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Uncertainty estimation in environmental road traffic noise measurements using ISO 1996-2:2017

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Abstract

When measuring the road traffic noise, the environmental noise levels are quantitatively described using the equivalent noise pressure level parameter (L_{eq}). The value of L_{eq} based on the measurements done with sound level meter would probably differ from the true one due to the sources that can cause measurement uncertainty. According to this, the ISO 1996-2:2017 standard proposes calculation of the standard measurement uncertainty, so that the results from the measurements could be more accurate. This paper proposes a guideline on estimating the measurement uncertainty in compliance with the ISO standard for short-term measurements of road traffic noise. To verify the proposed method, twenty short-term measurements are done in same spot in morning and afternoon period from Monday to Friday for two weeks; and afterwards, the measurement uncertainty is calculated for each measurement. To confirm the accuracy of the results, additional acoustic modeling was made. By comparing the results for the L_{eq} parameter from the measurements and from the acoustic noise maps in accordance with the calculated measurement uncertainty, it could be confirmed the results accuracy. In conclusion, this paper presents a reflection on why estimation of the uncertainty of the measurement is essential in environmental noise analysis.

Keywords: uncertainty estimation, environmental noise, noise measurements, acoustic noise maps

1 Introduction

Environmental noise is defined as any unwanted or harmful outdoor sound created by human activity, such as noise emitted from transport, traffic and industrial activity. Noise pollution is known to be one of the main reasons for environmental pollution in the urban areas, causing harmful effects on the quality of life of the population that is directly exposed to noise. The noise pollution is known to be mainly caused by noise sources in the heavy urban traffic and is followed with increasing number of complaints from the public [1]. According to this, significant health problem can be noticed followed with loss of hearing, sleep distribution, reduced productivity, and traffic accidents [2]. The traffic noise is major environmental noise source, and by the analysis made in [3], it is confirmed to be unpleasant and most influential sound source that causes urban noise pollution.

In order to properly determine the environmental noise pollution assessment and to design effective noise control, noise measurements are required. According to the research in [4], the noise measurement is an important diagnostic tool in noise control technology and noise pollution assessment. To quantitatively describe the environmental noise, the equivalent sound pressure level parameter L_{eq} is widely used, using the A weighted curve. The measured value of L_{eq} based on the sound pressure level measurements by sound level meter will probably differ from the true one because of the measurement uncertainty due to the sources that disturb the measurement operation, especially when measuring the outdoor noise pollution. The result from a measurement in the environment is only an approximation or estimate of the 'true' value, and thus, is only complete when accompanied by a statement of the uncertainty. The uncertainty leads in defining measurement accuracy, where the term 'accuracy' shows how a measurement result is close to the 'true' or accepted value.

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Guidelines on estimating the measurement uncertainty are given by the ISO Guide to Uncertainty of Measurements [5] and the ISO 1996-2:2018 standard [6]. According to the standard, the measurement uncertainty for outdoor noise measurements is caused by several parameters: type of the sound level meter, the residual sound, type of source, meteorological conditions, and source location. These guidelines are followed by a lot of researchers, leading in producing significant contribution in the field of environmental noise measurement uncertainty [7,8,9].

On the other hand, the noise level can be also calculated by creating acoustic noise maps. In addition to this, by using the number of vehicles from the traffic flow in chosen urban area as input in noise mapping software, the researchers in [10] use noise-mapping techniques as a cartographic representation of the noise level in a defined area and period. By comparing the noise level from the measurement and the predictive noise maps, the results in [11] show similar noise levels, indicating the traffic as main noise source.

It can be concluded that the noise level results can be validated by comparing the results for the L_{eq} parameter estimated using different methodologies. Followed by this, the calculation of the noise uncertainty can help in evaluating the results within the uncertainty range, and from here, verify their accuracy.

According to the previous work, this paper aims to evaluate the accuracy of the equivalent noise pressure level parameter using two methodologies: noise measurements using hand-held analyzer from 1st class using the ISO 1996-2:2018 standard; and acoustic modelling by creating predictive noise maps that use the vehicles as an input sound source. To verify the proposed method, twenty short-term measurements are done in same spot in morning and afternoon period from Monday to Friday for two weeks; and afterwards, the measurement uncertainty is calculated for each measurement. Also, the L_{eq} is estimated from the predictive noise maps that are generated using the traffic flow as line source for the same time period as the measurements.

