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Are noise events from surface transport predictable? Insights from a wide measurement campaign

Arnaud CAN[1]; Gwenaël GUILLAUME[1]; Benoit GAUVREAU[1]

[1] LUNAM Université, IFSTTAR, AME, LAE, Centre de Nantes CS 4 Route de Bouaye F-44341 Bouguenais, France

ABSTRACT

The negative effect of road traffic noise events on annoyance is now established. However, the assessment and monitoring of road traffic noise remain mainly based on energetic indicators, which are easy to handle but mask noise dynamic structure. Recent developments in dynamic road traffic modelling, and in urban sensor networks, suggest that introducing noise events in urban noise management is possible. This however raises statistical questions: although their inherent random origin (very noisy cars, sirens, etc.) make them hardly predictable, noise events are probably site dependent.

In this paper, we rely on a measurement campaign carried out in Toulouse (France), made of 20 1h-measurement periods covering both day and night time slots, to question some statistical matters relative to road traffic noise events. Firstly, some general reflections concerning candidate indicators for describing noise events are given, in line with road traffic noise dynamics. Then, a statistical method is proposed, which selects the frequency bands of interest, and then defines a set of indicators relevant to describe the urban soundscape of the site, in terms of noise events. Finally, some insights about the predictability of noise events are deduced from the spatial distributions of the selected set of indicators.

Keywords: Indicators, Noise Events, Mobile Measurements, Statistical Analysis

1. INTRODUCTION

There is a consensus that noise events negatively impact urban soundscapes (sleep disturbance, activity interference, annoyance, etc.). However, road traffic impact assessment and monitoring remain mainly focused on energetic indicators, which are easy to handle but mask the noise dynamic structure (1). Recent developments in dynamic road traffic modelling (2,3), and in urban sensor networks (4), suggest the possibility to introduce noise events in urban noise management, and advocate for the development of dedicated indicators, in order to evaluate and reduce their impact. Such indicators should: (i) capture the characteristics of noise dynamics that are correlated to sound agreement and annoyance; (ii) have a statistical behavior such as they can be measured or even better estimated.

Many event indicators have been developed in the last decades, in order to evaluate the effects of aircraft noise (5). However, their use might be not adapted to the urban road traffic context, which is characterized by a more pronounced dynamics. Moreover, in urban area noise peaks are caused to numerous sound sources; consequently they highly vary both in duration and intensity. Thus, proposing adapted indicators to capture urban road traffic noise events is crucial.

In addition, the assessment of urban road traffic noise events opens statistical questions. On the one hand, their random nature (sirens, noisy cars, etc.), makes them in theory unpredictable. On the other hand, noise events are certainly dependent on the location (e.g. more probable in a busy street than in a quiet side).

In this paper, we rely on a measurement campaign to question some aspects of road traffic noise events statistics and estimation. The measurement campaign consisted of 20 1h-mobile measurements

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[1] arnaud.can@ifsttar.fr

carried out at different moments of three consecutive days, following a predefined tour, in the city of Toulouse, in France. Section 2 gives several generalities and reflections about noise events in the urban road traffic context. In Section 3, a statistical method is proposed, which aims at selecting a relevant set of noise event indicators, able to describe the noise environment in terms of noise events. Section 4 investigates the spatial distribution and the predictability of these indicators. Finally, Section 5 concludes on some practical issues.

2. METHODS

2.1 General considerations about noise events

Urban soundscapes have a very pronounced dynamics, as shown in (6). They are characterized by numerous noise events, which vary in both amplitude and duration. Noise events are generally defined as parts of the sound pressure level time series when the sound pressure level exceeds a given threshold continually during a given duration. The Figure 1 depicts the known problematic of sound events capture through specific indicators. Firstly, the choice in the threshold value is crucial to define noise events. Depending on the value of the threshold, and depending on the duration of consecutive emergences retained to define peaks, one given event can be counted as a peak or not. Moreover, the period during which the threshold is calculated is also of importance, since events are appreciated relatively to the background noise. The Figure 1(a) shows that considering a fixed (e.g. 75dB) or an adaptive threshold (e.g. L_{A50} + 10 dB), shapes the definition of noise events. Indeed, adaptive thresholds allow accounting for the fact that a given noise event can be heard as a peak when the background noise is low (e.g. at 10 pm), and not anymore when it is higher (e.g. at 8 am). At a lower temporal scale, the Figure 1(b) shows that, in the vicinity of a road traffic intersection, one given event can be considered as a peak if it occurs when the traffic light is red and thus noise levels are low, and not anymore if it occurs 30s later when the traffic signal is green and thus noise levels are higher. Finally, it is important to distinguish between the number of events and the duration of events, to fully describe the structure of noise emergences of an urban site.

