ICBEN 18 – 22 JUNE ZURICH 2017

12th ICBEN Congress on
Noise as a Public Health Problem

How to test noise annoyance models based on psychoacoustic indices using socio-acoustic survey data? The case of aircraft noise annoyance models

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ABSTRACT

Noise annoyance affects health and well-being of residents in urban areas. For European cities of more than 100,000 inhabitants, strategic noise maps characterize noise exposure using the index L_{den}. This index was also used to propose dose-effect relationships. However, different studies showed that L_{den} insufficiently characterizes noise annoyance.
Indeed, noise annoyance is influenced by various acoustical features (*e.g.* spectral distribution of energy) and non-acoustical factors (*e.g.* noise sensitivity). Noise annoyance models based on noise sensitivity and different psychoacoustic indices were proposed in literature. The psychoacoustic indices account for auditory sensations. It will be interesting to test such models using *in situ* noise annoyance and noise sensitivity data. The difficulty lies in the lack of the values of psychoacoustic indices in database built from socio-acoustic survey. Thus a methodology is proposed in this paper to estimate the values of different psychoacoustic indices. Therefore models proposed for aircraft noise annoyance are tested. Their predictive power is assessed using survey data. Results show that the models led to an improvement in comparison with model only based on L_{den}.

INTRODUCTION

Annoyance is one of the most significant non-acoustical effects of noise exposure for non-critical noise levels. According to the European directive 2002/49/EC [1], European cities of more than 100,000 inhabitants produce noise maps for different environmental noise sources. These maps characterize noise exposure using the energy-based index L_{den} - the day-evening-night level. Relationships based on this index are also recommended by the European Commission for noise annoyance prediction [1]. However, studies showed that energy-based index explains only a small part of the whole variance in noise annoyance ratings (*e.g.* [2]), thus contributing to a non-adequate prediction (*e.g.* [3]). Indeed, noise annoyance is also influenced by other acoustical features (*e.g.* fluctuations, spectral content [4]), as well as by non-acoustical factors (*e.g.* noise sensitivity [5]).

Noise annoyance models based on noise sensitivity and psychoacoustic indices were proposed in literature for aircraft noise studied in laboratory conditions [6]. The psychoacoustic indices account for annoying auditory sensations such as sensations due to tonal components and amplitude fluctuations present in aircraft flyover noise. Taking into account such indices in annoyance models seems to be relevant. But proposed annoyance models have to be tested using *in situ* noise annoyance in order to assess their predictive power. To test these models, a main difficulty lies in the lack of values of psychoacoustic indices in database generally built from socio-acoustic survey. As an attempt to overcome this difficulty, a methodology is proposed in this work in order to estimate values of psychoacoustic indices. The methodology is assessed using data collected during a French socio-acoustic survey carried out in 2012. The database is constituted of noise annoyance and noise sensitivity responses as well as L_{den} values for each respondent.
First, the rational of the methodology proposed to estimate psychoacoustic index values at respondents' dwellings is presented. Then, the methodology is assessed comparing *in situ* measured annoyance and annoyance predicted from model using the estimated psychoacoustic index values.

METHODOLOGY FOR PSYCHOACOUSTIC INDEX ESTIMATION AT EACH RESPONDENT'S DWELLING

The methodology consists first in determining values of the psychoacoustic indices from few *in situ* recordings carried out in the survey area. For each index under study, a relationship between equivalent sound pressure level values and index values is determined. Based on the obtained relationships, the dependency of the psychoacoustic indices on L_{den} values is expressed to estimate for each respondent the values of the different psychoacoustic indices. The methodology is described in the following.

Values of psychoacoustic indices from limited *in situ* recordings in the survey area

Sound recordings of the noise source under study were carried out *in situ* at one receiver point in the survey area. From these recordings, psychoacoustic indices, denoted by X, were calculated. Mean values for the psychoacoustic indices, denoted by X_{mean}, and mean values of the A-weighted equivalent sound pressure level, denoted by $L_{Aeq\ mean}$, were determined for the sample of *in situ* recordings.
As it would be too fastidious to carry out noise recordings at each respondent's dwelling and to calculate psychoacoustic indices from the corresponding sound source excerpts, an estimation of values of psychoacoustic indices is proposed.

