Comparison of noise indicators in an urban context

Arnaud CAN[1]; Pierre AUMOND[1]; Sven MICHEL[1]; Bert DE COENSEL[2]; Carlos RIBEIRO[3]; Dick BOTTELDOOREN[2]; Catherine LAVANDIER[4]

ABSTRACT

Noise is a major environmental issue, which gave birth in the last decades to the development of many engineering methods dedicated to both its estimation and mitigation. The specificity of the noise pollution problem lies in the complexity of human hearing and subjective assessment, and in the high spatiotemporal variation and rich spectral content of the noise generated by a wide variety of sources in urban context. Indicators that encompass all these dimensions are required for the description of sound environments and for the evaluation of noise mitigation strategies. This paper compares usual and more specific indicators, dedicated to environmental noise analyses, by means of a literature review. The comparison is based on the three following criteria: i) the ability of indicators to describe and physically categorize the urban sound environments, ii) the relevance of indicators for describing the perceptive appreciations of urban sound environments, iii) the ability of indicators to be estimated through classical or more advanced traffic noise estimation models. A discussion compares the pro and cons of the selected indicators in an operational scope.

Keywords: Indicators, urban sound environments, perceptive assessment, noise mitigation, categorization

1. INTRODUCTION

The increasing urbanization accentuates the sound exposure issues, by simultaneously intensifying emissions and concentrating populations where sound levels are high. Appropriate indicators are required to describe sound environments, and evaluate noise mitigation strategies. The specificity of the noise pollution problem lies in the complexity of human hearing and subjective assessment, and in the high spatiotemporal variation and rich spectral content of the noise generated by a wide variety of sources in urban context. As a consequence, a large variety of indicators has been designed to encompass all these dimensions [1-2]. Selecting among these indicators the ones are the most relevant in urban context is a necessary work to enhance description and decision making.

A comparison of noise indicators has been pursued during the implementation of the European Directive 2002/49/CE, which led to the proposal of the L_{den} [3]. The criteria for selecting indicators were “validity”, “practical applicability”, “transparency”, “enforceability” and “consistency”. However, the criterion of “consistency”, defined as “as little difference as possible in practice”, although essential in a legislation context, does not necessarily fulfil research purposes. Moreover, the vision on indicators proposed in [3] mainly focuses on long term evaluations and effects. New paradigms for the evaluation of urban sound environments have been introduced since that date. The need to develop holistic evaluations of urban places, and to account for the perceptive effects when dealing with sound environments, is now receiving an increased attention. Moreover, the noise sources modelling saw the birth of new approaches, which open the door to the estimation of more advanced indicators that underlie noise levels variations. Finally, the physical description of urban sound environments has evolved towards more refined approaches, introducing for example sound categorization or sound events characterization.

This paper proposes a comparison of some existing indicators in this new paradigm context, that is based on the three following criteria: i) the ability of indicators to describe and categorize physically

---

[1] LUNAM Université, IFSTTAR, AME, LAE, Centre de Nantes CS 4 Route de Bouaye F-44341 Bouguenais, France
[2] Waves Research Group, Department of Information Technology, Ghent University, iGent Technologiepark Zwijnaarde 15, B-9052 Ghent, Belgium
[3] BruitParif ; 92B Avenue du Général Leclerc, 93500 Pantin, France
[4] Université de Cergy-Pontoise ; 5 Mail Gay Lussac - Neuville-sur-Oise - 95031 Cergy-Pontoise Cedex, France

urban sound environments, ii) the relevance of indicators to describe the perceptive appreciations of urban sound environments, iii) the ability of the indicators to be estimated through classical or more advanced traffic noise estimation models. The comparison relies on both a literature review and an analysis of a large database of physical and perceptive measurements collected in Paris, France. A discussion compares the pro and cons of the selected indicators in an operational scope.

2. NOISE INDICATORS AND PHYSICAL CHARACTERIZATION

The first of the three qualities that should answer noise indicators is their ability to precisely describe sound environments, that is: (i) to highlight the specific acoustical properties of a given sound environment, (ii) to discriminate efficiently different sound environments.

