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Urban Noise Recorded by Stationary Monitoring Stations

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Abstract. The paper presents the analysis results of equivalent sound level recorded by two road traffic noise monitoring stations. The stations were located in Kielce (an example of a medium-size town in Poland) at the roads in the town in the direction of Łódź and Lublin. The measurements were carried out through stationary stations monitoring the noise and traffic of motor vehicles. The RMS values based on A-weighted sound level were recorded every 1 s in the buffer and the results were registered every 1 min over the period of investigations. The registered data were the basis for calculating the equivalent sound level for three time intervals: from 6:00 to 18:00, from 18:00 to 22:00 and from 22:00 to 6:00. Analysis included the values of the equivalent sound level recorded for different days of the week split into 24h periods, nights, days and evenings. The data analysed included recordings from 2013. The agreement of the distribution of the variable under analysis with normal distribution was evaluated. It was demonstrated that in most cases (for both roads) there was sufficient evidence to reject the null hypothesis at the significance level of 0.05. It was noted that compared with Łódź Road, in the case of Lublin Road data, more cases were recorded for which the null hypothesis could not be rejected. Uncertainties of the equivalent sound level measurements were compared within the periods under analysis. The standard deviation, coefficient of variation, the positional coefficient of variation, the quartile deviation was proposed for performing a comparative analysis of the obtained data scattering. The investigations indicated that the recorded data varied depending on the traffic routes and time intervals. The differences concerned the values of uncertainties and coefficients of variation of the equivalent sound levels.

1. Introduction

The Resolution of the European Committee on the requirement of developing, making accessible and updating noise maps by local authorities has again drawn the attention of communities to environmental noise defined as a factor greatly affecting comfort of life [1]. Noise is evaluated using various measurands, including short- or long-term indicators [2]. To do this, acoustic measurements are made at selected sites of the assessment area and last from a few hours to several days. Then the values of these measurands and their uncertainties are determined through suitable models and simulations [3]. To enhance the monitoring accuracy, systems of permanent stations recording the values of these measurands throughout the year have been installed. The measurement results, available on the Internet in real time, reflect the changes in the structure and volume of traffic in the city and indicate the risks related to deleterious effects of noise on humans. Kielce has more than ten such stations, both in the centre and on the outskirts of the city.

2. Traffic noise monitoring stations in Kielce

This study is focused on the results of sound level measurements, collected from two automatic traffic noise and volume monitoring stations located at a distance of about 2 km away from each other in Łódzka and Jesionowa roads. Both roads, as shown in Fig. 1, constitute a traffic route defined as national road no. 74 connecting western and eastern city limits. Łódzka Rd, with four lanes of traffic separated by a 3-m grass median, is the major part of the Łódź-bound thoroughfare functioning as both the transit route and the city street. The structural condition of the bituminous pavement is good. The road is at grade. The 2013 data are analysed in this study.

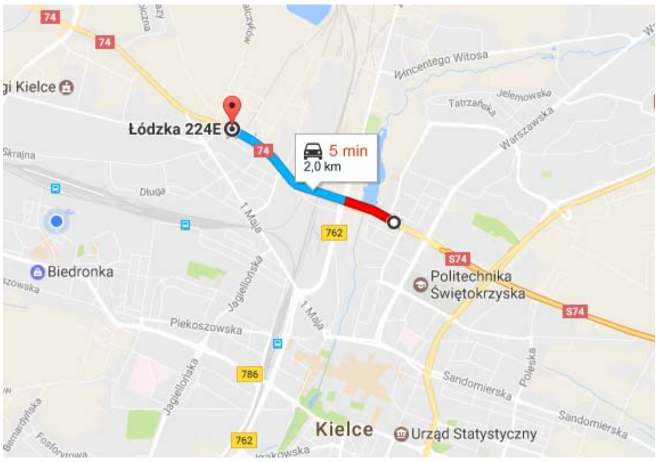

Figure 1. Location of noise monitoring stations in Łódzka Rd (50.894369 and 20.611445) and Jesionowa Rd (50.885759 and 20.636054) in the urban layout of Kielce [after Google Maps]

Databases of the recorded sound levels comprise calculated values of the equivalent sound level for year 2013 split into three time sub-intervals of a 24-hour period: day time, evening and night time. Due to various technical problems, the databases are not complete. Analysis of the data indicates that in the period 02-05-2013 to 13-06-2013 for Jesionowa Rd and 2-07-2013 do 28-08-2013 for Łódzka Rd, the stations failed to provide any equivalent sound levels. Thus the uncertainties of these measurements are higher. The location of the Łódzka Rd monitoring terminal within the urban layout of Kielce is shown in figure 1. It is situated between two busy intersections but at a substantial distance from them. There is a heat and power plant opposite. Jesionowa Rd, functioning as both the transit route and the city street, has four lanes of traffic separated by a 3-m grass median and connects Łódzka Rd with the expressway denoted as S74. The structural condition of the bituminous pavement is good. The road is level with the surrounding flat land. Between the terminals, there is a high railroad.

