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# Assessing the effects of noise abatement measures on health risks: A case study in Istanbul

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ABSTRACT

In recent decades, noise pollution caused by industrialization and increased motorization has become a major concern around the world because of its adverse effects on human well-being. Therefore, transportation agencies have been implementing noise abatement measures in order to reduce road traffic noise. However, limited attention is given to noise in environmental assessment of road transportation systems. This paper presents a framework for a health impact assessment model for road transportation noise emissions. The model allows noise impacts to be addressed with the health effects of air pollutant and greenhouse gas emissions from road transportation. The health damages assessed in the model include annoyance, sleep disturbance, and cardiovascular disease in terms of acute myocardial infarction. The model was applied in a case study in Istanbul in order to evaluate the change in health risks from the implementation of noise abatement strategies. The noise abatement strategies evaluated include altering pavement surfaces in order to absorb noise and introducing speed limits. It was shown that significant improvements in health risks can be achieved using open graded pavement surfaces and introducing speed limits on highways.



## 1. Introduction

Noise is defined as unwanted or unpleasant sound. In recent decades, noise pollution has been a worldwide concern due its adverse effects on the physiological and psychological well-being of people. The health effects of noise pollution include noise-induced hearing impairment, interference with speech communication, annoyance, sleep disturbance, performance loss, cognitive impairment in children, and cardiovascular diseases (WHO, 2012). Environmental noise pollution relates to noise caused by transportation, industry, construction work, as well as some other outdoor activities. Transportation noise is the most dispersed noise among the environmental noise sources. Comparative burden of disease studies have shown that transportation noise ranks the second major environmental health risk after air pollution in Europe (Stassena et al., 2008; Stansfeld, 2015). The marginal external costs of transportation have also been shown to have comparable effect to those of air pollution and global warming (Bickel and Schmid, 2002a, 2002b; Korzhenevych et al., 2014).

The response to noise may depend on the acoustical properties of sound, such as intensity, duration, and frequency, (Guski, 1999; Boman and Enmarker, 2004) as well as non-acoustics factors, such as location, time of day, and personal factors, including noise sensitivity (Guski, 1999; Boman and Enmarker, 2004), age, perceived quality of the living environment, and attitudes towards different means of transportation (Lam et al., 2009; Guski, 1999). Each transportation mode has different acoustical characteristics and hence different effects on health. More than 40% of the population living in Europe is exposed to transportation noise above the threshold levels for adverse health effects (EEA, 2013). Road traffic noise is the major contributor to overall transportation noise. The health effects of road traffic have been widely assessed in the literature, and cardiovascular diseases, sleep disturbance and annoyance have been the most-reported adverse effects of road noise exposure (EC, 2002; Miedama and Oudshoorn, 2001; Miedema et al., 2003; Kurra et al., 1999; Evans et al., 2001; Clark et al., 2005; Ohrstrom et al., 2007; Kim et al., 2010; Babisch, 2008).

Most industrialized countries have introduced regulations regarding maximum road traffic noise. Therefore, many highway agencies are implementing noise abatement measures to reduce noise levels. Noise abatement measures can be categorized into three: at the source, along the propagation path, and at the receiver (Bendtsen, 2010). Noise reduction at the source is obtained by reducing propulsion noise, pavement/tire noise, traffic volume, and traffic speed. Noise reduction along the propagation path can be achieved by noise barriers, while noise reduction at the receiver can be achieved through façade insulation and local barriers. These noise abatement actions can be implemented alone or in combination with each other in order to keep the noise levels below the threshold values.

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Transportation noise pollution is an important public health factor, however, it has been given limited attention in the environmental assessment of transportation systems. Even noise was considered, its effects were quantified in terms of either the number of people exposed to noise levels exceeding the specified limits or the incremental risk of disease incidence across the population (Steen, 1999; SEPA, 2002/2003; Dobranskyte-Niskota et al., 2007). However, disease severity should be included in impact assessment along with disease incidence to compare the health effects of noise with those of other environmental interventions (e.g. air pollutants and greenhouse gases). A few studies demonstrated methods for quantifying the health impacts of noise in terms of *DALY* to account for disease severity. Müller-Wenk (1999, 2002, 2004) developed the Swiss EPA method to incorporate the health impacts of noise into the Eco-indicator 99 Methodology (2000). The method included fate, exposure, effect, and damage analysis. The health effects evaluated include sleep disturbance, communication interference (Müller-Wenk, 2002, 2004), and cardiovascular diseases (Müller-Wenk, 2002). The method quantified the health effects of an additional 1000 vehicle-km of travel on the Swiss road network for day- and night-time in terms of *DALY*. However, the model was limited to evaluating only two types of road vehicles and two different road classes (e.g., national roads and country roads). Cucurachi and Heijungs (2014) developed a method to quantify the change in the health effects due to a change in the noise levels for different land uses, including rural, urban, suburban, and industrial as well as indoor environments, at the European level. The health impacts were evaluated only in terms of noise annoyance and quantified using *DALY*. This study evaluated the noise impacts of archetypal compartments of noise emissions rather than road transportation noise.