2.1 Description of urban sound environments

The first role of noise indicators is to describe urban sound environments; more specifically, they should correlate to a particular characteristic of the sound level and sound spectrum variations found in urban environments. The main noise indicators used in that purpose are presented here, classified regarding to their descriptive power:

- A first class of indicators comprises the classical energetic descriptors, such as L_{Aeq} or L_{den}. These indicators inform about the total sound level, but they give the same value regardless the temporal structure of sound environments. A given indicator value can then correspond to sound environments totally different in term of noise variations. Moreover, noise peaks highly affect the L_{Aeq} values when they are calculated on too short periods, or in highly eventful environments [4].
- Percentile descriptors describe one point of the $L_{Aeq,1s}$ distribution, and thus they mainly describe the dynamic range of the sound level. For example, the L_{10} measures the peaks in the noise, and is often used to characterize road traffic noise. Interestingly, the UK CRTN (Calculation Road Traffic Noise) method proposes instead of L_{den} the use of the $L_{10,A,18h}$, which is the arithmetic average of 18 $L_{Aeq,1h}$ values from 6:00 to midnight, to present road traffic noise exposures [5]. Relations have been proposed to link $L_{10,A,18h}$ and L_n and L_{den} values [6]. However, each statistical descriptor only corresponds to one point of the $L_{Aeq,1s}$ distribution and thus one descriptor value can also correspond to very different sound environments. Moreover, two criticisms can be formulated regarding their aptitude to describe sound levels variations: (i) the statistical descriptors fail to characterize the rhythm of sound levels variations (slow or fast, regular or irregular, etc.), (ii) this is in consequence often difficult to analyse their meaning [7].
- The “Number of Noise Event” NNE and “Mask Indexes” indicators are often used to describe emergences. NNE and MI are defined as the number of events, and the percentage of the time, that exceed a given threshold, respectively. The threshold can be a fixed value (i.e., 70 dB) or can be set adaptively, e.g. based on a noise indicator (i.e. L_{Aeq}+10, L_{10}+10). These indicators can be defined to measure either noisy or quiet periods. Thus they are more adapted than the previously cited indicators to describe sound levels variations. Nevertheless, each of the NNE or MI offers only a partial view of the emergences: the NNE takes the same value regardless the duration of events, and the MI takes the same value regardless the number of events. These two indicators can be merged into a map of emergences [8], which nonetheless loses in enforceability. However, the calculation of NNE and MI has not been standardized. Different algorithms to detect and count noise events within a sound level time history can result in vastly different values of NNE and MI [9]; the mechanics behind the detection of events has to date not been investigated in detail.
- Indicators dedicated to the noise rhythm have also been recently introduced. Descriptors that underline the 1s-scale sound variations (often presented as a descriptor of the sound roughness) are introduced in [10], by calculating statistics (average, spreading) on the noise differences $\delta_{Leq,1s}$ between consecutive $L_{Aeq,1s}$ values. Noise rhythm is considered in a global way in [11], by calculating the slope of the spectral distribution of 1s-sound levels, and relating this slope to the musicality of the sound environment.
- Specific urban noise indicators, adapted to the traffic signals period, are introduced in [12]. They consist of a mean noise pattern, level during green and red phases, variations around this mean noise pattern at the traffic signal scale. These indicators offer a very precise picture of the sound variations, but are dedicated to sound environments with a cadenced rhythm.

This overview underlines that no indicator can be considered as bad or good to underline sound levels variations, and that no dedicated indicator can fully describe a situation. Instead, each indicator offers an angle of view of these sound levels variations, what advocates for the use of a set of complementary indicators.

2.2 Categorization and indicators number reduction

The last decade viewed the birth of using categorization methods for designing sets of indicators that describe all dimensions of the sound environment. These indicators are then used to determine homogeneous sound environments, whose number can vary from 3, to 15 or 20, according to the corpus of sounds and the statistical methodology used ([13]; [14]; [15]). In [13], both semantical and physical indicators are used to categorize sound environments. A discriminative technique underlines 14 indicators that efficiently describe sound environments, namely the Crest Factor (CF), defined as the ratio between the maximum sound pressure and the root-mean-square value of the sound pressure [16], the frequency indicators $L_{eq,25Hz}$, $L_{eq,31.5Hz}$, $L_{eq,125Hz}$, $L_{eq,500Hz}$, $L_{eq,630Hz}$, $L_{eq,800Hz}$, $L_{eq,5kHz}$, $L_{eq,10kHz}$, $L_{eq,16kHz}$ and $L_{eq,20kHz}$, statistical indicators $L_{1,A}$ and L_{AImin} (minimum A-weighted sound-pressure level with an impulse response), and the L_{Aeq}. Among these indicators, the study reveals that the CF and the $L_{eq,125Hz}$ had the greatest impact on the differentiation of the soundscape typologies. However, the CF seems to not result in repeatable measurements, since it is based on maximum levels, which are known to be very random. The number of relevant indicators is reduced to three in [15] based on a clustering algorithm, mainly because the frequency indicators are "summarized" in to the Spectrum Gravity Centrum SGC (which however didn't emerge in the relevant indicators in [13]). The three selected indicators are then the $L_{50,A}$, the standard deviation of the $L_{Aeq,1s}$ values $\sigma_{LAeq,1s}$, and the SGC. This selection is extended in [8], where the selection of indicators adapts to the spatial scale of interest. To "zoom" on sound events indicators, the same procedure selects three indicators, namely the $L_{1,A}$, the $MI_{LA50+10}$ and the $MI_{LLF50+15}$. To "zoom" one step further, a "map of emergences" offers the most precise description. Event indicators also prove useful for describing sound environments in [17] ($NNE_{L>L\alpha}$, $MMI_{L>L\alpha}$).

