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Research article

Annual traffic noise levels estimation based on temporal stratification

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ABSTRACT

This paper proposes a temporal sampling strategy that increases the accuracy of long-term noise level estimation and allows to establish the estimation error according to the number of sampled days. Days of the week are stratified into working days and weekend days. This research shows how to use measurements of L_{eq} on working days to estimate the corresponding values for weekend days. This is possible because working days have higher noise levels and less variability than weekend days. The improvement in accuracy allows for a reduction in the number of required sampled days compared to taking samples randomly, which would help to reduce the uncertainty in environmental noise assessment. As a reference, to obtain a 90% confidence interval of ±1 dB for L_{day}, the proposed sampling strategy reduces the required measurement days by more than 38%. For L_{DEN}, the reduction is close to 18% of the total number of days. The proposed strategy could be adapted to different environments by simply changing a few parameters.

1. Introduction

Noise pollution is one of the main environmental issues in cities as it leads to health problems for inhabitants. The exposure to high noise levels can affect sleep, lead to cardiovascular diseases, cause cognitive problems and even cause property prices to fall (Stansfeld and Matheson, 2003; Sobotova et al., 2010; Basner et al., 2014; Blanco and Flindell, 2011; WHO, 2016). It is therefore essential to accurately assess the noise levels to which the population is exposed in order to draw up and evaluate the effect of environmental noise management strategies (King and Rice, 2009). The main basic tool for this purpose are noise maps. According to European Directive 2002/49/EC (Diario Oficial de las Comunidades Europeas, 2002), for strategic noise mapping, the minimum time recommended for noise assessment is one year and should be done (at least) for the indicators L_{DEN} and L_{night}. Such maps are available for many agglomerations in Europe but in most cases the information is incomplete due to the lack of data (Morley and Gulliver, 2016). Models and standards are also applied inconsistently (King et al., 2011) and the accuracy of the given results is unknown.

Although numerical noise models are the preferred tool for noise mapping, (Hamed and Effat, 2007; Advances in the development, 2014), undertaking noise measurements is an essential task for: calibrating noise map modelling tools (Givargis and Karimi, 2010; Morley et al., 2015), evaluating the effect of local noise reduction strategies such as green zones (Cohen et al., 2014; Maffei and Masullo, 2014; Avsar and Gumus, 2011), obtaining results in complex environments where the traffic is not the main noise source (Romeu Garbí et al., 2010) or traffic data is not available (Morley et al., 2015), and obtaining more accurate results (Salomons et al., 2014). The use of experimental noise measurements is a highly demanding task that is usually simplified using sampling strategies that, as a drawback, could lead to significant differences between the estimated and the actual annual values.

A good approach to reduce variability is to take into account the spatial and temporal correlation (Zuo et al., 2014; Barrigón Morillas et al., 2015). In terms of the temporal aspect of noise assessment, many studies have been carried out to estimate the day equivalent value, for which the actual noise level is approximated by one or a few short time measurements, for a duration that is much shorter than the full-day period, usually between minutes to a few hours (Safeer et al., 1972; Ng and Tang, 2008; Romeu et al., 2011; Prieto Gajardo and Barrigón Morillas, 2015). An example of street categorization method shows that it is possible to estimate the daytime noise level by taking short time measurements which, depending on the category, could be improved by restricting the measurements to certain periods of the day (Romeu et al., 2011). Regarding the minimum time needed for a sample to be representative of a specific place, it has been found that measurements

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between 10 and 20 min are enough to represent the day value (Romeu et al., 2011; Brocolini et al., 2013). Generally speaking, the criteria used to define the quality of the results is the time taken for the sound pressure to stabilize, e.g., that its fluctuation range be within a certain error interval, which is known as stabilization time (Torija et al., 2011).

In this way, the year equivalent value can be estimated with a certain level of precision using noise levels from a number of days corresponding to a time period much shorter than a whole year. For annual L_{DEN} estimation, researchers have shown that sampling random days during the year gives better precision and representativeness of year equivalent levels than other techniques such as sampling consecutive days, only workdays or only weekends, or random full weeks (Gaja et al., 2003). Moreover, several authors use random sampling as a basis for comparison of optimizations or improvements proposed in sampling techniques for long-term level estimation (Makarewicz and Galuszka, 2011; Prieto Gajardo et al., 2016; Can et al., 2011; Hueso et al., 2017).

The main objective of this study is to determine a sampling strategy which minimizes the estimation error and, consequently, allows for the estimation of the annual value with a reduced temporal sampling. A procedure involving temporal stratification could be used to reduce variability. It is possible to identify days within a week with lower variability that can be used to estimate unsampled days and lead to a better annual estimation. This study computes the average difference between weekend and workday equivalent noise levels, $L^{Wd} - L^{We}$, and uses it to estimate the weekend levels from the measurement of randomly selected workdays.

