applications are calculated by applying appropriate methods, e.g. presented in overview paper (Filippone 2014) for aircraft transport noise. The problems arise when the stated annual levels in noise maps must be verified by in situ noise measurements. One year-long measurements often are complicated and require a lot of efforts. It's clear that annual noise assessment using shorter time intervals is a very important and actual task. These shorter time intervals must fulfill some requirements. The conception of representative time interval, which is analyzed in this work, may help to solve this task.

Considering traffic situations in investigated site the strategies to achieve this goal for road, aircraft and rail transport are different, but may have some similarities. Traffic situations may be divided into such types:

- set of single passing bys and/or flying bys;
- simultaneous passing bys of transport units (traffic flow).

Determination of the representative time interval may be accomplished by following principles:

1. Choosing transport flow model, that corresponds to the type of real traffic situation;
2. Conditions (criteria) for representativeness formulation depending on the noise and traffic flow measurement procedures;
3. Continuous in situ measurements (the set of separate continuous measurement time intervals whose common duration is sufficient to be representative may be also used): representative data sample and appropriate representative time interval definition using chosen criteria;
4. Annual values assessment (forecast) of desired descriptors with certain accuracy (uncertainty).

In last investigations the representativeness sample of noise measurement data directed for evaluation of annual noise level is given insufficient attention. In the proposals of the standard ISO 1996-2:2007 the representativeness of separate parameters regarding the noise measurement are emphasized mostly, but the possibility of long term (annual) assessments on the base of representative measurement data is not directly pointed. It is stated, that "source operating conditions shall be statistically representative" of the considered environment and means, that measurement time interval shall incorporate all significant types of produced noise. For aircraft flying bys this is related to the types of aircrafts and their possible flights trajectories; for vehicle passing bys – to the all typical categories of vehicle and corresponding speed; for rail transport passing bys – to the all types of exploited trains' categories. The amount of recorded noise events must be large enough, so that the post processing estimations would be statistically reasonable.

Minimum amount of transportation noise events which should be recorded is also stated in ISO 1996-2:2007:

- road transport: for direct L_{Aeq} determination in the measured time interval the number N of every category transport passing by events is calculated from the formula:

$$N = \left(\frac{10 \cdot \gamma}{\varepsilon} \right)^2 , \tag{1}$$

where γ is a coverage factor for 95% confidence interval and ε is a desired expanded measurement uncertainty due to operation conditions only. For example, if ε is chosen equal to plus 3 dB, so it is guaranteed, that true equivalent level does not exceed measured value's L plus 3 dB, then in this case γ is equal to 1.63 and N must be chosen not less than 30 events. When equivalent level is determined using exposure levels of every vehicle passing bys or/and for maximal level determination, the minimum number of vehicles per every category is 30.

- air transport: for L_{Aeq} determination in the measured time interval noise from 5 or more each types of aircraft with highest levels must be determined and for L_{Amax} – minimum 5 and preferably 20 or more aircraft flying by events must be observed;
- rail transport: for L_{Aeq} determination the measurement time interval must comprise minimum of 20 trains passing bys and 5 trains of each category; for L_{Amax} – minimum 20 trains passing bys must be analyzed.

Presented minimum amount of events are not related to the assessment of annual noise levels and is not enough to get the statistical estimation of annual levels. Also, amount of recorded data (noise events) to be representative for assessment of annual levels must be determined by appropriate criteria or conditions.

Such criteria may be produced from the last investigations as a bootstrap procedure presented in (Mateus et al. 2015) for reducing the measurement time, assessing the one whole day L_{den} value. In (Ng, Tang 2008) one whole day estimations of L_{den} the procedure for short term measurements based on the 30 min. arbitrary chosen intervals during the whole day was proposed. These methods are developed for road traffic conditions in urban areas.