Finally, more specifically, indicators calculated at the traffic signal temporal rhythm were used in [7] to underline the difference in sound environments between road traffic situations (upstream and downstream of traffic signals, vicinity of bus stops, etc.), such as the mean noise level during green or red phases, or the number of cycles when sound levels does not fall under a given threshold.

All these approaches rely on the existence of redundant information (high correlations) between indicators to diminish the number of used indicators. These categorization works cannot be read as a selection of the indicators that should be imperatively used, they only inform on which indicators are meaningless to use conjointly because of a very high correlation between them.

3. NOISE INDICATORS AND PERCEPTIVE EVALUATION

The L_{den} is commonly recommended by legislation to assess urban sound environments. However, although energetic indicators are known to show good correlations with long term annoyance (which does not mean that other indicators do not), their deficiency for evaluating perceptively urban sound environments have been pointed out in several studies. Energetic indicators cannot solely explain all the sound pleasantness variance; in addition they fail in evaluating fluctuating sounds, which are very common in urban areas and negatively impact noise annoyance [18; 19]. In particular, noise peaks should receive increased attention [20]. The spectral dimension is also of importance: the presence of low frequency noise increases annoyance [21], as does the presence of tonal components [22]. Moreover, the relation between L_{eq} and sound pleasantness is far from linear; it is shown in [23] that if high L_{eq} values are associated with unpleasantness, low L_{eq} values can correspond to both pleasant and unpleasant perceptions, depending on the sound sources characteristics. Then it is not surprising that L_{Aeq} is often not the best found indicator to estimate sound pleasantness: L_{A50} and N_{10} outperform L_{Aeq} in [24] and [25], respectively. Finally, the A-weighting does not fulfil perceptive requirements, and L_{eq} is often more relevant than L_{Aeq} in this context [23].

Based on the finding that energetic indicators are avoiding the perceptive dimensions of sound environments, several authors concluded that perceptive noise assessment should rely on more qualitative and multidimensional approaches, either for urban [26; 27; 28] or rural soundscapes evaluations [29]. Similar to the objective description of sound environments to rely on physical descriptors that encompass all the noise dimensions, it has been demonstrated that at least three perceptive dimensions, namely the intensity, the noise variations and the noise spectrum, emerge when dealing with urban sound environment assessments [30], thus involving a wider range of indicators.

Models have been proposed in the last decade to link sound pleasantness with physical indicators, based on linear regressions [31], Principal Component Analyses [32; 25] or neural networks [24]. They inform on which indicators are relevant in a perceptive assessment perspective. Then, multidimensional sound pleasantness assessment often point L_{50}, SGC and $\sigma_{LAeq,1s}$ or L10-L90 as complementary descriptors [24,30]. However, the $\sigma_{LAeq,1s}$ is often poorly correlated to sound pleasantness [25,34]. In addition, specific psychoacoustic indicators such as Fluctuation strength [52] or the number of events [27] can explain the eventfulness of a soundscape. This affective quality is an independent dimension compared to the pleasantness dimension [25]. The Sharpness, generally well correlated with the SGC, characterizes the presence of fountains for [14], but does not succeed to discriminate the different type of fountains for [52].

In parallel, some studies showed that sound pleasantness can advantageously be related to the perceived sound sources: high correlations with technological or natural sounds are observed in [28; 25], and the time of presence of road traffic, birds and voices appear in [31]. Their estimation through physical parameters is required to assess sound pleasantness based on physical indicators. Such indicators intervene in the modelling proposed in [34]: variables linked to the presence of road traffic can be approximated by L_{50} the between 63 and 250 Hz, while the time of presence of birds and voices can be approximated by the Time and Frequency Second Derivatives $TFSD_{mean,4kHz}$ and the $TFSD_{mean,500Hz}$, respectively, which are two indicators specifically proposed for this context, that underline the temporal and spectral sound levels variations at a given frequency. These indicators offer a dedicated and more focused view on sources spectral representation, than the Spectrum Gravity Centrum does.

