Applied Acoustics 111 (2016) 170–178

Contents lists available at ScienceDirect

Applied Acoustics

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

A road traffic noise pattern simulation model that includes distributions of vehicle sound power levels

Bert De Coensel [a,*], A.L. Brown [b], Deanna Tomerini [b]

[a] Waves Research Group, Department of Information Technology, Ghent University, Belgium
[b] Urban Research Program, Griffith School of Environment, Griffith University, Brisbane, Australia

ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form 11 February 2016
Accepted 12 April 2016
Available online 3 May 2016

Keywords:
Environmental sound
Noise pollution
Road traffic
Microscopic simulation
Noysim
Python

ABSTRACT

Annoyance, sleep disturbance and other health effects of road traffic noise exposure may be related to both level and number of noise events caused by traffic, not just to energy equivalent measures of exposure. Dynamic traffic noise prediction models that include instantaneous vehicle noise emissions can be used to estimate either of these measures. However, current state-of-the-art vehicle noise emission models typically consider a single emission law for each vehicle category, whereas measurements show that the variation in noise emission between vehicles within the same category can be considerable. It is essential that the influence of vehicles that are producing significantly more (or less) noise than the average vehicle are taken into account in modeling in order to correctly predict the levels and frequency of occurrence of road traffic noise events, and in particular to calculate indicators that characterize these noise events. Here, an approach for predicting instantaneous sound levels caused by road traffic is presented, which takes into account measured distributions of sound power levels produced by individual vehicles. For the setting of a receiver adjacent to a dual-lane road carrying free flow traffic, the effect of this approach on estimated percentile levels and sound event indicators is investigated.

1. Introduction

Road traffic noise prediction models are usually directed towards the estimation of L_{Aeq} or derived indicators such as L_{den}. The main reasons are that energy equivalent levels for road traffic streams are relatively simple and robust to estimate, and that they have a reasonable correlation with annoyance [1]. Criterion levels for road traffic noise utilized for mitigation and planning purposes generally use these single-number energy equivalent metrics of the fluctuating road traffic noise signal. As such, they constitute the predominant indicators used in policy and management (see, for example, the Environmental Noise Directive of the European Commission [2]). However, energy equivalent noise descriptors say very little about the pattern of fluctuations of noise levels over time, yet it may be this temporal pattern that is of particular interest with respect to specific dimensions of human health effects that arise from road traffic noise [3,4].

Sleep disturbance is a major health issue associated with transportation noise [5,6], and the research evidence is that the physiological effect of such noise on human sleep may depend more on the level and number of noise events in traffic streams than on energy equivalent measures [7–9]. Community reaction to sleep disturbance from night-time noise has been highlighted in a review of the increased operations of night-time freight traffic in Australia [10]. That review recognized that community reaction to the noise made by heavy vehicles on urban roadways, particularly late at night when many trucks prefer to travel because of lower levels of congestion, will be a major constraint to the future movement of trucks in urban areas. It also noted that authorities have yet to develop criteria defining acceptable incidence (and magnitude) of traffic-related noise events, and that current noise measurement techniques do not readily accommodate the assessment of the discontinuous nature of the noise of large vehicles traveling at night.

Further, it has been suggested that noise annoyance may also be determined, at least in part, by noise events from road traffic streams [11–13]. When noise events are noticed, they may distract attention and interfere with activities [14–16]. Roberts et al. [17], too, note that various studies demonstrate anomalies to the accepted view that it is the energy equivalent level that is important for annoyance responses, postulating that it is the pattern of road traffic noise—the presence of noise peak events—that may be critical, also suggesting that response to road traffic noise may be better assessed by some combination of the conventional

* Corresponding author.
E-mail addresses: bert.decoensel@intec.ugent.be (B. De Coensel), lex.brown@griffith.edu.au (A.L. Brown), d.tomerini@griffith.edu.au (D. Tomerini).

http://dx.doi.org/10.1016/j.apacoust.2016.04.010
0003-682X/

continuous noise measures with pattern variables such as the number of noise events. In this context, several indicators for traffic noise annoyance that take into account the fluctuation strength of the sound pressure level (Traffic Noise Index, Noise Pollution Level, Common Noise Index [18], etc.) have variously been proposed. Finally, models for the prediction of road traffic noise are increasingly used for urban planning and soundscape planning, where a notion of the expected strength and occurrence of noise events is essential, for example for estimating the efficiency of measures for masking road traffic noise [19,20].

Based on the above, it is evident that it is of interest to be able to estimate the occurrence, both in magnitude and number, of noise events that can be expected from road traffic streams. There are traffic situations where this may be of particular interest. For example, arterial roads often cross urban areas where, due to signalized intersections, traffic may not be distributed uniformly over time. Moreover, the traffic stream may contain heavy vehicles. When people live at close distance to such roadways, high vehicle passby levels may result in them noticing these events and/or their sleep disturbance. Energy equivalent levels can be, in these and other circumstances depending on the volume of traffic flow, relatively insensitive to the number and level of individual noise peaks from high-noise-emission vehicles in the road traffic stream.