Noise index evolution with equivalent sound pressure level

To be able to define respondent's noise exposure using psychoacoustic indices at least approximated as a function of sound pressure level, the evolution of the psychoacoustic indices with A-weighted equivalent sound pressure level is determined using the *in situ* sound recordings equalized at various L_{Aeq} values. This was performed in order to simulate a wider range of L_{Aeq}. Indeed, the *in situ* recordings were performed at one receiver point of the survey area, and therefore corresponded to the same value of L_{den}.
From the different equalized noises, values of psychoacoustic indices were computed in order to determine their evolution with a variation of L_{Aeq}, denoted as ΔL_{Aeq}. From the equalized noise sample, the coefficient a of the relationship accounting for the evolution of each psychoacoustic index was defined in terms of mean value a_{mean} and standard deviation.

Using the evolution of the indices with ΔL_{Aeq}, the psychoacoustic indices were expressed using their *in situ* mean value X_{mean} and as a function of L_{Aeq} and its *in situ* mean value $L_{Aeq\ mean}$, as following:

$$X = X_{mean} \times e^{a_{mean} \times (L_{Aeq} - L_{Aeq\ mean})} \qquad (1)$$

MODEL TESTING USING THE METHODOLOGY AND DISCUSSION

The methodology was assessed testing literature models proposed for noise annoyance due to aircraft noise. The noise annoyance models under study used psychoacoustic indices and noise sensitivity as variables [6]. For this testing, a database of a French survey is used. First the socio-acoustic survey is briefly presented. Secondly, results of the testing are presented and discussed.

Socio-acoustic survey

A socio-acoustic survey funded by the French Ministry of Ecology was carried out in 2012 to study annoyance due to combined transportation noises [7]. The survey was performed in 8 French cities (for a brief summary, see [3]). Two cities in close proximity to Orly and Roissy Charles de Gaulle airports were exposed to aircraft noise.
Questions on noise annoyance due to aircraft noise complied with recommendations provided by the ISO 15666 standard [8]. Respondents were asked to give an annoyance rating on a continuous scale from “0” to “10”, with 11 evenly spaced numerical labels and two verbal labels at both ends (“not at all” and “extremely”). The way of questioning and of rating noise sensitivity was similar to the one concerning annoyance.
The noise exposure of respondents was determined using the noise maps, available in 2012 for the studied cities. These noise maps were calculated following the guidelines defined in the European Directive 2002/49/CE [1]. They were established for each noise source in isolation and displayed noise exposure in terms of L_{den}. The survey database thus contained noise annoyance, noise sensitivity responses and L_{den} index values. Data obtained for 212 respondents were used in the current work.

Index estimation

Aircraft flyover noises were recorded *in situ* at one receiver point in the survey area. From these recordings, psychoacoustic indices and $L_{Aeq\ mean}$ were calculated. From the recorded noise sample equalized at 7 noise levels, values of psychoacoustic indices were computed in order to determine their evolution with ΔL_{Aeq} in terms of mean value and standard deviation.
An example of an evolution obtained for one index calculated on one aircraft flyover noise equalized at 7 noise levels is displayed in Figure 1.
This psychoacoustic index $\sigma'(N)$ [9] is the derivative loudness index accounting for sound intensity variation. Due to its dependency to loudness, its evolution with ΔL_{Aeq} is an exponential function.

