644. Mathematical models for acoustical pollution prognosis at signalized intersections

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Abstract. Noise related problems are increasing worldwide with detrimental effects on health and quality of life[18]. The regulations and laws of European Union and Lithuania emphasize the importance of noise reduction, the necessity to collect and disseminate information related to traffic flow, the development of traffic flow mathematical models and their implementation for noise evaluation. In this paper, mathematical methods are applied to determine the noise intensity. Measurements of urban traffic noise were performed at the arterial street intersections in Kaunas ant its suburbs. At this location traffic flow rates are high and noise is dominated by low frequencies. It was determined that the L_{Aeq} levels decrease continuously till the end of cycle of the green traffic signal. The developed methodology can be used to estimate traffic noise levels in a city and country districts using data provided by the automated traffic flow registration system. The aim of the article is to develop the mathematical model of a longitudinal noise sources and to apply it for the prediction of acoustical pollution in an environment of roads and streets intersections.

Keywords: traffic noise, intersection, mathematical model.

Introduction

Traffic flow patterns in cities, especially in city centers and at the arterial roads in suburbs, are intensive and uneven. In most cases the noise levels exceed allowable limits [1, 2]. The analysis of transport generated noise indicators and possible means of reducing noise levels are urgent issues in Lithuanian cities and in the entire country wide transport system.

The number of transport type vehicles in Lithuania is constantly increasing. This is particularly evident in large cities. Negative effect of transport generated noise is especially evident at streets and road intersections, where traffic density is comparatively high, the speed is low with frequent accelerations and decelerations [2-6]. The noise is more perceived to human from the traffic excited pollutant factors of psychological influence of the physical technological environment. In the living environment for this population health risk factor is characteristic the irritation and disturbing perceive of information, or also the factors making an unfavorable influence on the full sleep. The health risk by environmental noise is assessed in project stage of buildings and provided any means of noise reduction related with the noise mapping works [5, 7, 8, 9]. Fulfilling the assessment of noise influence on the environment the acoustical sound components, the radiation and damping factors are estimated. The following data is required for calculating the source level: vehicle data (number of vehicles per hour, % of heavy vehicles), speed for cars and trucks, road surface adjustments, road gradients, multiple reflection addition.

The results of scientific studies indicate [2] that the A-weighted equivalent sound pressure level $L_{pA,eq} \geq 55$ dBA increased by 40 % in Kaunas city since 2004. The average values of $L_{pA,eq}$ reached 72,9–79,4 dBA in the biggest cities of Lithuania. This is significantly larger than the typical noise levels $L_{pA,eq}$ = 65 dBA in European countries (according to data of World Health Organization) and the requirements imposed by Lithuanian regulations.

The environmental regulations and legal requirements of European Union and Lithuania emphasize importance of noise reduction [10, 11]. The environmental issues, necessity to collect and store information related to traffic, introduction of traffic flow mathematical models and their implementation, and noise evaluation have been presented in many scientific papers [3, 5, 9, 12, 13, 14].

Methodology

Depending on the sound radiated intensity and direction, the acoustic emission of continuously changing noise at different time-spans can be calculated using a specified statistical distribution of sound pressure levels [13-15]. The following simplified formula can be used to calculate the equivalent constant A-weighted sound pressure level:

$$L_{A,eq} = 10 \cdot lg\left[\frac{1}{T}\sum_{i=1}^{n}\left(t_i \cdot 10^{0.1 \cdot L_{A,i}}\right)\right] \tag{1}$$

where $L_{A,i}$ is obtained by direct measurement of the equivalent A-weighted sound pressure level at *i*- time-span of t_i, or from the average A-weighted sound level at *i*- time-span when noise can be described as continuous (constant) at time-span t_i; n is the number of time-spans t_i over duration *T*.