Finally, exterior variables, describing the visual amenity or the familiarity of the environment, are also known to affect sound pleasantness [24], although they fall out of the scope of acoustical indicators.

4. NOISE INDICATORS AND NOISE MITIGATION

The third criterion for noise indicators investigated in this paper is their relevance concerning the evaluation of mitigation plans that aim to improve sound environments. Unfortunately, no actual model is able to account for all sound sources to permit a global evaluation and improvement of the sound environment. Instead models focus on road traffic, which is the main noise source in urban environments. Thus one will focus here on road traffic mitigation plans, which received much attention in last years and generate a high demand from decision makers.

Usual road traffic estimation models, such as CNOSSOS [35], rely on a static description of road traffic (mainly traffic volumes and mean flow speeds), coupled with geometric sound propagation calculations. This modelling is dedicated to equivalent sound pressure levels assessment, but prevents from calculating sound levels variations. As a consequence, they cannot provide an estimate of one of the main categories of noise indicators listed in the previous sections, namely sound event indicators. Even statistical indicators cannot be estimated, as they would require knowing the $L_{Aeq,1s}$ sound levels distribution. Although they show some limitations, static road traffic models are by far the mostly used representation, thus one has to keep in mind the difficulty to base the assessment of noise mitigation plans on other indicators than L_{Aeq} or frequency band-limited energetic indicators. This is problematic knowing the drawback of these indicators mentioned in this review. Recent works aimed to relate L_{Aeq} indicators to more advanced indicators (statistical indicators and TFSD frequency indicators) through statistical modelling that depend on the site characteristics [36]; if the study shows the potential of such modelling, further investigations will however be required to propose reliable relations.

Recent advances in sound propagation modelling open the door to the calculation of more advanced indicators, and thus to a more refined evaluation of strategies to improve sound environments. Temporal sound propagation models, such as geometric models (ray tracing or beam tracing), FDTD (Finite Difference Time Domain) or TLM (Transmission Line Matrix), allow the estimation of indices up to now dedicated to room acoustics, such as the reverberation time [37]. This allows more qualitative analysis, for example in shielded urban areas [38]. However, despite their known high relations with perceptive evaluations, indicators such as the reverberation time fail in describing globally a sound scene (they rely instead on a noise pulse which is not realistic). Thus they cannot stand alone to describe sound environments. Furthermore they are not modified by road traffic strategies; thus they should be seen as a complementary indicator that describes the architectural characteristics of a scene.

In parallel, a new generation of road traffic estimation models is being developed since more than a decade. They rely on microscopic traffic models that represent the motion of vehicles on the network: SYMUVIA in [39] and [40]; HUTSIM in [41]; PARAMICS in [42]; DRONE in [43]; AVENUE in [44]. Since the traffic model outputs are the position, speed and acceleration of each vehicle on the network at each time step (typically 1s), such modelling enables estimating the $L_{Aeq,1s}$ time series. One must keep in mind that this $L_{Aeq,1s}$ evolution is not the expected output, but the base of advanced indicators calculation (as said above, the $L_{Aeq,1s}$ evolution is a required intermediary for calculating statistical or a emergence indicators). Consequently, indices have been proposed to reflect urban traffic noise dynamics:

- The indicators that describe noise fluctuations at the traffic cycle scale have been introduced in [7] and [12]. Some indicators highlight the two modes of the noise distribution observed in the vicinity of traffic signals, corresponding to red and green traffic light phases. Complementing these, indices such as the $N_{L95>65}$ (percentage of traffic cycles t_c when $L_{95,tc}$ exceeds 65 dB(A)) are proposed to underline the periodic rarefaction of calm periods. Finally, indices such as the $N_{Lmax>80}$ (percentage of traffic cycles when $L_{max,tc}$ exceeds 80 dB(A)) are proposed to underline periodic peaks of noise. These indices have been estimated successfully in [40], using the microscopic traffic model SYMUVIA. Finally, indices adapted from the building acoustics have been estimated in [12], such as the Noise Rating curves, which underline the emergent frequency bands, which reveal some tonality.
- The use of the slope of the Fast Fourier Transform of the $L_{Aeq,1s}$ evolution was proposed in [45] and [46] to underline the rhythm of road traffic noise (at the 1s- scale), adapted from works in the musical context that proved that regular spectra are associated with more pleasant sound environments [47]. This index has been estimated in [42], using the microscopic traffic model PARAMICS. The same modeling chain has been used in to estimate sound emergence indicators [9].

