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Spectral information in noise mapping: an exploratory study

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Abstract

International Standards such as ISO 1996 and ISO 717 as well as noise regulations in several countries are increasingly relying on spectral information in order to assess the acoustical behaviour of materials and structures and the effects of noise on people. Nevertheless, the new European Union Directive on the assessment and management of environmental noise reinforces the A-weighted equivalent level (with appropriate night and evening corrections) as the preferred indicator for noise mapping. Considering that noise maps are a powerful zoning and planning resource, the idea of reporting the mean spectrum of noise at each selected location at different times is proposed and thoroughly justified. Arguments in favour of its feasibility are given, showing that, in spite of the widespread opinion, costs and required time may be reduced considerably by the use of low-priced, new-technology auxiliary equipment. Then an exploratory study is reported, in which a) the spectrum of traffic noise in Rosario (Argentina) is compared with the internationally standardised traffic noise spectrum, and b) the noise spectrum at an open street is compared with the noise spectrum at a street with an U-profile owing to the same vehicles.

1. Introduction

Noise assessment as regards its effects on the human being has been carried out for many years using the A-weighted sound pressure level along with some related indicators, such as the equivalent level, L_{Aeq}, or the day-night level, L_{Adn}.

Widespread availability of relatively inexpensive sound level meters capable of directly performing such measurements in addition to the success in the use of those indicators for the prediction of effects of noise such as hearing impairment (ISO, 1990), and, to a lesser degree, annoyance (Schultz, 1978; Fidell et al., 1991; Miedema et al., 1998; Miedema et al., 2001), have certainly influenced the universal acceptance of the A weighting.

This has led, in turn, to the widespread adoption of A-weighting-based ordinances and regulations for community noise control and abatement, creating an increased demand for A-weighted sound level meters. Consequently, manufacturers virtually flooded the market with this sort of instruments, making it ever more difficult to depart from the general trend.

A patent example of this situation has been the recent approval of the EU Directive 2002/49/CE on the assessment and management of environmental noise, which adopts the day-evening-night level and the night level, both A-weighted, as the official indicators. One of the arguments supporting this decision has been to deviate as little as possible from "current practice", unless it could be shown that an alternative indicator has significant advantages over existing ones (European Commission, 2000). Even if other indicators (to be mentioned later) have proved better in many cases, they do not qualify as "practical"—another criterion to be complied with by an "acceptable" indicator.

It is interesting to note that similar arguments had been put forward in earlier major research works, such as the one reported in the so-called *Levels Document*, published by the US Environmental Protection Agency in 1974 (EPA, 1974).

Unfortunately, this approach may have hindered the development and adoption of indicators that might be more correlated with noise effects than the traditional ones. It may have even prevented medium- or large-scale testing of new, cutting-edge hypotheses. Indeed, the lack of decided official interest and support usually discourages research on radical perspectives concerning such a practical issue as community noise control and assessment.

It could even be argued that the universal adoption of the A weighting might have been decided on too early, without sufficient evidence. In fact, its adoption has relied on several misconceptions. Firstly, it was assumed that noise effects on human beings are closely related to the sensation of loudness, which is clearly not the case (as shown by the example of the noise of a leaking tap in the night). Secondly, it was accepted that the response of the ear to pure tones could be extrapolated to combinations of them, or even to wide-band noises, in a linear fashion. Finally, the A weighting had been originally intended for the assessment of sound between 24 dB and 55 dB, but it is used to measure much louder sounds (Beranek, 1954, 1961).

The preference for A-weighting-based indicators has led naturally to their adoption for noise mapping. Noise maps, being an important tool for diagnosis, zoning and planning purposes, should render as much information as possible as regards the prevailing noise over a given area. The aim of this paper is to introduce spectral noise maps as an alternative to traditional maps capable of providing such information.

2. Dose-effect relationships

One of the main concerns among noise researchers has been to derive so-called dose-effect relationships, i.e., mathematical or statistical relationships between some exposure indicator (such as L_{DN}) and some measure of the extent of a given effect (for instance, the percentage of highly annoyed people). The prevalent paradigm since the first example of this kind of research (Schultz, 1978) has consisted in translating the results of studies carried out at different locations into a uniform format and then integrating them into a single meta-study or synthesis allegedly representative of varied situations. Base studies used for this purpose have generally been performed using A-weighted indicators, and in most cases have considered traffic noise.

