Technical Note

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A NOTE ABOUT ASSESSING CHARACTERISTICS OF ENVIRONMENTAL NOISE

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INTRODUCTION

Numerous guidance documents for environmental noise assessment ([1] [2] [3] [4] [5] [6] [7]) recognise that sounds with certain characteristics can be perceived as more annoying to a listener. For example, Section 4.1 of the New South Wales Industrial Noise Policy [6] notes:

> *Where a noise source contains certain characteristics ... there is evidence to suggest that it can cause greater annoyance than other noise at the same noise level.*

Similarly Appendix B of NZS6808:2010 [5] notes:

> *Sound that has special audible characteristics ... is likely to cause adverse community response at lower sound levels, than sound without such characteristics.*

These characteristics cannot be sufficiently described by broadband sound level alone as other features of the sound create a response for listeners. Examples of characteristics, referred to here as special audible characteristics or SACs, encountered in environmental acoustics are listed in Table 1.

This note outlines the mechanisms used in guidance documents for addressing SACs, such as penalties. Consideration is then given to general approaches for assessing SACs which can comprise objective and/or subjective methods and which can be evaluated either on-site or using unattended measurements. A number of advantages and disadvantages for these various approaches are discussed, with examples provided in the context of wind farm noise assessment.

MECHANISMS FOR ADDRESSING SACS IN GUIDANCE DOCUMENTS

SACs are not always directly evaluated during a noise assessment as many noise sources do not exhibit them. When SACs are evaluated, assessments are typically undertaken at receptor locations such as residential dwellings, where annoyance is likely to occur, and are generally addressed in two steps:

- Assessment: SAC(s) are evaluated using objective measures or a subjective appraisal or both.
- Penalty: If the assessment (Step 1) indicates significant presence of one or more SACs, measured sound levels are typically adjusted through the addition of a penalty or rating level to account for the additional character.

For example, Section 6.1 of ISO 1996-1:2003 [1] comments:

> *Research has shown that the frequency weighting A, alone, is not sufficient to assess sounds characterized by tonality, impulsiveness or strong low-frequency content. To estimate the long-term annoyance response of a community to sounds with some of these special characteristics, an adjustment, in decibels, is added to the A-weighted sound exposure level or A-weighted equivalent continuous sound pressure level.*

Similarly, Section 8 of British Standard 4142:1997 [2] notes:

> *Certain acoustic features can increase the likelihood of complaints over that expected from a simple comparison between the specific noise level and the background noise level. Where present at the assessment location, such features are taken into account by adding 5 dB to the specific noise level ...*

The magnitude of an applicable penalty depends on the guidance document and, in some cases, the type of SAC. As noted, BS 4142:1997 applies a penalty of 5 dB for the presence of a SAC and, by implication, a penalty of 0 dB when no SAC is present: the penalty takes the form of a step function with a value of either 0 dB or 5 dB. Conversely, for an assessment

Table 1: Examples of characteristics of sound considered during environmental noise assessments

Characteristic	Definitions
Amplitude modulation (AM)	Sound with a noticeable regular and repeating change in sound level can in some cases be describe as amplitude modulation.
Impulsiveness	"*... sound characterized by brief bursts of sound pressure* *NOTE The duration of a single impulsive sound is usually less than 1s*." [1]
Low frequency noise	"*… sound containing frequencies of interest within the range covering the one-third octave bands from 16 Hz to 200 Hz*." [8]
Tonality	"*… noise containing a discrete frequency component …*" [9]

of tones, ISO 1996-2:2007 [8] details a sliding penalty scale ranging from 0dB to 6dB such that the size of the penalty applied to the measured sound level is, approximately, in proportion to the audibility of the tone.

Some guidance documents recommend a single penalty regardless of the number of SACs identified in a sound. For example, Section B4 of NZS 6808:2010 states that:

> *Only one adjustment value ... shall be applied to each measurement, even if more than one type of special audible characteristic is present.*

Conversely, the *South Australia Environment Protection (Noise) Policy 2007* [7] details an accumulating penalty:

> *(3) If the noise from the noise source contains characteristics, the source noise level (continuous) must be further adjusted in the following way ...:*
>
> *(a) if the noise from the noise source contains 1 characteristic, 5 dB(A) must be added to the source noise level (continuous);*
>
> *(b) if the noise from the noise source contains 2 characteristics, 8 dB(A) must be added to the source noise level (continuous);*
>
> *(c) if the noise from the noise source contains 3 or 4 characteristics, 10 dB(A) must be added to the source noise level (continuous).*

SAC ASSESSMENT METHODS

As noted, SAC assessment methods can be subjective or objective. Subjective methods, such as listening studies, are directly referenced in some guidance documents, for example Section B1 of NZS 6808:2010 states:

> *Subjective assessment can be sufficient in some circumstances to assess special audible characteristics.*

Objective methods are also commonly cited in guidance documents ([5] [8] [10]) and typically involve processing measured sound levels and comparing results with a pre-determined threshold.