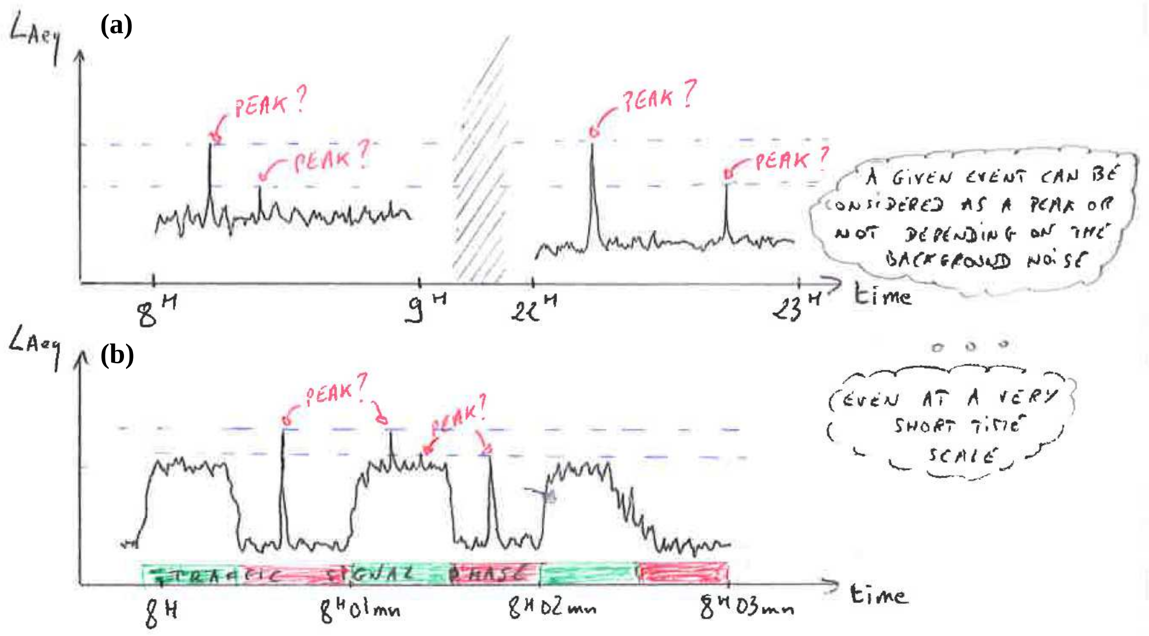

Figure 1 – What is a noise event?

2.2 Possible noise event indicators

The combination of these clue parameters leads to a huge number of candidate indicators, to describe urban noise events and capture their effects:

- The maximum sound pressure level L_{max}, calculated in this study with $\tau = 1$ s;
- The statistical level L_x, which represents the noise level (usually $\tau = 1$ s) exceeded X% of the observation period (7);

- The cumulative time (in percent) when the L_{1s} exceeds the threshold L_α, named the Mask Index, expressed as $MI_{L>L\alpha}$, which can be calculated with a fixed threshold (L_α=Y dB) or an adaptive threshold (e.g. $L_\alpha=L_{x+Y}$). This indicator takes the same value regardless the duration of events (e.g. 2 events of 5s each or 1 event of 10s);
- The number of events that exceed, during *z* consecutive seconds (*z* can take for example the values 1 s, 3 s, or 5 s), a given threshold L_α, expressed as $NNE_{z,L>L\alpha}$, with a fixed threshold (L_α=Y dB) or an adaptive threshold (e.g. $L_\alpha=L_{x+Y}$). This indicator takes the same value regardless the duration of the events (e.g. 2 events of 5 s each or 2 events of 10 s each);
- All these indicators can be calculated for each 1/3 octave band, and for global A-weighted levels.

In this paper, we rely on the mobile measurement campaign described in the next section, to propose a statistical analysis that selects the more relevant indicators, among this large set of indicators, for describing the noise environment in terms of noise events. The method that has already been proposed in (8) to reduce the number of indicators required to characterize sound environments, is adapted to the noise events context.

