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Dynamic simulation and characteristics analysis of traffic noise at roundabout and signalized intersections

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ABSTRACT

Traffic noise prediction is an important topic for traffic environment planning in cities. The complex traffic flow at road intersections makes the prediction of traffic noise challenging. In this paper, a dynamic traffic noise simulation method based on microscopic traffic simulation is used to study the traffic noise near roundabout and signalized intersections. A vehicle noise emission model that considers the effect of acceleration is established using an experimental method. The accuracy of the model is verified by comparison with measured data. Traffic noise near roundabout and signalized intersections under different traffic volume levels is simulated, and the results are compared. Some significant relations between traffic noise and traffic volume are obtained, and the mechanisms are analyzed. The results show that traffic noise reaches an upper limit when traffic is saturated, and the noise energy contribution of the exit lane is far greater than that of the entrance lane.

1. Introduction

The development of road traffic has produced serious noise pollution in cities. Long-term living and working in a high-noise environment leads to serious health problems [1,2]. Traffic noise prediction is a precondition of traffic noise control and an important task of environmental management. Many research works on traffic noise prediction have been performed, and various traffic noise prediction models have been established. The main traffic noise prediction models can be classified into two types: steady-state calculation models [3] and dynamic simulation models [4]. Steady-state calculation models can be applied to predict the average traffic noise over a period of time, such as the FHWA highway traffic noise prediction model in the United States [5], the CRTN model in the United Kingdom [6], the ASJ RTN-model in Japan [7], the CNOSSOS model in Europe [8,9], models for interrupted traffic [10,11], and models for intersections [12,13]. Dynamic simulation models that combine microscopic traffic simulations can be applied to predict not only the average traffic noise over a period of time but the second-by-second dynamic changes of the noise level [14–17]. Dynamic approaches have been used for traffic noise simulation on intersections and roundabouts.

Almost all steady-state models and dynamic models are based on a vehicle noise emission model, which is one of the key factors affecting the accuracy of the model. Most vehicle noise emission models are obtained by experimental measurements. Vehicle noise emission is usually expressed by a linear regression equation related to vehicle speed, and few models have considered the effect of vehicle acceleration. This approach may result in error, especially for road segments where vehicles are accelerating or decelerating. Although some studies have considered the effect of acceleration, acceleration was not incorporated into the linear regression equation [18,19].

Roundabouts and signalized intersections are two common forms of road junctions in urban road networks. The varying state of vehicle motion near an intersection makes traffic noise calculations challenging. The prediction of traffic noise near intersections has attracted wide attention, and many prediction models and methods have been proposed [20–24]. However, the influence of the degree of traffic saturation on the noise and the difference in noise emission between different types of lanes is not clear. In reality, traffic speed and volume cannot be infinitely increased, which means traffic noise also has a maximum value. Therefore, finding the relationship between traffic saturation and traffic noise is important to predict the maximum value of noise. Furthermore,

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finding the difference on traffic noise emission between different types of lanes is helpful to analyze the main sources of noise and make the traffic noise control more targeted.

The purpose of this paper is to establish a vehicle noise emission model that considers the effect of vehicle acceleration based on an experimental method and to combine the emission model with a microscopic traffic simulation tool to simulate traffic noise near roundabout and signalized intersections. Additionally, the differences in traffic noise between the two types of intersection are explored, and the influences of the degree of traffic saturation and lane type on traffic noise are analyzed.

2. Dynamic traffic noise simulation method

To study the fluctuation of traffic noise, we use a dynamic traffic noise simulation method to simulate the dynamic noise change. The dynamic traffic noise simulation method is composed of three modules, a microscopic traffic simulation tool, a vehicle noise emission model and a sound propagation model (Fig. 1). The microscopic traffic simulation tool is applied to simulate the traffic flow on the road network and to obtain status data of the vehicles, including the type, position, speed and acceleration of each vehicle at each time-step of the simulation. The vehicle type, speed and acceleration data are input into the vehicle noise emission model to calculate the noise emission of each vehicle at a specific moment. The vehicle position and noise emission are input into the sound propagation model to calculate the individual contribution of each vehicle at the receiver. Thus, the instantaneous sound pressure level at the receiver can be obtained by summing the contribution of each vehicle at the corresponding time-step. A series of 1-s resolution sound pressure levels are obtained by running the simulation with a time-step of 1 s. Then, the time equivalent sound level L_{eq}, and the cumulative statistical sound levels L_{10}, L_{50}, and L_{90}, can be calculated.