The annual assessment of urban road noise level L_{den} was proposed in (Jagniatinskis, Fiks 2014) using 7 consecutive measurement whole days with normal weather conditions as it is introduced in ISO 1996-2. For suburbia highways when traffic flow is dense and vehicle passing bys can not be separated properly to estimate the produced noise level, the annual noise assessment is proposed in (Makarewicz 2013) and based on the traffic speed-flow diagram analysis. In the last method the available annual traffic parameters, such as traffic flow capacity, free traffic speed, and traffic capacity speed may be considered as conditions for representativeness. In the case when the passing bys may be separated it is shown (Jagniatinskis et al. 2014) how the annual noise levels may be measured using data from short term time interval, however the annual average content of vehicle categories and their speed must be available as well.

For aircraft noise assessment the strategy for prediction based on the dominant noise contributions among all aircraft flying bys is considered as one of the way to estimate corresponding annual noise levels (Filippone, 2014) and is noted, that in practice the reduction of measurement time interval shall be accounted with statistical analysis of recorded data samples. In (Schäffer et al. 2011) the importance of accounting for night time levels, not only the number and dominant types of aircraft but also the flight trajectories must be considered. So in this point of view, the radar data must be available and therefore introduced in the conditions for representativeness. The importance of statistical assessment of aircraft flying bys sound exposure levels, as well as their energy average value for aircraft noise annual assessment; especially for airports with low flight intensity is dealt in (Jagniatinskis et al. 2012).

Comparison between railway and aircraft noise impact on the community is considered in (Elmenhorst et al. 2012). Parameters, such as the number and duration of noise events, background noise level, events maximal and equivalent levels are common for trains and aircrafts and may be used in model for determination of the sample representativeness. Note, that for railway and so for road transport the distance from the track is useful, when the annual noise impact is assessed for particular environment point.

Thus, the common criteria for determination of the representative sample from which the annual noise level at the environmental site may be assessed with some accuracy are not developed yet.

2. Representative time interval for annual noise assessment of transportation

It is obvious, that as the annual noise impact assessments are based on the equivalent level, which in principal is an integral (or average) of measured results, so during the measurements (data storage) the "weight" of the current result becomes larger. Thus, with time the influence of new data on the result of integrations becomes smaller and thus must exist a time point t_n, when may be found, that result of noise level assessment, denote it as $R(t_n)$, differs from the actual annual result R^*, less than on some value ε:

$$\left|R(t_n) - R^*\right| \leq \varepsilon \,. \tag{2}$$

Depending on the traffic model and noise measurement procedure descriptor $R(t_n)$ there may be a function of the day (evening, night) of one whole-day equivalent level L_d (L_e, L_n) or of the single event exposure level L_E. This is suitable for determination of the representative sample amount in the case of annual noise assessments. If only the one whole day rating periods (12 h day; 8 h evening; 4 h night) equivalent levels are estimated by using short term measurements, $R(t_n)$ is an integral of instantaneous sound pressure levels acquired by a measurement system with some sampling time interval, e. g. 100 ms.

Descriptor L_den that describes the noise impact value in the environment is determined from L_d, L_e, L_n values using formula:

$$L_\mathrm{den} = 10\lg\left(\frac{10^{\frac{L_\mathrm{d}}{10}}}{2} + \frac{10^{\frac{L_\mathrm{e}+5}{10}}}{6} + \frac{10^{\frac{L_\mathrm{n}+10}{10}}}{3}\right). \tag{3}$$

Also, in the case where the exposure levels of passing by or flying by events are used for noise assessment, L_d, L_e and L_n values are determined using formula:

$$L_\mathrm{d(e,n)} = 10\lg\left[\frac{\tau_\mathrm{ref}}{T_\mathrm{d(e,n)}}\sum_{i=1}^{N_\mathrm{d(e,n)}}\left(10^{L_{\mathrm{E,d(e,n)},i}/10}\right)\right], \tag{4}$$

where $N_\mathrm{d(e,n)}$ – number of events, $L_{\mathrm{E,d(e,n)},i}$ – sound exposure level of i-th event and $T_\mathrm{d(e,n)}$ – rating time interval duration in seconds equal to 43 200 s, 14 400 s and 28 800 s for day (d), evening (e) and night (n) respectively; $\tau_\mathrm{ref} = 1$ s.

