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Technical note

Urban railway traffic noise: Looking for the minimum cost for the whole community

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ABSTRACT

Nowadays, railway traffic noise is acknowledged to negatively impact the wellbeing of the whole community, particularly in urban environments. Unfortunately, the traditional approach to support decision making in noise reduction intervention seems to start only from the compliance to the regulations in place, rather than from the identification of an optimal trade-off between the cost of the annoyance of the community and the cost of the intervention. An advanced approach is proposed, which starts from any annoyance due to traffic noise, and which aims at identifying an optimal trade-off by means of evaluation of the minimum cost for the whole community. A case study in a railway noise-affected urban cluster of Milan, Italy, has been performed, which is representative of any urban environment affected by traffic noise. The sensitivity analysis on the parameters of the approach (the size of the buildings; the level of railway traffic; the cost per square meter of the acoustic barriers) shows that the results are robust and reliable, and in the specific case a noise reduction of 15–25 dB is optimal for the community.

1. Introduction

Noise is a considerable social problem as it can be considered a kind of urban pollution. The transport sector is one of the main contributors to society's noise problem, and the combination of increasing traffic volume and urbanization implies that the problem would increase if no measures were taken to stem it [1–3]. Road traffic is the largest single source of noise in the transport sector, but other means such as aircraft and trains substantially contribute to noise emissions too [3,4]. It is estimated that more than 20% of the EU's population are exposed to higher levels of noise than those deemed acceptable [5]. The estimates of the European population continuously exposed to values higher than 55 dB, from rail traffic, fluctuate from 10% [6] to over 44% [7], highlighting a widespread phenomenon with potentially negative effects of different extents and natures [7–9]. Recent investigations indicate that railway noise leads to significant sleep fragmentation and cardiovascular activations during sleep, and to subjective distress, as well as long-term effects of prolonged exposure to noise [10]. The study by the World Health Organization (WHO) (Regional Office for Europe, NIGHT NOISE GUIDELINES FOR EUROPE), issued in 2009 [9], indicates that "considering the scientific evidence on the thresholds of night noise exposure indicated by $L_{night,outside}$ as defined in the Environmental Noise Directive (2002/49/EC), an $L_{night,outside}$ of 40 dB should be the target of the night noise guideline (NNG) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly. $L_{night,outside}$ value of 55 dB is recommended as an interim target for the countries where the NNG cannot be achieved in the short term for various reasons, and where policy-makers choose to adopt a stepwise approach". Moreover, the WHO estimates that more than 1 million healthy life years are lost every year in western Europe due to noise exposure [11]. In order to quantitatively evaluate the impact of noise on the exposed population, some methods of quantification of the disorder (or annoyance) are known [12], as for example, in [3,4].

Despite the magnitude of the effects of noise, the Italian legislation [13,14] and the literature in general do not offer models for the quantification of the annoyance, nor do they offer useful methodologies to support decision-making about the possible remediation interventions (i.e., interventions to reduce the acoustic impact). These limitations are reflected in the approaches that are traditionally used to establish the means of intervention to reduce noise in an urban context; they are characterized by the fact that:

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1. The need for intervention arises only from the requirements and not by the discomfort actually suffered by the community. This means that, in situations where the law is flawed and does not work properly, the possibility of any intervention of noise abatement is not considered.
2. If the legislation obliges to take action to reduce the noise, the criterion to choose the best of several possible interventions is the minimum cost. In other words, the cost curves of the different interventions are taken into consideration and, at equal levels of noise abatement, the one that presents the minimum cost of implementation is chosen. This means that the intervention often aims at reducing the sound level to an acceptable level (within the parameters of law), without taking into account the benefits that a further reduction could bring to the community.

On the other hand, the growing attention to the problem in Europe [15], with reference to the railway [16,17], highlights the need to overcome the legislative approach in favor of methodologies based also on finding a trade-off between costs and benefits deriving from an intervention.

1.1. The possible interventions to reduce the acoustic impact

The negative effects of noise may be reduced through legislation, by means of requirement of less noisy technology, or by investments, such as noise barriers, or by sanctions that punish noisier vehicles and lead to a reduction of the noise level. Noise-reducing measures often result in a cost, for instance longer travelling times or costs of physical measures such as noise barriers and façade insulation [18,19]. This, and the fact that society also faces other needs, implies that a form of prioritization must be defined when it is necessary to decide on resource allocation. Benefit-cost analysis (BCA) is a potential basis for decision making, but it requires both benefits and costs to be measured in a common metric.