The goal of this study is to set up a framework for a health impact assessment (HIA) model for road transportation noise emissions. Because noise effects are site-specific, a local HIA method was proposed to evaluate the effects of road noise. The model quantifies the change in the health effects due to a unit change in the noise levels. The health damages evaluated in the HIA model include annoyance, sleep disturbance, and cardiovascular disease in terms of acute myocardial infarction (AMI). The disease burden is calculated in terms of DALY per person. This allows noise effects to be addressed with those of air pollutant and greenhouse gas emissions in the environmental assessment of road transportation systems. The proposed model can also be used to evaluate the environmental consequences of public plans or programs with respect to noise. To illustrate the applicability of the model, a case study evaluating the change in health risks due to the implementation of noise abatement strategies in Istanbul is presented. The noise abatement strategies considered include reducing traffic noise using noise absorbing pavement surfaces and reducing traffic speed by introducing speed limits.

## 2. Background

### 2.1. Noise basics

Highway noise arises from automobiles, buses, trucks and motorcycles in motion. The level of highway noise depends on the traffic volume, traffic composition, speed and acceleration/deceleration of each vehicle, and vehicle type. Vehicle noise has three components: aerodynamic noise, propulsion noise, and tire/pavement noise (Nelson and Phillips, 1997). Vehicle noise depends on pavement surface characteristics, vehicle speed, environmental conditions, type of tire, and the dynamics of the rolling process (McDaniel and Thorton, 2005). Both propulsion and tire/pavement noise levels increase with increasing speed (Nelson and Phillips, 1997).

Noise levels can be expressed in terms of sound pressure level ($L_p$) or sound power level ($L_w$). $L_w$ and $L_p$ are calculated relative to a reference sound power ($W_o$) and sound pressure ($P_o$) as shown in Eqs. (1) and (2), respectively.

$$L_w = 10 \times \log(W/W_0) \tag{1}$$

where $L_w$ is the sound power levels in decibels (dB), $W$ is the sound power in watts (W), and $W_o = 10^{-12}$ is the reference sound power in watts.

$$L_p = 10 \times \log\left(P^2/P_0^2\right) \tag{2}$$

where $L_p$ is the sound pressure level in decibels (dB), $P$ is the root mean square sound pressure in pascal (Pa), and $P_o = 2 \times 10^{-5}$ is the reference sound pressure in pascal.

Long term noise exposure is evaluated by equivalent sound level ($L_{eq,T}$) over a period of time, $T$. For environmental health assessment purposes, A-weighted equivalent sound levels [$L_{eq}$,dB(A)] on an annual basis are used. Noise indices used for environmental health assessment usually include day time noise levels ($L_{day\text{-}12\ h}$ or $L_{day\text{-}16\ h}$), night time noise levels ($L_{night}$), and day-evening-night level ($L_{den}$). $L_{day\text{-}12\ h}$ refers to equivalent sound levels between 07:00 and 19:00, $L_{day\text{-}16\ h}$ refers to equivalent sound levels between 07:00 and 23:00, and $L_{night}$ refers to equivalent sound levels between 23:00 and 7:00. $L_{den}$ is the equivalent sound level over 24 h, however night time (23:00–7:00) sound levels are increased by 10 dB(A) and evening (19:00–23:00) sound levels are increased by 5 dB(A) to account for people's extra sensitivity to noise during night and evening time.

### 2.2. Health effects of noise

Road traffic noise has many adverse effects on human health (WHO, 2012). NIOSH. (1998) indicated that exposures to sound levels at 85 dB(A) or above for 8 h or longer may cause noise induced hearing loss. However, road traffic noise next to highways doesn't reach such high levels to cause hearing impairment. Therefore, road traffic noise effects are evaluated only in terms of annoyance, sleep disturbance, and AMI in this study.

The Working Group Dose/Effect of European Commission (EC, 2002) developed a dose–response function for road traffic and annoyance based on a meta-analysis of studies conducted in Europe, North America and Australia. The percentage of highly annoyed people (*%HA*) due to road traffic noise is given in Eq. (3). The range of noise levels used in the study was between 45 dB(A) and 75 dB(A).

$$\%\text{HA} = 0.5118 \times (L_{den} - 42) - 1.436 \times 10^{-2} \times (L_{den} - 42)^2 + 9.868 \times 10^{-4} \times (L_{den} - 42)^3 \tag{3}$$

High noise levels may also result in sleep disturbance. Miedema et al. (2003) conducted a meta-analysis to study the relationship between noise-induced sleep disturbance and night time exposure to aircraft, road traffic and railway noise ($L_{night}$) based on different field studies conducted in Netherlands. The percentage of highly sleep disturbed people (*%HSD*) due to road traffic noise is given in Eq. (4). The range of noise levels used in the study was between 45 dB(A) and 65 dB(A).

$$\%\text{HSD} = 20.8 - 1.05 \times L_{night} + 0.01482 \times L_{night}^2 \tag{4}$$

Chronic noise exposure may cause release of stress hormones. Prolonged exposure to noise and hence prolonged secretion of stress hormones may increase the risk of cardiovascular diseases (Berglund and Lindvall, 1995). Babisch (2008) conducted a meta-analysis on the association between traffic noise and cardiovascular risk. A pooled dose-effect curve for association between road traffic noise levels in terms of $L_{day,16\ h}$, equivalent noise levels between 7:00 and 23:00 and the risk of AMI in terms of odds ratio (*OR*), was established as shown