The main conclusion from these works is the possibility to estimate in theory any noise indicator within the dynamic modelling framework.

5. DISCUSSION

The three previous sections showed the difficulty to highlight an optimal set of indicators for characterizing and evaluating urban sound environments. Indeed, indicators are rarely relevant for each of the three listed criteria. In addition, studies not necessarily converge to the same results, and the high correlations between indicators add some partiality in the choices made. The Table here below attempts to summarize the pros and cons of each listed indicator over the three dimensions of interest, to guide their selection.

If the evaluation of road traffic mitigation strategies is included in the criteria, either a dynamic road traffic modeling is available, and almost all the indicators can be calculated, or only a static road traffic modeling is available, and then the L_{Aeq} appears as the default indicator choice. This is unfortunate since this indicator is criticized by many aspects: (i) it is not the best indicator for estimating sound pleasantness, (ii) it covers only the energetic dimension of noise and thus discriminates poorly sound environments.

In the case when a dynamic road traffic modeling is available, or if the evaluation of road traffic mitigation strategies is not included in the indicator selection criteria, the choice remains open to all indicators. Then, L_{Aeq} can be advantageously replaced by $L_{50,A}$ or L_{50}, which show higher correlations with sound pleasantness, and more often emerge from categorization works. These indicators should then be completed with indicators that reflect the other dimensions of sound environments. Both works on sound environment categorization and perception insist on the interest of relying on the three dimensions that are the energetic, the temporal, and the spectral:

- The L_{50} appears as the best descriptor of the energetic dimension;
- To deal with the dynamic range of levels encountered, $\sigma_{LAeq,1s}$ and the L_{10}-L_{90} proved useful in a categorization context, but are not often mentioned as relevant indicators in the perception context. Nevertheless no better alternative has been proposed yet.
- To deal with the spectral dimension, the SGC emerged similarly from categorization works, but not from perceptive ones. In addition, it is criticized for is too high sensitiveness to events. Preferably, low frequency indicators, such the L_{125} in [13], or the sound sources dedicated indicators $TFSD_{mean,4kHz}$ and $TFSD_{mean,500Hz}$ proposed in [34], could be of interest both for categorization and perception; however the possibility to estimate the two latter ones through

modelling has not been proved yet. Note that in [34] he introduction of the TFSD indicators made the $\sigma_{LAeq,1s}$ irrelevant, what could mitigate for its simple avoiding.

In addition, the recent interest in peaks of noise estimation through dynamic road traffic modeling [9-48], and their known importance in a perceptive context, mitigate for their introduction in an "ideal" set of indicators. Then the $L_{1,A}$, the $MI_{LA50+10}$ and the $MI_{LLF50+15}$, which emerged from [8], could be used.

Thus, the conclusion of this state-of-the-art could be the proposal of a set of indicators that rely for example on: L_{50}, $\sigma_{LAeq,1s}$, $L_{125,}$ $TFSD_{mean,4kHz}$, $TFSD_{mean,500Hz}$, $L_{1,A}$, $MI_{LA50+10}$ and $MI_{LLF50+15}$. As said above, similar or a reduced set of indicators could of course also show similar relevance. To conclude, such a set of indicators, if it improves the description and understanding of sound environments, and permits to estimate more precisely the perceptive effects associated with a given urban sound environment, has in counterpart the drawback of its lack of enforceability. Its complexity makes it rather inefficient as a communication tool. Thus, the next work should be the proposal of a sound indicator much easier to understand, based on the set of indicators from this state-of-the-art (or similar), but with higher enforceability. Aggregating complex noise indicators into a single dimensionless indicator (that varies for example from 0 to 10), which combines this set of indicators into one single indicator, as proposed in [49], could be an option.