Depending on risk level of time acoustical characteristics ("*d*" – day, "*e*" – evening, "*n*" – night) in a living environment, permissible sound levels (L_d, L_e, L_n, $L_{den} \leftrightarrow L_{pA,eq}$) are described in a Lithuanian hygiene norm (HN 33–1–2007). In respect to this legal requirement, zones of silent agglomeration are defined.

Sometimes, the L_{eq} alone may not be sufficient to assess noise annoyance since it does not provide information on noise fluctuations. The relatively steady noise from a motorway with constant traffic density and the highly fluctuating noise from a succession of aircraft flyovers in an otherwise quiet environment may result in the same L_{eq}, but the annoyance level will probably not be the same. Attempts have been made to incorporate a "variability" factor in some noise descriptors, for example by combining L_{eq} and the standard deviation, σ, to give the noise pollution level, L_{NP}:

$$L_{NP} = L_{eq} + K\sigma \tag{2}$$

where *K* is the constant, tentatively set to 2,56.

If the distribution of the noise is Gaussian, eq.(2) may be replaced by:

$$L_{NP} = L_{eq} + \left(L_{10} - L_{90}\right) \tag{3}$$

The quantity L_{10}–L_{90}, sometimes called the Noise Climate, which are the statistical levels, accordingly 10% and 90%, at investigation time t_i. Generalized statistical noise levels (L_5, L_{10}, L_{50} L_{90} L_{99} and etc.) are described as L_{AN} in Lithuanian Standard LST ISO 1996–1– 2004.

Finally, it should be mentioned that many different noise ratings are found for long-term aircraft noise descriptions. They are normally based on an average of the maximum levels (or on the sound exposure levels) and introduced by various adjustments such as the time of the day, number of aircraft, percentage of runway usage, etc. However, the different ratings often show good correlation with each other [16].

Using statistical traffic noise distribution level L_{AN} , the environmental acoustical pollution is properly described (for example $(L_{10}\ L_{90})$; L_{NP} to TNI index) in time interval $T_i \le T_{ref}$. An environmental noise permissible (limited) level is estimated in point of L_{den} or L_d , L_e, L_n .

$$L_A, eq, x \le L_{den} + 10\log T_i / T_0 \tag{4}$$

where $T_i \le \sum t_i$ is the noise exposure time.

When noise source sound radiation intensity is variable at time $t_i \ll T_i$, other index for the investigation of an acoustical environmental is used, for example index L_{AE} .

The second basic quantity is the sound exposure level:

$$L_{AE} = 10\log\left(\frac{1}{t_0}\int_{t_1}^{t_1+T}\frac{p_A^2(t)}{p_0^2}dt\right) \tag{5}$$

where t_0 is the reference duration (1 s).

The sound exposure level (often abbreviated as *SEL*) may be used to express the energy contents of isolated noise events, for example, planes and like so events can be described by momentary process. Like a process at a start of transport $(t_i = 0)$ and motion of time t_i , is generated by the acoustical signals of intensity $L_{pA,max}$. When transport vehicles pass with acceleration an intersection at time interval from 0 till T , the momentary acoustical signals L_{AX} are generated. The equation of equivalent sound intensity $L_{pA,eq}$ is expressed by:

$$L_{eq} = 10\log\left(\frac{T_{ref}}{T}\sum_i 10^{\frac{L_{AX}}{10}}\right) \tag{6}$$

where T_{ref}=1 s, L_{AX} is the noise exposure level.

$$L_{AX} = L_{Amax} + \Delta_A \tag{7}$$

where Δ_A is duration allowance, $\Delta = 10\log\left(\frac{t_2 - t_1}{2T_{ref}}\right)$; $t_2 - t_1$ is time interval.

It can be stated that the investigation of intersection zones of acoustical environment can be fulfilled by using the information in the index L_{AN} and L_{AX} .