2 Estimation of the equivalent noise pressure level (L_{eq}) from road traffic noise

2.1 Measurement methodology in chosen urban area

Twenty short-term measurements of the traffic noise were carried out at one measurement point in the central part in the city of Skopje known to have constant noise pollution as shown. Figure 1 shows the measurement location and setting.

The measurements were done in two weeks period from Monday to Friday in the first week of June and the first week of September.

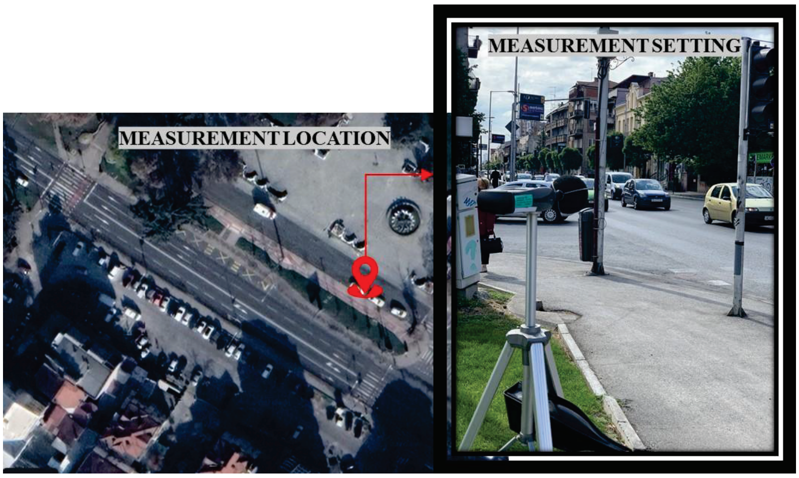

Figure 1. Location of the measurement point

The applied methodology for the noise measurements is based on the European Noise Directive and the international standards transposed by the national by-laws. For the noise measurements, 1st class hand-held analyzer Brüel & Kjær 2250 was used, using the A-weighting filter. Before the measurements, the hand-held analyzer was calibrated at 94 dB and 114 dB. Each measurement lasted 10 minutes, which is long enough to identify the road traffic noise sources. The hand-held analyzer was set at 1.5 meters height and 3 meters horizontal distance from the edge of the road. The atmospheric impact, such as temperature, humidity and wind speed have also been noted for every conducted measurement.

2.2 Modelling of acoustic predictive noise maps

Using the French Method for Road Traffic Noise Prediction (NMBP routes 96) which is transposed in the national by-laws, the traffic flow is considered as main parameter when creating acoustic prediction model. The acoustic modeling was made using the IMMI software. When creating the predictive noise maps, three operational phases must be considered: input of the topography and geometry, the road surface topology, the average vehicle speed, and the traffic flow as line noise source. The flowchart indicating the operational phases is shown on figure 2.

For the traffic flow input, the number of vehicles for the crossroad on the selected location was provided for the same period as the measurements were done from the Traffic Management and Control Center. After statistically processing and analyzing the traffic flow data, the number and type of the vehicles were set as an input noise source.

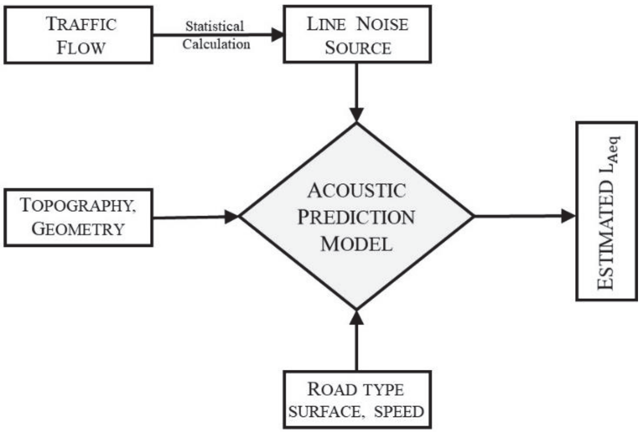

Figure 2. Flowchart of the methodology for creation of acoustic noise maps

By inserting the above-mentioned parameters, the IMMI software calculates the noise maps dispersion models, from where the equivalent sound level parameter L_{eq} can be obtained.