So in all cases, values of desired L_d, L_e and L_n descriptors may be determined. Note, that in formula (2) estimation of the considered parameter is done in time interval $(0 - t_n)$ that is shorter than one year interval. To get the estimation in formula (2), the unknown value of R^* may be assessed using the statistical data of recorded levels considering the worse and averaged cases. Formulated with expression (2), condition for representativeness is fundamental but not exclusive for annual assessments, as shown in section 1. Consider the possible cases for transportation noise measurement.

3. Road traffic case

On Fig. 1 and 2 typical one whole day time history of 1 s equivalent noise levels and 1 h equivalent noise levels are presented.

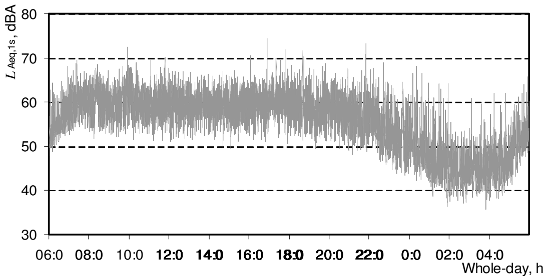

Fig. 1. Typical view of one whole day registered on microphone 1 s equivalent noise levels produced from road traffic.

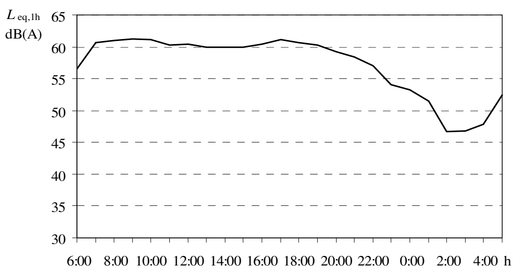

Fig. 2. Typical 1 h Leq changes of road traffic noise during the whole day.

Such graphical dependencies may be registered practically in all environmental sites because, in many cases, the road traffic noise is a main contribution to the overall environmental noise as for urban and as well as for suburbia areas.

3.1. Urban road traffic

Traffic flow in urban areas is often characterized by high level of density. Since the noise levels registered on microphone are a superposition of the noise levels produced from the passing bys of several vehicles, thus their exposure levels can not be detected separately. Variations of speed, permanent traffic congestions do the urban vehicle flow characteristics, in principle, not stable. On the other hand, the overall levels presented on Fig. 1 and 2 are repeated from day to day. So the overall whole-day equivalent levels in rating time intervals L_d, L_e and L_n may serve as a parameter for determination of representative measurement time interval for annual noise assessment. The annual L_d, L_e and L_n values are the energy average of appropriate whole day k levels $L_{d(e,n),k}$ and are found from formula:

$$L_{d(e,n)} = 10\lg\left[\frac{1}{365}\sum_{k=1}^{365}\left(10^{L_{d(e,n),k}/10}\right)\right]. \tag{5}$$

Now the representativeness condition may be formulated as follows:

$$\left|E_N\left(L_{d(e,n)}\right) - L^*_{d(e,n)}\right| \le \varepsilon , \tag{6}$$

where $E_N(L_{d(e,n)})$ – energy average of N equivalent levels in appropriate rating time intervals of representative N whole days; $L^*_{d(e,n)}$ – actual annual result.

So, for this case of transportation the representativeness of the sample may be formulated as follows:

1. Number N of measurement whole days must fulfill to condition (6) with desired accuracy ε. Value of N is determined separately for every rating time interval of day, evening and night, so the largest value of these three ones is accepted as N;
2. Weather conditions must be normal: dry weather (dry road surface), restricted wind velocity and etc. (ISO:1996-2:2007). Whole days for representative measurements may be chosen as not successive.

Note, that as can be seen from Fig. 2, the 12 h day's rating time interval levels from 06:00 to 18:00 (by Lithuanian Noise Law) are stable and varies slightly compared with evening (from 18:00 to 22:00) and night (from 22:00 to 06:00) levels. So, for day period the measurement of $L_{d,k}$ levels may be accomplished in smaller, to about 30–60 min. time interval. In this case, the representativeness conditions similar to (6) must be also formulated additionally.

