Traffic Management as a Means of Protection Against Road Noise

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Abstract

Road noise pollution constitutes one of the primary health threats to residents living near roads. An important aspect is the limitation and counteraction of excessive exposure to road noise. Existing protection measures vary in effectiveness and applicability. One of the potential solutions involves activities related to traffic management. Based on a review of current knowledge and own analyses, the authors propose noise protection measures focused on the noise source. In the monograph 'Modelling and Assessment of Solutions for Protection Against Road Noise' (2017), Bohatkiewicz J. suggested a classification of noise protection measures, where one group involves reducing noise in the emission zone through: optimizing communication efficiency, planning and managing parking zones, organizing, slowing down and directing traffic, Intelligent Transport Systems (ITS) management and direction systems, traffic calming, and rerouting and combining traffic on certain connections related to traffic organization. Existing relationships between road traffic conditions and road noise allow for the selection and application of the aforementioned measures. To verify this thesis, the authors conducted studies and analyses on the impact of road traffic conditions on the noise level. To determine these conditions, the Highway Capacity Manual 6th method was used. Meanwhile, road noise was determined based on simulations using the NMPB-Routes and CNOSSOS-EU models. Traffic management, as well as the potential introduction of autonomous vehicle traffic, can lead to a reduction in road noise emissions. Most research and analysis rely on computer simulation results, due to the small share of autonomous vehicles in current traffic. However, an increase in the number of autonomous vehicles can positively affect road traffic capacity and safety by increasing vehicle flow capabilities. In scenarios of autonomous vehicle traffic, two basic parameters play a key role: speed and vehicle spacing. By optimizing these parameters, the environmental impact can be minimized. A detailed examination of the impact of road traffic conditions will contribute to the development of new methods for protection against road noise. Choosing appropriate traffic and vehicle management scenarios can significantly reduce road noise emissions.

Keywords: *road noise, traffic engineering, traffic management, speed management, autonomous vehicles*

1. Introduction

According to the World Health Organization (WHO), in the European Union, over 120 million residents experience the effects of road noise [1]. This results in costs related to the loss of quality of life and health, which are estimated at 40 billion euros annually. The European Union, in its strategic plans and actions, aims to eliminate the negative impact of road noise emissions. According to the zero emissions plan, the European Union intends to completely reduce the environmental impact. As part of this effort, the number of people at risk from road noise is to be reduced by 30% by 2030 [2]. Achieving such a goal requires an appropriate strategy and resources. Polish literature identifies four groups of measures for protection against road noise. The most commonly used solution is noise barriers [1]. According to data from the General Directorate for National Roads and Motorways (GDDKiA) in Poland, 6 million m² of noise barriers have been constructed on national roads, motorways, and expressways [3]. This solution is effective but incurs significant costs and requires frequent maintenance. Other methods for reducing road noise might include traffic management strategies.

The article proposes methods for reducing road noise that utilize traffic parameters, traffic conditions, and traffic management. These methods relate to the source of the noise, namely the vehicle flow. In these methods, fluctuations in traffic must be considered as a significant parameter affecting traffic conditions. Two groups of methods for protection against road noise were selected. The first group aims to reduce noise in the emission zone through: optimizing communication efficiency, planning and managing parking; organizing, slowing down, and directing traffic, ITS management and control systems, and traffic calming [4]. Another solution involves relocating and combining traffic on certain connections related to traffic organization. By utilizing the relationships between traffic conditions and road noise, traffic management methods can be applied using intelligent transportation systems (ITS). The use of relationships between traffic fluctuations and conditions with road noise affects the effectiveness of noise reduction solutions. By applying traffic control measures and using appropriate scenarios, a reduction in the equivalent sound level can be achieved. Traffic conditions were determined using the Highway Capacity Manual 6th method [5]. Using the NMPB-Routs [6] and CNOSSOS-EU [7] models, the equivalent sound level was determined.

One way to reduce the equivalent sound level could be through traffic control and, in the future, the movement of autonomous vehicles (AV) at various levels of autonomy. Due to the small existing population of highly autonomous vehicles in road traffic, most studies and analyses are based on the results of computer simulations [8]. According to simulation studies, an increase in the number of AVs could positively impact the capacity and safety of road traffic, potentially increasing vehicle flow by up to 75% [9].

By managing speed and spacing between vehicles, analyses can optimize the flow of autonomous vehicles with regard to traffic conditions criteria to minimize environmental impact. The article discusses noise protection methods related to traffic management using the ITS system and autonomous vehicles.