A combination of approaches is also possible, such as in UK document ETSU-R-97 [9] which states:

> *The determination of the character of the noise emitted by wind turbines is performed by both a subjective and an objective test. This takes the form of listening to the emitted noise at the affected property and/or performing objective measurements of the incident noise at the property.*

SUBJECTIVE METHODS

The success of subjective methods depends critically on the experience of the assessor and the time and location of the assessment. Outcomes will naturally vary with differences in opinion between assessors, meaning subjective assessments will not be appropriate in all cases. However it is considered that variations will be reduced provided assessors are sufficiently qualified and experienced with the sound being evaluated. Objective methods can also be helpful for validating a subjective appraisal, particularly in cases of dispute.

On-site subjective assessments will only address the source operating conditions encountered during the visit, which could be limiting for sources that vary with time or occur irregularly. For example, as wind turbine sound levels vary with wind speed, direction and shear, on-site SAC assessments have often required multiple many trips to site to assess a sufficient range of turbine operating conditions ([11] [12] [13]). On-site assessments are, however, generally less prone to influence from extraneous noise as, on-site, an assessor can distinguish whether a particular SAC originates from the source of interest.

It is also possible to carry out subjective assessments using audio recordings, during post-processing. However, this may misrepresent the significance of a SAC because of variability or limitations of the audio playback system, as recently noted by Hansen [14]:

> *There are several reasons why the replayed levels would not be accurately reproduced and these include: self-noise of the instrumentation (headphones/computer), ambient noise in the listening room, frequency roll-off of the headphones and/or sound card and inaccurate amplification.*

Additionally, field recordings from sound level meters are generally single channel rather than stereo which reduces an assessor's ability to localise a sound and/or discriminate between two different sounds from different locations. These issues of variability could be particularly significant if assessing a SAC with a sliding penalty, where comparatively subtle influences of the recording and playback systems could affect the prominence of the identified SAC, resulting in a penalty which differs by several decibels from what may have been determined from an on-site assessment. In light of such issues, subjective review of unattended recorded audio samples may be best suited simply for source identification.

OBJECTIVE METHODS

Efficient objective assessment methods should:

- Identify a SAC when it is present at a sufficient level
- Not identify a SAC when there are none present
- Where a SAC is present, provide a relationship between the objective results and expected levels of annoyance and/or an applicable penalty

Indentifying a SAC when it's present

Objective methods can be reasonably efficient at identifying SACs provided there is a good signal to noise ratio for the source of interest. As an example, a set of planning conditions for a proposed wind farm in the UK included a method for assessing high levels of amplitude modulation (AM). In broad terms, the method involves reviewing a time series of $L_{Aeq,125ms}$ values, evaluating local minimum-maximum-minimum combinations in this series across 2 second windows and tallying the number of windows in a one minute period where the minimum-maximum-minimum variation is greater than 3 dB [15]. The method has been reported ([16], [17]) as having a low rate of false negatives or, in other words, it can identify high levels of wind turbine AM when they are present. Figure 1 shows how the method would apply to a 2 s window of $L_{Aeq,100ms}$ sound levels of a wind turbine at a distance of approximately 120 m (an IEC 61400-11:2006 [10] test position).

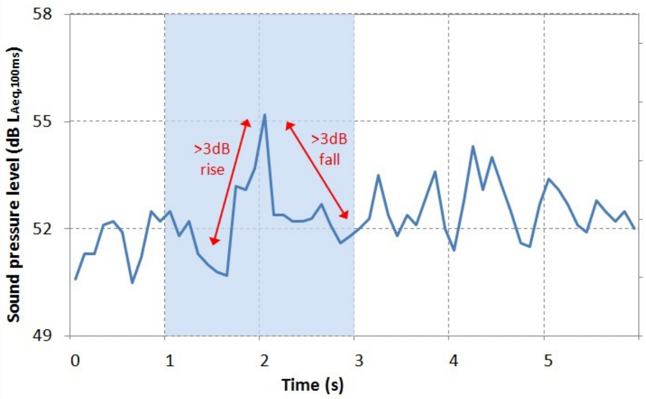

Figure 1: An $L_{Aeq,100ms}$ time series, wind turbine sound power level test location

Some objective methods do, however, give rise to false negatives in some circumstances. For example, NZS6808:2010 prescribes a 'simplified' tonality assessment method based on one-third octave bands but notes in Section B2.1 that:

If the simplified method does not indicate tonality, it may still be necessary to use the reference method to confirm the presence or absence of tonality.

