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Research paper

Urban traffic noise and the relation to urban density, form, and traffic elasticity

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HIGHLIGHTS

- ► The spatial distribution of traffic noise in a city is related to the traffic elasticity of the city.
- ► The use of traffic elasticity in relation to urban traffic noise in this work is new.
- ► The spatial distribution of traffic noise in a city is related to the Spacematrix, a 3D representation of urban density.
- ► Closed building blocks lead to lower noise levels at quiet façades than open building blocks do.
- ► Numerical calculations are presented for the cities of Amsterdam and Rotterdam, and for idealized urban fabrics.

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ABSTRACT

Traffic noise in cities has serious effects on the inhabitants. Well-known effects are annoyance and sleep disturbance, but long-term health effects such as cardiovascular disease have also been related to traffic noise. The spatial distribution of traffic noise in a city is related to the distributions of traffic volume and urban density, and also to urban form. This relation is investigated by means of numerical calculations for two cities, Amsterdam and Rotterdam, and for various idealized urban fabrics. The concept of urban traffic elasticity is introduced to relate local population density to local vehicle kilometers driven on the urban road network. The concept of Spacematrix is used to represent urban density and urban form. For the two cities it is found that the average sound level in an urban area decreases with increasing population and building density. The results for idealized urban fabrics show that the shape of buildings blocks has a large effect on the sound level at the least-exposed façade (quiet façade) of a building, and a smaller effect on the sound level at the most-exposed façade. Sound levels at quiet facades are in general lower for closed building blocks than for open blocks such as strips.

1. Introduction

Environmental noise has serious effects on the health of people. Health effects considered by the World Health Organization include annoyance, sleep disturbance, and cardiovascular disease (WHO, 2009, 2011). Exposure-response relations indicate that the prevalence of noise-related health effects gradually increases with increasing noise exposure (Miedema & Oudshoorn, 2001; Miedema & Vos, 1998; WHO, 2011).

A major source of environmental noise is road traffic noise. Other types of environmental noise are rail traffic noise, aircraft noise, and industrial noise. To assess and control the effects of environmental noise, European cities regularly produce noise maps and distributions of noise levels at façades of dwellings in the cities (EC, 2002). The calculation of traffic noise levels is based on detailed traffic and building data, and is very time-consuming (King & Rice, 2009). Similar types of noise maps have also been produced for cities outside Europe (Guedes, Bertoli, & Zannin, 2011; Lee, Chang, & Park, 2008; Pinto & Mardones, 2009; Zannin & Queiroz de Sant'Ana, 2011).

For rapid scenario studies, such as urban development studies or impact assessments of environmental measures, a less detailed approach would often be sufficient. In this article we explore possibilities for developing such an efficient approach for assessing urban traffic noise. Based on detailed noise mapping calculations, we present statistical correlations between three types of quantities, all three averaged over urban areas (cells) of the order of 250 m × 250 m:

(i) façade noise level,
(ii) traffic volume,
(iii) urban density.

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Traffic volume is represented by vehicle kilometers (VKM) driven on the road network. Urban density is expressed in various ways, such as building density, road network density, and population density.

Traffic volume and urban density are related to each other. For example, automobile use may be low in dense areas such as the city center, and higher in suburban areas. The relation between traffic volume and urban density plays an important role in this study. In the following paragraphs, literature on this relation is briefly described, and the concept of urban traffic elasticity is introduced.

Badoe and Miller (2000) have presented a review of empirical studies of the impact of urban form on urban travel behavior in North American cities. The review describes that in some studies it was found that residential density is the most important factor for travel parameters such as public transport use and automobile vehicle kilometers. In other studies it was found that travel behavior may be explained more directly by other variables, such as car ownership, employment density, accessibility of trip destinations, and neighborhood design.

An example of studies focusing on residential density is the work of Kenworthy and Laube (1999), which presents an extensive study of automobile use in a large number of international cities. A general conclusion of the study is that car use is more strongly related to urban density than to wealth (represented by gross regional product). Car use decreases with increasing urban density, and public transport use increases with urban density.

Cameron, Lyons, and Kenworthy (2004) have presented a mathematical model for urban mobility, which they use to analyze observed increases in the total number of VKM in seven large cities in the period 1960–1990. Four 'drivers' for VKM increase are distinguished: population growth, urban sprawl, increased vehicle ownership, and decreased vehicle occupancy. In many cases the third driver, increased vehicle ownership, dominates. Policies aimed at reducing vehicle use and promoting public transport have limited the increase of VKM in European and Asian cities.

