AT THE HEART OF HARMONICA PROJECT: THE COMMON NOISE INDEX (CNI)

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ABSTRACT

The difficulty for the general public to understand the standard acoustic indicators expressed in decibels limits their suitability. Therefore, since 2011, Bruitparif and Acoucité (agencies in charge of assessing and monitoring noise in the two major French urban areas) have been working on a proposal to create a new index that is closer to what the population feels, based on a score from 0 to 10. This work is being carried out within the framework of the Harmonica project, financed by the European Commission (LIFE+ program). Four proposals of indices have been developed, based on different approaches, but all integrating both the continuous and the sporadic nature of noise. The new indices were adjusted and evaluated through *in situ* inhabitants' surveys and in laboratory with a larger public. The results were also compared with values supplied by the usual indicators. Easy to produce, the index selected will be tested on the information platforms associated with the noise monitoring networks of Bruitparif and Acoucité, as well as on the European on-line platform dedicated to communicating on the Harmonica project www.noiseineu.com (at the beginning of 2014). This article details the composition of the indices and the methodological approach used to create them.

1. INTRODUCTION

The main mission of the two regional noise observatories, Bruitparif and Acoucité, is to assess and monitor the exposure to noise of inhabitants in their respective regions; Ile-de-France for Bruitparif and Greater Lyons for Acoucité. These observatories are both non-profit associations. Bruitparif was founded in 2003 on the initiative of the Ile-de-France regional council, while Acoucité was founded in 1996 by the Greater Lyons urban community and five public technical research centres (IFSTTAR, CERTU, CETE, CSTB, and ENTPE). Acoucité operates at national level in 12 other French towns.

The objectives shared by both associations soon led them to see certain limitations with the regulatory acoustic indicators, in particular in terms of informing the public. The difficulty for the general public to understand standard acoustic indicators expressed in decibels limits their acceptance by the population. Therefore, since 2011, Bruitparif and Acoucité have been working on a proposal for new noise indices that are closer to what inhabitants feel, based on a score of 0 to 10. This work is being carried out as part of the Harmonica project, financed by the European commission (LIFE+ programme). For more information about the harmonica project visit the website www.harmonca-project.eu

Bruitparif is the project leader and is, in particular, coordinating the actions that concern the creation of the Common Noise Index (CNI). The project's partner, Acoucité, is coordinating actions that concern the evaluation of the public's expectations by setting up and conducting *in situ* and laboratory perception surveys with the public. This part is the subject of a specific article presented at Internoise 2013 ("How to characterize environmental noise closer to people's expectations," Bruno Vincent, psychoacoustic PhD, V. Gissinger, J. Vallet, F. Mietlicki, P. Champelovier, S. Carra) [1].

The present article explains how the indices are composed and presents their design methodology.

2. OBJECTIVES

The suggested indices were designed in order to meet different criteria. The new index must give a score of 0 to 10 [2], with 0 being an excellent acoustic environment and 10 being an abysmal acoustic environment. The choice of an “nuisance” scale rather than a “quality” scale was preferred, in keeping with standard acoustic indices expressed in decibels (dB), where the higher the dB level, the higher the disturbance level is assumed to be.

The new index, called the Common noise index (CNI), must be easy to produce for Noise monitoring networks. To this end, preliminary studies dedicated to making an inventory of all the resources, measurement, and analysis methods used have been carried out with 15 noise monitoring networks around Europe (IBGE in Belgium; DCMR Rotterdam, Schiphol airport, Oss, Sansornet and Municens in the Netherlands; Madrid in Spain; Dublin in Ireland; the Environmental Agency of Tuscany; Aéroports de Paris, Greater Lyons urban community, Acoucité, and Bruitparif). Bodies that are creating noise measurement networks in France (Aix-en-Provence, Saint Etienne, Grenoble, etc.) have been informed of the objectives of the Harmonica project and the imminent availability of the CNI index. Furthermore, Nice, Dublin, London, and Frankfurt, who all operate mini noise measurement networks, are all ready to test the new index. Likewise, Chemnitz, Zagreb, and Stockholm, who don't have measurement networks, are also ready to test the CNI. Approaches that take into account the spectral nature or the specificity of noise sources are of particular interest. However, they require advanced equipment and measurement and analysis methods that are not available to several of the observatories listed. As a result, the indices are based exclusively on the elementary data LAeq1s, which is available to all European noise monitoring networks surveyed. As with the LAeq, it must be possible to produce the new index over different periods of time (a few minutes, an hour, a day, a month, etc.).