For noise assessment and management where noise events are likely to be prevalent within road traffic streams, knowledge of the time history of the sound level caused by road traffic is required. A number of traffic noise models have been developed in the past that are suited for predicting the time history of the sound level arising from a traffic stream. Examples are the models developed at INRETS [21,22], at Ghent University [23,24] and at EPFL [25]. These models predict the instantaneous contribution of single vehicles to the sound level at a receiver location over time, and account for dynamic effects of vehicular traffic, such as the excess noise emission due to acceleration of vehicles (although limitations still exist because of the relative scarcity of measurement data on emissions during acceleration, and because of the limited accuracy of the estimated traffic variables, in particular acceleration, within dynamic traffic models). This dynamic approach can be used to estimate more advanced indicators, such as indicators that assess the impact of traffic light cycles [26–28] or indicators that assess the temporal structure of the sound [29]. Clearly, this approach is a refinement of conventional traffic noise prediction models in which emission calculations are based only on average speeds and intensities [30–32]. However, the state-of-the-art vehicle noise emission models, for example those used in the FHWA Traffic Noise Model or the European Imagine model [33], still consider a single, prototypical emission law for each vehicle category. This is sufficient for correctly predicting energy equivalent sound levels, as these emission laws are determined on the basis of measurements on a sufficiently large number of vehicles sampled from the vehicle fleet. Note that the Imagine model takes into account factors such as the percentage of vans or the percentage of vehicles having illegal exhaust adjustments, but only as corrections to the prototypical emission law for each vehicle category.

Roadside noise measurements of real traffic streams show that differences in noise emission levels (due to age, maintenance, modifications, driving style, etc.), between different vehicles within a single vehicle category (for example, cars, trucks, etc.) can be considerable, and that emission distributions for different vehicle categories overlap considerably [34–36]. Consequently, maximum levels obtained by models that use a single emission law per vehicle category may misrepresent reality. To accurately predict the occurrence and strength of noise events caused by road traffic, the influence of vehicles that are producing more/less noise than the average vehicle has to be taken into account. In Section 2 of this paper, a methodology to do this is outlined. The approach uses individualized vehicle emission laws for predicting the instantaneous overall sound pressure level caused by road traffic. In Can et al. [37], a similar approach, where each vehicle in the simulation is assigned an emission law randomly selected from a small number of emission laws for each vehicle category, has been shown to affect the estimation of the levels of vehicle peaks. In the present work, the approach is taken one step further. A distribution of the sound power levels of individual vehicles, based on maximum levels sampled from a large measurement database for cars and trucks under real operating conditions [34], is used as a correction to the prototypical emission law for each vehicle category [38]. The effect of this approach on estimated energy-equivalent levels, percentile levels and sound event indicators is illustrated in Section 3.

2. Methodology

2.1. Overview

The proposed approach for predicting the traffic noise level time history near roadways is similar in structure to other dynamic traffic noise prediction models [22,23], and consists of coupling a microscopic road traffic simulation model with a model for instantaneous vehicle noise emission and a point-to-point sound propagation model. A general overview of the model is shown in Fig. 1.

A microscopic simulation of road traffic, in which the movement of individual vehicles is simulated, forms the basis of the proposed approach. Given a road network, vehicle fleet properties and aggregated traffic demand data, a simulation run of such a model provides the instantaneous position, speed and acceleration of each vehicle at each timestep during a predefined simulation period. Subsequently, instantaneous emission spectra for all sources are calculated using a noise emission model. Instead of using prototypical vehicle emission factors to estimate the average noise emission for a vehicle given its category, speed and acceleration, the proposed approach extends existing models by taking into account a realistic distribution of vehicle noise emission levels (grayed box in Fig. 1). The latter is implemented by adding a

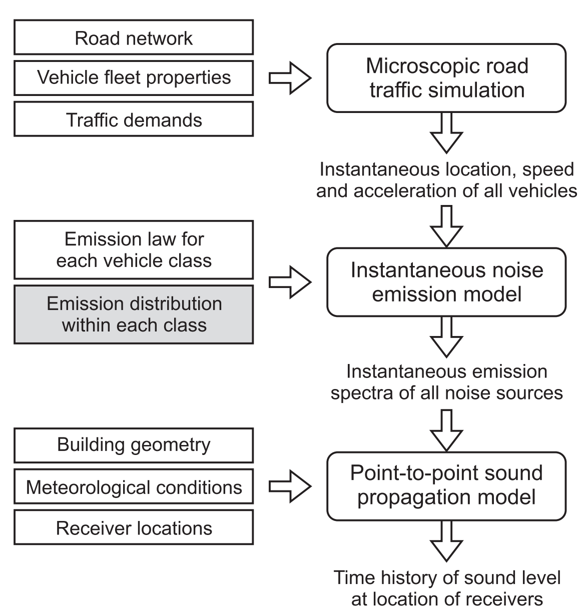

Fig. 1. General overview of the proposed methodology. The left column shows the inputs; the right column shows the models applied and the outputs. The grayed box marks the difference between the proposed model and existing models (for present purposes, this paper considers a simplified propagation model with no buildings and fixed meteorological conditions).