3 Measurement uncertainty estimation

Measurements of environmental noise are complex to perform because of the great number of variables that have to be considered. As each measurement occasion is subject to current source and meteorological conditions which cannot be controlled by the operator, it is often not possible to control the resulting uncertainty of the measurements. Instead, the uncertainty is determined after the measurements based on an analysis of the acoustic measurements and collected data on source operating conditions and on meteorological parameters important for the sound propagation.

The measurement uncertainty of sound pressure level depends on several sources: sound source, measurement time interval, meteorological conditions, distance from the source and the measurement method and instrumentation. According to ISO 1996-2 and the ISO/IEC Guide 98-3 (GUM), there are several methods for noise level estimation:

- Modelling approach by identifying and quantifying all major sources of uncertainty by using the uncertainty budget;
- Inter-laboratory approach by carrying out a round-robin test to determine standard deviation of reproducibility of the measurement method;
- Hybrid approach by combining the modelling and the inter-laboratory approach.

The modelling method consisted of determining the budget uncertainty is preferred and highly used method, especially when having short-term measurement. That is why, this method will be described and analyzed in the following paragraph, and later will be used for determining the measurement uncertainty of the applied measurements. According to the modelling method, the measurement uncertainty will be explained, focusing on the general model and the environmental noise measurement uncertainty.

3.1 General model

According to the ISO/IEC Guide 98-3, the mathematical general model for uncertainty estimation needs to identify and determine the measurement uncertainty of each source that causes uncertainty. The value of the measurement L is function of the measured parameters x_i that have influence on the uncertainty is determined:

$$L = f(x_1, x_2, x_3, \dots, x_j) \tag{1}$$

If each of the parameters x_j has standard uncertainty u_j, the combined standard uncertainty will be:

$$u(L) = \sqrt{\sum_{1}^{n} (c_j u_j)^2} \tag{2}$$

The parameters x_j are independents, and the c_j is sensitivity coefficient that is calculated as a function of the measured parameter:

$$c_j = \frac{df}{dx_j} \tag{3}$$

The overall measurement uncertainty is shown as expanded uncertainty, that is product of the combined standard uncertainty (u) and the numerical coverage factor (k):

$$U = ku \tag{4}$$

The coverage factor is a numerical factor used as a multiplier of the combined standard uncertainty to obtain an expanded uncertainty. The coverage factor is stated so that the standard uncertainty of the measured quantity can be used in calculating the combined standard uncertainty of other measurement results that may depend on that quantity. The value of the coverage factor is chosen based on the level of confidence (confidence level) required of the interval. The coverage factor is based on Gauss distribution. The mean $k = 1$ corresponds to 68%, the $k = 2$ to 95%, and $k = 3$ to 99.7% confidence interval.

Usually, the used coverage factor is 2 $(k = 2)$, which confirms the result with 95% accuracy. The final given value is the corrected result with the expanded measurement uncertainty in the following form:

$$L \pm 2u \tag{5}$$

3.2 Budget uncertainty for outdoor environmental noise measurements

Determining the measurement uncertainty of environmental noise in road traffic measurements is complex operation to determine the function f as influence of the measured parameters. The estimated value during the specified conditions followed with the measurement uncertainty based on the measurement budget is calculated with the following equation:

$$L = L' + 10\lg\left(1 - 10^{-0{,}1(L'-L_{res})}\right) dB + \delta_{sou} + \delta_{met} + \delta_{loc} \tag{6}$$

Where:
L is the estimated value during the specified conditions expressed in decibels (dB);
L' is the measured value including residual sound;
L_{res} is the residual sound;
δ_{sou} is an input quantity that shows the uncertainty due to deviations from the expected operating conditions of the source;
δ_{met} is an input quantity to allow for any uncertainty due to meteorological conditions deviating from the assumed meteorological conditions;
δ_{loc} is an input quantity to allow for any uncertainty due to the selection of receiver location.

