Study of traffic noise exposure on street and road networks in a megapolis

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Abstract. The article analyses the regularities of the acoustic impact of motor transport on the inhabited territory of a large city. It is noted that noise from motor transport has a noticeable negative impact on human health, especially in large cities, industrial centres and transport hubs. The results of field research on automobile noise level are presented in sections of a road network of a large city characterised by a high level of road accidents. Accident sites are shown to be characterised by high values of the equivalent level of sound and exposure to traffic noise. The values of equivalent sound level in the investigated sections during the period of maximum intensity of traffic significantly exceed the maximum permissible level. Exposure values of vehicular noise to which road users as well as residents of nearby neighbourhoods are exposed on the studied sections of the street and road network vary in the range from 1-3 to 320 Pa²∙s. The results of the correlation and regression analysis are presented. Measures are proposed to reduce the degree of acoustic load caused by road transport in the residential area.

1 Introduction

The negative impact of traffic noise on the environment is a global environmental problem, the relevance of which is increasing with increasing levels of motorisation. Noise from motor vehicles is among the most aggressive anthropogenic factors that have a harmful (adverse) impact on the health and well-being of people (population), especially in large industrial centres. The residents of urbanized areas with dense urban development and high population concentration are most exposed to the negative impact of transport (automobile) noise [1, 2]. As the authors of article [3] specify, in Europe more than 100 million people live in regions where influence of transport noise exceeds the permissible norms. In a number of works ecologically-biological consequences of transport noise on physical and psychological condition of inhabitants are considered of the surrounding highways. Long-term exposure to traffic noise has been shown to cause health problems such as diabetes [4,5], sleep disorders [6,7] and irritability [8]. The authors in [9] have shown that noise exposure is associated with reduced levels of physical activity, which can lead to an...
in increased risk of cardiovascular disease. As a major stressor, vehicle noise can cause reduced body defences and a weakened immune system, leading to various physical and mental disorders, including hearing impairment to deafness, autoimmune diseases, endocrine system disorders, cognitive impairment and other problems [10-12].

The degree of acoustic impact of motor transport on a residential area is determined by various factors, including transport, architectural and planning, and climatic factors [13, 14].

Dependence of the noise characteristic of traffic flows, expressed in the form of an equivalent sound level, on the most significant factors can be represented in general form:

\[ L_{eq} = f(N, V, X_1, X_2, k_1, k_2, k_3) \]

where:
- \( L_{eq} \) is equivalent sound level, dB(А);
- \( N \) defines traffic intensity;
- \( V \) is an average speed of traffic flow;
- \( X_1 \) – share of trucks in the flow;
- \( X_2 \) – share of passenger cars in the flow;
- \( k_1 \) – indicator describing road features (junction configuration, number and width of lanes, quality of pavement affecting reflection, absorption of sound waves);
- \( k_2 \) – an indicator describing the characteristics of the infrastructure (presence and type of residential buildings, presence and type of green spaces);
- \( k_3 \) – an indicator of climatic and weather conditions (wind strength and direction, air temperature and humidity).

Noise in a moving vehicle arises from engine, transmission, air conditioning compressor and also from the interaction of tyres with the road surface and the formation of swirling air currents, depending on the shape of the vehicle body [15-18].

The magnitude of the negative impact of automobile noise on the environment is expected to increase in the near future due to increasing levels of motorisation. In this regard, the study of the impact of automobile noise on urbanized areas is an important and urgent technical and environmental task. The aim of the work was to investigate the regularities of change in automobile noise on the street and road network of a large city and to develop on their basis the ways to reduce the acoustic load on the inhabited territories.

2 Materials and Methods

Studies of the noise characteristics of traffic flows were conducted on sections of the street and road network of the city of Naberezhnye Chelny, a major centre of the automotive industry with a population of 540,000 people.

Noise can be quantified by calculation or by measurement [14, 19]. In this paper, the noise characteristics of traffic flows were determined in a field study by measuring the equivalent sound level \( L_{eq} \) (dB) using a noise meter of the first accuracy class. Measurements were taken at ambient air temperatures above 0°C, the wind speed did not exceed 1 m/s. At the same time, the intensity and composition of traffic flows were determined using the videorecording method. The results were analysed using Statistica, Statgraphics and Microsoft Office Excel. Initially, the experimental data were checked for compliance with the normal law of distribution.

The traffic noise exposure was calculated using the formula:

\[ E = \int_{t_1}^{t_2} p(t) dt \]

where:
- \( E \) – sound exposure, Pa \(^2\)∙s;
- \( p \) – sound pressure, Pa;
- \( t_1 \) – start of research period, s;
- \( t_2 \) – end of research period, s.

Sound pressure at known equivalent sound levels was calculated using the formula:

\[ p = 2 \times 10^{-5} \times 10^{\left(\frac{L}{10}\right)} \]

where:
- \( p \) – threshold sound pressure, Pa;
- \( L \) – equivalent sound level, dB.
3 Results and discussions

Measurements of motor vehicle noise were made on difficult, problematic sections of the city's street and road network. The main criterion in selecting the sections for the study was their accident rate, i.e., the increased level of traffic accidents, which was determined by data from the Road Safety Inspectorate and the accident rate map.