It must also be easy to understand for the general public and the authorities. Therefore, part of the study carried out for this project was dedicated to evaluating how well the two targets understood the four suggested indices. The index must be close to the public's feeling in terms of the noise score and annoyance level. The studies carried out in situ and “in laboratory” made it possible to estimate this feeling for the eight sites studied [1].

In order to guarantee its novel aspect, the suggested index must be notably different from the usual acoustic indicators, in particular the LAeq. Their capacity to reflect the public's feeling will be systematically compared to that of the LAeq. The indices suggested must be designed using different approaches. This strategy helps to maximise the chances of finding an index that is close to what the public feels. The four indices suggested meet all of these requirements.

3. CHOICE OF PARAMETERS THAT MAKE UP THE INDICES

The choice of parameters that make up the suggested indices was based on a preliminary statistical analysis. The aim was to favour the selection of acoustic parameters that, on their own, reproduce the variability of many acoustic indicators. A database bringing together 24 sites that are representative of all the different acoustic environments documented by the noise observatories in the environment was created (with different categories of road noise, aircraft noise, rail noise, quiet areas, and areas exposed to multiple source of transport noise). The elementary data are the LAeq1s values based on of 24 consecutive hours. Bruitparif, Acoucité, and IBGE[3] contributed to the creation of this database.

For each site, 60 usual hourly acoustic indicators were calculated using LAeq1s as the elementary data: LAeq1h, L90, LA10, LA01, [LA10-LA90], standard deviation (σ), SEL, number of noise events above or below various predefined thresholds Lα (NNEL>Lα, NNEL<Lα), and percentage of time associated (MIL>Lα, MIL<Lα).

Despite their specificity, several of the acoustic indicators are correlated. As a result, a limited number of parameters suffices to explain a significant proportion of the data variance. A Principal Component Analysis (PCA) [3] was carried out in order to quantify the potential variance that could be reproduced by the appropriate choice of a few acoustic variables. Figure 1 presents an illustration of this work. The first four factor axes of the PCA alone explain 70 % of the data variance. In other words, three or four well-chosen variables can allow you to explain a significant proportion of the variance associated with the 60 initial variables.

The first factor axis provides approximately 33 % of the variance. It essentially represents the element provided by the LAeq and the background noise (LA90). The second axis is the noise dynamics (nearly 20 % of the variance), it is well reproduced by the [LA10-LA90]. And finally, the NNEL55 is a good representation of the factorial axes 3 and 4 (nearly 15 % of the variance).

It is worth selecting variables LA90, [LA10-LA90] and NNEL55 (NNEL > 55 dBA). They are uncorrelated, therefore they provide different and complementary information. These three variables explain a significant proportion of the data variance. This does not, however, guarantee that the suggested indices will be correlated with what the public feels. Indeed, it cannot be excluded that this feeling is provided by other axes of the PCA, or simply that it cannot be fully explained by the 60 initial variables. Part of the annoyance can be due to non-acoustic factors.