The equation (6) shows that each source of measurement uncertainty is function of several sources of uncertainty and in addition, it will be applied for the short-term measurements that were carried out for the purpose of this paper. The measurement uncertainty that depends on the sources δ_{sou} and the meteorological characteristics δ_{met} are determined directly from the measurements' conditions. The measured sound pressure level L' and the residual sound level L_{res} depend on the measurement uncertainty arising from the measuring instrument (δ_{slm}).
Table 1 shows the budget of the measurement uncertainty when measuring the sound pressure level, including all of the sources that can cause uncertainty, which are discussed in detail in section 3.3. According to the ISO 1996-2, the estimated value in dB from the source and meteorological conditions is considered to be 0, while the measurement uncertainties for both parameters vary, and their calculation is showed in section 3.3.

Table 1. Budget of measurement uncertainty

Value	Estimated value (dB)	Standard measurement uncertainty y, u_j dB	Magnitude of sensitivity coefficient, c_j	Determined measurement uncertainty, $c_j u_j$, dB
$L' + \delta_{slm}$	L'	$u(L')$	$\frac{1}{1-10^{-0,1(L'-L_{res})}}$	
δ_{sou}	0	u_{sou}	1	
δ_{met}	0	u_{met}	1	
δ_{loc}	0.0 – 6.0	u_{loc}	1	
$L_{res} + \delta_{res}$	L_{res}	u_{res}	$\frac{10^{-0,1(L'-L_{res})}}{1-10^{-0,1(L'-L_{res})}}$	
Combined measurement uncertainty			$u(L) = \sqrt{\sum_{1}^{n}(c_j u_j)^2}$	
Expanded measurement uncertainty (95% confidence level k=2), $2u$				
Final value				$L \pm 2u$

Depending on the sources that cause the measurement uncertainty in the measurement of environmental noise, the combined measurement uncertainty is calculated according to the formula:

$$u(L) = \sqrt{(c_{slm}u_{slm})^2 + (c_{sou}u_{sou})^2 + (c_{met}u_{met})^2 + (c_{loc}u_{loc})^2 + (c_{res}u_{res})^2} \tag{7}$$

3.3 Sources of measurement uncertainty

The measurement uncertainty can be caused by:

1. Standard measurement uncertainty from the sound level meter ($L' + \delta_{slm}$)

According to the standards IEC 61672 and ISO 1996-2:2018 [6, 12], for sound level meter that refers to a class 1, the standard uncertainty should be taken as 0.5 dB.

2. Standard measurement uncertainty from the source (δ_{sou})

For road traffic noise measurement, the standard measurement uncertainty depends on the number of vehicles n and the coefficient that depends on the type of vehicles C:

$$u_{sou} \cong \frac{C}{\sqrt{n}}\, dB \tag{8}$$

3. Standard measurement uncertainty from the meteorological conditions (δ_{met})

According to the meteorological conditions if the weather is favorable and stable then the default uncertainty will be:

$$u_{met,fav} = 2\, dB \tag{9}$$

This applies only when the horizontal distance between the noise source and the receiver is less than 400 meters ($D < 400\, m$).

4. Standard measurement uncertainty from the microphone location (δ_{loc})

Depending on the location of the microphone, the noise level can be adjusted between 0 and 6 dB. If the microphone is set on a distance lower than 0.5 meters of reflecting surface, the noise level should be corrected for 6 dB, while if the distance is between 0.5 to 2 meters, correction of 3 dB should be applied. For measurements in free field with more than 2 meters distance from reflecting surface, no correction is applied (the value should be set to 0). Because the measurements in this study are done in free field, this value is set to be 0.

5. Standard measurement uncertainty from the residual sound ($L_{res} + \delta_{res}$)

The residual sound while measuring road traffic noise can be calculated by comparing measured equivalent sound level with the residual sound which can be considered as the indicator L_{95} which represent the noise level present in 95% of the time.

