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Derivation of sound-level characteristics to assess traffic development scenarios

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ABSTRACT

Functional relationships are derived between the long-term average sound level and parameters which describe the time variation of sound levels in the vicinity of transport routes under idealized conditions. The parameters comprise the peak sound level and sound-level rise rate associated with the passing of road vehicles and trains. These parameters can be relevant for health effects and annoyance. The method is designed to supplement conventional noise prediction methods for the use in wide-area appraisals of traffic development scenarios with respect to their potential impact on noise. The proposed method is preliminarily applied to a small selection of measured situations and the results are successfully compared.

1. Introduction

An environmentally friendly and sustainable transport is a major goal of the transport policy in many countries [1]. Future trends of transport volumes and distributions within countries or even continents are predicted for one or more scenarios of economic, social and technological developments or administrative constraints [2]. Macroscopic traffic demand and route assignment models are applied to these scenarios and provide relevant parameters like mean flow, mean speed, fleet composition, etc. on route sections (edges) [3]. Based on traffic scenarios the impact of possible future transport on climate, air pollution or noise can be investigated [e.g. 4]. Alternative scenarios are used to find conditions for minimal adverse environmental effects. In the case of noise this requires a traffic noise calculation method that transforms the simulated traffic parameters as input of an emission and propagation model into noise metrics (e.g. sound levels).

Most traffic-noise prediction procedures and national standards only provide energy-equivalent average sound levels L_{eq} on the base of traffic parameters for roads and railway lines. Principally, they can be applied to transport scenarios, but the assessment and ranking should also be interpretable with respect to possible noise effects on human beings such as health impairments, sleeping disturbances or annoyance. Conventional exposure–response relationships rely on average sound levels [5–7]. However, recent studies also consider event-related noise parameters which characterize the time variability of sound levels like the number of events, the maximum level, the noise duration or the rise time (e.g. [8]). Elmenhorst et al. [9] found that the maximum level of an event and the maximum level rise are highly significant indicators of sleep disturbances caused by railway noise. For annoyance they found that L_{eq} alone are not significant predictors, while the number of events in combination with non-acoustical parameters is significant.

To use these findings in traffic scenario assessments, the present study aims at establishing relationships between average sound levels L_{eq} and two parameters which characterize the time variation of the sound level near roads or railway lines, viz. the maximum level and the maximum level rise. Analytical solutions are derived as far as possible or feasible. The paper provides the derivation of these relationships and preliminarily comparisons with measurements near a road and a railway line.

2. Basic assumptions

The relationships are derived under the assumption that different scenarios only differ in traffic parameters and noise emissions while parameters which determine the propagation (local climate, ground properties, buildings, noise barriers, etc.) are retained unchanged. This and the fact, that a relative ranking of traffic scenarios is sought, allow a couple of simplifications: it is sufficient to

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determine relative values while absolute values are of minor interest. Noise metrics can be evaluated in a statistical sense at standard distances; it is not necessary to determine them at distinct locations or situations like in noise mapping or approval procedures. Complex geometries (e.g. buildings) and propagation conditions can be disregarded since they determine the absolute values of noise metrics rather than differences between traffic scenarios. These simplifications make large-scale applications feasible, e.g. nationwide evaluations of transport scenarios with simulated traffic parameters for a very large number of route segments.

We consider point and line sources of sound to represent road vehicles and trains, respectively. The sources move with constant speed V on the x-axis. The receivers are located on the y-axis (Fig. 1). For convenience we define the time $t = 0$ when the source passes the origin, i.e. $x(t = 0) = 0$. The squared distance r^2 between source and receiver is given by

$$r^2(t) = x^2(t) + y^2 = V^2t^2 + y^2 \tag{1}$$

Road traffic of a specific class of vehicles is represented by a large number of point sources which move at a unitary speed V. If the traffic volume is given by the number of vehicles N_T per time interval T, the mean distance between them is $d = V\tau = VT/N_T$ where τ is the time interval between two following vehicles (Fig. 1a). Trains are represented by moving line sources of length ξ. The train position $x(t)$ refers to the middle of the train (Fig. 1b).

The sound energy is characterized by the squared sound pressure amplitude p^2 which either refers to broad band sound or to a specific frequency band. The sound emission is prescribed by the squared sound pressure amplitude p_E at a short distance r_E from the source, or alternatively, by the source power P_E with the air density ρ and the sound speed c. In the following we use

$$E_P = p_E^2 r_E^2 = \rho c \frac{P_E}{2\pi} \text{ and } E_L = p_E^2 r_E^2/\xi = \rho c \frac{P_E}{2\pi\xi} \tag{2}$$

to provide the emission of a point and line source, respectively. For a line source of length ξ the emission refers to the unit length. Line sources are considered as an infinite number of point sources between the positions $x(t) - \xi/2$ and $x(t) + \xi/2$. The sound pressure amplitude at the receiver depends on the emission and propagation effects. As stated before, topographical and meteorological effects can be disregarded. Only two propagation effects are considered in the following, viz. spherical spreading and an excess attenuation which represents e.g. air absorption. Instantaneous propagation is assumed because the sound speed is one to two orders of magnitude higher than the speed of the vehicles.