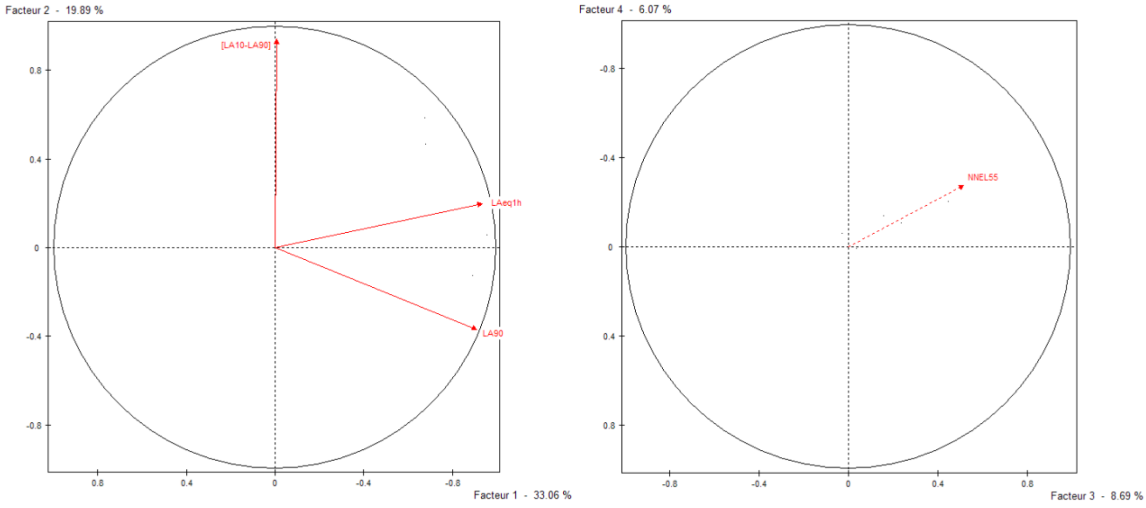

Figure 1 – *PCA, correlation circles*

[3] IBGE: Institut Bruxellois pour la Gestion de l'Environnement (Brussels Institute for Environmental Management)

4. SUGGESTED INDICES

The four indices suggested were designed before the survey phases, in order to present them to the public and thereby evaluate their comprehensibility, their acceptability, and their relevance with respect to their capacity to accurately reflect the quality of the acoustic environment. In this article, the four suggested indices are named as follows: P1, P2, CY, and CC[4]. The P1 and P2 indices include the parameters highlighted in section 3 (LA90, [LA10-LA90] and NNEL55). The CY and CC indices were created using other parameters in order to provide different orientations.

4.1 The P1 index

This index is made with two simple components that describe the noise:

- a continuous component, called "BGN", related to background noise,
- a dynamic component, called "EVT", related to noise events that emerge from the background noise.

$$BGN = LA90^{5} \tag{1}$$

$$EVT = DYN + C \times MAJ \tag{2}$$

$$DYN = \left[LA10 - LA90\right] \tag{3}$$

$$MAJ = \log\left(1 + \frac{NNEL55}{50}\right) \tag{4}$$

DYN is the noise dynamics. A majorizing factor called MAJ is included. This takes into account the number of disturbing noise events during a quiet period. MAJ is calculated based on the number of hourly events that break the 55 dB(A) mark, called NNEL55[6]. The coefficient C governs the strength of this majorization.

P1 is based on two scores (Score 1a and Score 1b, which range from 0 to 10) and are related to components BGN and EVT respectively. Score 1a = 0 for BGN < 25 dB(A) and Score 1a = 10 for BGN > 70 dB(A), in between these two values, the scores are obtained by applying a linear function (cf. figure 2). The same approach is used for Score 1b with 1b = 0 for EVT < 3 dB(A) and 1b =10 for EVT > 27 dB(A) (cf. figure 2).The maximum score between 1a and 1b is attributed to P1.