In spite of the different views on the relation between urban form and traffic volume, it is widely accepted that traffic is an important source of environmental pollution, both air pollution and noise pollution. Although environmental pollution is just one aspect of a wide range of aspects that determine whether an urban form is 'sustainable' (Jenks, Burton, & Williams, 1996; Wheeler & Beatley, 2009), it is certainly an important aspect. An environmental argument against low-density sprawling cities (and therefore in favor of compact cities) is that enhanced car use in sprawling cities would automatically lead to enhanced air pollution and noise pollution. This argument appears too simple, and needs further quantitative study. For noise, the present article presents such a quantitative study.

For air pollution, a quantitative study was reported by Marshall, McKone, Deakin, and Nazaroff (2005). These authors have investigated effects of urban density and traffic volume on inhalation of air pollutants emitted by motor vehicles. Three types of changes in urban population and urban land area are considered:

(i) infill (population increase at constant land area),
(ii) sprawl (land area increase at constant population),
(iii) constant-density growth (increase in population and area at constant ratio),

with increasing (i), decreasing (ii), and constant (iii) population density, respectively. The effects of these changes on per capita inhalation of (primary nonreactive) pollutants from passenger vehicles are analyzed.

For the case of sprawl, two opposing effects are identified:

(1) Vehicle kilometers per capita increase, so more pollutants are produced.
(2) However, the pollutants are produced in a larger area, so exposure concentrations (and thus health risks) may be lower.

So the simple idea that urban sprawl always leads to increased air pollution inhalation is refined. Whether an increase or decrease of inhalation occurs for a scenario depends on a parameter called *urban (traffic) elasticity*, denoted as ε, which appears in the power law expression for VKM per inhabitant:

$$\mathrm{VKM} = A\rho^{\varepsilon},$$

where A is a constant and ρ is population density. For large negative value of ε, say $\varepsilon < -0.3$, an increase of population density corresponds to a decrease of VKM per inhabitant. Elasticity may originate from a tendency that people in more densely populated cities make less (local) car movements per person, and walk, bike, or use public transport more often. Values of ε between 0 and -0.5 are presented for US cities. More recently, Marshall (2008) reported a value of -0.32 for ε as representative for 47 larger US urban areas.

The relation between urban scenarios and traffic noise is expected to be more or less similar to the relation between urban scenarios and air pollution emitted by motor vehicles. For example, in the case of urban sprawl, the total noise emission increases because the number of VKM increases, but on the other hand the noise sources are distributed over a larger area so the sources are on the average located at larger distance from the people. Whether this leads to an increase or decrease of noise exposure levels depends on the elasticity.

In this article urban elasticity is used as a parameter to analyze spatial variations of population density and local traffic volume *within* a city, and to derive spatial variations of traffic noise levels. This intra-urban use of elasticity differs from the inter-urban use of elasticity as a parameter describing developments and comparisons of whole cities. Intra-urban elasticity describes traffic-volume differences between urban areas within a city, while inter-urban elasticity describes differences between cities. Intra-urban elasticity may be used as a parameter describing developments of a city aimed at reducing high noise levels in densely populated areas (noise action plans) (EC, 2002). In the literature we did not find a previous application of the concept of intra-urban elasticity to urban traffic noise analysis.

Traffic noise is a very local phenomenon, with large variations in noise level over small distances. For example, a building located directly along a busy road may have a high noise level at the façade, while a nearby building that is shielded by other buildings may have a much lower façade level. The height of the buildings and openings between the buildings play a crucial role in the spatial distribution of traffic noise in a city. In other words, urban form is a crucial factor for urban traffic noise.

Consequently, characterizing urban density simply by a single number, such as population density, may be a too limited approach for traffic noise. Population density as a single number has a very weak relationship with building type (Alexander, 1993; Forsyth, 2003; Lozano, 2007). The same density can be obtained with radically different building types, and the same type can be used to obtain different densities. Therefore we decided to make use of the recently developed concept of Spacematrix (Berghauser Pont & Haupt, 2010), which is a three-dimensional representation of urban density (described in Section 2).

This study consists of two parts. First we present results of calculations for two real cities in the Netherlands, Amsterdam and Rotterdam. We analyze spatial variations of urban density and traffic noise levels in the cities, and we derive the local values for the (intra-urban) elasticity for VKM per inhabitant. Next, we present