As limits on noise emission for technology products (vehicles included) have been also stated in terms of A-weighted indicators, industry has directed its efforts towards attenuating middle frequencies since they influence A-weighted sound level to a greater extent (and they are easier to control). In consequence, dominant frequencies in the noise spectrum have shifted to the low frequency range. This means that the noise in the last few years may be spectrally different from the prevailing noise 3 or 4 decades ago. Two facts are significant in this context. First, low-frequency noise has been recognised as a source of considerable annoyance (Berglund, 1996). Second, sound insulation provided by façade structures is rather weak at low frequency. This suggests that the way A-weighted indicators correlate with annoyance might have been changing with time.

Even accepting (with some concern) that A-weighted indicators exhibit a fairly good correlation with noise effects on man, A-weighted exposure measured or computed at a given location would allow us to predict its effects only at that very location. For logistical reasons most noise measurements (and, accordingly, noise computations) correspond to outdoor locations; hence, in rigour, only the effects on the people at the street could be assessed. If the spectrum of the prevailing noise and the acoustical properties of the buildings on a given area were fairly uniform, then a functional relationship would exist between the A-weighed sound level outside and inside. It would be possible, in turn, to correlate indoor effects with outdoor A-weighted sound level. However, in the usual case in which both noise and construction are heterogeneous, there is no such functional relationship.

This introduces a random variable which seems to partially explain the significant spread observed in dose-effect relationships (Miedema et al., 2001). It could be argued that by limiting the analysis to specific noise types, such as road traffic noise, source-related differences are minimised. However, the spectral distribution of sound energy depends to some extent on the proportion of heavy vehicles. Moreover, substantial differences as regards propagation conditions due to façade geometry and materials are not taken into account.

Other indicators, apart from those based on A-weighted sound level, have been proposed or even customarily used in certain cases. C-weighted levels, for instance, are found to be better correlated with the annoyance due to low-frequency noise. Recent research by Schomer (Schomer, 2000, 2001, 2002a, 2002b; Schomer et al., 2001) shows that noise metrics based on loudness-level weighting provide a better correlation with annoyance. Moreover, Schomer points out that on a per subject basis people may be classified according to their noise-perceiving response (Schomer, 2002b).

3. Spectral noise maps

One of the aims of traditional noise maps is to provide a graphic representation of a series of pertinent noise data, either measured or computed, over a given geographic area. Those data may be the hourly, daily or annual equivalent level, the associated statistical levels, L_n, or any other convenient indicator. In order to convey visual information in an attractive fashion, level contours such as those used in topographic maps are customarily drawn. Areas between adjacent contours may be coloured or shaded according to an agreed scale.

This representation has the advantage that with a simple visual inspection one may get a fair idea of the location and magnitude of the main noise pollution issues. However, costs incurred to elaborate a noise map (including the planning and performance of the required measurements) are high enough to make it advisable to allow other uses for the information. For instance, it can be used as a basis for a noise-zoning ordinance, which would attempt to preserve quiet areas (the so-called acoustic sanctuaries) from future noisy activities.

Another very interesting use for noise maps is to provide quantitative and qualitative data useful for urban infrastructure planning as well as building projects. It is well known that whenever the effects of noise or the acoustic response of a space, material, or structure are to be assessed, it is necessary to have spectral information of the noise. The same is true for any situation in which engineering criteria are to be applied. This is the result of the frequency-dependent nature of acoustic phenomena.

With the introduction of computational techniques for handling large amounts of data, traditional maps have turned gradually into *geographic information systems* (GIS), i.e., data bases containing information pertaining to each relevant location in a given geographic area (georreferenced information). An important feature of these systems is the possibility of linking and correlating different variables, often resorting to simple mathematical or statistical relationships. For instance, the percentage of highly annoyed people may be computed from the noise exposure, or from traffic flow along the nearest street (Miedema, 2001). Noise maps are no longer just a static picture, but instead an interactive resource in which the same basic information may be combined in new ways to produce meaningful results.

Spectral information of noise is particularly suitable for its inclusion in a GIS. Indeed, being a multidimensional property, its direct representation on a conventional map would require the use of several layers (one for each band). This would not be very practical. When loaded into a GIS, on the contrary, other uses may arise, such as applying new frequency weightings, computing loudness level by means of ISO 532, or estimating the sound level indoors from the knowledge of the sound insulating properties of façades.

As in the case of A-weighted metrics, spectral information must be averaged over an appropriate time interval in order to be meaningful for noise mapping purposes. The primary magnitude to be reported is the *band equivalent level*, $L_{eq,Bi}$, but the statistical distribution of each band, $L_{n,Bi}$ might also be of interest.

4. Issues in data collection

Spectral noise mapping presents several difficulties when compared with traditional mapping. In the first place, we have the instrumentation issue. While traditional mapping may be accomplished with relatively low-priced integrating sound level meters, in principle spectral information would require the use of a spectrum analyzer capable of computing the equivalent level simultaneously for all bands. Although the cost of these instruments is not prohibitively high, it is indeed an issue and alternatives should be considered.