3.2. Suburban road traffic

Conditions formulated in previous section are suitable for representative measurements time interval determination of noise produced from suburbia road traffic. But in this case, the unique possibility to estimate the annual L_{den} value using short-term 1–2 h continuous measurement results of road traffic noise has real opportunities. This assumption is based on the vehicle flows characteristics in the suburbia areas, such as:

- the speed for each of considered categories of vehicles and thus produced noise levels practically do not depend on the time of rating time intervals of the whole day (12 h day; 8 h evening; 4 h night);
- traffic flow is not dense, so every single vehicle passing by may be detected as shown in Fig. 3 and it's sound exposure level may be determined.

Examine the case when two categories of vehicle (light and heavy) are considered. The representativeness of the sample may be formulated as follows:

1. Number of recorded each category vehicle passing bys time histories of noise levels must correspond to the selected accuracy ε and calculated using formula (1). All vehicle passing bys must be incorporated into single continuous measurement time interval – the representative interval. In any case, the number of registered every categories vehicle must be not less than 30.
2. Registered vehicle content by amount, percentage and speed must be close to the declared annual average traffic flow parameters for measurement time interval.
3. Annual average of every considered vehicle category flow parameters (percentage content, speed) must be available.
4. Then annual L_d, L_e and L_n levels may be assessed using following formula:

$$L_{\mathrm{d(e,n)}} = 10\lg\left[\sum_{k=1}^{K} R_{k,T_{\mathrm{d(e,n)}}} 10^{\frac{\overline{L}_{\mathrm{E},k,\mathrm{meas}}}{10}}\right] + 10\lg\left[\frac{N_{\mathrm{d(e,n)}}\tau_{\mathrm{ref}}}{T_{\mathrm{d(e,n)}}}\right], \tag{7}$$

where K is a number of vehicle categories considered; $\overline{L}_{\mathrm{E},k,\mathrm{meas}}$ is energy average of measured each category vehicle sound exposure levels; $N_{\mathrm{d(e,n)}}$ and $T_{\mathrm{d(e,n)}}$ as in formula (4) and $R_{k,T_{\mathrm{d(e,n)}}}$ are coefficients, that depend on the proportion between the measured and declared vehicle category percentage for every rating time interval.

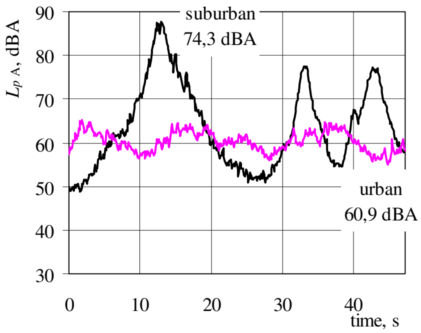

Fig. 3. Examples of 1 min. instantaneous noise level time histories produced by suburbia traffic of 74.3 dBA L_{eq} (one heavy and 2 light vehicles passing bys) in comparison with urban traffic produced noise levels of 60.9 dBA L_{eq} (red lower curve).

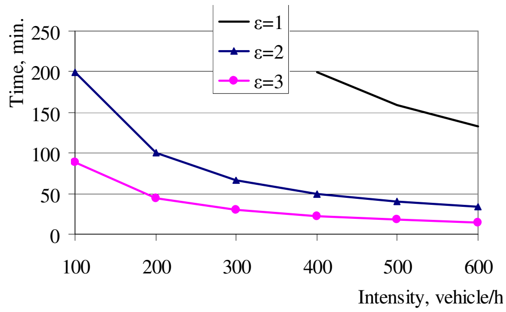

Fig. 4. Minimal representative measurement time dependency from the flow intensity and noise measurement accuracy ε for heavy vehicle percentage of 20%.

Possible values of N, which determine the representative measurement time interval, for some typical Lithuania traffic flow cases may be found from Fig. 4, where the minimal representative measurement time of traffic flow noise dependency from flow intensity and measurement accuracy ε for heavy vehicle percentage of 20% is presented.

4. Representative time interval for aircraft transport noise measurements

The difference from the section 3 cases, where the measurement microphone must be placed in the vicinity of road for aircraft transport noise measurements is that the microphone usually is placed in desired outdoor environment point. Typical aircraft flying by time history is presented on Fig. 5.

