Applied Acoustics 74 (2013) 614–621

Contents lists available at SciVerse ScienceDirect

Applied Acoustics

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

Modeling urban traffic noise with stochastic and deterministic traffic models

Alberto Ramírez *, Efraín Domínguez

Facultad de Estudios Ambientales y Rurales, Pontificia Universidad Javeriana, Transversal 4, No. 42-00, Piso 8, Bogotá, Colombia

A R T I C L E I N F O

Article history:
Received 27 January 2012
Received in revised form 6 June 2012
Accepted 1 August 2012
Available online 3 September 2012

Keywords:
Noise pollution
Urban modeling
Traffic noise prediction model
Traffic dynamics
Urban noise monitoring

A B S T R A C T

This paper presents the development and evaluation of a stochastic dynamic traffic noise prediction model based on noise curves for vehicle classes and their speed. The model was tested on urban two-lane roads in the city of Bogotá and was established on the basis of the fit of single $L_{i,17\text{sec}}$ noise functions for different types of vehicles. The model showed a slightly better fit than was found in four deterministic models that are highly internationally recognized. Additionally, a deterministic model was derived contextualized to the city of Bogotá. The approach used is promising for further investigations of urban traffic noise given the traffic conditions in these systems.

1. Introduction

Urban noise pollution is causing increased health risks in the population. This is due both to the fact that noise levels, particularly those associated with transport, have increased dramatically since the mid-twentieth century and that a higher percentage of the world population is now concentrated in urban systems [1,2]. This problem has also increased economic costs due to failing health and reduced productivity of the population, affecting between 0.2% and 2% of gross domestic product in the US [3]. In the European Union, the costs range between $13 billion and $38 billion per year [4]. In addition, traffic noise causes the depreciation of properties exposed to high noise levels [5].

Studies on urban noise are becoming more numerous, reflecting the growing importance of this pollutant, for which levels currently exceed those specified by regulations in Spain [6], Iran [7], India [8], Egypt [9], China [10], Brazil [11] and Colombia [12,13], among others.

Computer models are highly valued in developed countries for assessing environmental problems, including sources of pollution, their spreading in the environment, impacts on human populations and associated regulatory processes, many of which follow the guidelines of the USEPA [14]. Modeling of traffic noise represents an example of this technique and has been implemented in the context of environmental impact studies for transport projects [15]. Additionally, this type of modeling has played an important role in the analysis of mitigation measures during road construction [16,17] and in identifying the variables with the highest noise incidence [9,18]. Noise prediction also plays a prominent role in planning and development of new urban projects and roads [16].

The traffic noise model plays an important role in the construction of noise maps, since they combine both observed and simulated records. These maps have been employed mainly for urban planning, environmental risk assessment [19], identification of hotspots, evaluation of the exposed population and simulation of mitigation measures [20,21].

The simplest models have been designed based on relationships between the logarithm of the number of vehicles and the level of noise they generate [7,22–24]. The relationship between these two variables is obvious, as the greater the number of vehicles that are simultaneously on the road, the greater the number of emissions sources there will be. More elaborate models have also included the proportion of heavy vehicles and speed, and even variables such as pavement type, width and inclination of the track and height of buildings, among others [7,15,23,25–30].

These models are based on theoretical factors that are applicable based on statistical relationships and on macroscopic traffic variables such as total flow and average speed. Their results have been very good related to roads and highways where traffic prevails, and flow conditions are relatively homogeneous [9,16,17]. In contrast, these same models have rarely been applied to urban roads where traffic volumes and speeds are not fixed due to the start-stop and acceleration–deceleration situations that are typical of these systems [5] and because of cycles in traffic and noise associated with traffic lights [13,31].

Nevertheless, research on urban intersections has achieved a good fit between the continuous equivalent level, (L_{eq}), and the traffic volume, the number of heavy vehicles, the slope and the type of pavement [32].

* Corresponding author. Tel.: +57 1 3208320x4819; fax: +57 1 3208320x4859.
E-mail address: alberto.ramirez@javeriana.edu.co (A. Ramírez).

0003-682X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apacoust.2012.08.001

Other mathematical approaches that have achieved good performance include neural networks [33,34], microscopic traffic models [35,36] and models based on single traffic noise [37].

In Colombia, the problem of traffic noise has been largely overlooked by environmental authorities. Very few studies have involved modeling, and their results have been highly variable [12,13,38,39]. This report presents the results of a study in which a stochastic and dynamic microscopic model is developed, and its performance is analyzed in the city of Bogotá based on the single noise generated by each vehicle during its passage in front of a measurement point. Additionally, we compare the results of this model with a deterministic model derived from it, as well as four international deterministic models that are widely used.

2. Methodology

2.1. Single noise

This study was conducted in Bogota. As a starting point, vehicles were classified into the following categories: motorcycles, cars (including cars, trucks, small delivery vans and microbuses), buses, mini-buses (small buses) and trucks (over 3 tons). Subsequently, we conducted measurements of single noise on the streets of the city (n = 533 vehicles), seeking to exclude the impact of other vehicles and other sources of noise. To this end, we used an integrated Extech type II sound level meter (SLM) to evaluate the instantaneous sound level ($L_{i,1\text{sec}}$) during the approach and passage of each vehicle in front of the SLM on roads with 1 and 2 lanes. These measurements followed conventional techniques [15] and were conducted using a tripod and a windscreen at a height of 1.2 m at a distance of 1 m from the road with A and slow weights. In parallel, we measured the speed at which each vehicle was traveling using manual Bushnell equipment. In all cases, the prevailing conditions included flat, dry roads, wind speeds less than 4 km/h and a low incidence of other noise sources.

