Transportation Research Part D 49 (2016) 313–322

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

A new probability statistical model for traffic noise prediction on free flow roads and control flow roads

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ARTICLE INFO

Article history:
Available online 10 November 2016

Keywords:
Traffic noise
Prediction model
Probability distribution

ABSTRACT

A new traffic noise prediction approach based on a probability distribution model of vehicle noise emissions and achieved by Monte Carlo simulation is proposed in this paper. The probability distributions of the noise emissions of three types of vehicles are obtained using an experimental method. On this basis, a new probability statistical model for traffic noise prediction on free flow roads and control flow roads is established. The accuracy of the probability statistical model is verified by means of a comparison with the measured data, which has shown that the calculated results of L_{eq}, L_{10}, L_{50}, L_{90}, and the probability distribution of noise level occurrence agree well with the measurements. The results demonstrate that the new method can avoid the complicated process of traffic flow simulation but still maintain high accuracy for the traffic noise prediction.

1. Introduction

The current development of road traffic has brought about serious noise pollution in cities. Accurate traffic noise prediction is a precondition of traffic noise control and an important task of environmental management. There are currently two types of popular traffic noise prediction models: steady-state calculation models and dynamic simulation models. A steady-state calculation model can be applied to predict the average traffic noise over a period of time on the basis of the average traffic volume, average traffic speed, etc. Researchers have performed a large body of work in traffic noise prediction and established various influential steady-state calculation models, such as the FHWA highway traffic noise prediction model in the United States (Rochat and Fleming, 2002), the CRTN model in the United Kingdom (Department of Transport and Welsh Office UK, 1988), the RLS90 model in Germany (Road Construction Section of the Federal Ministry for Transport, 1990), the ASJ RTN-model in Japan (Yamamoto, 2010) and the CNOSSOS model in Europe (Kephalopoulos et al., 2012). In addition, some specific models for intersections (Makarewicz et al., 1999; Makarewicz and Kokowski, 2007; Abo-Qudais and Alhiary, 2007) and roundabouts (To and Chan, 2000; Covaciu et al., 2015) also belong to the steady-state calculation model category. Although all of the above models can predict the equivalent noise level L_{eq} or the time average noise level L_{AT} over a given period of time, they cannot calculate the dynamic change of noise.

A dynamic simulation model can be used to predict not only the L_{eq} over a period of time but also the second-by-second dynamic changes of the noise level (Jacobs et al., 1980; Chevallier et al., 2009; Guarnaccia, 2013). This approach generally

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http://dx.doi.org/10.1016/j.trd.2016.10.019
1361-9209/

works by combining a dynamic traffic simulation model, a vehicle noise emission model, and a sound propagation model (Can et al., 2010; Luo et al., 2012). Dynamic simulation models are more and more widely used in predicting traffic noise with the development of computer technology. For instance, Suzuki et al. proposed a dynamic traffic noise simulation model for a large intersection (Suzuki et al., 2003). Chevallier et al. developed a new traffic simulation tool for roundabouts and combined it with noise emission laws and a sound propagation model to study the dynamic noise near a roundabout (Chevallier et al., 2009). Li et al. established a dynamic model for signalized road intersections among buildings and studied the effect of traffic lights on the traffic noise (Li et al., 2011). Cai et al. used a dynamic simulation model to simulate the dynamic change and study the characteristics of traffic noise near a signal-controlled pedestrian crossing junction (Cai et al., 2011). However, almost all of the dynamic simulation models rely on a complex traffic simulation model. Furthermore, almost all of the vehicle noise emission models within the dynamic simulation models are fixed algebraic expressions related to the speeds and types of vehicles, which makes it difficult to represent the varied noise emission in the actual situation.

The Monte Carlo method is a computational algorithm that relies on repeated random sampling to obtain numerical results. It can be used to solve any problem having a probabilistic interpretation (Kroese et al., 2014). In transportation engineering, it has been applied for traffic speed forecasting (Jeon and Hong, 2016), traffic flow simulation (Waldeer, 2003), and traffic noise simulation based on speed distribution of vehicles (Alberto and Efraín, 2013; Iannone et al., 2013). To simplify the process of microscopic traffic flow simulation and to preserve the diversity and accuracy of the prediction parameters, this paper proposes a new traffic noise prediction approach that is based on a probability distribution model of vehicle noise emissions and achieved by Monte Carlo simulation. First, we used an experimental method to obtain the probability distributions of the noise emissions of three types of vehicles; then, on this basis, we established a probability model for traffic noise prediction on free flow roads and control flow roads; finally, we verified the accuracy of the model with measured data.

2. Model development

2.1. Model for free flow roads

Whenever a car is travelling on a long straight road, as shown in Fig. 1, the sound pressure level at the receiving point can be expressed as:

$$L_j = L_{j,0} + L_{j,D} + L_{j,Other} \tag{1}$$

where $L_{j,0}$ denotes the sound pressure level of a single vehicle measured at a standard distance, which can be seen as the noise emission of a single vehicle; $L_{j,D}$ denotes distance attenuation; and $L_{j,Other}$ denotes the noise attenuation caused by other factors, such as air absorption and shielding by barriers.

According to the Chinese Standard "GB 1495-2002" (Anon., 2002), $L_{j,0}$ can be expressed as the sound pressure level of a single vehicle measured at a standard distance d_0 = 7.5 m. In past studies, $L_{j,0}$ is related to the vehicle type and speed and is commonly presented as a fixed expression that is fitted to a large amount of experimental data (Steele, 2001). However, the noise emissions of different vehicles are not fixed but instead fluctuant within a certain distribution, even if the vehicles travel at the same speed. Therefore, we assume that the noise emission of each type of vehicle in each certain speed range obeys a certain distribution, whose probability density function can be expressed as:

$$y = f(L_{j,0}) \tag{2}$$

By classifying the vehicles into several types according to their weight and further classifying each type of vehicle into several speed grades, the probability density function $f(L_{j,0})$ can be obtained from a large number of experimental data analysis.

Distance attenuation can be expressed as:

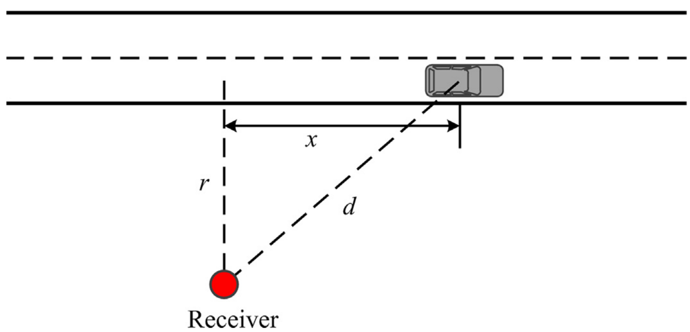

Fig. 1. Traffic noise propagation for the case of a long straight road.