The squared sound pressure amplitude at the receiver is given by

$$p^2(t) = E_P \frac{\exp(-\alpha(r(t) - r_E))\Gamma}{r^2(t)} \tag{3}$$

as a function of time. The distance r can be expressed according to Eq. (1). α is the attenuation coefficient. Γ is a directivity factor which depends on the angle β between the propagation path and the y-axis with $-\pi/2 < \beta < +\pi/2$ (see Fig. 1). β varies with time as the source passes by. As far as the directivity is caused by the elongation of a vehicle or train the directivity factor is here assumed to be described by the following function

$$\Gamma = (1 - g)\cos\beta + g = (1 - g)\frac{y}{r(t)} + g \quad \text{with } 0 \leqslant g \leqslant 1 \tag{4}$$

Alternatively, $\cos^2$ is sometimes used instead of cos in Eq. (4). A discussion of different formulae for horizontal directivity is found in Zhang and Jonasson [10]. The sound pressure amplitude at the receiver is usually expressed as a sound level

$$L(t) = 10\lg\left(\frac{p^2(t)}{p_0^2}\right) = 10\lg\frac{E_P}{p_0^2 r^2(t)} + D_A(t) + D_\Gamma(t) \quad \text{(in dB)} \tag{5}$$

with $p_0 = 2 \cdot 10^{-5}$ Pa, $D_A = -10\,\alpha \lg e(r(t) - r_E)$, $D_\Gamma = 10\lg\Gamma$, and $\lg e \approx 0.42429$.

The energy-equivalent average sound level within a time period T is provided by

$$L_{eq} = 10\lg\left(\frac{\langle p^2\rangle}{p_0^2}\right) \text{ with the mean pressure amplitude } \langle p^2\rangle = \frac{1}{T}\int_{-T/2}^{+T/2} p^2(t)dt \tag{6}$$

Further sound indicators of interest are the maximum sound level

$$L_{max} = \max(L(t)) \quad \text{for } t \in [-T/2, +T/2], \tag{7}$$

the difference $L_{max} - L_{eq}$, the sound-level change rate

$$\frac{\partial L}{\partial t} = \frac{\partial}{\partial t}\left(10\lg\left(\frac{p^2(t)}{p_0^2}\right)\right) = 10\frac{\partial p^2/\partial t}{p^2}\lg e \quad (\text{in dB s}^{-1}), \tag{8}$$

and the maximum sound-level rise

$$\left.\frac{\partial L}{\partial t}\right|_{max} = \max\left(\frac{\partial L}{\partial t}\right) \quad \text{for } t \in [-T/2, +T/2]. \tag{9}$$

3. Road traffic

3.1. Basic relationships

We consider an infinitely long single-lane road with uniform traffic of a specific type of vehicles (cars, trucks, etc.). The vehicles move with a speed V. The traffic volume is given, for instance, as the average hourly traffic (AHT), i.e. the mean number of vehicles (of the chosen type) per hour. Then, by assuming uniform traffic density we find $\tau = 3600\,\text{s}/AHT$ and $d = V\tau$ as the time lag and spacing between two consecutive vehicles, respectively. The propagation effect is mainly determined by spherical spreading

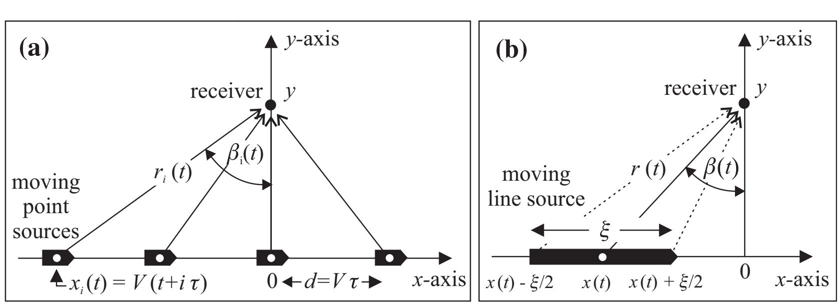

Fig. 1. Source-receiver geometry for (a) moving point sources (road traffic) and (b) a moving line source (train).