2. Methods

In the road traffic simulation, the car-following model developed by Rainer Wiedemann in 1974 was employed [10]. This model reflects drivers' behaviours and their changes while driving [11] and is implemented in the VISSIM software [12]. The parameters described by Wiedemann include the minimum gap between vehicles at a stop, minimal distance at small speed differences, maximum distance, and acceleration [10, 13]. The model calibration was conducted based on data from real-world studies on roads with similar geometric parameters, taking into account four key parameters: safe gap between stopped vehicles, time gap between vehicles in motion, expected acceleration from a stop, and overall expected acceleration [12, 14]. These parameters are interrelated and affect the traffic conditions and traffic intensity during the simulation [13]. The range of parameter adjustments was tailored based on own analyses and the studies by Lownes and Machemehl [12]. After calibration, trial simulations were conducted, and the results were compared with control data, confirming the model's adequacy as demonstrated by statistical studies.

In the modelling of road noise, two models were utilized: NMPB Routes and CNOSSOS-EU. The NMPB, developed in France and first published in 1980, was used in accordance with Directive 2002/49/EC [15] for predicting noise during the creation of acoustic maps and other environmental studies. This model takes into account factors such as the type of road surface, road incline, temperature, and the driving style of drivers. Subsequently, in 2009, the CNOSSOS-EU model was introduced, created by European experts to standardize methods of predicting road noise and to support the creation of environmental studies in EU countries and others obligated to produce acoustic maps. This model categorizes vehicles and considers wheel rolling noise and the propagation of road noise, taking into account variables such as traffic intensity, vehicle speed, and many other factors [16]. Similar to road traffic models, these models were calibrated using actual measurement results.

Simulation studies have allowed for the analysis of the impact of intelligent transportation systems (ITS) and autonomous vehicles on road noise levels. Precise calibration of the models enabled accurate simulations.

3. Results

Based on the analysis of the impact of traffic conditions on road noise levels, a proposal has been formulated to use traffic management systems to reduce the adverse environmental impact of roads. By utilizing basic elements of ITS (Intelligent Transportation Systems), it is possible to collect individual parameters and perform necessary calculations and analyses. Based on the obtained results, the system decides whether to implement appropriate actions or if the road noise level is within acceptable limits. The proposed action scheme is presented in Figure 1.

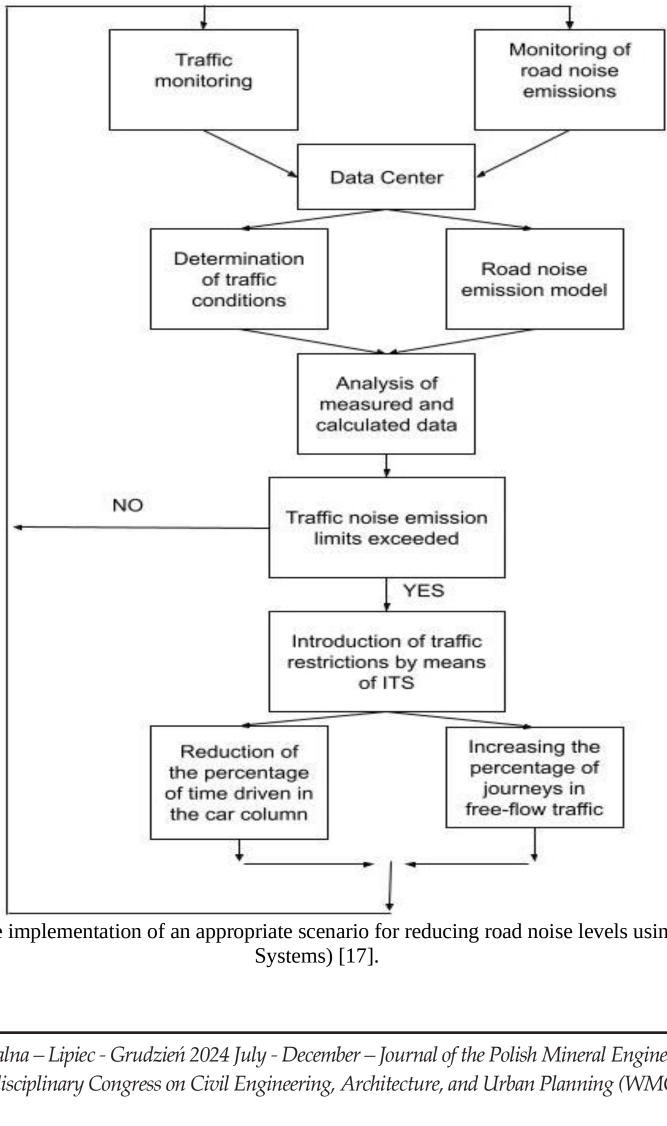

Fig. 1. A diagram illustrating the implementation of an appropriate scenario for reducing road noise levels using ITS (Intelligent Transportation Systems) [17].