The monitoring terminals mounted in Kielce include a sound level meter, a safety camera and a weather station [4]. Terminal configuration and data recording can be controlled remotely. The acoustic measurements were carried out using SVAN 958A device, which is a four-channel digital vibration analyser and a class 1 sound level meter. The measuring microphone used in this study was a Microtech Gefell MK250 free-field, repolarised 1/2" condenser microphone with a sensitivity of 50 mV/Pa, SV 12L preamplifier, a frequency range 3,5 Hz to 20 kHz and a dynamic range from 15 dB to 146 dB. The temperature range within which the device is operable is from -10º C to 50º C owing to the nickel membrane. The resolution of the signal RMS detector is 0.1 dB. The microphone for the acoustic pressure measurements is mounted at a distance of 4 m from the edge of the road and 4 m above ground level. The measurements were carried out 24 hours a day. The RMS values of the A sound level were registered in the buffer every 1 s and the results were recorded every 60 seconds. The equivalent sound level was calculated from the recorded data for three time intervals, i.e., from 6:00 to 18:00, from 18:00 to 22:00 and from 22:00 to 6:00. The traffic volume was measured using a digital radar with an operating frequency of 245 MHz, manufactured by WAVETRONIX. The weather data were recorded by a VAISALA WTX 510 automatic meteorological station.

3. Review of the state of the art in traffic noise uncertainty measurements

Analysis of the literature [5] indicates that traffic noise measurement results are hardly ever normally distributed. That is why the authors of [2, 6] propose non-conventional statistical methods to evaluate noise measurement uncertainty. The noise pollution (nuisance) due to long-term exposure to noise is very often measured by the equivalent sound level ($L_{Aeq,T}$), expressed in (dB), defined as

$$L_{Aeq,T} = 10 \cdot \log\left[\frac{1}{T}\int_0^T \left(\frac{p_A(t)}{p_0}\right)^2 dt\right] \tag{1}$$

where p_0 is the standardized reference acoustic pressure of 20 μPa. According to the ISO standard, this parameter can be determined from [6]

$$L_{eq} = 10\log\left(\frac{1}{N}\sum_{i=1}^{i=N} 10^{0.1L_{A,i}}\right) \tag{2}$$

where $L_{A,i}$ is the A-weighted acoustic pressure level measured in the measurement interval i. The average sound level can be determined as expected value from

$$\overline{L} = \frac{1}{N}\sum_{i=1}^{i=N} L_{A,i}. \tag{3}$$

Standard deviation of the measurement results can be then calculated from

$$\sigma_{L_{Aeq}} = \sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{i=N}\left(L_{A,i} - \overline{L}\right)^2} . \tag{4}$$

The equation for the equivalent sound level can be written, with some degree of approximation, as

$$L_{eq} \approx \mathrm{L_{eq}}(\sigma) = \overline{L} + 0.115\,\sigma^2 \tag{5}$$

Expanded uncertainty of measurements is determined from

$$u(t_{\alpha;N-1}) = \pm\sqrt{\frac{\sigma^2}{N} + \frac{0.026\sigma^4}{N-1}}\; t_{\alpha;N-1} \tag{6}$$

where $t_{\alpha;N-1}$ is the quantile of the t – distribution at the confidence level α, standardized at 0.05. The relationships from (3) to (6) can be applied, as stated in [6], assuming that the null hypothesis about normal unimodal distributions of the measured sound levels $L_{A,i}$, independent variables, adequately large quantity of data, and low standard deviations can be accepted. If the values of distribution skewness and kurtosis are close to zero and three, respectively, equation (5) can be used to determine $L_{Aeq,T}$ with an acceptable degree of approximation. The variability of L_{Aeq} can also be evaluated with the use of the coefficient of variation determined from [7]

$$COV_{L\,Aeq} = COV = \frac{\sigma_{L\,Aeq}}{L\,Aeq} * 100\% \tag{7}$$

The coefficient of variation is a relative non-dimensional measure of equivalent sound level dispersion.