2.3 Experimentation

A mobile measurement campaign was conducted during three consecutive days, from Tuesday 28/01/2014 to Thursday 30/01/2014, in Toulouse, France. Geo-referenced mobile noise measurements were collected over soundwalks, during 20 1h-periods covering different periods of both day and night. Each soundwalk followed the same predefined route of about 2.5 km long, during which 9 stops at predefined points, each of about 2mn30s, were done. During these stops, the 1s-evolution of A-weighted sound pressure levels, and the 1s-evolution of the 31 1/3rd octave bands from 20 Hz to 20 kHz, were measured with the DUO Smart Noise Monitor from 01dB-Metravib®. The sound level meter was carried in a backpack, so that as its omnidirectionality was ensured. The sound level meter was calibrated before each soundwalk using a Sound Calibrator Type 4231 from Brüel & Kjær®.

The site, displayed in Figure 2, has been selected for its high landscape spatial contrasts. The North of the site is residential and made up of calm streets with individual houses (P_8 and P_9). The center of the site is also residential, but made of 4-storey buildings (P_1) to 12-storey buildings (P_6). The South West of the site is crossed by the highway A620, whose habitat is protected by a noise barrier (P_2, P_4, and P_5). The East of the site is crossed by a noisy street named "route de Seysse" (P_3 and P_7).

Figure 2 – Experimental site and experimental set-up

2.4 Noise event indicators calculation

For each soundwalk, the data samples collected at each location are used to calculate the set of noise events indicators. A first selection is applied based on the threshold, to only keep data that are statistically relevant. Indeed, a threshold so high that its level would never be exceeded cannot be used for a statistical analysis. In the same way, a threshold so low that its level would be exceeded all the time would not define events anymore. Moreover, based on the consideration upon peaks of noise of Section 2.2, it is decided to focus on adaptive thresholds, which are less site dependent than fixed thresholds.

As a result, the 13 following indicators are calculated for each of the 1/3 octave bands, as well as for the A-weighted levels: L_{max}, L_1, L_5, L_{10}, $MI_{L>L50+10}$, $MI_{L>L50+15}$, $MI_{L>L50+20}$, $NNE_{1s,L>L50+10}$, $NNE_{1s,L>L50+15}$, $NNE_{1s,L>L50+20}$, $NNE_{3s,L>L50+10}$, $NNE_{3s,L>L50+15}$, $NNE_{5s,L>L50+10}$. Note that this initial set of indicators is linked to the experimental data collected in this study and could vary from one measurement campaign to another. Further extension to different periods and sites will help globalizing the conclusions of this article.

The noise samples collected at each of the 9 points and for each soundwalk are gathered, in order to enlarge the size of the samples. Samples collected between 6:00 and 22:00 are gathered to form the sample S_{day} (15 periods, and 163s of measure for each location on average, thus approximately 41 mn of data for each point). Samples collected between 22:00 and 06:00 are gathered to form the sample S_{night} (5 periods, and 115s of measure for each location on average, thus approximately 10 mn of data for each point). S_{day} and S_{night} are gathered into S_{all} (20 periods, and 156s of measure for each location on average, thus approximately 52 mn of data for each point). The values calculated for each of the 13 indicators are averaged over these periods, to give one indicator value at each point, for S_{day}, S_{night} and S_{all}.

3. SELECTION OF RELEVANT PEAK INDICATORS

3.1 Selection of relevant frequency bands

A first statistical analysis is carried out, in order to reduce the high number of frequency bands. Indeed, except in some specific cases (e.g. if one focuses on tonal emergences), enlarging the frequency bands might be relevant to reduce the number of noise event indicators (13 x 27 if all the 1/3 octave bands were conserved). This assumption is supported by the high correlations calculated between the sound pressure evolutions at different 1/3 octave band frequencies.

In order to reduce the number of frequency bands, the correlation matrix of size 27 x 27 is calculated, between the $L_{eq,f}$ values, with f varying between 20 Hz to 8 kHz, for all periods and locations. One assumes that the highly correlated 1/3 octave bands contain redundant information and can thus be merged into one larger frequency band.

An agglomerative hierarchical cluster tree is applied to the 27 L_f indicators, using the Ward method. The algorithm begins with $n_{ind} = 27$ single-member groups, and merges two groups at each step, until all data are in a single group after $n_{ind} - 1$ steps. The criterion for choosing which pair of groups to merge at each step is that, among all possible ways of merging two groups, the pair to be merged is chosen that minimizes the sum of squared distances between the points and the centroids of their respective groups, summed over the resulting groups.