The application of the procedure outlined in Figure 1 is feasible by considering the impact of traffic parameters on the level of road noise. The first parameter analysed is the percentage of time spent driving in a column (platoon). As the value of the percentage of time driving in a column increases, the equivalent sound level also rises. This is directly related to the increase in traffic intensity and changes in traffic conditions. Implementing changes through traffic control can cause a reduction in the percentage of time spent driving in a column. The relationship between the percentage of time driving in a column and the equivalent sound level is presented in Figure 2.

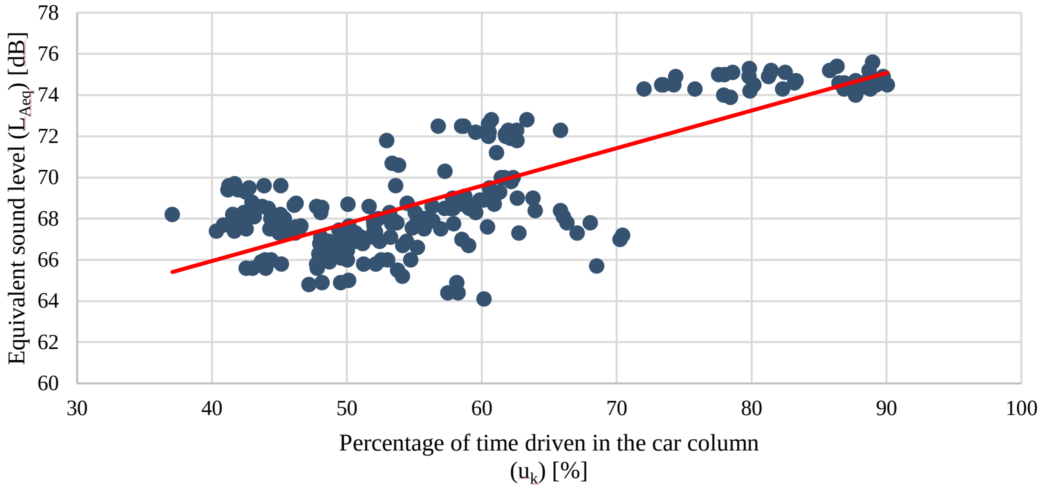

Fig. 2. The impact of the percentage of time spent driving in a column on the equivalent sound level in the vicinity of the road [17].

In the case of the criterion of the percentage of travel in free-flow traffic, an inverse relationship is observed compared to the percentage of time spent driving in a column. As the percentage of travel in free-flow traffic increases, the equivalent sound level decreases. This is associated with a decrease in traffic intensity, which leads to a reduction in road noise emissions. This relationship is confirmed by research results obtained under real conditions. The results of the analysis are presented in Figure 3.