For each type of vehicle, we conducted a regression analysis between the maximum noise level (when passing in front of the SLM) and speed. Because this yielded low coefficients of determination, we implemented classification trees to dissociate subgroups depending on the speed of vehicles. Subsequently, we averaged all noise levels recorded in each subgroup at time zero (passing in front of the SLM) and during the approach at times −1 through −8 s in time steps of 1 s. Using these values, we tested various models of linear and nonlinear regression and chose the model with the highest coefficient of determination using SPSS v.15 (statistical software) and Curve Expert v.1.3 (nonlinear regression). The noise level was assumed to be symmetric for the approach and retreat of vehicles.

2.2. Stochastic model

Based on this information, we built a dynamic model using the Stella v.8 program (dynamic modeling software) consisting of 3 segments:

i. A stochastic Monte Carlo traffic simulator for each lane, with sampling without replacement, which defines for each second whether or not a vehicle is present and the class to which it belongs, along with its speed simulated from a normal distribution with estimated parameters (μ, σ^2) for each vehicle class and station. In this regard, the model follows the guidelines given by the [5] regarding including specific conditions for each lane.
ii. A time window of 17 s (−8 ... 0 ... +8) for each lane, in which the vehicle is moving and sends information about instantaneous sound pressure ($L_{i,1\text{sec}}$) from the Weibull functions estimated from vehicle type and speed.
iii. A collection point for the information, which receives the instantaneous sound pressure of the two lanes every second and calculates the continuous equivalent level (Eqs. (1) and (2)). This descriptor is the constant sound level over a stated period of time which is equivalent in total sound energy to the time-varying sound level measured over the same period of time and is used worldwide in traffic noise evaluation [15,26]. The simulation and sampling time was 10 min, which is a duration that was previously shown (presampling) to be sufficient for L_{Aeq} stabilization. This unit of time was reported as suitable for such measurements [35].

Calculation of the continuous equivalent level for each lane was determined as follows:

$$L_{eq,10\text{min}} = 10\log_{10}\left\{\frac{1}{600}\sum_{i=1}^{600}10^{Li,1s/10}\right\} \tag{1}$$

For the two lanes:

$$L_{eq,10\text{min}} = 10\log_{10}\left[10^{\frac{L_{eq,10\text{min lane 1}}}{10}} + 10^{\frac{L_{eq,10\text{min lane 2}}}{10}}\right] \tag{2}$$

The model is dynamic and is based on the physical principle of the addition of sound pressure per vehicle and lane, along with empirical equations for single noise based on speed and vehicle type, which in this case, correspond to the Weibull function. The model also incorporates randomness derived from the speed of each vehicle, which is why the continuous equivalent level estimated at each station was obtained from the average of 10 simulations.

The assumptions included in the model were as follows: (a) conservation of vehicles during the 17-s window; (b) sound energy conservation, but with divergence based on the distance between the vehicle and the level meter, which is implied in the Weibull function; (c) constant vehicle speed during passage through the time window; (d) no vehicle passing any other vehicle or changing lanes; (e) negligible effects of reflection due to walls, reflection and shielding between vehicles and refraction and absorption by other elements present in the acoustic field; (f) negligible impacts of other noise sources compared to the sound pressure arising from the vehicle; and (g) the climatic impact is considered negligible given the distance.

2.3. Deterministic models

For comparison purposes, we evaluated the German model RLS90 – Richtlinien für den Lärmschutz an Straben [25]; the English model CoRTN – Calculation of road traffic noise [40]; the Nordic model Nordic prediction method for road traffic noise-statens planverk 96 [25,41] and the Northamerican model TNM – Traffic noise model V.2.5 [27]. Previous models estimate the L_{eq} based on traffic flow, speed and heavy vehicle proportion. They are static and deterministic.

We also derived and evaluated a deterministic model based on the TNM, but operating with the single noise levels measured in Bogotá (Eq. (3)).

$$\begin{aligned} L_{Aeq,10\text{min}} = 10\log\Bigg\{&\left[\sum Q_{Cars,s}\times 10^{\frac{L_{Aeq,17\text{seg}(Cars,s)}}{10}}\right] \\ &+\left[\sum Q_{Motorcycles,s}\times 10^{\frac{L_{Aeq,17\text{seg}(Motorcycles,s)}}{10}}\right] \\ &+\left[\sum Q_{Buses,s}\times 10^{\frac{L_{Aeq,17\text{seg}(Buses,s)}}{10}}\right] \\ &+\left[\sum Q_{Small\ Buses,s}\times 10^{\frac{L_{Aeq,17\text{seg}(Small\ Buses,s)}}{10}}\right] \\ &+\left[\sum Q_{Trucks,s}\times 10^{\frac{L_{Aeq,17\text{seg}(Trucks,s)}}{10}}\right]\Bigg\} \end{aligned} \tag{3}$$