$$Score = \max\left(\left\{Score1a; Score1b\right\}\right) \tag{5}$$

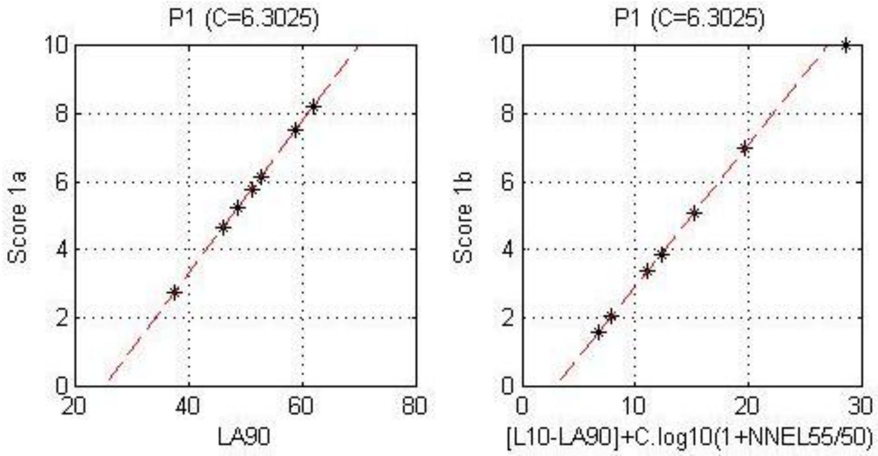

Figure 2 – *Score 1a and Score 1b for C = 6.3025*

[4] In the article "How to characterize environmental noise closer to people's expectations," B. Vincent, PhD, V. Gissinger, J. Vallet, F. Mietlicki, P. Champelovier, S. Carra) [1], the P1 and P2 index are referred to as "Index 1", while CC and CY are called "Index 2" and "Index 3" respectively.

[5] LA90: LAeq1s exceeded for 90 % of the time

[6] Over a period of time T, NNEL55 is cumulated over 5 minute periods. If $[LA10\text{-}LA90]_{5min}<5$ ⇨ $NNEL55_{5min}=0$.

4.2 The P2 index

This index delivers a score of between 0 and 10 directly using three parameters: BGN, DYN, and MAJ, which are presented in section 4.1.

$$Score = \sqrt[n]{A \times (BGN - 20)^n + B \times EVT^n} \quad (6)$$

Out of the four indices suggested, this is the only one based on a non-linear model, as illustrated in figure 3. This is an interesting approach. Indeed, considering the complexity of relationships between the physical parameters related to noise and the public's feeling, we can assume that a simple linear model would not be adequate for modelling this relationship. It is worth noting then that in the specific case where n=1, the recommended approach is a linear model.

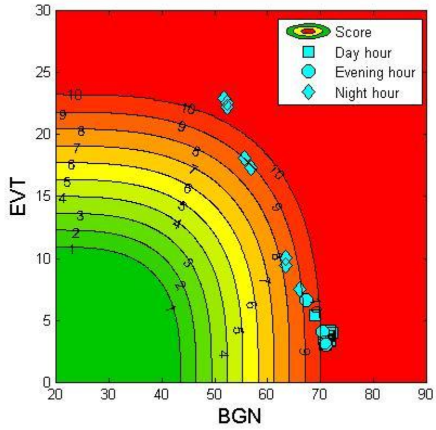

Figure 3 – *example of P2 scores on an hourly basis for A, B, C and set arbitrarily (here n=3)*

4.3 The CY index

This index is based on five simple parameters that describe the noise: LAeq, LA90, LA01, number and cumulated duration of events not exceeding LA90 over an hourly basis[7] (scored $NNEL90_{neg}$ and $T90_{neg}$ respectively). The CY index is based on five scores of 0 to 10 related to these five parameters respectively. Score = 0 for LAeq < 48 dB(A) and Score = 10 for LAeq > 75 dB(A), in between these two values, the scores are obtained by applying a linear function (cf. figure 4). The same approach is used for the scores linked to the four other parameters. The values that give a score of 0 and 10 are presented below.

- *LAeq score: 0 for LAeq ≤ 48 dB(A), 10 for LAeq ≥ 75 dB(A);*
- *LA90 score: 0 for LA90 ≤ 38 dB(A), 10 for LA90 ≥ 68 dB(A);*
- *LA01 score: 0 for LA01 ≤ 55 dB(A), 10 for LA01 ≥ 85 dB(A);*
- *$NNEL90_{neg}$ score: 0 for $NNEL90_{neg}$ ≥ 18 events, 10 for $NNEL90_{neg}$ ≤ 1 event;*
- *$T90_{neg}$ score: 0 for $T90_{neg}$ ≤ 200 s, 10 for $T90_{neg}$ ≥ 20 s.*