Objective methods may also include inherent assumptions about the nature of a SAC which may limit its general application in some cases. For example, the tone assessment procedure detailed in IEC 61400-11:2006 notes:

In exceptional cases (for example very broad tones consisting of many lines or masking noise with very steep gradients) this [tone assessment] method may not give the correct results. In such cases, deviations from the prescribed method may be needed and must be reported.

Indentifying a SAC when it is not present

A significant risk with objective SAC assessment methods is false positives. That is, identifying a SAC as being part of a sound when it is not. Arguably the greatest cause of false positives is the influence of extraneous noise.

Continuing the AM example above, it has been documented [15] that the minimum-maximum-minimum method demonstrated a high rate of false positives when "*...applied to a large body of acoustical data obtained from two rural sites where no wind turbines exist and where there is therefore no possibility of wind turbine induced AM being present.*" Bird chirp, for example, could cause a brief spike in an otherwise flat $L_{Aeq,125ms}$ time series to trigger the 3 dB minimum-maximum-minimum criteria for a 2 s window. Clearly an isolated bird chirp should not register as AM from a wind turbine, however, this objective assessment method would falsely produce a positive result in a 2 s window. The crux of this example is that the proposed method was likely developed with an inherent, and quite reasonable, assumption that the sound of interest dominates the sound field: ambient or extraneous noise is not significant. In many cases, such as at receptor locations which are sufficiently far from a noise source, this fundamental assumption of the assessment method may not be satisfied.

In practice, false positives can usually be managed during an on-site objective assessment as the assessor can identify extraneous noise events. False positives are a much more significant issue with unattended measurements which rely on automated processing (as it is generally impractical to listen to large amounts of audio data). Significant effort can be required to reduce their occurrence, as noted in a recent study of wind farm amplitude modulation by Cooper & Evans[18]:

The advantage of the more intensive signal analysis techniques is that they can be used to automatically calculate the level of amplitude modulation during long-term measurements of several weeks duration. The disadvantage of these methods is the susceptibility of extraneous noise, which may be falsely identified as amplitude modulation, or may make identification of the level of amplitude modulation due to the wind farm noise indistinguishable from other sources.

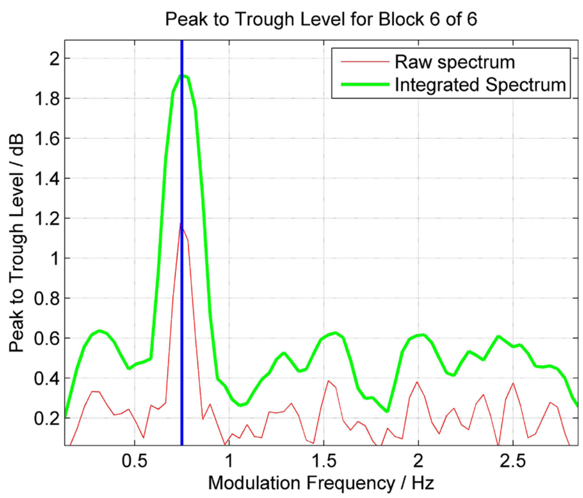

Figure 2: Example Power spectrum from an $L_{Aeq,100ms}$ time series

Cooper & Evan's study documents development of automated routines to assess AM in accordance with NZS6808:2010, where AM is described as "... *a greater than normal degree of fluctuation as a function of the blade passing frequency*" (BPF). A key component of the study is establishing the BPF, which is estimated by calculating modulation spectra for sets of one-third octave band $L_{eq,100ms}$ time series. Figure 2 shows an example spectrum calculated from the $L_{Aeq,100ms}$ referenced in Figure 1, using the RenewableUK AM tool [20].

Cooper & Evan's study provides an example of extraneous noise corrupting initial attempts at the automated routines and several sophisticated refinements are employed to better identify the BPF and, in turn, the potential occurrence of wind farm AM, including:

- Averaging a number of individual modulation spectra across a nominated 2 minute assessment period rather than determining a single spectrum for that entire period.
- Preferential weighting of potential BPF bins across time periods such that a particular BPF is considered more likely in time period X if it had just been identified in period X-1.

The refinements employed work well and allow for a helpful assessment of AM at the investigated site, across a broader range of conditions than could reasonably be assessed with discrete site visits.