Studies so far have analysed mostly long-term indicators, covering the whole year. This study, unlike others, looks at the results split into week days and sub-intervals of a 24-hour period. The $L_{Aeq,T}$ results will be subjected to statistical analysis with the use of a commonly available R program. The analysis aims at determining days of the week and 24-hour period sub-intervals for the traffic in a medium-sized city such as Kielce, when the requirements of the ISO standards are met and the approximate value of $L_{Aeq,T}$ calculated from (5) can be used instead of the exact value resulting from (2). Equivalent sound level values and expanded uncertainties determined using different methods will be compared.

4. Sound level measurement results

Examples of diagrams showing recorded $L_{Aeq,T}$ for all the measurement days in 2013, split into 24-hour period sub-intervals are shown in figure 2a for Łódzka Rd and in 2b for Jesionowa Rd.

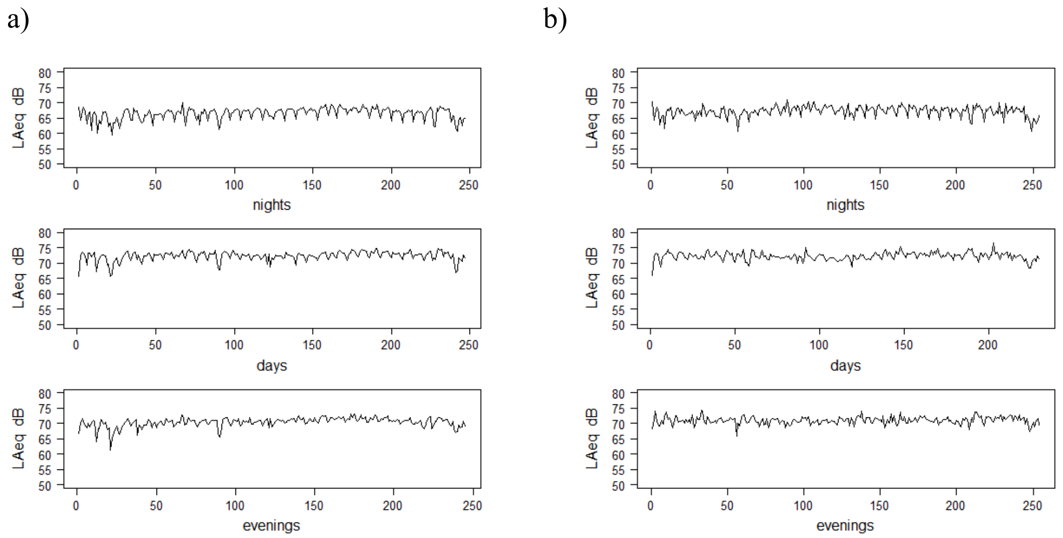

Figure 2. Equivalent sound levels for all measurement days in 2013 split into time sub-intervals; a) Łódzka Rd, b) Jesionowa Rd.

Tables 1 and 2 show basic statistics $L_{Aeq,T}$ for the 24h periods and three time sub-intervals determined from measurement data collected from Łódzka and Jesionowa roads, expressed in decibels. The Lilliefors and Shapiro-Wilk statistical tests rejected the null hypothesis that the data (figure 2) followed a normal distribution, because the calculated significance levels were lower than the required level of 0.05. The H_0 in further parts of this paper was tested for the significance level of 0.05. In cases where the normal distribution of given data was doubtful, the Jarque-Bera test was additionally used. This test is in a group of tests based on moments on a given data sample [4]. The results of those tests are not included in the tables. Nevertheless, the statistical tests showed that for some of the week days and for certain time intervals within a 24-hout period there was not enough evidence to reject the null hypothesis, especially for Jesionowa Rd. In most cases, the statistical tests [4] rejected the null hypothesis H_0 that the measurement data follow a normal distribution, because the calculated limiting significance levels were zero.

Table 1. Values of basic statistical measures $L_{Aeq,T}$ determined for all the measurement data collected in 2013 from Łódzka Rd in Kielce.