As expected, the clustering procedure merges neighbor frequency bands, since they are the most correlated. The procedure ends with 3 groups, which cuts the noise spectrum in three. The first group contains the 1/3 octave bands from 20 Hz to 125 Hz, and will be named LF further (for low frequency). The second group contains the 1/3 octave bands from 160 Hz to 2 kHz, and will be named MF further (for medium frequency). The third group contains the 1/3 octave bands from 2.5 kHz to 8 kHz, and will be named HF further (for high frequency).

3.2 Selection of relevant noise event indicators

Although the number of frequency bands has been reduced in the previous section, the remaining indicators remains too numerous to support decision making. Indeed, the previous procedure reduced the number of indicators to 13 x 4 (global A, LF, MF, HF) = 52 indicators.

Despite the large variety in duration and intensity of the noise events that are described in Section 2.1, high correlations are observed between some of these indicators, because they sometimes correspond to the same events (for example, one given event that exceeds the L_{A50+10} might also exceed the L_{A50+15}). Thus, it seems relevant to reduce once more the number of indicators through a clustering analysis.

An agglomerative hierarchical cluster tree is applied to the 52 indicators, using the Ward method. Its result is depicted in Figure 3. The dendrogram shows that this is relevant to keep 3 or 5 indicators to describe the sound environment in terms of noise events distribution.

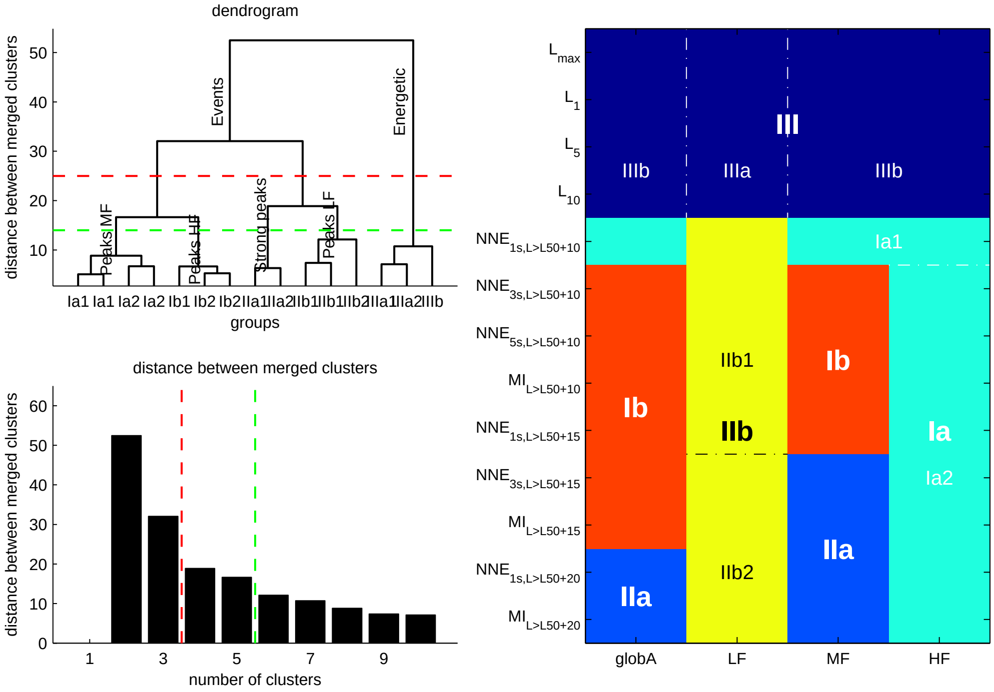

Figure 3 – Number of sound event indicators reduction based on a clustering analysis; each indicator is calculated for the 9 locations and 20 periods

The clustering clearly distinguishes the energetic indicators (group III) from the event indicators (group I and group II). The subdivision into three groups separates the groups I and II. The group II contains the “low frequency events” indicators and the “intense events” indicators (e.g. $\mathrm{MI}_{L>LA50+20}$). The group I contains the “high frequency events” indicators ($\mathrm{NNE}_{3s,L>LHF50+15}$), and the “moderately intense events” indicators (e.g. $\mathrm{MI}_{L>LA50+10}$). The groups I and II are both divided into two subgroups to form 5 groups:

- The group I is made up of the groups Ia and Ib. The group Ia contains the high frequency events and the $\mathrm{NNE}_{1s,L>L+10}$. The group Ib contains the “moderately intense events” indicators, in medium frequencies and in global A-levels. Note that this is not surprising to find in the same group MF and global A indicators, since the main part of the spectrum energy is in the mid-frequencies.
- The group II is made up of the groups IIa and IIb. The group IIb gathers all the event indicators in the low frequencies, making it clear that these events are not correlated to the other indicators. The group IIa contains the “intense events” indicators, in the mid-frequencies or in global A.