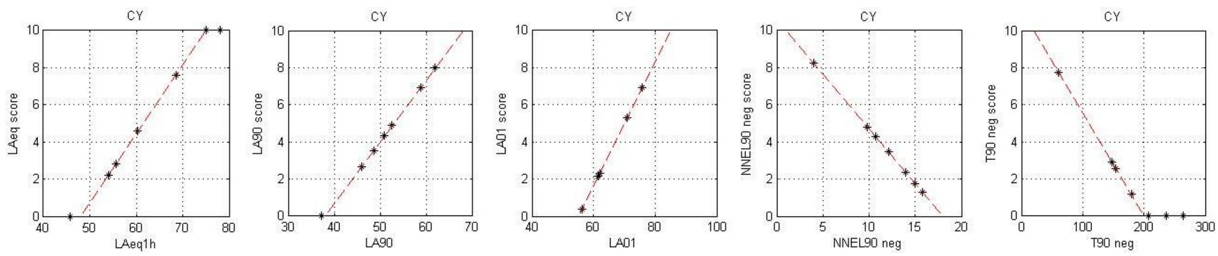

Figure 4 – *example of sub-scores for CY*

CY's score is obtained using a weighted average of all these scores.

[7] Events lasting at least 10 seconds.

$$Score = A \times LAeq_{score} + B \times LA90_{score} + C \times LA01_{score} + D \times \left(\frac{NNEL90_{neg_{score}} + T90_{neg_{score}}}{2} \right) \quad (7)$$

4.4 The CC index

This index is based on a simple principle: The quality of the acoustic environment is evaluated based on the percentage of time that the noise levels are below certain pre-defined thresholds. These thresholds are adjusted according to the time of day. The thresholds for evening and night-time are lower. Table 1 shows the five threshold values for the periods from 6am to 6pm, 6pm to 10pm, and 10pm to 6am.

Period	Threshold 1	Threshold 1	Threshold 1	Threshold 1	Threshold 1
6am to 6pm	40 dB(A)	50 dB(A)	60 dB(A)	70 dB(A)	80 dB(A)
6pm to 10pm	35 dB(A)	40 dB(A)	55 dB(A)	65 dB(A)	75 dB(A)
10pm to 6am	30 dB(A)	40 dB(A)	50 dB(A)	60 dB(A)	70 dB(A)

Table 1 – *Thresholds associated with the CC index*

The five levels, p_1 to p_5, related to the threshold values 1 to 5 are converted into scores of 0 to 10. A score of 0 means p = 100 % (LAeq1s level below the relevant threshold for 100 % of the time). A score of 10 means p = 0 % (LAeq1s level below the relevant threshold for 0 % of the time). Between these two values, the scores are obtained by applying a linear function (cf. figure 5). CC's score is obtained using a weighted average of all these scores.

$$\begin{aligned} Score = A \times [\%T < th1]_{score} + B \times [\%T < th2]_{score} + \ldots \\ C \times [\%T < th3]_{score} + D \times [\%T < th3]_{score} + E \times [\%T < th5]_{score} \end{aligned} \quad (8)$$

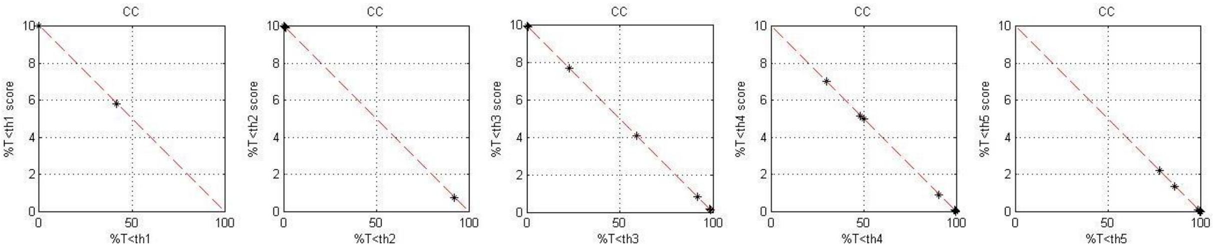

Figure 5 – *example of sub-scores for CC*

5. INDICATOR ADJUSTMENT COEFFICIENTS

The indices suggested have been deliberately designed with adjustable weighting coefficients. These coefficients can, therefore, be optimised in order to get as close as possible to the feeling score given by the public. The index's capacity to accurately reflect their feeling will essentially depend on the parameters that make up the index and the mathematical model chosen (linear, non-linear, etc.). The optimal coefficients for each index are determined by multiple linear regression.