4 Results

4.1 Short-term measurements

According to the proposed methodology in section 2, short-term noise measurements are done in the chosen location in urban area, and afterwards, the measurement uncertainty is calculated according to the methodology shown in section 3. Table 2 shows the calculated L_{eq} for each measurement with their measurement uncertainty. For the measurements number which is shown in the format MX-Y-Z, the M stands for measurement, the X is the number of the day of the measurement (ex. 1 for Monday, 2 for Tuesday etc.), the Y represents the week (1 is for the first week of June, while 2 is for the first week of September), and Z represents the time when the measurement is done (1 for the morning measurements and 2 for the afternoon measurements).

For example, for measurement M1-1-1, the calculated equivalent noise level is 67.28 with measurement uncertainty of ±4.26. The measured L_{eq} is 67.33 dB, while the residual sound is 57.57 dB. By applying the formula (6), the calculated L_{eq} is measured to be 67.28 dB. Next, the measurement uncertainty is calculated. The measurement uncertainty for the sound level meters is $u(L') = 0.5$, while the magnitude of sensitivity coefficient is calculated due to the formula shown on table 1 and its value is 1.12. The measurement uncertainty from the source is calculated from formula 8 and its value is estimated to be 0.48, having $n = 432$ number of vehicles with $C = 10$ coefficient for mixed types of vehicles, while the magnitude of the coefficient is set to be 1. Next, the measurement uncertainty from the meteorological condition is shown, which is set to be 2 as favorable meteorological conditions were followed during the measurements. As stated earlier, the microphone location was in free field, and according to the standard [6], the measurement uncertainty of the location is set to be 0, with magnitude of sensitivity coefficient 1. At the end, the measurement uncertainty from the residual sound has value 0, because according to the standard, if the values between the Leq and Lres differ more than 5 dB, then the uncertainty from the residual sound would be close to 0. As for the magnitude of the sensitivity coefficient, according to the formula shown on table 1, this value is 0.08. After evaluating all the measurement uncertainty parameters, the equation (7) is applied, from where the combined measurement uncertainty is calculated to be 2.13 dB. As the confidence level of the result is 95%, the expanded measurement uncertainty multiplied with 2, this leading to a value of 4.26 dB. From here, it could be stated out that the equivalent noise level for the measurement M1-1-1 is 67.28 ± 4.26 dB. This methodology is applied to all measurements, and the results could be seen on table 2.

Table 2. Calculated equivalent noise level and measurement uncertainty

Morning measurements (09:00 – 09:10)
From Monday to Friday in the first week of June

Measurement number	Date	Calculated L_{eq} (dB(A))	Measurement uncertainty (dB)
M1-1-1	31.05	67.28	±4.26
M2-1-1	01.06	67.73	±4.25
M3-1-1	02.06	71.8	±4.25
M4-1-1	03.06	72.23	±4.27
M5-1-1	04.06	71.56	±4.25

Afternoon measurements (14:00 – 14:10)
From Monday to Friday in the first week of June

Measurement number	Date	Calculated L_{eq} (dB(A))	Measurement uncertainty (dB)
M1-1-2	31.05	67.37	±4.24
M2-1-2	01.06	69.72	±4.24
M3-1-2	02.06	72.89	±4.26
M4-1-2	03.06	73.65	±4.26
M5-1-2	04.06	67.29	±4.28

Morning measurements (09:00 – 09:10)
From Monday to Friday in the first week of September

Measurement number	Date	Calculated L_{eq} (dB(A))	Measurement uncertainty (dB)
M1-2-1	30.08	73.18	±4.25
M2-2-1	31.08	74.92	±4.24
M3-2-1	01.09	75.33	±4.25
M4-2-1	02.09	73.3	±4.25
M5-2-1	03.09	76.7	±4.26

Afternoon measurements (14:00 – 14:10)
From Monday to Friday in the first week of September

Measurement number	Date	Calculated L_{eq} (dB(A))	Measurement uncertainty (dB)
M1-2-1	30.08	73.27	±4.23
M2-2-1	31.08	73.94	±4.26
M3-2-1	01.09	74.28	±4.24
M4-2-1	02.09	72.47	±4.25
M5-2-1	03.09	73.36	±4.25