Interval	Med dB	L_{eq} dB	$\overline{L}$ dB	$\sigma_{L_{Aeq}}$ dB	$L_{eq}(\sigma)$ dB	$u(t_{\alpha;N-1})$ dB	u_{CA} dB	COV %
24h	70.50	70.59	69.73	2.95	70.73	0.237	0.216	4.24
Nights	67.10	66.82	66.46	1.91	66.88	0.250	0.235	2.87
Days	72.70	72.55	72.32	1.55	72.59	0.200	0.196	2.14
Evenings	70.70	70.63	70.41	1.51	70.67	0.195	0.196	2.14

Denotation: Med – median, $\sigma_{L_{Aeq}}$ – standard deviation, $u(t_{\alpha;N-1})$ – expanded uncertainty dependent on the quantile of the t – distribution at the confidence level α, u_{CA} – Type A expanded uncertainty

This results in discrepancies between the arithmetic mean, L_{eq} and $L_{eq}(\sigma)$ of the equivalent sound level. Small differences between L_{eq} and $L_{eq}(\sigma)$ are in agreement with the literature data [6]. The differences between type A expanded uncertainties $u(t_{\alpha;N-1})$ and u_{CA} are smaller than 0.021 dB. The values of $L_{Aeq,T}$ are similar for both roads.

Analysis of the medians in Tables 1 and 2 for each time subinterval show the following differences:

1. Łódzka Rd: 5.6 dB between day and night time sub-intervals, 2.0 dB between day and evening time sub-intervals, and 3.6 dB between evening and night time sub-intervals.

2. Jesionowa Rd: 4.9 dB between day and night time sub-intervals, 1.3 dB between day and evening time sub-intervals, and 3.6 dB between evening and night time sub-intervals.

Table 2. Values of basic statistical measures $L_{Aeq,T}$ determined for all the measurement data collected in 2013 from Jesionowa Rd in Kielce.

Interval	Med dB	L_{eq} dB	$\overline{L}$ dB	$\sigma_{L_{Aeq}}$ dB	$\mathrm{L_{eq}}(\sigma)$ dB	$u(t_{\alpha;N-1})$ dB	u_{CA} dB	COV %
24h	70.68	70.75	70.07	2.60	70.85	0.205	0.196	3.72
Nights	67.43	67.44	67.14	1.72	67.48	0.221	0.216	2.57
Days	72.29	72.42	72.24	1.26	72.43	0.167	0.157	1.74
Evenings	71.03	71.20	71.03	1.22	71.20	0.156	0.157	1.72

Note small differences between the medians of the 24-hour period sub-intervals, especially between the day and evening time intervals for both roads, while the differences between these values for either of the roads separately are different. A comparison of the COV of the $\mathrm{L_{Aeq,T}}$ results shown in Table 1 and Table 2 indicates that the values determined for Łódzka Rd are about 0.45% higher than those for Jesionowa Rd. This observation is confirmed by the analysis of standard deviation of the $L_{Aeq,T}$ results both in the case of 24-hour periods and of the time sub-intervals.

The box plots shown in figure 3 and figure 4 show data that can be considered atypical [4]. Because no causes were identified for the occurrence of atypical data, these data were taken into account in further analysis of the recorded samples. This phenomenon is thus characterized by high randomness, which is consistent with the findings reported in the literature [5].

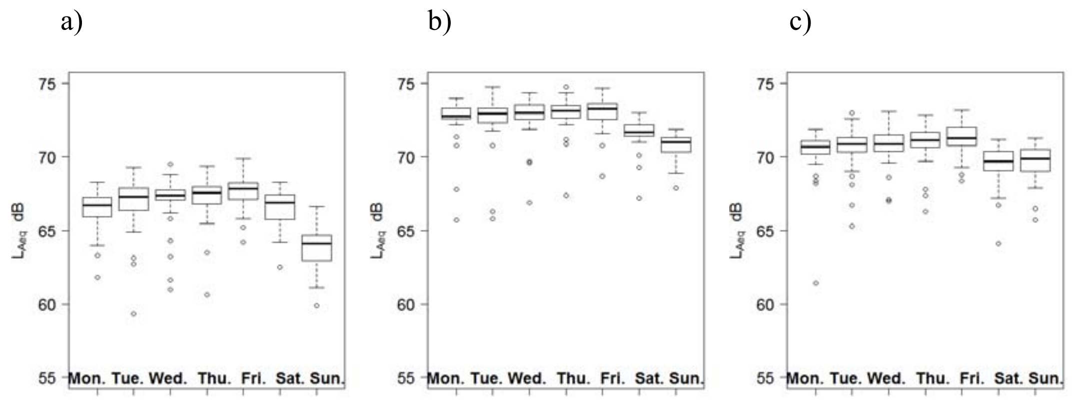

Figure 3. Box plots of $L_{Aeq,T}$ for all days of measurement in 2013 split into time sub-intervals a) nights, b) days, c) evenings, Łódzka Rd.