Another difference from the road traffic case is that the equivalent levels for the rating time intervals can not be measured directly, because the flying by events appears episodically on the residual urban noise. So all flying bys must be separated, which is not difficult to do taking into account that produced noise levels are much higher than urban residual noise as shown in Fig. 5. In this case the representativeness condition may be formulated using energy summation of noise levels from flying by events, i.e. – applied A weighted sound exposure levels (SEL) $L_{\mathrm{AE,\,d(e,n)}}$ of flying bys separately for every rating time interval as follows:

$$\left|E_N\left(L_{\text{AE,d(e,n)}}\right)-L^*_{\text{AE,d(e,n)}}\right| \le \varepsilon \,, \tag{8}$$

where $E_N(L_{\text{AE,d(e,n)}})$ is energy average of all aircraft flying by events SEL in appropriate rating time intervals of representative N whole days; $L^*_{\text{AE,d(e,n)}}$ is actual annual result – energy average of appropriate annual SEL's.

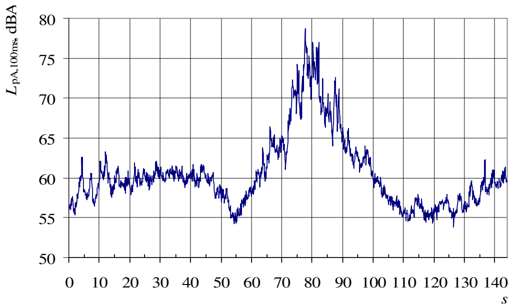

Fig. 5. Example of instantaneous noise level time history produced by one flying by event at the urban environment.

Additionally, the requirement based on the assumption, that at least 20 of aircraft flying by events with highest levels must be registered during the representative measurements (it follows from the requirements of ISO 1996-2:2007 related to the L_{Amax} determination), must be checked. This set of events may contain events with SEL values higher than, e. g. energy or arithmetic average of SEL's of all events.

So, for this case of transportation the representativeness of the sample may be formulated as follows:

1. Number N of measurement whole days must fulfill to condition (8) with desired accuracy ε. Value of N is determined separately for every rating time interval of day, evening and night, so the largest value of these three ones is accepted as N;
2. Whole days for representative measurements may be chosen as not successive and the extreme weather conditions must be avoided.

Such conditions for representativeness ensures that representative sample of events includes enough number of all types of aircrafts with possible flight trajectories and operation parameters.

5. Representative time interval for railway transport noise measurements

For this case microphone for representative measurements must be placed in the vicinity of track analogously as for road traffic case. Typical train rolling by time history is presented on Fig. 6.

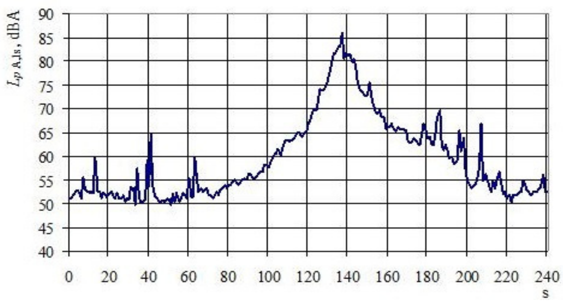

Fig. 6. Example of instantaneous noise level time history produced by freight train rolling by event at speed of 20 km/h.

Due to the same reasons as for aircraft noise, the equivalent levels $L_{\text{d(e,n)}}$ for the rating time intervals can not be measured directly and must be calculated from the train rolling by events SEL's using formula:

$$L_{\mathrm{d(e,n)}} = \overline{L}_{\mathrm{AE,d(e,n)}} + 10\lg\left[\frac{N_{\mathrm{d(e,n)}}\tau_{\mathrm{ref}}}{T_{\mathrm{d(e,n)}}}\right], \tag{9}$$

where $\overline{L}_{\mathrm{AE,d(e,n)}}$ is energy average of measured trains rolling bys sound exposure levels for appropriate rating time intervals; $N_{\mathrm{d(e,n)}}$ and $T_{\mathrm{d(e,n)}}$ as in formula (4).