Finally, the correlations within each of the three groups are analyzed to keep *in fine* three noise events indicators only. The selected one is the indicator of the group that has the highest averaged correlation with the other members of the group. Note that, in the case when correlations are really close from each other, one takes the liberty to choose the indicator that seems the easiest to handle (that is the less complex or the most common one), within the ones that give the highest scores. In practice we choose the final indicator between the indicators that are at less than 0.05 from the highest average correlation.

The following three indicators are selected by the procedure:

- Group I: $\mathrm{MI}_{L>LA50+10}$
- Group II: $\mathrm{MI}_{L>LLF50+15}$
- Group III: L_{A1}

It is expected that this set of indicators characterizes physically the sound environment of the site of experimentation, in terms of sound events distribution, since it highlights the main information contained in events.

4. DESCRIPTION OF THE SITE IN TERMS OF NOISE EVENTS

The three indicators selected by the procedure are calculated at each of the 9 locations and for each period. Their mean values calculated over all the periods are depicted in Figure 4, in addition to the L_{A50} value. In complement, the Figure 5 describes in details the emergences at each of the 9 locations. Each subplot represents the noise event occurrences (in number per minute), as a function of the threshold (L_{A50+X}) and the duration of consecutive emergences above the threshold needed for the noise event to be counted as a peak. The Figure 5 offers a complete description of the noise events structure, but it is too complicated to be represented on a map or to be used for decision making. However, it can serve to evaluate the relevance of the description of the noise event distribution in space given by the three selected indicators.

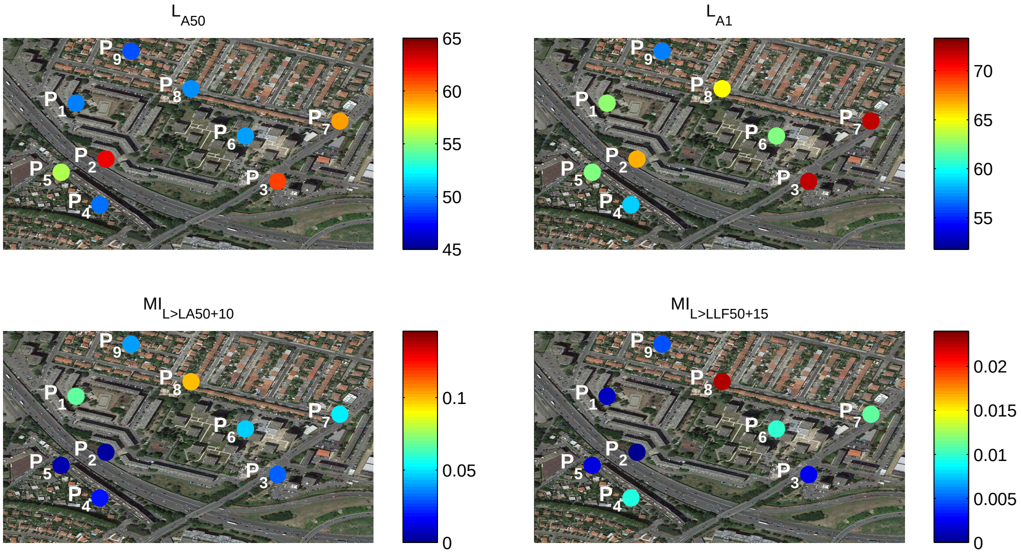

Figure 4 – Noise map of the three noise event indicators selected and of the L_{A50}, including both day and night periods.