From figure 3 it follows that the median of $L_{Aeq,T}$ for each time sub-interval increases from Monday to Friday. On Saturday and Sunday, it decreases gradually by about 3 dB for the night time and day time sub-intervals, whereas at weekend evenings, it decreases in steps by about 2 dB. The quantity of atypical data is high.

Variations in the $L_{Aeq,T}$ value (from Monday to Friday) shown in figure 4 for each time sub-interval are 1 dB. On Saturdays and Sundays, the median decreases gradually by 3 dB for the nigh time, about 2 dB for the day time, and about 1 dB for evenings. The amount of atypical data is smaller here than in the case of Łódzka Rd.

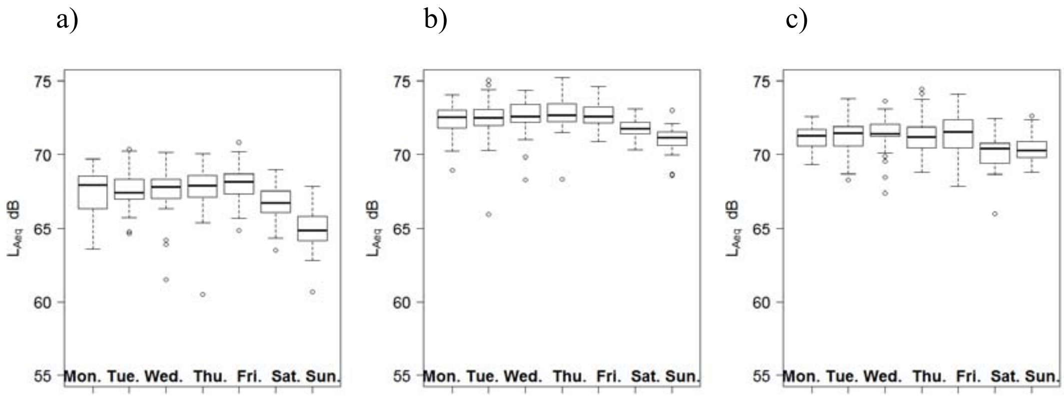

Figure 4. Box plots of $L_{Aeq,T}$ for all days of measurement in 2013 split into time sub-intervals a) nights, b) days, c) evenings, Jesionowa Rd.

Figure 5a illustrates the calculated COV changes for each week day in Łódzka Rd.

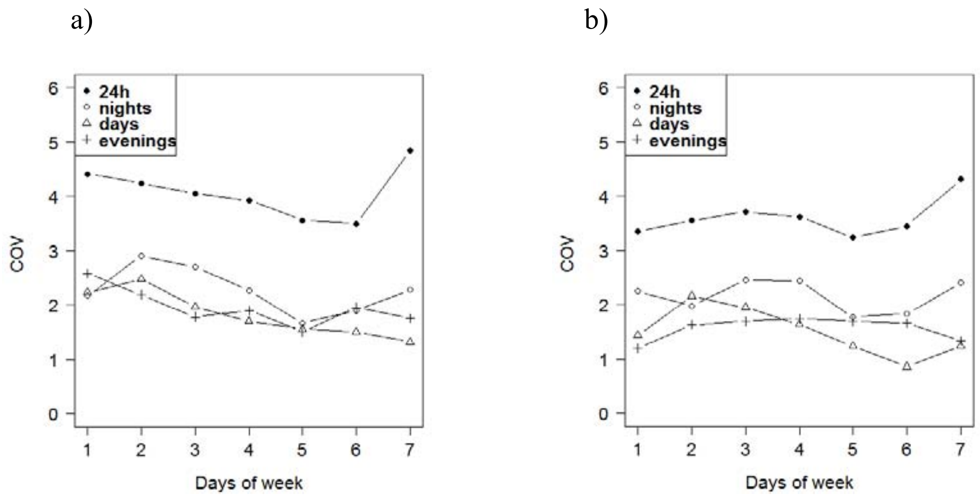

Figure 5. Changes in $\mathrm{COV}_{\mathrm{L\ Aeq}}$ on particular days of the week a) Łódzka Rd, b) Jesionowa Rd