In the traffic noise calculation, each vehicle on the road network is regarded as a point sound source. The sound pressure level of the i-th second at the receiving point that is emitted by the j-th car can be expressed as:

$$L_{i,j} = L_0 + L_{D(i,j)} + L_{Other(i,j)} \tag{1}$$

where L_0 denotes the sound pressure level of a single vehicle measured at a standard distance and can be considered a vehicle noise emission model, $L_{D(i,j)}$ denotes the distance attenuation, and $L_{Other(i,j)}$ denotes the noise attenuation caused by other factors, such as air absorption, ground effect, and shielding by barriers. $L_{D(i,j)}$ and $L_{Other(i,j)}$ depend on the sound propagation model.

The distance attenuation can be expressed as:

$$L_{D(i,j)} = 10\log_{10}\frac{d_0^2}{d_{i,j}^2} = 10\log_{10}\frac{d_0^2}{(x_{i,j}-x_0)^2+(y_{i,j}-y_0)^2} \tag{2}$$

where d_0 denotes the reference distance when measuring the noise emission of a single vehicle, which is 7.5 m in the Chinese Standard "GB 1495-2002" [25], $d_{i,j}$ denotes the distance from the vehicle to the receiving point, $x_{i,j}$ and $y_{i,j}$ denote the coordinates of the vehicle, and x_0 and y_0 denote the coordinates of the receiving point.

By summing the sound energy of each vehicle at a time-step, we can obtain the instantaneous sound level:

$$L_i = 10\log_{10}\left(\sum_{j=1}^{m_i}10^{0.1L_{i,j}}\right) \tag{3}$$

where m_i is the number of vehicles on the road at the i-th second.

In this work, we used Paramics 6.5 (a microscopic traffic simulation software) as to simulate the traffic on the road network. The software includes a vehicle generator that will generate some simulated vehicles randomly at any time-step based on the traffic OD of the road network. The generated vehicles will travel on the road network following the vehicle-following model, lane changing rules, signal control rules, and so on until they leave the road network. In the simulation process, there may be different numbers of vehicles running on the studied road network at different time-step. We developed a dynamic link library plug-in using C programming language to connect the Paramics software and collect the number of vehicles m_i and their driving status data at each time-step. Then the traffic noise at each time-step during the traffic simulation is calculated based on these dynamic traffic data.

3. Experiment for the noise emission of a single vehicle

We used the experimental method to measure the noise emission of a single vehicle and to establish a vehicle noise emission model. The experimental scenario was set according to the Chinese standard GB 1495-2002 (Limits of external noise of an accelerating vehicle and relevant measurement methods) [25]. The experiments were performed on straight roads with low traffic and approximately 100 m without obvious reflectors. Three types of road segment (acceleration, deceleration and constant speed road segments) were chosen to measure the vehicle noise in different states of motion. The sound level meters were placed 1.2 m above the ground and 7.5 m from the traffic lane on each side of the road. The speed of each vehicle was recorded by radar speed indicators and video cameras. The acceleration of the vehicle was calculated based on the velocities when the vehicle passed two neighboring observation points.

The vehicles were classified into three types: light vehicles, with a length less than 6 m and a weight less than 2 tons; heavy vehicles, with a length greater than 10 m or a weight greater than 12 tons; and medium vehicles, i.e., anything other than a light vehicle or heavy vehicle. The noise emissions of 3372 vehicles (including 2451 light vehicles, 375 medium vehicles and 546 heavy vehicles) were measured as they passed a sound level meter. The noise emission data of 4 driving states were collected, including accelerating, decelerating, steady driving and idling. Linear regression was used to generate a vehicle noise emission model, as shown in Table 1. For steady driving noise, we established a relationship between noise emission and speed; for accelerating and decelerating noise, we established a relationship between noise emission and speed and acceleration; and for idling noise, we used a constant to represent the noise emission. The correlation coefficients were high, except the fitted formulas for medium vehicle acceleration and heavy vehicle acceleration and deceleration. To ensure the accuracy of the model, we conducted an F test and t-test for the fitting formulas. At the 0.05 significance level, all test values were greater than the critical value, which means the fitting formulas are credible.

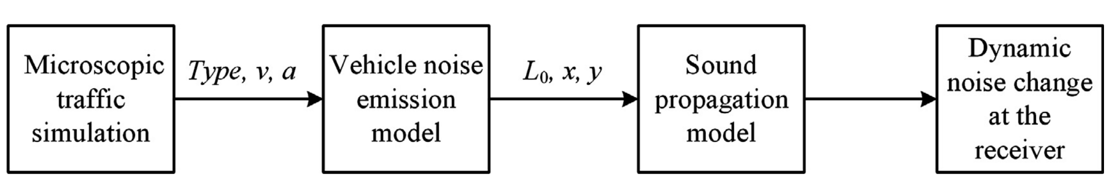

Fig. 1. Principle diagram of the dynamic traffic noise simulation method.