It is important, however, to balance the advantages offered by such refinements with limitations that they may introduce. For example, focusing an assessment using BPF, typically around 1Hz for a multi-MW three-bladed turbine, may discount any potential AM that occurs at a less regular rate: such as at a rotational frequency of around 0.3Hz as could occur if the AM characteristics were attributable to only one of the rotating blades. Similarly, while the preferential weighting filter is likely to work well during periods where turbine operation is relatively constant it may unduly discount periods when the turbine operation is changing. For example, at cut-in wind speeds when the turbine is beginning to generate power or when the turbine is yawing. Pragmatically in the context of wind farms, comparatively short term events such as these may not influence study outcomes which typically rely on regression analysis of large data sets. Nonetheless, it may be that the short term events are a significant cause of neighbour annoyance that a wind farm operator may wish to address.

Relationship between objective results and expected levels of annoyance and/or penalty

The relationship between objective SAC assessments methods and the subjective impressions of a 'typical' listener is variable and uncertain in many cases. For example, a recent review of two different tone assessment methods demonstrated that each method achieved a different level of correlation with the subjective assessment of 23 different listeners [19].

Moreover, not all objective methods include information about applicable penalties. For example, IEC61400-11:2006 specifies a method for assessing tones from wind turbines but provides no guidance about penalties.

Also, in cases where a step penalty applies, it can be unclear where the onset of the penalty should occur. For example the New Zealand Standard NZS 6808:1998 [4], which is still used as a guidance document for some Australasian wind farm projects, requires application of a 5 dB penalty where wind farm sound is identified as having clearly audible tones and references the Joint Nordic Method (JNM) as being an appropriate assessment standard. Version 2 of the JNM, as described [19] in Annex C of ISO 1996-2:2007, provides a sliding penalty scale for tonality meaning a degree of interpretation is required to estimate what level of *sliding* tonality penalty may be appropriate as an onset for the 5 dB step penalty required by NZS608:1998.

DISCUSSION

Recent developments with sound level meters and noise loggers, such as audio recording and SD-card based data storage, readily allow detailed sound data to be collected during medium and long term unattended measurements. This has created new opportunities for detailed post-processing of data, including assessment of SACS. Indeed, intensive data collection methods are beginning to be integrated into guidance documents for wind farm noise assessment. For example, Section 2.3.4 of the recent IOA Wind Farm Working Group Consultation Draft of Supplementary Guidance Note 5 Post-completion measurements, [21] states:

> *... it may be useful to carry out audio recordings for 2 minute samples in every 10 minute interval in all cases to allow for subjective evaluation of any noise effects and particularly of any time histories produced to assist with any discussions about the acoustic character of the noise.*

However, from the discussions above it is apparent that the merits of any particular SAC assessment method should

Table 2: SAC assessment methods pros and cons

	Assessment Type			
	Attended		Unattended	
SAC Assessment outcome	**Objective**	**Subjective**	**Objective**	**Subjective**
All potential SACs considered*	✘	✔	✘	✘
All relevant operating conditions considered	✘	✘	✔	✔
Assessment of applicable penalties	✘	✔	✘	✔
Copes with extraneous noise influences	✔	✔	✘	✔
Avoids intensive data analysis	✘	✔	✘	✔
Generally repeatable outcomes	✔	✘	✔	✘
Avoids influence of audio playback systems	✔	✔	✔	✘

* There is no combination of objective SAC methods that will ensure all SACs are always identified. Also, some SACs may not be identifiable from recorded audio samples.

be judged with a degree of pragmatism. Table 2 summarises a number of key advantages and disadvantages for the approaches considered.

Recent experience with wind farm noise assessment suggests that intensive, unattended data collection can demand prolonged periods of data post-processing which produce less reliable results, because of extraneous noise effects, but across a wider range of weather conditions. This can mean that assessments are not necessarily any better informed than more conventional attended studies which could produce results of greater reliability but for a limited range of conditions.

It is therefore considered that SAC assessments are often best approached using a combination of subjective and objective methods. In particular, it is recommended that any objective assessment of unattended measurements should generally be complemented by attended subjective and objective assessments as a check on the nature and magnitude of the SACs that are being assessed. If a SAC assessment is proposed to address a specific complaint, it is recommended that an on-site subjective evaluation of the SAC should occur in the first instance, ideally making reference to a complaint diary or some other record of the type of sound causing annoyance and the periods when it occurs. The subjective review can be used to assess not only the significance of the potential SAC but also its classification. For example, a 2006 UK study investigating low frequency noise complaints [22] found that what residents were describing as low frequency noise was perhaps better classified acoustically as amplitude modulation:

> *The common cause of complaints associated with wind turbine noise at all three wind farms is not associated with low frequency noise but is the audible modulation of the aerodynamic noise ...*

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