Results and discussions

Noise measurements were conducted according to the approved methods (LST ISO 1996-1-2004 „Acoustics.-Description and measurement of environmental noise“ and HN 33–1–2007 „Acoustic Noise. Limit Values of Noise in Residential and Public Buildings and their Environment”) in Kaunas city centre and the area of roads near the camp of Lithuanian University of Agriculture (Fig. 1). Four intersections of different type were selected for the measurements. The highest intensive traffic flow, the low velocity (till 50 km/h) (Fig 1. a, b, d), the hill (Fig 1. c) was observed at these intersections. Measurements of traffic noise levels were performed only at the green light traffic cycles and at peak hours in the morning. It has been established that the A-weighted measurement scale is the most appropriate procedure to account for the human hearing sensitivity at different frequencies. Using this approach, approximate loudness contours were developed that can be used for practical applications in assessing noise criteria [2].

The A-weighted noise levels in dB(A) were measured using noise level meter 'CEL - 440'. Measurements were performed when wind speed was less than 5 m/s. Noise was measured at a distance 1.5 m from the ground and more than 7.5 m from the walls of the surrounding buildings as recommended by the Lithuanian standard LST ISO 1996-1-2004 „Acoustics.- Description and measurement of environmental noise".

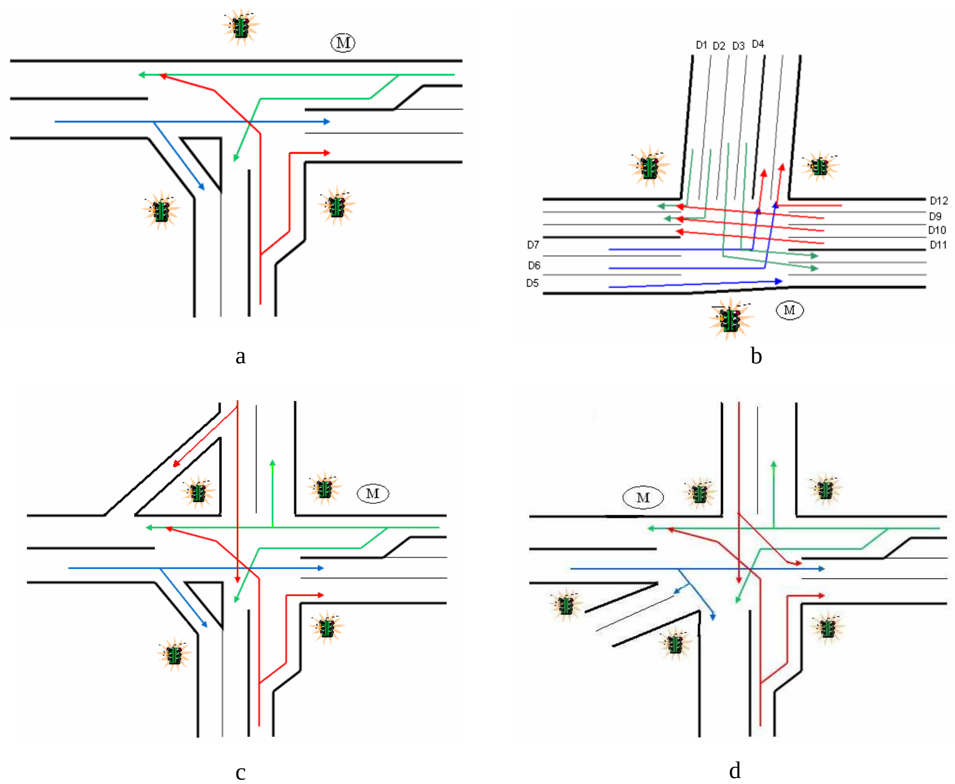

Fig. 1. Scheme of street intersections: a - at Gertrudos st. and Birstono st., b - at Karaliaus Mindaugo av. and Birstono st., c, d - near the camp Lithuanian University of Agriculture (M - location of measurements)

Evolution of the L_{Aeq} levels was recorded during the green traffic signal cycle (t = 10 s). It has been noted that L_{Aeq} levels almost continuously decrease till the end of the green traffic signal cycle. At the beginning of the green traffic signal cycle, the measured maximum noise level is 97.9 dB(A) and at the end of the cycle minimum noise level is 49,9 dB(A). The maximum noise level was observed at intersection with the hill. Interrupted traffic flow generates higher noise levels due to acceleration (hot-starts) of the vehicles. The intersections are empty of vehicles after 10 s and the background noise is dominant. Measured noise levels at the four intersections are presented in Fig. 2.