Indicator	Mathematical expression	Coefficients
P1	$EVT = DYN + C \times MAJ$	C
P2	$Score = \sqrt[n]{A \times (BGN - 20)^n + B \times EVT^n}$	A, B, C, n

CY	$Score = A \times LAeq_{score} + B \times LA90_{score} + ...$ $C \times LA01_{score} + D \times \left(\frac{NNEL90_{neg_{score}} + T90_{neg_{score}}}{2} \right)$	A, B, C, D
CC	$Score = A \times [\%T < th1]_{score} + B \times [\%T < th2]_{score} + ...$ $C \times [\%T < th3]_{score} + D \times [\%T < th3]_{score} + E \times [\%T < th5]_{score}$	A, B, C, D, E

Table 2 - *Coefficients to adjust for each index*

The adjustment of the coefficients related to the four indices' input parameters is based on a statistical approach, therefore requiring a database linking the indices' parameters to the response variable (noise or annoyance score given by the public).

5.1 Regression database

As *in situ* and laboratory surveys can give different types of annoyance results (long-term annoyance and short-term annoyance), their use was analysed separately. We preferred the used of *in situ* surveys - and therefore, *in theory*, long-term annoyance - when adjusting coefficients. The database used contains data from *in situ* surveys in Bellecour, Parilly, Zola, and Rillieux in the Greater Lyons territory; and Gonesse, Paris-Coriolis, and Villeneuve-Saint-Georges, in the Ile-de-France region. [8]. Around 30 people were surveyed on each site [1]. The times of day studied were 6pm to 8pm, on week-days, for sites in the Ile-de-France region, and between 6pm and 7pm for the sites in Greater Lyons.

For the sites documented by Bruitparif's and Acoucité's permanent measurement stations, there was enough data to allow an analysis of the statistical distribution of each parameter (LAeq1h, LA90, LA01, etc.) during the times of day studied. The values of the parameters attributed to the sites studied therefore correspond to the values most frequently observed by Bruitparif's and Acoucité's measurement stations on the sites studied during the year 2012 (cf. figure 6). When there was insufficient data to carry out this type of analysis, the average value was used (Bellecour and Parilly).

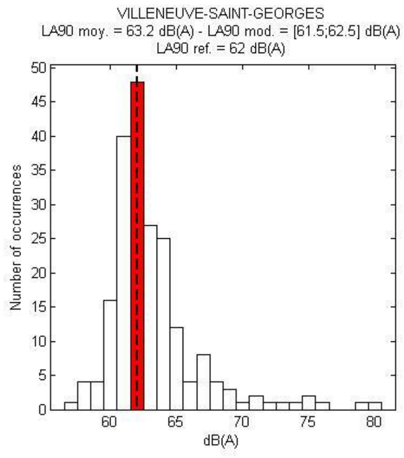

Figure 6 – *LA90 statistical distribution for the "Villeneuve-Saint-Georges" site*

The feeling variables (annoyance and noise) being particularly highly correlated (r = 0.85 between individual values and r = 0.98 between average values per site), we simply chose the *in situ* annoyance value as the response variable for the public's feeling. We chose the value most frequently expressed by the persons interviewed on the eight sites studied (cf. figure 7).

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[8]For Limours, wind conditions have a huge impact on how aircraft noise affects the site. This observation resulted in the use of dramatically different acoustic parameters between days with easterly wind flight patterns and days with westerly wind flight patterns. Including this site would introduce confusion, thereby adversely affecting the quality of the indices' adjustment coefficients. As a result, this site was eliminated from the regression database.

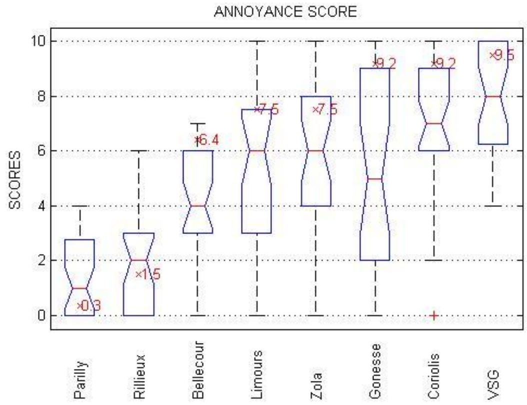

Figure 7 – *Statistical distribution of annoyance scores for the in situ survey*

5.2 Analysis of correlations between the indices' parameters

Before carrying out multiple linear regressions, we must study correlations between the four suggested indices' parameters. Figure 8 presents correlation matrices for all the indices suggested.