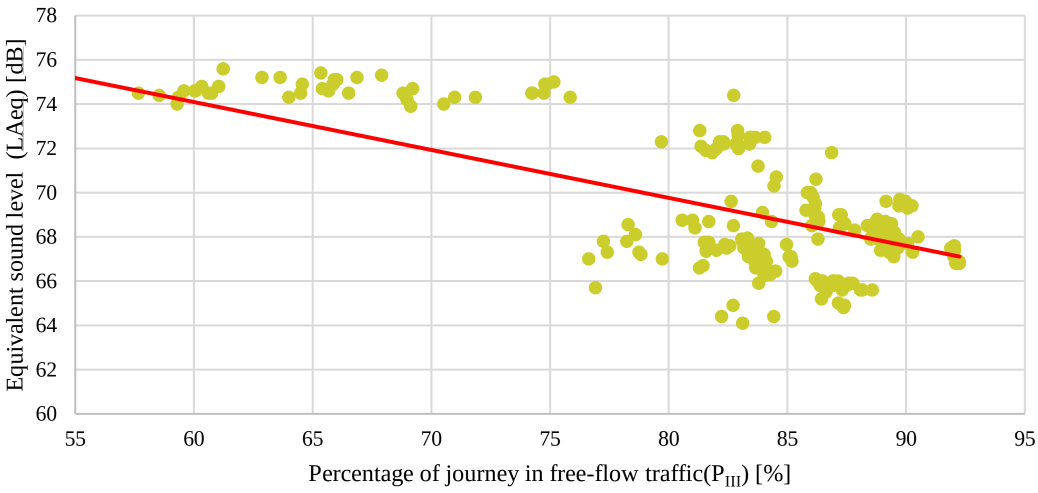

Fig. 3. The impact of the percentage of travel in free-flow traffic on the equivalent sound level in the vicinity of the road [17].

Using the aforementioned relationships in ITS systems, appropriate scenarios can be developed to reduce road noise when permissible sound levels are exceeded. By changing traffic parameters through speed adjustments, tonnage limitations, or rerouting traffic to alternative roads, these parameters can be managed to reduce road noise and lessen environmental impact.

In the future, the majority of vehicles will be autonomous vehicles (AVs). When all vehicles are autonomous, using their control systems will allow not only for influencing traffic conditions, safety, and travel time but also for reducing road noise levels. Optimizing vehicle control scenarios considering only traffic conditions could have adverse effects on the environment and traffic safety. It is crucial to include these elements within the framework of scenarios and decisions of autonomous vehicles. Figure 4 proposes an expansion of the basic elements of autonomous vehicle scenarios with two additional elements related to traffic conditions and environmental protection.

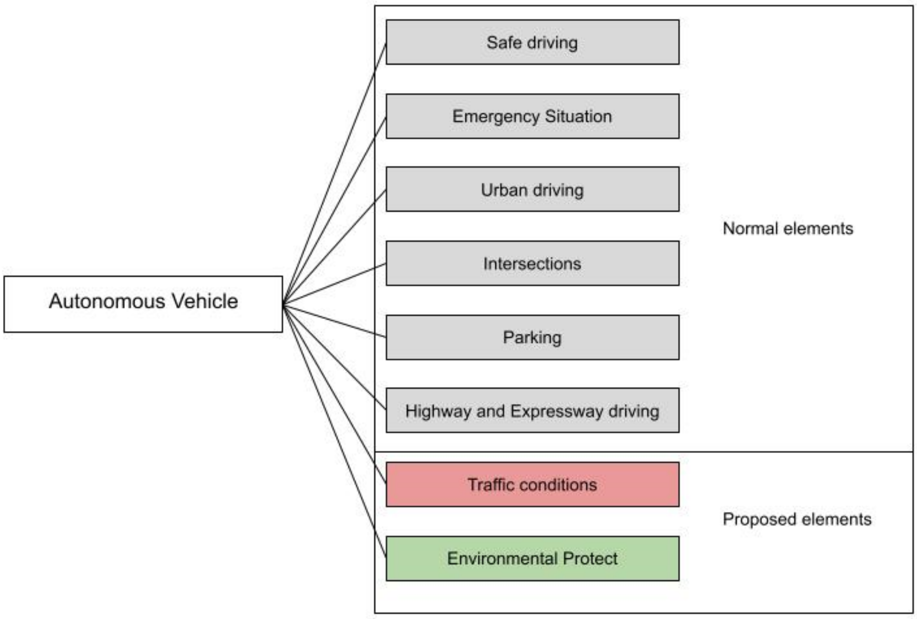

Fig. 4. Scenario and actions of an autonomous vehicle within the framework of appropriate measures.

Incorporating these two parameters could revolutionize existing methods, setting new boundaries of possibilities. The simplest method of traffic control involves maintaining an appropriate distance from the preceding vehicle. In the case of autonomous vehicles, there is the possibility to safely maintain small gaps, which can positively affect the throughput of road traffic. However, in terms of environmental protection, such an approach might worsen the situation by increasing road noise emissions, as more vehicles move at higher speeds through a given cross-section in the analysed period, leading to increased noise.

Therefore, analyses and scenarios should consider two additional aspects. To illustrate these relationships, a simulation was conducted using various vehicle spacings. Three criteria were applied: traffic throughput, traffic safety, and the level of road noise. The largest vehicle spacings were used in the analysis focused on reducing road noise. The other spacings were similar to each other. The results were presented in Figure 5.