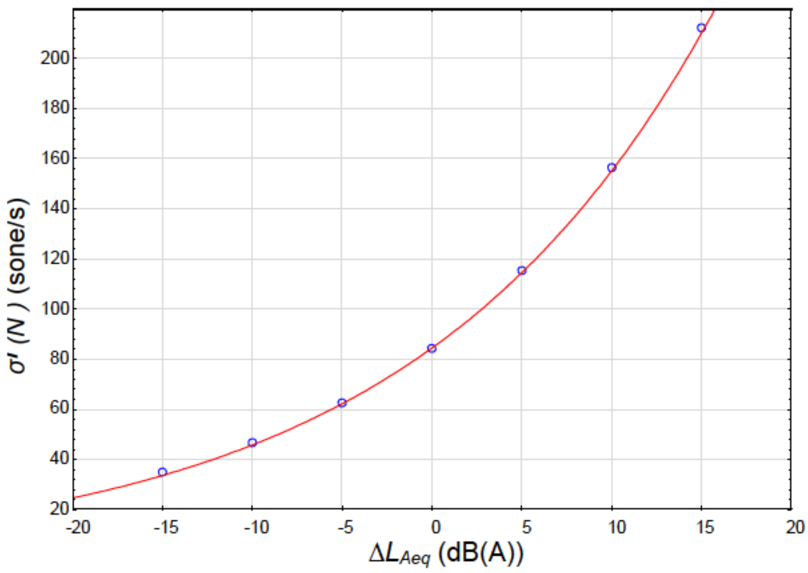

Figure 1: Evolution of the derivative loudness index *σ'(N)* with ΔL_{Aeq}, for an aircraft flyover noise. ΔL_{Aeq}=0 dB(A) corresponds to values of *σ'(N)* and of L_{Aeq} of the aircraft flyover noise recorded *in situ*.

Different psychoacoustic indices based on loudness also evolve exponentially with ΔL_{Aeq}. Such evolution obtained for the loudness index *N* is in agreement with Stevens' law [10]. The analytic development of the exponential function leads to the Steven's law with the pressure exponent equal to 0.6.

In the used survey database, noise exposure is defined by L_{den} from noise maps. From Equation 1, L_{Aeq} is therefore replaced by L_{den}, which is constructed from L_{Aeq}. Such approximation consisting of replacing L_{Aeq} by L_{den} in models was also considered in literature for models initially developed with L_{Aeq} (*e.g.* [11]).

Thus, each psychoacoustic index X was estimated for each respondent of the survey as following:

$$X = X_{mean} \times e^{a_{mean} \times (L_{den} - L_{Aeq\ mean})} \tag{2}$$

with X_{mean} and $L_{Aeq\ mean}$ the mean values of *X* and L_{Aeq} calculated on recorded excerpts at one receiver point in the survey area.

Noise annoyance model testing

The model proposed by Gille *et al.* [6] and based on the psychoacoustic index *σ'(N)* is considered in the following to illustrate the assessment of the proposed methodology to test annoyance models based on psychoacoustic indices using database of socio-acoustic survey.

This noise annoyance model based on the psychoacoustic index σ'(N) was constructed from a multilevel regression analysis using noise sensitivity $Sens_i$ of respondent i. The prediction of noise annoyance response A_i of a respondent i is given as follows [6]:

$$A_i = (1.22 + 0.6 \times Sens_i) + (0.08 + 0.01 \times Sens_i) \times (\sigma'(N)_i - 27.5) \tag{3}$$

with $Sens_i$ the measured noise sensitivity collected *in situ* and $\sigma'(N)_i$ the value of the psychoacoustic index $\sigma'(N)$ estimated at the respondent i's dwelling by following the proposed methodology. The predicted annoyance A_i was compared with individual annoyance ratings measured *in situ.* The correlation coefficient for the regression analysis carried out between measured annoyance and predicted annoyance was equal to 0.52. This comparison constitutes a testing of both the noise annoyance model proposed in a previous work [6] and the methodology proposed in this work to estimate psychoacoustic index values from L_{den} values available in survey database.

Considering only L_{den} index leads to a correlation coefficient inferior to 0.40 which is in agreement with other findings from literature (e.g. [12-13]).

CONCLUSION

A methodology was proposed to determine values of psychoacoustic indices from *in situ* recordings carried out at one receiver point in a survey area. For each psychoacoustic index, a relationship between equivalent sound pressure level values and index values was determined. Based on the relationship between each index and L_{Aeq}, the dependency of the psychoacoustic indices on L_{den} values was expressed to estimate the psychoacoustic index values for each survey respondent.

Results highlighted that a model based on psychoacoustic index and noise sensitivity enabled to better predict measured noise annoyance responses than L_{den} index did. Furthermore results also highlighted that the methodology proposed to approximate psychoacoustic index values for each survey respondent allowed to further consider psychoacoustic indices to enhance models for a better prediction of noise annoyance felt by inhabitants. The methodology proposed in a simple form in this work has to be deeply studied in order to reduce as far as possible approximations. Such endeavor will contribute to better predict *in situ* noise annoyance.

Acknowledgements

This work was performed within the framework of the Labex CeLyA of Université de Lyon, operated by the French National Research Agency (ANR-10-LABX-0060/ANR-11-IDEX-0007). This work used data from a socio-acoustic survey funded by the French Ministry of Ecology (convention no. 2100966391).

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