As it can be noticed from the results, for the measurements in the first week of June, the noise level is in the range of $67.28 - 73.65$ dB(A). The expanded measurement uncertainty is calculated due to the proposed uncertainty budget, and it is in range of $4.24 - 4.28$ dB(A). This means that the result of the calculated L_{eq} could vary between the calculated measurement uncertainty for each measurement.
From the results from the first week of September higher values of L_{eq} could be noticed. According to the number of vehicles and the traffic in this week, there could be noticed higher number of vehicles. Due to this, we can find relation why the noise level is higher.

4.2 Acoustic predictive noise maps

In relation with the measured noise levels in the proposed time intervals, the number of vehicles was provided by the State Traffic and Control Management Center. In order to make comparison between the measured value of the L_{eq} and the predicted value of L_{eq} from the acoustic prediction maps generated in the IMMI software, 20 different maps were generated. Figure 3 shows one representative predictive noise map, while table 3 shows the results of the calculated L_{eq} from the noise maps for each measurement with no uncertainty estimate.

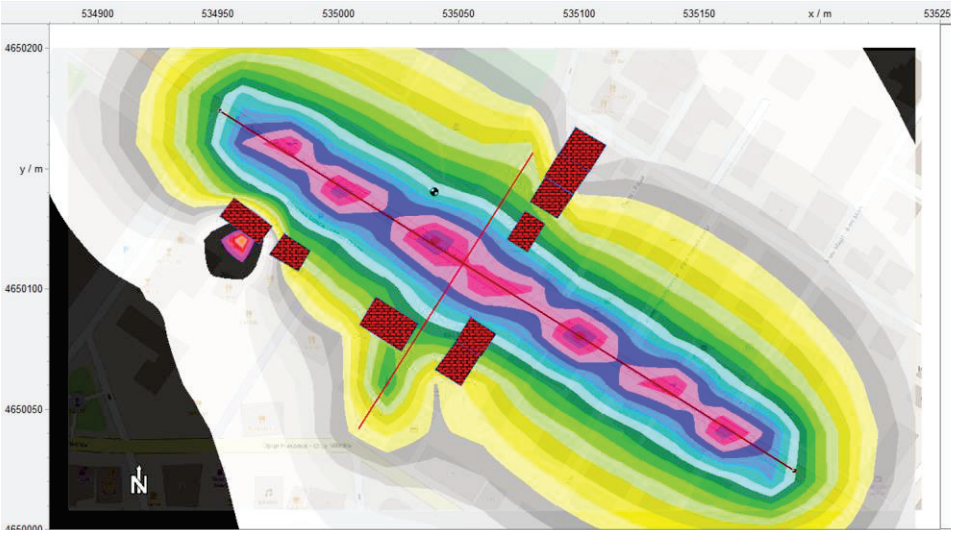

Figure 3. Representative predictive noise map generated from the IMMI software

Table 3. Results from the predicted equivalent noise level L_{eq}

Results from IMMI software (09:00 – 09:10) From Monday to Friday in the first week of June		
Measurement number	Date	Calculated L_{eq} (dB(A))
M1-1-1	31.05	65.43
M2-1-1	01.06	66.4
M3-1-1	02.06	69.78
M4-1-1	03.06	70.54
M5-1-1	04.06	70.77

Results from IMMI software (14:00 – 14:10) From Monday to Friday in the first week of June		
Measurement number	Date	Calculated L_{eq} (dB(A))
M1-1-2	31.05	66.37
M2-1-2	01.06	70.12
M3-1-2	02.06	70.32
M4-1-2	03.06	71.62
M5-1-2	04.06	65.9

Results from IMMI software (09:00 – 09:10) From Monday to Friday in the first week of September		
Measurement number	Date	Calculated L_{eq} (dB(A))
M1-2-1	30.08	70.28
M2-2-1	31.08	74.12
M3-2-1	01.09	73.78
M4-2-1	02.09	73.24
M5-2-1	03.09	72.52