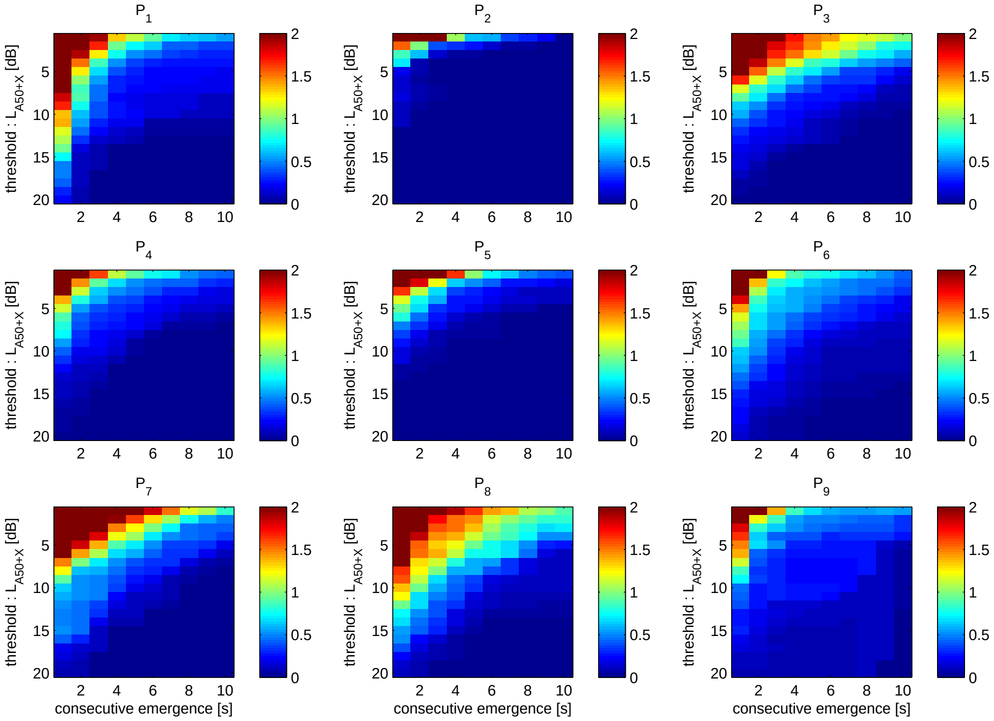

Figure 5 – Noise event occurrences, defined as a function of the threshold (L_{A50+X}) and the duration of emergence above the threshold required for the noise event to be counted, including both day and night periods.

The selected set of indicators allows a refined description of the sound environment of the site, and discriminates the nine locations in terms of noise events:

- The point P_1 is rather calm (see L_{A50}), but it is marked by many noise events, which are due to human activities. Indeed, the point is located in a courtyard surrounded by buildings, which contains a playground. As a result the $MI_{L>LA50+10}$ is quite high (nearly 10% of the time above the L_{A50+10});
- The point P_2 is the noisiest location of the site, as reveals the L_{A50} value. Sound variations are low, since noise is mainly due to constant flow of the highway A620, from which the location is protected by a noise barrier of poor quality. As a result, both the $MI_{L>LA50+10}$ and the $MI_{L>LLF50+15}$ are very low. The low number of noise events is confirmed by the Figure 5: even with a very short duration of threshold (e.g. 2 s) and a very low threshold (e.g. L_{A50+5}), the number of noise events occurrences remains very low;
- Although the point P_3 is almost as noisy as the point P_2 (see the L_{A50} value), their sound environments are very different. Indeed, noise variations are higher at P_3 than in P_2, because the main sound sources at this location are the contribution of both the highway and the “route de Seysse”. Noise variations are increased by the fact that the point is located close to a traffic signal, which alternates between red and green phases. As a result, also because of numerous buses pass-byes, the L_{A1} is very high. However, the $MI_{L>LA50+10}$ and the $MI_{L>LF50+15}$ remain low, although they are a bit higher than P_2. Actually, the Figure 3 reveals that the noise events are of low intensity (mainly below L_{A50+10}). The 3 selected indicators permit distinguishing the point P_3 from the points with more intense noise events (such as P_7);
- The point P_4 is protected from the highway by a 4-storey building; as a consequence it has both lower noise levels and lower noise variations than P_2 or P_3 (see L_{A50} and L_{A1} values). This shielded position makes rare the noise events that exceed the L_{A50+10}, despite a low L_{A50} value favorable to emergences. However, some strong noise events in low frequencies are highlighted by the $MI_{L>LLF+15}$; they are certainly due to local traffic, that is vehicles evolving at slow speed or parking in the street;
- The point P_5 is located at the corner of the 4-storey building mentioned above, thus it is less shielded, what explains the higher L_{A50} and L_{A1} values, in comparison with P_4. Its higher median levels compared to the point P_4 explains the lower number of noise events that emerge (see the $MI_{L>LLF+15}$ and the $MI_{L>LLF+15}$ values compared to P_4);
- The point P_6 is located in the middle of a courtyard surrounded by high buildings, thus its noise environment is similar to the one observed at P_1. However, these two points differ in terms of noise events. P_6 is characterized by fewer events than P_1, because it has no human activity. However, the strong emergences in low frequencies are higher, and could be due to local traffic. Indeed, local traffic was made of vehicles starting and evolving at very slow speed, whereas P_1 was a no traffic zone;
- The point P_7 is located on the “route de Seysse”, as the point P_3, but a bit further from the highway, what explains its similar L_{A1} but lower L_{A50} values. The high L_{A1} value at these two points might be due to buses pass-byes, as for P_3. However, noise environment at P_7 is characterized by more pronounced emergences than P_3. This is explained by the local activity. Indeed, there are two active local shops at this point (a kebab restaurant and a hair salon), which generate a high human activity: talks, car parking and starting, etc. This activity increases the $MI_{L>LA50+10}$ and the $MI_{L>LLF50+15}$ values;
- The point P_8 is located in a low traffic residential street. It is thus characterized by low sound levels (see L_{A50}). However, compared to the other points with similar noise levels (e.g. P_1 and P_6), its number of noise events is very high. These events are due to local traffic, which is made of single vehicles that pass by at their free speed and generate contrasted high levels compared to the low background noise. These emergences are depicted in Figure 5 too, which reveals that there are both numerous brief (e.g. t = 2 s) and long (e.g. t = 8 s) emergences. Since the traffic intensity is weak, this traffic impacts noise event indicators but it has no impact on the L_{A50}, distinguishing this location from the other calm ones;
- The point P_9 is located in a very calm street, with almost no traffic. Thus, the L_{A50} and L_{A1} values observed at P_9 are unsurprisingly the lowest in the site. Moreover, as it is in a residential street of low density, human noises are also quite rare. As a result, noise event indicators are also low, and this location is the calmest one in the site.