The study of the structure of traffic flows on the specified sections showed a significant predominance of passenger cars in the flow, the share of which exceeds 93%, while the share of trucks and buses of various carrying capacity in total is 6%.

Equivalent sound levels on the surveyed road network sections during the period of maximum traffic volume exceed 75 dB(A), which is 20 dB(A) greater than the maximum permissible level for residential areas. The check showed that the results of the equivalent sound level measurements conform to the normal law of distribution, hence the use of parametric statistics methods in their processing is correct.

A correlation analysis of the experimental data was carried out and the conclusion was made that the equivalent sound level depends mainly on the total intensity of traffic flows and the content of passenger cars in them. At the same time, the influence of other groups of vehicles on the value of automobile noise is not so significant due to their small number in the total flow. Table 1 shows the results of the correlation analysis of equivalent sound level $L_{eq}$ from the number of different types of vehicles in the traffic.

Table 1. Results of correlation analysis $L_{eq}$ from the composition of the flows

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Correlation coefficient $R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$, traffic intensity, cars/h</td>
<td>0.975</td>
</tr>
<tr>
<td>$N_L$, number of passenger cars/h</td>
<td>0.946</td>
</tr>
<tr>
<td>Number of trucks/h</td>
<td>0.120</td>
</tr>
<tr>
<td>Number of minibuses up to 3.5 t/h</td>
<td>0.258</td>
</tr>
</tbody>
</table>

A regression analysis was carried out to establish the analytical function of the equivalent sound level versus traffic intensity, the results of which are contained in Table 2.

Table 2. Results of regression analysis of the dependence of the equivalent sound level $L_{eq}$ on the parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Regression equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$, traffic intensity, cars/h</td>
<td>$L_{eq} = 332.11 \ln(N) + 1302.8$</td>
<td>0.945</td>
</tr>
<tr>
<td>$N_L$, number of passenger cars/h</td>
<td>$L_{eq} = 333.50 \ln(N_L) + 5043.3$</td>
<td>0.904</td>
</tr>
<tr>
<td>$l$, distance from the road, m</td>
<td>$L_{eq} = 32.78491 + 0.004913 \ln(l)$</td>
<td>0.967</td>
</tr>
</tbody>
</table>
It is shown that the equations of dependence \( L_{eq} \) of total traffic and number of passenger cars are logarithmic with high determination coefficients \( R^2 = 0.945 \) and \( R^2 = 0.904 \) respectively. The regression equation for the equivalent sound level from distance to the road is linear with a coefficient of determination \( R^2 = 0.967 \).

As high regression coefficients are found for total traffic flows and distance to the road with \( L_{eq} \), the dependency has been examined \( L_{eq} \) from both of these parameters. Based on the results of the field studies, a three-dimensional graph of the dependence of the equivalent sound level on traffic intensity and distance from the road to the noise measurement point is plotted (Fig. 1).

**Fig. 1.** Dependence of equivalent sound level on traffic volume and distance to road

The maximum values of the equivalent sound level were recorded at the highest traffic intensity and the minimum distance from the road. At points located more than 70 m away from the road, the value of \( L_{eq} \) increases at relatively low traffic levels (3,000 vehicles/hour and above), presumably due to the superposition of sound waves from other sources. There is also a decrease in the rate of decay \( L_{eq} \) as the distance from the road increases at all recorded intensities. The change in distance from the road has a more pronounced effect on the value of \( L_{eq} \) than the change in intensity, as evidenced by the smaller degree of curvature of the graph on the respective axis.

When investigating road noise for the purpose of environmental assessment of its impact on residential areas, it is necessary to consider not only the equivalent sound level \( L_{eq} \), which is a normative parameter, but also the duration of exposure. In order to estimate the total energy of vehicular noise over a specific time period, the noise exposure value \( E \) calculated by formula (1) from the results of in-situ measurements was used. The results are presented as a three-dimensional surface plot in Figure 2.
Exposure values of road noise to which road users (drivers, pedestrians, passengers) as well as residents of nearby neighbourhoods are exposed on the considered sections of the street and road network vary from 1 to 320 Pa$^2\cdot$s. The lower values of the noise exposure (below 10 Pa$^2\cdot$s) correspond to short exposure times and/or relatively low values of equivalent sound level. The highest exposure values (above 210 Pa$^2\cdot$s) correspond to high equivalent sound levels and long exposure times. Increased noise exposure can increase the frequency and severity of adverse health effects in populations exposed to traffic noise.

The following measures are advisable to protect residential areas in the vicinity of roads from traffic noise:

- Use of low-noise materials in road construction,
- Placement of noise screens in the near-roadside areas,
- Implementation of modern infrastructure projects, construction of bypasses for transit and freight road transport,
- Reducing noise at source, i.e., improving engine and vehicle design.

4 Conclusions
To quantify automotive noise, it has been proposed that in addition to the equivalent sound level $L_{eq}$, which measurement is regulated by the standard, also the value of exposure $E$. It is shown that the exposure values of road noise to which road users (drivers, pedestrians, passengers) as well as residents of nearby neighbourhoods are exposed in the considered street and road network sections vary from 1-3 to 320 Pa$^2$∙s.

References


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https://doi.org/10.1007/s41104-016-0001-5

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