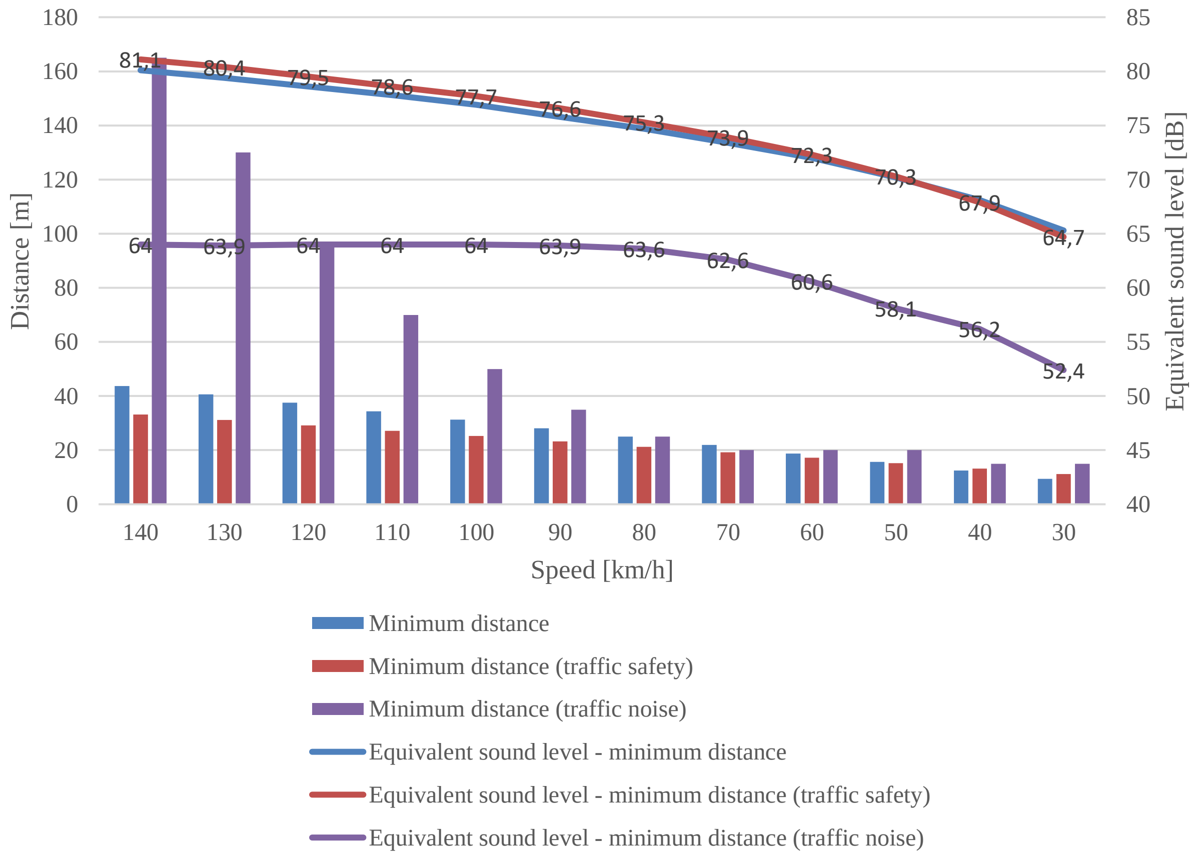

Fig. 5. The impact of the distance between vehicles on road noise emissions in the case of autonomous vehicles [17].

Increasing the distance between vehicles results in a decrease in the equivalent sound level. However, focusing on optimizing the management of autonomous vehicles solely in terms of travel time can lead to significant environmental issues. The differences between the optimal conditions for environmental protection and those focused on traffic optimization can exceed 17 dB. This is a significant disparity that should be considered in traffic control algorithms.

4. Conclusion

Research confirms that improving acoustic conditions near roads is possible through traffic management, considering its variability and characteristics. Using ITS systems to regulate traffic can contribute to reducing noise emissions, if fluctuations and traffic conditions are taken into account. A precise analysis of the impact of these factors on road noise is crucial for the proper selection of actions such as parking planning and management, organization, slowing down and directing traffic, as well as transferring and integrating traffic routes. Appropriately configured ITS systems can serve as effective tools for protecting against road noise, offering an alternative to acoustic barriers that does not require physical changes to the road environment. Such solutions are flexible and can adapt to current road situations. Additionally, autonomous vehicles may serve as another means of noise protection, but their usage scenarios should include environmental protection aspects to avoid increasing the negative impact on the environment.

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