Minimal measurement time interval must comprise 20 trains passing bys and 5 trains of each category to properly estimate equivalent level produced from trains at this measurement interval. But for annual assessment of equivalent level sample of more events must be chosen. So the representative time interval, analogously as for aircraft case, must fulfil representativeness conditions 1 and 2, presented in section 4.

6. Conclusions

1. Principles for the annual assessment of transportation noise equivalent L_{d}, L_{e} and L_{n} levels in appropriate rating time intervals of day 12 h, evening 8 h and night 4 h periods using direct noise measurements in representative, shorter than annual, time interval are formulated. These annual levels are used to determine the composite L_{den} level, which is obligatory for noise mapping and is mainly used for community noise impact assessment.
2. Conditions for determination of representative data sample amount are proposed taking into account noise produced from various transportation situations as road, aircraft and railway traffic.
3. Is shown that depending on the accuracy of L_{d}, L_{e} and L_{n} levels assessment, the representative noise measurement interval must consist from 4 to 10 whole days for urban road traffic produced noise measurements; from 4 whole days for high intensity airports to 30 whole days for low intensity airports related to aircraft flying bys produced noise; from 1 whole day for high intensity traffic to 7 whole days for low intensity traffic related to trains rolling bys produced noise.
4. For annual suburbia traffic noise assessment is shown exclusively that representative measurements practically may be accomplished in short-term interval from 30 min. to 120 min. depending on the measurement accuracy and traffic intensity.

References

Committee of the regions on 'the Environmental Noise Directive – the way forward', 2012, *Official Journal of the European Union*, 2012/C 113/08, 18.4.2012.

Elmenhorst, E-M.; Pennig, S.; Rolny, V.; Quehl, J.; Mueller, U.; Maaß, H.; Basner, M. 2012. Examining nocturnal railway noise and aircraft noise in the field: Sleep, psychomotor performance, and annoyance, *Science of the Total Environment* 424(1): 48–56.

Filippone, A. Aircraft noise prediction. 2014, *Progress in Aerospace Sciences* 68(1): 27–63.

ISO 1996-2:2007 Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environ-mental noise levels.

Jagniatinskis, A.; Fiks, B. 2014. Assessment of environmental noise from long-term window microphone measurements. Applied Acoustics 76(2): 377–385, http://dx.doi.org/10.1016/j.apacoust.2013.09.007.

Jagniatinskis, A.; Fiks, B.; Dimitriu, D. 2014. Annual assessment of highway traffic noise using two channel short-term measurements, *Transport* 29(2): 204–211, doi: 10.3846/16484142.2014.931295.

Jagniatinskis, A.; Fiks, B.; Zaporozhets, O. 2012. Estimation of low intensity airport noise impact using different descriptors, in *Proc. EURONOISE Prague*, Czech Republic, June 10–13, p. 1495–1500.

Mário Mateus, João A.; Dias Carrilho, Manuel C.; Gameiro da Silva. 2015. Assessing the influence of the sampling strategy on the uncertainty of environmental noise measurements through the bootstrap method, *Applied Acoustics* 89(1): 159–165.

Ng, C. H.; Tang, S. K. 2008. On monitoring community noise using arbitrarily chosen measurement periods, *Applied Acoustics* 69(7): 649–661.

Rufin Makarewicz, R. 2013. The annual average sound level of road traffic noise estimated from the speed-flow diagram, *Applied Acoustics* 74(5): 669–674.

Schäffer, B.; Bütikofer, R.; Isermann, U. 2011. Aircraft noise: accounting for changes in air traffic with time of day, *Acoust Soc Am* 129(1): 185–199, http://dx.doi.org/10.1121/1.3518729.

WHO Regional Office for Europe, 2009, *Night noise guidelines for Europe*. Copenhagen, ISBN 978 92 890 4173 7.

WHO Regional Office for Europe, 2011, *Burden of disease from environmental noise*, ISBN: 978 92 890 0229 5 (http://www.euro.who.int/data/assets_pdf_file_0008_136466_e94888.pdf).