		Physical descriptive power	**Perceptive descriptive power**	**Noise mitigation**
Energetic Indicators	$\mathbf{L_{eq}}$	☹ Highly impacted by noise peaks [4] ☹ Hides the sound levels dynamics [7] ☹ Same L_{eq} value whatever the sound variation are [15]	☺Correlated to long term health effects [3]	☺ Estimated with Static modelling
	$\mathbf{L_{Aeq}}$	☹ A-weigthing often criticized for underestimating low frequencies at sound levels encountered in cities	☹ A-weigthing does not fulfil perceptive requirements [23]	☺ Estimated with Static modelling
Statistical indicators	$\mathbf{L_{90}}$	☺ Describes background noise [50] 😐 Low range of variation in urban context	😐 Does not emerge from studies	😐 Estimated with Dynamic modelling
	$\mathbf{L_{50}}$, $\mathbf{L_{50,A}}$	☺ Good for discriminating sound environments [15]	☺ Very good correlation with perceived sound intensity and sound pleasantness; outperforms L_{Aeq} [24]	😐 Estimated with Dynamic modelling
	$\mathbf{L_{10}}$	☺ Describes high noise levels [50]	☺ Outperforms L_{Aeq} [25]	😐 Estimated with Dynamic modelling
	$\mathbf{L_{10}-L_{90}}$, $\mathbf{L_5-L_{95}}$	☺ Describes the amplitude of noise variation (Boulevard vs irregular traffic street)	😐 No consensus concerning the perceptive effects ([24],[34],[28])	😐 Estimated with Dynamic modelling
noise variations indicators	$\mathbf{\sigma_{LAeq,1s}}$	☺ Describes the width of the sound levels distribution ☺ Good for discriminating sound environments [15] 😐 Assumes a normal distribution of $L_{Aeq,1s}$ values	😐 No consensus concerning the perceptive effects	😐 Estimated with Dynamic modelling
	$\mathbf{\delta_{LAeq,1s}}$	😐 Discrimination of traffic situation based on 1-s dynamics [51], although its discriminative power is not proved	☹ Difficult to handle and relate with effects	😐 Estimated with Dynamic modelling
	Slope of 1s-fft	☺ Discrimination of road traffic situations [11]	☺ In musical context acknowledged as a sound quality descriptor ☹ Further studies required to demonstrate link to sound quality	😐 Estimated with Dynamic modelling
Spectrum indicators	**SGC**	☺ Good for discriminating sound environments based on their spectral content [15]. ☹ Highly unstable.	😐 No consensus concerning the perceptive effects	😐 Estimated with Dynamic modelling
	$\mathbf{TFSD_{mean,4kHz}}$	☹ Never investigated	☺ Related to perceived birds time of presence [34] ☹ Only appears in one paper	☹ No current model allows its estimation
	$\mathbf{TFSD_{mean,500Hz}}$	☹ Never investigated	☺ Related to perceived voices time of presence [34] ☹ Only appears in one paper	☹ No current model allows its estimation
	$\mathbf{L_f}$, **with *f* frequency of interest**	☺ Related to road traffic time of presence (f=65 Hz,125 Hz) [34] ☺ Good for discriminating sound environments frequency content [13] ☹ Spectrum described through a large number of indicators	☺ Low frequencies and tonal components increase annoyance [20,21]	😐 Estimated with Dynamic modelling
Emergences indicators	$\mathbf{L_{1,A}}$,	☺ Good for discriminating sound environments based on emergences [8]	☹ Never investigated	😐 Estimated with Dynamic modelling
	$\mathbf{MI_{LA50+10}}$	☺ Good for discriminating sound environments based on emergences [8]	☹ Never investigated	😐 Estimated with Dynamic modelling
	$\mathbf{MI_{LLF50+15}}$	☺ Good for discriminating sound environments based on emergences [8]	☹ Never investigated	😐 Estimated with Dynamic modelling
	CF	☺ Good for discriminating sound environments [13] ☹Based on max values so no repeatable measurements	☹ Never investigated	☹ No current model allows its estimation
	$\mathbf{N_{Lmax>80}}$	☺ Good for discriminating sound environments in the vicinity of traffic signals [7]	☹ Never investigated	😐 Really specific to urban corridors
	$\mathbf{N_{L95>65}}$	☺ Good for discriminating sound environments in the vicinity of traffic signals [7]	☹ Never investigated	😐 Really specific to urban corridors

ACKNOWLEDGEMENTS

This work has been funded by Ademe, within the Grafic project.