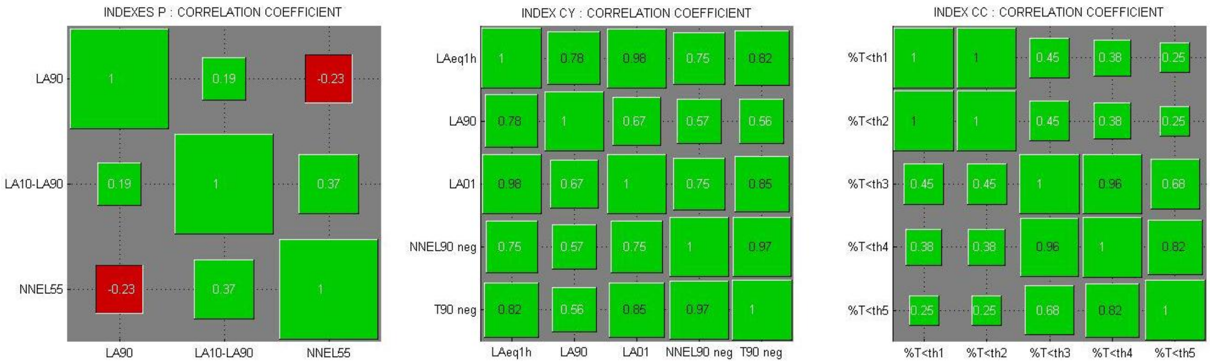

Figure 8 – *Correlation matrix*[9]

For P1 and P2, the three input parameters (LA90, [LA10-LA90] and NNEL55) are not correlated. For CY and CC, several input parameters are correlated. This multi-colinearity of input parameters causes a great variation in coefficients given for a standard multiple linear regression. In other words, a minor modification to the database can have a major impact on the coefficients, which means the model is not robust with data that was not used to calibrate the model. For CY and CC, a Ridge regression [4], which makes it possible to get past this limitation, was carried out.

5.3 Cross-validation

The coefficients were adjusted in such a way as to best predict the *in situ* annoyance scores. But what about new data that has not been used to calibrate the suggested models? The quality of models suggested must be evaluated based on their capacity to predict annoyance levels for data that has not been used to calibrate the model (robustness). Considering the small number of sites, a cross-validation [3] was carried out to evaluate the performances of the four models suggested in terms of robustness. The principle is as follows: one-by-one, each site is eliminated from the coefficient calibration database. The prediction linked to each site eliminated is compared to its *in situ* annoyance value. This way, we can estimate the capacity of each model to accurately reflect annoyance levels on new data.

[9] Values that are not statistically significant written in white.

6. RESULTS

Each index was evaluated on the basis of its ability to predict *in situ* annoyance levels through cross-validation. These results were measured using the mean square error and the correlation coefficient between the indices' scores and the *in situ* annoyance scores. The models with the best results are P2 where n=1 and n=½ (correlation coefficient with *in situ* annoyance scores: r > 0.98 - cf. figure 9). The other models prove to be less accurate than the traditional LAeq (cf. figure 10). P2 is also the index that is the least correlated with the LAeq, which also makes it novel (cf. figure 10). Furthermore, in terms of "comprehensibility", it is one of the two indices preferred by the interviewees, along with CY [1] [10]. For all the above reasons, we have chosen the simplest P2 model (linear model n=1) as the Common Noise Index (CNI).

$$Score = A \times LA90 + B \times \left[LA10 - LA90\right] + C \times \log\left(1 + \frac{NNEL55}{50}\right) + Cste \qquad (9)$$

