Reducing exposure to traffic noise using microscopic simulation

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Abstract. The article presents an analysis of the patterns of changes in the level of automobile noise in a residential area depending on the parameters of traffic flows. The results of field studies of noise characteristics in accident-prone areas of the city road network are presented. It is shown that these areas are characterized not only by a high level of road traffic accidents, but also by high values of noise pollution indicators, such as equivalent sound level L_{eq} and noise exposure E. The use of microscopic simulation modeling is proposed to reduce exposure to traffic noise and reduce acoustic load to a residential area. A simulation model of an emergency-prone section of a city highway has been developed and validated using standard statistical parameters: the Cochran criterion and the approximation coefficient. High validity indicators indicate the homogeneity of variances and the adequacy of the model. A method has been proposed to increase the capacity of this section of the road network, and virtual experiments have been carried out. As a result, the average time for cars to cross this section of the road decreased by 33.3%, and exposure to traffic noise decreased by 14.2%.

1 Introduction

Noise from road transport is one of the greatest impacts on human health and well-being. Experts believe that in terms of the degree of negative impact, traffic noise is second only to the quality of atmospheric air [1]. It has been shown that the harmful effects of traffic noise are determined not only by the magnitude of the sound pressure, but also by the duration of its exposure [2]. In a number of works, automobile noise is considered as a serious environmental problem that requires an immediate solution [3-4]. Thus, long-term exposure to excess vehicle noise leads to hearing loss [5], diabetes [6], deterioration of memory, attention, and decreased performance [7]. According to the authors of works [8, 9], noise from vehicles can weaken the body's defenses, reduce immunity and subsequently lead to cognitive disorders, the appearance of neuroses, autoimmune diseases, and cause neurovegetative problems. Sleep disturbance resulting from exposure to traffic noise has been studied by a number of researchers [2, 10]. The article [11] shows that noise has the most adverse impact on the health of children and adolescents.

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The authors of [12] note that the intensity of automobile noise depends on the types of vehicles and their technical condition, traffic conditions, and driver behavior. The sources of noise in cars (vehicles) during their movement are internal combustion engines, transmission units, as well as the interaction of tires with the road surface [13-15].

The values of the noise characteristics of traffic flows can be determined experimentally or calculated using mathematical models [16].

To reduce the acoustic impact caused by road transport, individual and collective protection methods can be used. Personal protection includes the use of headphones, helmets and other equipment. Methods of collective protection include the construction of noise barriers that prevent the propagation of sound waves, and the use of road surfaces with low noise levels [7]. Effective methods for reducing transport noise are considered to be optimization of road traffic, speed control, moving noise sources away from residential areas, as well as improving the design of vehicles [17].

It is expected that due to the growing level of motorization, the scale of the negative acoustic impact of road transport on residential areas will increase [18]. In this regard, the study of the patterns of propagation of automobile noise and the development of ways to reduce acoustic load is an urgent technical and environmental problem.

The purpose of the work was to study the patterns of changes in the noise characteristics of traffic flows in residential areas and to develop a method for reducing acoustic load through the use of simulation modeling.

2 Materials and methods

Field studies of the intensity and composition of traffic flows in sections of the urban road network were carried out using the video recording method. An analysis of the composition of traffic flows showed a significant predominance (more than 93%) of passenger cars.

The value of the noise characteristics of traffic flows was determined by two indicators: the equivalent sound level Leq and exposure to automobile noise E. The equivalent sound level refers to standardized parameters, its value should not exceed 55 dBA in a residential area. The L_{eq} value was determined by a certified sound level meter of the first accuracy class in accordance with the requirements of the Russian standard GOST 20444-19. The measurements were carried out at an ambient air temperature of at least 5 ^{o}C, mainly during periods of temperature inversions in the absence of significant air turbulence. Before statistical processing of the obtained measurement results, they were checked for compliance with the normal distribution law using the Statistica software product.

Exposure to transport noise E ($Pa^2 \cdot s$) was calculated using equation (1) based on the sound pressure value and duration of exposure to transport noise:

$$E = \int_{t_1}^{t_2} p^2(t)dt \tag{1}$$

Where: p – sound pressure value, Pa.

To develop a simulation model of an emergency-prone road section and conduct virtual experiments, the Anylogic software package was used.

3 Results and Discussion

The studies were carried out on accident-prone areas of the city road network, which were determined using the accident rate map and information from the Road Safety Inspectorate. During field experiments in these areas, the magnitude of automobile noise and the dependence of the noise characteristics of traffic flows on external predictors were investigated. It is shown that the results of measurements of the equivalent sound level correspond to the normal distribution law, and when analyzing them, the use of parametric statistics methods is correct.