REFERENCES

1. Can A. Noise Pollution Indicators, in : Environmental Indicators (Armon, R. and Hanninen, O. Eds), Springer. ISBN 978-94-017-9498-5, p.501-513, 2015.
2. Marquis-Favre C, Premat E, Aubrée D, Vallet M. Noise and its effects – a review on qualitative aspect of sound. Part I: Notions and acoustic ratings. Acta Acust Acust. 2005;91(1):613–25.
3. European Commission. Position paper on EU noise indicators, 2000. ISBN 92-828-8953-X, 80p.
4. Alberola J, Flindell IH, Bullmore AJ. Variability in road traffic noise levels. Appl Acoust. 2005; 66:1180–1195.
5. UK Department of Transport (1988) Calculation of road traffic noise. The stationary office books, London, HMSO, 1988.
6. O'Malley V, King E, Kenny L, Dilworth C. Assessing methodologies for calculating road traffic noise levels in Ireland – converting CRTN indicators to the EU indicators (Lden, Lnight). Appl Acoust. 2009;70(2):284–296.
7. Can A, Leclercq L, Lelong J, Defrance J. Capturing urban traffic noise dynamics through relevant descriptors. Appl Acoust. 2008;69(12):1270-80.
8. Can A, Guillaume G, Gauvreau B. Noise indicators to diagnose urban sound environments at multiple spatial scales. Acta Acust unit Acust. 2015;101:964-74.
9. De Coensel B, Brown AL, Tomerini D. A road traffic noise pattern simulation model that includes distributions of vehicle sound power levels. Applied Acoustics (accepted, doi: 10.1016/j.apacoust.2016.04.010).
10. Defrance J, Palacino J, Baulac M. Acoustic auscultation of urban bikeways. In: Proceedings of the CFA 2010, Lyon, France, 2010 April 12–16.
11. Botteldooren D, De Muer, De Coensel B. The temporal structure of urban soundscapes, Journal of Sound and Vibration. 2006; 292(1–2): 105-123.
12. Can A, Leclercq L, Lelong J, Botteldooren D. Traffic noise spectrum analysis: Dynamic modeling vs. Experimental observations, Applied Acoustics. 2010; 71(8): 764-770.
13. Torija A, Ruiz DP, Ramos-Ridao AF. Application of a methodology for categorizing and differentiating urban soundscapes using acoustical descriptors and sementic-differential attributes. Journal of the Acoustical Society of America. 2013;134(1):791-802.
14. Rychtarikova M, and Vermeir G. Soundscape categorization on the basis of objective acoustical parameters. Applied Acoustics. 2013;74:240–47.
15. Can A, Gauvreau B. Describing and classifying urban sound environments with a relevant set of physical indicators. J Acoust Soc Am. 2015;137(1):208-18.
16. Torija AJ, Ruiz DP, De Coensel B, Botteldooren D, Berglund B, ramos Ridao A. Relationship between road and railway noise annoyance and overall indoor sound exposure. Transportation Research Part D. 2011;16:15-22.
17. Brocolini L, Lavandier C, Quoy M, Ribeiro C. Measurement of acoustic environments for urban soundscapes: choice of homogeneous periods, optimization of durations, and selection of indicators. J Acoust Soc Am. 2013;134(1):813-21.
18. Schomer PD. Criteria for assessment of noise annoyance. Noise Control Eng. 2005; J 53(4):132–144.
19. Fujii K, Atagi J, Ando Y. Temporal and spatial factors of traffic noise and its annoyance. J Temp Des Arch Environ. 2002; 2(1):33–41.
20. Björkman M. Maximum noise levels in road traffic noise. Journal of Sound and Vibration. 1988; 127(3): 583-587.
21. Berglund B, Hassmen P, Soames Job RF. Sources and effects of low-frequency noise. J Acoust Soc Am. 1996; 99(5):2985–3002.
22. Beaumont J, Petitjean E. Driving forces, pressure and state indicators, EH indicators and EU. legislation. WHO technical meeting on noise and health indicators, Brussels, Belgium, April 7–9, 2003.
23. Rey Gozalo G, Trujillo Carmona J, Barrigón Morillas JM, Vílchez-Gómeza R, Gómez Escobara V. Relationship between objective acoustic indices and subjective assessments for the quality of soundscapes. Applied Acoustics. 2015; 97: 1–10.
24. Ricciardi P, Delaitre P, Lavandier C, Torchia F, Aumond P. Sound quality indicators for urban places in Paris cross-validated by Milan data. J Acoust Soc Am. 2015;138(4): 2337–2348.
25. Axelsson O, Nilsson ME, Berglund B. A principal components model of soundscape perception. J Acoust Soc Am. 2010; 128(5): 2836.
26. Notbohm G, Västfjäll D, Gärtner C, Schwarze S. Subjective evaluation of the sound quality of urban traffic noise situations. In: Proceedings of the 18th ICA, Kyoto, Japan, April 4–9 2004.