An interesting option is to use a conventional sound level meter with calibrated audio output (AC) and a digital audio recorder. The signal is digitally recorded and analysed later with suitable computer software. Several recording media and equipment have been tested (Miyara, 2001). Probably the use of a portable hard disc recorder provides the most reliable results, since a wave file is generated which may be readily uploaded to a computer for subsequent processing. Interestingly, the combined cost of a sound level meter, a digital recorder and a computer is far below the cost of a spectrum analyzer.

As regards the software to be used for spectral analysis, there are several possibilities ranging from freeware, multi-purpose software, like GNU-Octave, to high-priced commercial packages such as Matlab. There are also several sound editing programs with spectrum analysis capabilities.

Time consumption must also be considered, particularly in the case of large areas encompassing many measurement sites. Work associated with each site may be separated into several tasks: training time share, site selection, field measurements and contextual information acquisition, data upload into a computer, signal processing and documentation.

Personnel training and site selection do not differ essentially from typical non-spectral maps. Field measurements involve digital recording of both signal and a calibrated tone. Although further research is necessary to obtain the stabilisation time for the various bands and acceptable error thresholds, preliminary results suggest that it is similar to the time required to stabilise the equivalent level (figure 1).

Data upload time depends strongly on the selected recording media. When the signal is to be transferred through an analog or a digital audio connection, upload takes as much time as the total recording. If signal has been recorded into a hard disc as a file, time is usually much shorter. For instance, a USB connection upload takes less than one half of the recorded time.

Finally, computer analysis time depends on the algorithm to be used and the computer performance. In this paper, only Fast Fourier Transform (FFT) techniques have been tested, but other very efficient spectral power estimation algorithms could be used. Using a Pentium 4 processor, the required time to perform a 4096-point FFT is less than one half of the recorded time.

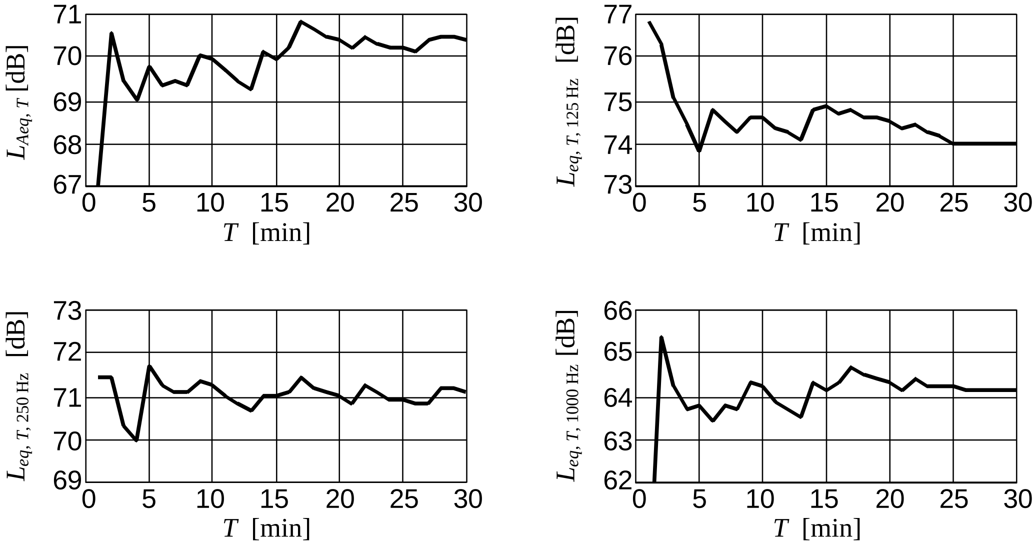

Figure 1. An example of time stabilization of A-weighted, 125 Hz, 250 Hz, and 1000 Hz equivalent levels.

5. Sample results

In order to test the ideas put forward above, two sites approximately 100 m apart were selected with almost identical traffic flow. The first one had an open profile and the other a U profile. Noise was recorded at both sites simultaneously by means of two identical sets made up of a type 1 sound level meter (Rion NL-15) and a hard disc digital audio recorder (Creative Nomad).