Numerous field studies indicate that on the analyzed sections of the road the equivalent sound level exceeds the standardized value of 55 dBA in the daytime and evening, that is, emergency areas are characterized not only by a high probability of road accidents, but also by a high level of transport noise . To the greatest extent, the equivalent sound level depends on the overall intensity and average speed of traffic flows (Figure 1).

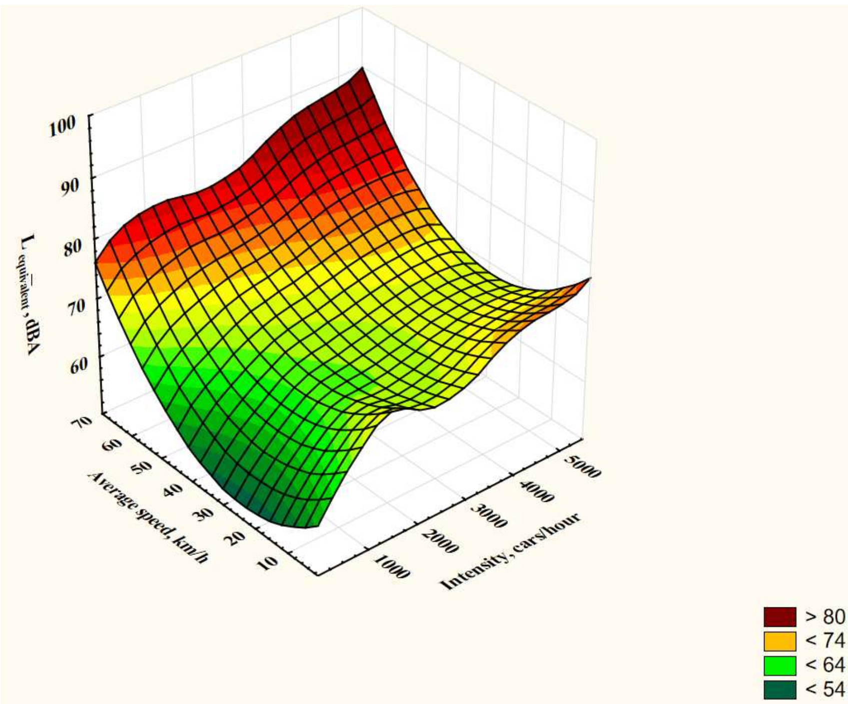

Fig. 1. Dependence of the equivalent sound level on the intensity and average speed of road transport.

An analytical equation was obtained for the dependence of the equivalent sound level on intensity and average speed:

$$L_{eq} = 11.22 \cdot \ln(N) + 5.805 \cdot \ln(V) + 6.341 \quad (2)$$

Where: N – traffic intensity, vehicles/hour; V – speed, km/h.

The maximum values of the equivalent sound level are observed at the highest values of average speed and intensity of traffic flows. Determination coefficient R^2 = 78.7%, which indicates a high dependence between the studied quantities. The resulting regression equation can be used to predict the level of L_{eq} depending on the total intensity and average speed of traffic flow.

Based on the results of field studies, the noise exposure value E was determined, the results are presented in the form of a three-dimensional surface graph in Figure 2.

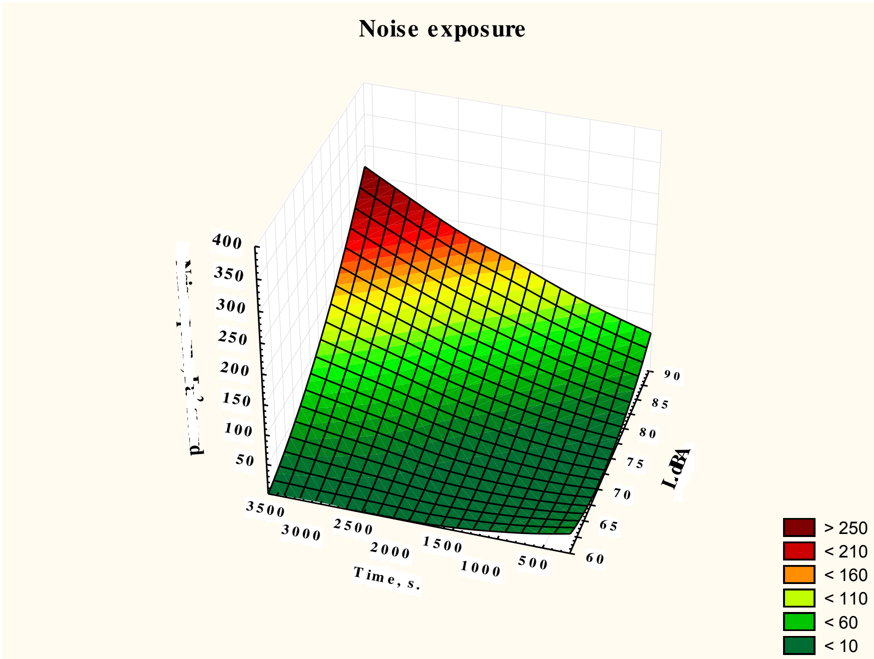

Fig. 2. Exposure to traffic noise on the road network.