27. Raimbault M, Lavandier C, Bérengier M. Ambient sound assessment of urban environments: field studies in two French cities. Appl Acoust. 2003; 64:1241–1256.
28. Nilsson ME, Botteldooren D. Acoustic indicators of soundscape quality and noise annoyance in outdoor urban areas. In: Proceedings of the 19th ICA, Madrid, Spain, September 2–7, 2007, 6p.
29. De Coensel B, Botteldooren D. The quiet rural soundscape and how to characterize it, Acta Acust. united with Acust. 2006; 92(6): 887–897.
30. Lavandier C, Bidault A, Chouard N, Viollon S. Auditory perception of road traffic noise, The 29th International congress and exhibition on noise controll engineering, 2000.
31. Lavandier C, Defreville B. The contribution of Sound Source characteristics in the assessment of urban soundscapes, Acta acustica united with Acustica. 2006; 92: 912-921.
32. Raimbault M, Lavandier C, Bérengier M. Ambient sound assessment of urban environments: field studies in two French cities. Appl Acoust. 2003; 64:1241–1256.
33. Brambilla G, Maffei L, Di Gabriele M, Gallo V. Merging physical parameters and laboratory subjective ratings for the soundscape assessment of urban squares, Journal of the Acoustical Society of America. 2013; 134(1):782-90.
34. Aumond P, Can A, Lavandier C, De Coensel B, Botteldooren D, Ribeiro C. Modeling soundscape pleasantness using perceptive assessments and acoustic measurements along paths in urban context, submitted for publication.
35. Kephalopoulos S, Paviotti M, Anfosso-Lédée F, Van Maercke D, Shilton S, Jones N. Advances in the development of common noise assessment methods in Europe: The CNOSSOS-EU framework for strategic environmental noise mapping. Science of the Total Environment. 2014;482-483:400-10.
36. Michel S. Exploring the relationship between acoustic indicators in urban areas, according to the configuration of the site. Internship report, in French.
37. Guillaume G, Gauvreau B, Fortin N. Numerical predictions for sustainable development of cities: acoustic propagation in presence of urban vegetation. In: Proceedings of the 41st Internoise, New-York, USA, 2012 August 19–22.
38. Forssén J, Hornikx M. Statistics of road traffic noise levels in shielded urban areas. In: Proceedings of the 36th inter-noise, Istanbul, Turkey, 2007 August 28–31.
39. Leclercq L, Lelong J (2001) Dynamic evaluation of urban traffic noise. In: Proceedings of the 17th ICA, Roma, Italy.
40. Can A, Leclerc L, Lelong J, Defrance J (2009) Accounting for traffic dynamics improves noise assessment: experimental evidence. Appl Acoust 70(6):821–829.
41. Heltimo J, Niitymaki J, Bjo¨rk E (2003) A microlevel method for road traffic noise prediction. Advances in transport 8, urban transport VIII: urban transport and the environment in the 21st century
42. De Coensel B, De Muer T, Yperman I, Botteldoren D. The influence of traffic flow dynamics on urban soundscape. Applied Acoustics 66 (2005) 175‐194.
43. Bhaskar A, Chung E, Kuwahara M (2007) Development and implementation of the areawide dynamic road traffic noise (DRONE) simulator. Transp Res D 12:371–378.
44. Oshino Y, Tsukui K (2006) Investigation into the noise map based on traffic flow prediction in the citywide road network. In: Proceedings of Euronoise, Tampere, Finland, May 30–June 1 2006, 6p.
45. De Coensel B, Botteldoren D, De Muer T (2003) 1/f noise in rural and urban soundscape. Acta Acust Acust 89:287–295.
46. Botteldoren D, De Coensel B, De Muer T (2006) The temporal structure of urban soundscapes.J Sound Vib 292(1–2):105–123.
47. Voss RF, Clark J (1978) “1/f noise” in music: music from 1/f noise. J Acoust Soc Am 63:258–263
48. Can A, Leclercq L, Lelong J. Dynamic urban traffic noise: do individualized emission laws improve estimation? Proceedings of the 19th International Congress on Acoustics (ICA), Madrid (Spain), 2007, 6 p.
49. Harmonica (2013). http://www.harmonica-project.eu/en. Cited 18 Jan 2013.
50. Nelson P. Transportation noise. Reference book. London: B. Scientific Ltd./Butterworth; 1987, ISBN 0-408-01446-6.
51. Defrance J, Rapin J, Rondeau J. Traffic noise in Paris, 30 years later. 2000; No. ER 712.99.0131:37p [in French].
52. Rådsten Ekman M., Lundén P., Nilsson M.E., Similarity and pleasantness assessments of water-fountain sounds recorded in urban public spaces J. Acoust. Soc. Am. 138, 3043 (2015); http://dx.doi.org/10.1121/1.4934956.