The COV for the time sub-intervals decreases systematically by about 0.2% from Monday to Saturday to increase in steps by about 1.5% on Sunday. These changes range from 4.5 % to 5%. In the case of Jesionowa Rd, the changes of COV range from about 0.25% from Monday to Friday and increase by about 1% on Saturday and Sunday, as shown in figure 5b. These changes occur in the COV range of 3.2% to 4.2%. For the 24-hour sub-intervals (nights, days, evenings), the COV changes range from 1.5% to 3% for Łódzka Rd and from 1% to 2.5% for Jesionowa Rd.

5. Summary

The paper analyses the equivalent sound levels recorded by two automatic permanent stations for monitoring noise level and traffic volume. Both stations, located at a distance of 2 km from each other, have been installed along the national road 74. In most cases, the statistical tests allow rejecting the null hypothesis H_0 about normal distribution of the measurement data. This results in a discrepancy between the values of arithmetic mean, L_{eq} and $\mathrm{L_{eq}}(\sigma)$ of the equivalent sound level. The values of these parameters range from 0.08 dB to 0.68 dB. Analysis of the medians of the equivalent sound level indicates that greater differences between time sub-intervals occur for Łódzka Rd: 5.6 dB between day and night time subintervals, 2.0 dB between day and evening time sub-intervals, and 3.6 dB between evening and night time sub-intervals. The median of $L_{Aeq,T}$ for each time sub-interval for Łódzka Rd increases from Monday to Friday. On Saturday and Sunday, it decreases gradually by about 3 dB for the night time and day time, whereas for weekend evenings, it decreases in steps by about 2 dB. For Jesionowa Rd, the variations in the $L_{Aeq,T}$ value (from Monday to Friday) for each sub-interval are 1 dB and on Saturday and Sunday, the median decreases gradually by 3 dB for the nigh time, about 2 dB for the day time, and about 1 dB for evenings.

Analysis of measurement uncertainties shows that the highest type A expanded uncertainty values occur for the night time sub-intervals: 0.235 dB at Łódzka Rd site and 0.216 dB at Jesionowa Rd site. The comparison of COVs of $L_{Aeq,T}$ measurements demonstrate that the values determined (for the whole year) for the Łódzka Rd site are about 0.45% higher than those for Jesionowa Road. The COV for sub-intervals but at each day of the week decreases systematically by about 0.2% from Monday to Saturday to increase in steps by about 1.5% on Sunday. The changes in the COV values range from 4.5 % to 5%. At the Jesionowa Rd site, the COV values are about 0.25% from Monday to Friday and increase on Saturday and Sunday by about 1%. These changes range from 3.2% to 4.2%. It follows from the above that at the Łódzka Rd site, the component variables constitute a greater share in the noise than at the Jesionowa Rd.

References

[1] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental Noise, Official Journal of the European Communities – 18.07.2002

[2] W. Batko, B. Stępień, "Type A Standard Uncertainty of Long-Term Noise Indicators", *ARCH. ACOUST., Vol. 39, No. 1, pp. 25–36 (2014), DOI: 10.2478/aoa-2014-000*

[3] A. Jagniatinskis, B. Fiks, O. Zaporozhets, "Annual Assessment of Transport Noise Using Representative Time Measurements", *Procedia Engineering 134 (2016) 301 – 308*

[4] A. Bąkowski, L. Radziszewski, Z. Skrobacki, "Assessment of uncertainty in urban traffic noise measurement", *Procedia Engineering 177 (2017) 281 - 288, ISSN 1877-7058*

[5] T. Wszołek, M. Kłaczyński, "Effect of traffic noise statistical distribution on L_{AeqT} measurement uncertainty", *ARCH. ACOUST. 31, 4 (Supplement), 311–318 (2006)*

[6] B. Przysucha, W. Batko, A. Szeląg, "Analysis of the Accuracy of Uncertainty Noise Measurement", *ARCH. ACOUST. Vol. 40, No. 2, pp. 183–189 (2015), DOI: 10.1515/aoa-2015-0020*

[7] A. Bąkowski, L. Radziszewski, M. Žmindak, "Analysis of the coefficient of variation for injection pressure in a compression ignition engine", *Procedia Engineering 177 (2017), 297 - 302 ISSN 1877-7058*