Results from IMMI software (14:00 – 14:10) From Monday to Friday in the first week of September		
Measurement number	Date	Calculated L_{eq} (dB(A))
M1-2-1	30.08	69.7
M2-2-1	31.08	71.27
M3-2-1	01.09	72.18
M4-2-1	02.09	70.98
M5-2-1	03.09	74.16

4.3 Comparison between the results

When comparing the results from calculated L_{eq} generated from the measurements shown on table 2 with the predicted L_{eq} from the IMMI software shown on figure 3, there could be noticed deviation between the results. The results for the L_{eq} parameter from the measurements and from the acoustic noise maps were compared in accordance with the calculated measurement uncertainty. On figure 4, the measurement uncertainty is shown as a range, while the value shows the difference between the measured and the predicted L_{eq} in dB(A). From the comparison, it could be stated out that the differences between the results are within the limits of the measurement uncertainty, which confirms that the used methodologies are correctly proposed and used.

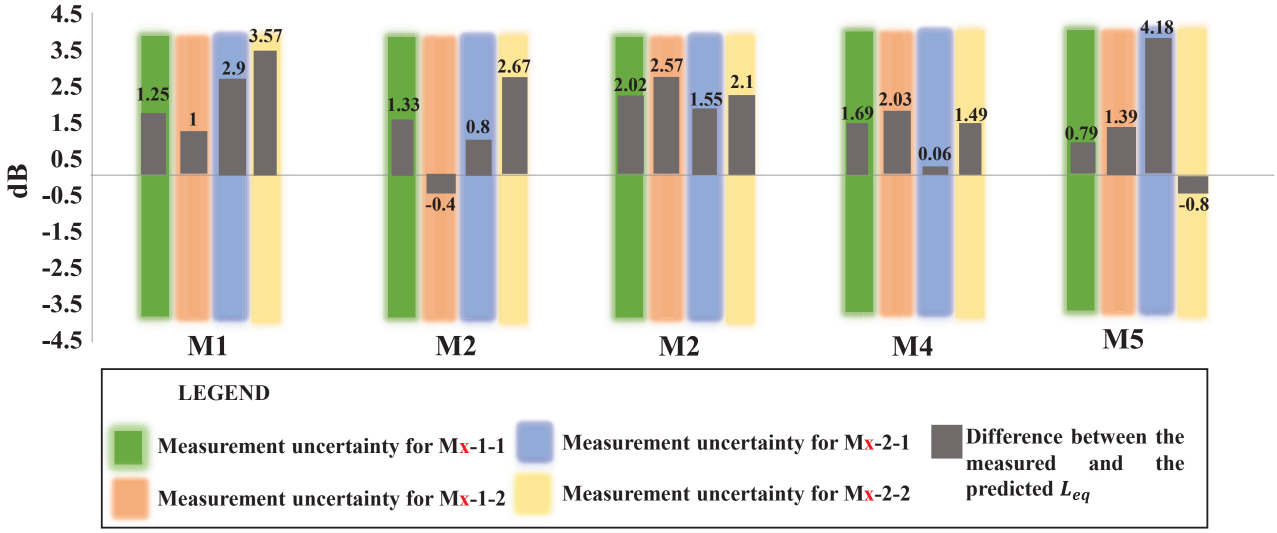

Figure 4. Difference between the measured and the predicted L_{eq}

In 90% of the measurements, the values from the calculated equivalent noise level from the acoustic maps are lower than the measured ones. This is expected, as for the acoustic noise maps the vehicles are the only noise source, while when doing the measurements, there are more parameters causing noise. That is why, when measuring the noise level with hand-held analyzer, in order to get the real value, the measurement uncertainty should be calculated.

5 Conclusions

The outdoor measurements of the environmental noise pollution can be complex to perform as there are several parameters that cause measurement uncertainty. By using the ISO 1998-2:2018 standard, the sources of uncertainty were defined and calculated, providing the equivalent noise level parameter with 95% confidence interval. The results were further compared by estimating the L_{eq} parameter from the predictive noise maps that use the traffic flow as an input parameter. Given the measurement accuracy, by comparing the results for the L_{eq} parameter, the accuracy of the proposed methodologies and the results was confirmed.

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