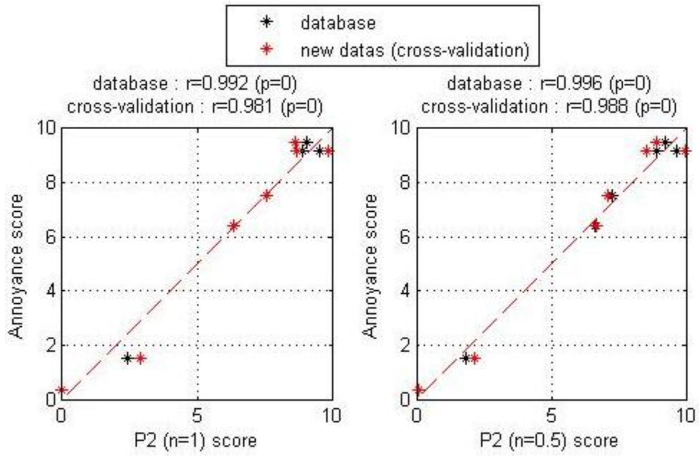

Figure 9 – *correlation coefficients of P2 (n=1) et P2 (n=½) with the in situ annoyance levels*

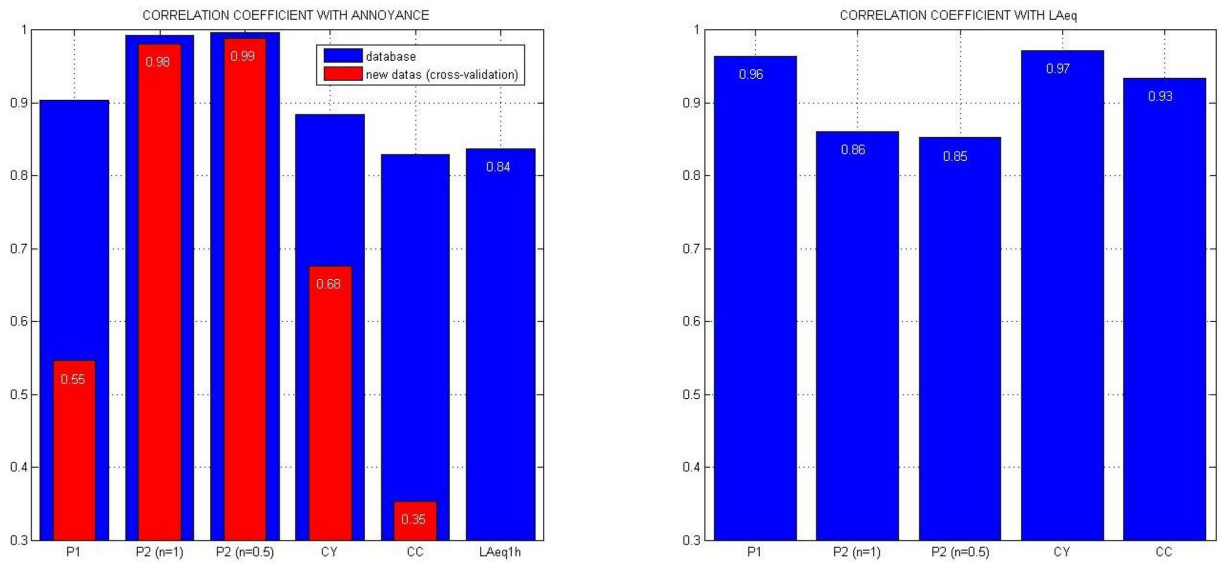

Figure 10 – *correlation coefficients of indices with the in situ annoyance levels and the LAeq*

[10] In the article "How to characterize environmental noise closer to people's expectations," B. Vincent, PhD, V. Gissinger, J. Vallet, F. Mietlicki, P. Champelovier, S. Carra) [1], the indices called "Index 1" and "Index 3", which are the same as P2 and CY respectively, was preferred index of the public surveyed.

7. CONCLUSION

Work on the CNI is currently being finalised. It still remains to evaluate the index on a database that is representative of all acoustic environments, generally documented by noise observatories in the environment (cf. §3) and to use the data from the laboratory survey. The coefficients will be made public when the work is completed.

In the coming months, the CNI index will be experimented on the information platforms of Bruitparif's and Acoucité's noise monitoring networks as well as the European communication platform dedicated to the Harmonica project (www.noiseineu.eu will be online at the beginning of 2014).

For more information about the harmonica project visit the website www.harmonca-project.eu

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