Vehicle noise exposure values for road users vary from 10 to 300 $Pa^2 \cdot s$ depending on the equivalent sound level and the duration of the acoustic exposure.

If it is impossible to reduce the number of vehicles, solutions are needed that provide for a reduction in the duration of vehicle movement on a given section of the road. In order to optimize road traffic, simulation modeling of transport and pedestrian flows is used, which is divided into microscopic and macroscopic, depending on the degree of detail of the objects under study [19-21].

To reduce exposure to traffic noise, we used the method of microscopic simulation modeling in the Anylogic environment. An accident-prone section of the highway on Mira Avenue in the city of Yelabuga in the Republic of Tatarstan was selected as a modeling object. A simulation model of this section was developed, a fragment of the structure of which is presented in Figure 3.

The simulation model was validated to assess its adequacy to a real section of the road network, and the data obtained as a result of the modeling were compared with the results of field studies. Validation of the simulation model was carried out using standard statistical parameters: Cochran's test and approximation coefficient with a confidence level of $P = 0.95$ (Table 1).

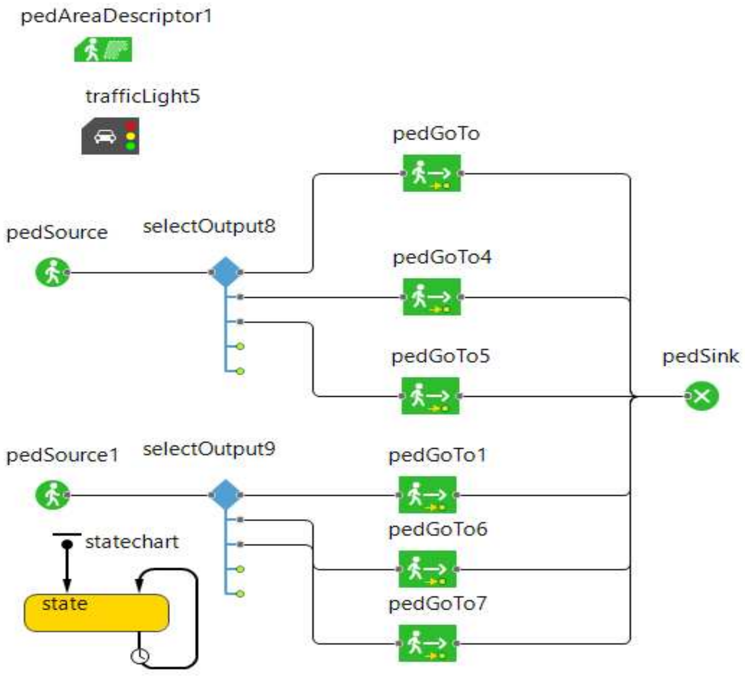

Fig. 3. Fragment of the structure of a simulation model of an emergency-hazardous section of the road network.

Table 1. Results of checking the adequacy of the model.

Parameter	Parameter value
Experimental value of Cochran's criterion G_{exp}	0.3780
Table value of Cochran's criterion G_{table}	0.3910
Average approximation error, %	4.3

It is shown that the following condition is satisfied for the obtained values: $G_{exp} \leq G_{table}$, and the average approximation error is 4.2%. This indicates the homogeneity of the variances under consideration, the validity of the developed model and its suitability for conducting computer experiments.

Since the number of cars crossing this section of the road network cannot be reduced, a solution was found that involves increasing speed, reducing vehicle travel time and, as a result, reducing noise exposure. To optimize the movement of traffic flows in the analyzed area, it is proposed to clearly mark the intersection by applying horizontal markings using wear-resistant materials, since currently there is no such marking.

Virtual experiments were conducted using an improved simulation model, which showed: as a result of increasing capacity, the average time for vehicles to travel through an intersection decreased by 33.3%, and the amount of exposure to vehicle noise decreased by 14.3%.

4 Conclusion

The use of microscopic simulation modeling is effective for solving problems of increasing the environmental safety of the motor transport complex, in particular, reducing the noise impact on residential areas. For an emergency-hazardous section of the city road network, an option has been proposed to increase capacity by improving the technical means of organizing traffic. The results of virtual experiments showed: an increase in the average speed of vehicles and an increase in the throughput of a highway section leads to a decrease in exposure to traffic noise and a decrease in environmental acoustic load on a residential area.

Using existing road infrastructure facilities and increasing the efficiency of their functioning makes it possible to reduce material costs and shorten the time required to achieve a positive environmental effect.

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