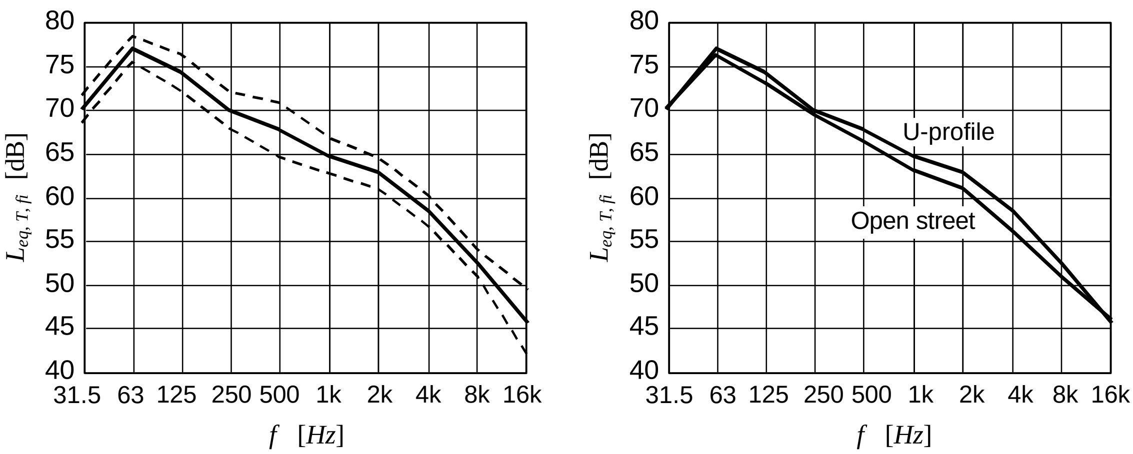

Figure 2. Left: trafic (octave band) noise spectrum at a U-profile site; doshed lines represent upper and lower one standard deviation limits. **Right**: Comparison between a U-profile and an open street noise spectra.

The plot at the left of figure 2 shows the octave band spectrum of the noise recorded at a U-profile location. Also shown in dashed lines are the $\pm\sigma$ statistical limits. At the right, spectra at both locations (open street and U-profile) are compared. As it can be seen, noise is louder in the second case due to the presence of reflective surfaces.

Figure 3 shows the comparison between the noise recorded at the U-profile location and the standard traffic noise according to the International Standard ISO 717-1 (displaced to be equal to the recorded noise at 1 kHz). Note that for the sake of consistency with the arguments put forward above, the A weighting has been removed from the standard traffic noise. Also shown is the spectrum of the background noise, obtained by selecting the quietest 5 s from each 5-minute period and then averaging.

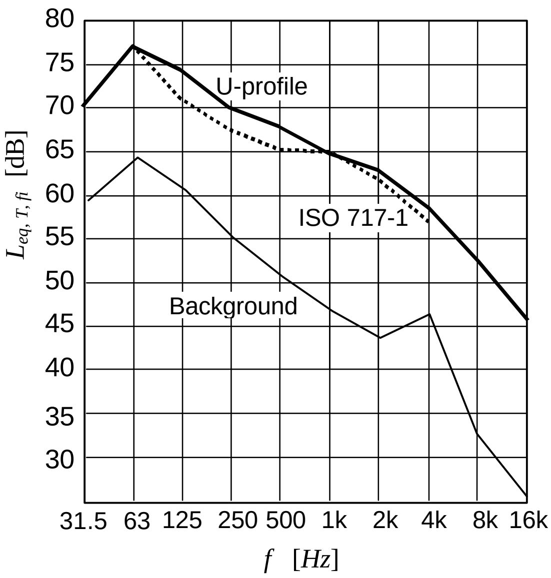

Figure 3. A comparison between the spectum of the noise recorded at a U-profile location and the unweighted spectrum of the standard traffic noise as defined in the International standard ISO 717-1. The light contour at the bottom is the spectrum of background noise. The bump at 4 kHz is due to birds' sounds.

Even if the difference between the actual and standard trafic noise spectra is not very large, it is large enough to suggest that traffic noise in different countries may exhibit significant spectral differences. This might be particularly true in the case of developing countries.

6. Perspectives of future research

It would be very interesting to adapt or develop models for computing noise spectra from source descriptors such as traffic flow and constitution (type of vehicles, percentage of heavy ones, average speed, etc.) as well as environmental conditions (street profile, roadway materials). The parameters to be used in such models should be frequently updated to accomodate the technical improvements on noise emission.

In order to describe noise in areas with low traffic flow it is also necessary to model background noise. An inspection of figure 3 suggests that background noise spectrum might be an attenuated version of traffic noise at neighbouring areas plus other noise sources, such as birds, dogs, people, stores, industry.

7. Conclusion

It has been argued that the traditional way of conceiving a noise map, i.e., reporting the geografic distribution of some kind of A-weighted exposure indicator, may be not adequate. Instead, the idea of including detailed spectral information is put forward, and its feasibility discussed in terms of the incorporation of a digital recorder and a computer for subsequent spectrum analysis. Finally, the whole process to obtain the average spectrum has been tested at two locations.

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