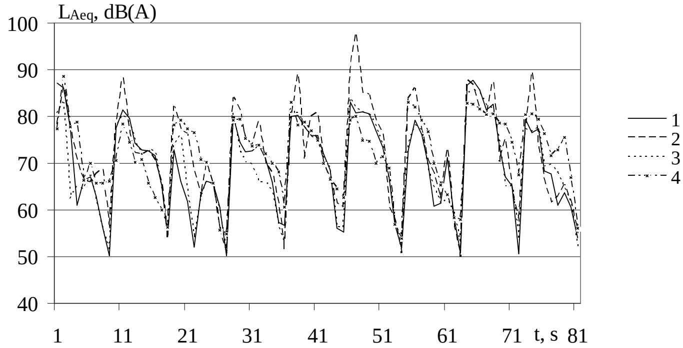

Fig. 2. Measured noise level L_{Aeq} at intersections: 1 - Gertrudos st. and Birstono st., 2 - near the camp Lithuanian University of Agriculture, 3 - Karaliaus Mindaugo av. and Birstono st., 4 - near Ringaudai village

Distribution of noise level L_{Aeq} measured and calculated is presented in Fig. 3.

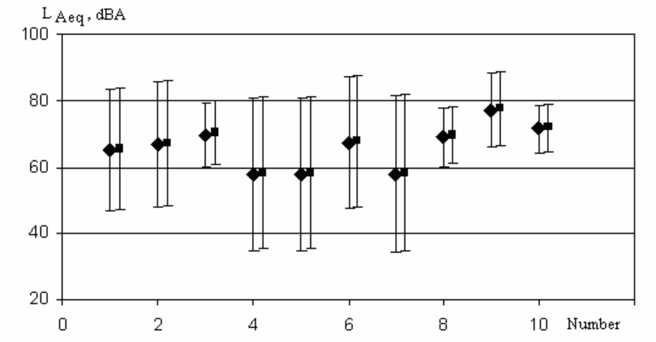

Fig. 3. Measured and calculated noise level L_{Aeq}

To evaluate conformity of the mathematical model to the measured of noise levels L_{Aeq} at the analyzed intersection mathematical statistics was applied: there were compared means of L_{Aeq} and their 95% CI (Fig. 3) [17]. However, due to nonconformity of data to some minimum requirements, one of which is that data need to be distributed according to Gauss (normal) distribution. The analysis and data indicate that means of noise levels during the green signals are not statistically different and 95% CI are the same. Results of this verification indicate that the developed models possess a good prediction capability.

Analyzed method can provide the information that is required for noise quality transport management systems.

Conclusions

The developed prediction models enable to estimate simultaneously noise levels using data provided by the automated traffic flow registration system.

It was determined that at the intersections, the L_{Aeq} levels almost continuously decrease from 97.9 dB(A) to 49,9 dB(A) till the end of the green traffic signal cycle, i.e. noise generated by ”hot starts“ dominates. The intersections were empty of vehicles after 10 s and the background noise was dominant. Thus, the aim is to minimize interrupted and to maximize continuous intervals of traffic flow in order to reduce noise levels in urban environment.

The measured and calculated noise level L_{Aeq} analysis indicates that means of noise levels during the green signals are not statistically different and 95% CI are the same. This verification confirmed that the developed models are able to provide reliable predictions.

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