The research is structured as follows: section 2 presents information related to sampling points and measurement analysis; section 3 presents the proposed methodology; section 4 presents the weekday analysis that led to the proposed formula and the results of its application to different day periods and parameters; section 5 presents a discussion of the results and the temporal stratification strategy application for different day periods; and finally, section 6 presents the conclusions.

2. Data

Barcelona is the capital of Catalonia, which is one of the 17 autonomous communities of Spain. It is an important hub for services and tourism, with a land area of around 102.2 km^2 and a population of about 1.6 million people according to the municipal register of inhabitants. It is the centre of a conurbation of about 3 million inhabitants. In summer, the climate is humid and hot, with temperature ranging between 23 °C and 30 °C, while in winter it ranges between 9 °C and 12 °C. Average annual rainfall is approximately 600 mm, with autumn being the most rainy season of the year.

A total of 14 Type 1 CESVA and 01 dB sound level meters, equipped with an outdoor protection kit, were placed in 14 different streets in the city of Barcelona, at an equivalent height of around one storey (approximately 4 m above the ground according to the European Noise Directive). Measurements of L_{Aeq} were continuously taken between 2010 and 2015. The measurement equipment was calibrated every year to ensure proper operation and accurate measurements according to regulations. Time integration for the noise level was originally set at between 1 s and 10 min for different sound meters. In the end, this study only used the data of one full year for each street. The chosen year for each street was the one with the fewest missing measurements.

Streets were categorized according to three different categories in which urban traffic is considered to be the main source of noise (Morillas et al., 2005; Jiménez et al., 2008):

- Category 1: Urban ring roads or access roads. Roads that surround the city or that allow access to the city.
- Category 2: Main streets. Roads within the city which mainly distribute traffic throughout the urban area.
- Category 3: Ordinary streets. Mainly destination streets which are commonly used for residential, commercial or leisure purposes.

The locations of the measurements points are shown in Fig. 1. According to previous experience (Romeu et al., 2006, 2011; Jiménez et al., 2008), higher traffic flow means more stable values and the categorization is stablished according to traffic flow order. The number of streets was also selected according this previous knowledge in order to get representative results. For category 1, less points were selected and measurement points were located in places where it is known to exist constant traffic flow. For category 2 and 3, the number of points was increased and they were located in streets with different traffic conditions and different use of the territory in order to verify that the proposed strategy was applicable in a more general way, i.e. not to be limited to certain types of streets or cities. Categories and supplementary information about each measurement point can be found in Table 1.

3. Methodology

The values in dBA of L_{DEN} and L_{day} (from 7 a.m. to 7 p.m.), $L_{evening}$ (from 7 p.m. to 11 p.m.) and L_{night} (from 11 p.m. to 7 a.m.) for every single day and the actual annual level in each measurement point were calculated and stored in a local database. As described in (Diario Oficial de las Comunidades Europeas, 2002), L_{DEN} is calculated using the following equation:

$$L_{DEN} = 10log\left\{\frac{1}{24}\times\left(12\times10^{\frac{L_{day}}{10}}+4\times10^{\frac{L_{evening}+5}{10}}+8\times10^{\frac{L_{night}+10}{10}}\right)\right\} \quad (1)$$

For each street, noise levels were analyzed in order to find any anomaly that could alter the actual year value (Gajardo et al., 2014). For all the data presented in this paper, a total of 14 days had L_{DEN} values larger than $<L_{DEN}> + 4\sigma$. These 14 values were considered abnormal and eliminated. Furthermore, 70% of these eliminated days had values of L_{DEN} larger than $<L_{DEN}> + 6\sigma$. 9 of the eliminated days were especially noisy local celebrations (Sant Joan, la Mercè and a Champions League celebration). The reason for the high levels of the other 5 days eliminated could not be found.

3.1. Statistical data calculation

This paper presents a methodology for long term L_{DEN} estimation based on temporal stratification. The methodology proposed is compared to the random days sampling strategy (Gaja et al., 2003; Barrigón Morillas and Prieto Gajardo, 2014).

Then, for each measurement point i, 1000 samples of N measurement days are taken according to each sampling strategy. The difference in dBA between the equivalent level of each sample and the actual value is computed as:

$$\Delta L_j^{i,N} = L_p^{i,N}(j) - <L_p^i> \quad (2)$$

where $<L_p^i>$ is the actual annual value computed using all the days of the year for measurement point i and period p. Where p is *day*, *evening*, *night* or *DEN*. $L_p^{i,N}(j)$ is the level for period p and