5. DISCUSSION

The aim of this paper is to select noise indicators able to describe the noise environment in terms of noise events, and give first insights about their predictability. The study relies on a measurement campaign, which consisted of 20 1h mobile measurements in the city of Toulouse, in France. About 50 mn of data were collected at 9 locations, which differ in terms of both exposure to noise sources (traffic, human activity) and land use. A statistical analysis allows reducing to three the number of indicators, the final set of indicators being constituted of the L_{A1}, the $MI_{L>LA50+10}$ (time during which the $L_{Aeq,1s}$ exceeds the L_{A50}+10 dB), and the $MI_{L>LLF50+15}$ (time during which the $L_{LF50,1s}$ exceeds the L_{LF50}+15 dB, with L_{LF} the sound pressure level averaged between 20Hz and 125 Hz).

The set of three indicators proposed allows a clear discrimination between the 9 locations, and a relevant description of the noise environments in terms of sound events. This discrimination between the locations, which is underlined by the indicators, can be explained by the differences in the functionality of the location: human activity, local traffic, distance to the highway, etc. Moreover, the information contained in the restrained set of indicators is validated by a refined descriptor of noise events, which characterize both the duration and the intensity of the noise events.

This tends to prove that the values of the noise event indicators are coherent and significant of the sound environment, despite the relatively low number of measurements achieved in this study. This is a good signal towards the use of sound event indicators to discriminate noise environments in terms of sound events, and describe them in details, in addition to the classical energetic indicators such as the L_{A50}. This also tends to prove that, since their value are coherent, their estimation is possible.

However, investigating in details the predictability of these indicators cannot be fully achieved based on this experiment, which is restrained to three days of measurements only. It will be necessary to extend the measurement campaign, in order to define the size of the samples needed to estimate accurately these indicators.

Finally, this set of indicators has been proposed based on solely physical considerations. It has to be confronted to perceptive assessment to define indicators relevant both physically and perceptively. Indeed, some indicators might emerge from a statistical analysis because they are relevant to discriminate spatially the sound environment, but have in a mean time low interest in terms of corresponding perceptive effects. Moreover, the thresholds have to be defined additionally both in duration and intensity, based on a perceptive study. These further research, which will benefit from the statistical work started in this paper, and will hopefully help accounting for noise events in urban noise mitigation measures.

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