1.2. Noise: characteristics, social costs and evaluation

The issue about health problems raises the question of whether people are informed about the negative health effects and their costs when they reveal their willingness to pay (WTP) in order to reduce their noise exposure. If not, this needs to be taken into account when the benefit measures have to be calculated. To estimate the social value of noise abatement we combine measures that reflect individuals' preferences to reduce the noise levels from a study of the hedonic property price with estimates for the social cost related to health effects from noise exposure.

The A-weighted sound pressure level, measured over 24-h and usually denoted LAEq,24h, is often used as an indicator of noise levels. It is an energy mean level and it correlates well with the general annoyance due to noise at a given place. A more relevant measure for sleep disturbance is the maximum level combined with the number of occurrences (LAFmax). Different sources have different noise profiles over a 24-h period. Rail traffic sometimes has a higher proportion of freight trains running at night, and it is therefore not unusual for the equivalent level at night (22–06) to be higher than during the day (06–22). Rail traffic typically has a high maximum level compared to the equivalent level; that is, the individual passages are separated, with silent periods in between. The EU joint noise indicator LDEN is an attempt to balance the 24-h effects of traffic. This is, in principle, a weighted equivalent level where passages in the evening and at night are counted as 5 dB and 10 dB noisier, respectively, than is actually the case. Therefore, evening and night time noise are penalized, in the sense that they are given more weight in the model. The evaluation of annoyance due to traffic noise by means of questionnaires is often carried out on a 5-point scale, in accordance with ISO/TS 15666 [20]. One can also predict the number of people on the various annoyance levels according to [21], which is based on a meta-analysis of many studies [22]. Noise does not cause any direct environmental damage but incurs costs for society in the form of disturbances for the individual (sleep, conversation, recreation, etc.), worsened health and loss of production. The latter may be due to absence from work or reduced capacity to work, or that if a person doesn't sleep well at night, he is consequently less productive than usual. The social costs of noise exposure may be divided into three groups (e.g. [23]):

1. Resource costs in the form of medical and health care. Includes costs financed by taxes and direct payments by the individual.
2. Opportunity costs in the form of loss of production. Includes "non-market services" carried out in the household and lost recreation time.
3. Dis-utility in the form of other negative influences resulting from noise exposure. Two examples are: the disturbances in different forms and the increased concern about the after effects as a result of exposure.

Dis-utility is estimated by means of the WTP approach, which is usually divided into two main groups depending on how the information is used. Preference estimates based on market data and hypothetical market situations are called "revealed preferences" (RP) and "stated preferences" (SP), where the notations show whether the actual or hypothetical choice is used. If individuals in the WTP studies were fully informed of the total cost of noise exposure and if they themselves would bear the costs completely, the values from such studies would reflect the social costs in the form of COI as well. The great majority of the WTP studies to elicit preferences for noise abatement has employed the RP approach using the hedonic price regression technique [24]. The "noise sensitivity depreciation index" (NSDI) has evolved as the standard measure of the WTP of this literature. This is a measure of the percentage change in the price as a result of a unit change in the noise level [25]. The EU project HEATCO [26], carried out in several European countries, was aimed at estimating the WTP to reduce noise from road and railway traffic.

The evaluation technique used to derive monetary values for noise annoyance can be based on the hedonic regression method [27]: the estimates are based on the price data from the property market and, according to the hedonic method, the price (P) becomes a function of the various attributes that constitute the property,

$$P = P(L, A) \tag{1}$$

where L denotes the noise attribute railway and $A = [a_1, \ldots, a_n]$ a vector with other attributes. Let pi, $i \in \{1,2\}$, denote the marginal WTP for a reduction of the noise level from source i, which is given by,

$$\mathrm{pi} = \partial P(L, A)/\partial \mathrm{Li} \tag{2}$$

Eq. (2) gives the marginal WTP. To estimate the theoretically consistent welfare measure for non-marginal changes, the demand functions should be estimated. If we assume that WTP studies do not capture the total social cost from noise exposure, it happens that the values from these studies need to be adjusted so that also the health effects of noise are included. In the first place, noise causes increased stress and poor sleep quality that may lead to high blood pressure and a higher risk of cardiovascular diseases over time [28]. There is also evidence that prolonged noise exposure not only increases the risk of myocardial infarction but also stroke. Health costs should be evaluated by means of the impact pathway