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Are There More Definitive Ways to Manage Environmental Noise?

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ABSTRACT

Environmental noise, the name given to sound produced by the activities of humans, is regulated by legislation that aims to achieve an acceptable balance between activities that emit sound energy and activities or situations that exhibit sensitivity to sound. Much of this legislation, or its legal instruments, draws on quantification provided by A-weighted sound pressure levels. There are many instances where the A-weighted level does not provide a particularly realistic measure of impact and there have been some adjustment schemes established to account for attention-attracting features such as tonal features and various forms of modulation. This arrangement appears to have been successful over many decades and currently forms the basis of much environmental noise impact assessment. Even so, there are situations where the apparent level of impact appears to be inconsistent with the appropriately adjusted A-weighted sound pressure level and there have been some strong criticisms directed at the approach. Some of the advantages and disadvantages of this approach are discussed, particularly in relation to sound emitted from industrial activities. The need to assess highly complex sounds and sound propagation regimes in relation to a range of noise sources and receiving environments suggests the need to draw on a wider range of analysis methods. The ultimate intent, to either minimise sound pressure levels or the annoyance that it causes, is still somewhat unclear. This, in turn, has ramifications for the formulation of legislation intended to control the sources of environmental noise.

INTRODUCTION

The considerations presented in this paper result from a desire to manage sounds that are clearly attention-attracting but do not present the technical characteristics, such as tonality, that are relatively easy to identify and quantify.

It is probably reasonable to expect that, if the underlying human response to a specific sound stimulus is sufficiently well understood, it should be possible to estimate the likelihood of subsequent annoyance. There is some clear support for this provided by the dose-response curves synthesised by Schultz [1] for road, rail and aircraft noise. These curves relate the proportion of a community that is annoyed to the A-weighted sound pressure level for each of the three types of transport noise. The curves show that it is possible to establish relationships between annoyance and day-night average dB(A) level for some types of sound. It would appear that it is thus possible to establish the relative annoyance of different noise types. However, the use of Schultz-like curves for such a purpose would have to be treated with some caution because the nature of the source of noise would be expected to vary as a function of the sound level [2]. For example, low sound level traffic is characterised as a series of separated vehicle pass-by sounds whereas high sound level traffic is characterised as a constant stream of vehicles producing a constant high level of sound.

There are some situations that cast doubt on the universal applicability of Schultz-like dose-response relationships. The wide range of human responses, including the apparent almost illogical response of some individuals to low frequency noise [3] does suggest that it may not be possible to achieve a consistent relationship between annoyance and objective noise parameters.

In relation to industrial noise, the lack of a generally consistent Schultz-type response to industrially generated noise is expected to relate to a basic lack of consistency in noise character between one industry and another. It does, however, highlight the importance of achieving an empirical appreciation of the annoyance response.

What is, then, a reasonable level of noise from an industrial activity, a major construction job or a rock concert?

A WORKING EXAMPLE

The noise produced by large merchandising wood chippers has resulted in many complaints over the years. These chippers usually consist of a large disk, containing 6 or more radial knives or blades, spinning on an axis set at about 45 degrees to the log feed direction. The resulting sound is very dependent upon the the components of the chipper system including the motor or engine, drive system, knife configuration and the in-feed throat that directs the logs towards the rotating blades. Some chippers are driven by large electric motors that tend to operate at constant speed while others utilise diesel engines that can reduce their speed significantly when under load.

The emitted sound can include a harmonic series of tones based on the blade-passing frequency but this is not always the case. The amplitude of the sound generally increases significantly when chipping, compared to idle conditions. There is generally a change in the sound as a log is fed into the chipper, partly due to the acoustic influence of the length of the log remaining and partly due to changing conditions in the chipper throat. The net result is something like a long growl for each log that is chipped, with individual growls displaying some similarities and some differences from each other.

INITIAL REACTION TO SOUND AND ITS CONTROL

Everybody has a story about an annoying sound. There is probably a good reason for this – sounds are designed to create an impression. Or more correctly, those that hear do so to aid their chances of survival and thus forming opinions about specific sounds is an important life skill.

It is surprisingly easy to form opinions about the impact of environmental noise. It seems completely reasonable that the level of annoyance increases as the level of the noise increases. With similar logic, it also seems reasonable that a schedule of noise limits could be devised that would ensure that noise did not cause annoyance – in a similar fashion to enforced speeding limits.

The issue is, however, significantly more complicated than this simplistic analysis. What is it about the sound from the chipper that creates an adverse reaction? There are several dimensions to the evaluation of the impact of noise that are outlined in the following sections.

THE NORMAL GENERATION AND INTERPRETATION OF SOUND

Before considering a person's reaction to a specific noise, it is worth remembering that sound is generated by many things and we make use of these sounds as part of our normal sensing of the nearby surroundings. Our sensing capacity is extended by some very clever neuron-based interpretation. Some of this interpretation is carried out in fast-response logic which provides rapid response to potentially threatening situations. Visually, this could result in ducking out of the path of a fast moving projectile. Similar responses can result from auditory stimuli such as a plover squawking just behind your head. These immediate and often evasive responses can also be evoked by virtual stimuli that are incorrectly assessed as potentially threatening. There is usually an appreciation of motion or dynamics associated with this type of response. Binaural listening ability provides directional information and changes in both differential intensity and pitch change increase our sensitivity to moving sources of sound.

There are also many types of sound that take somewhat longer to resolve but are still identified and assessed quite rapidly. Short duration sounds that fit this category include bird calls, animal growls, the glumpf of waves on the beach and the soft tread of a foot-fall on the path behind you in a dark place at night. These sounds can be, technically, quite poor in structure but present to the auditory system as highly textured and very identifiable sounds.

Thus, the importance of a sound to the listener is not particularly related to its absolute intensity but more to the potential threat it may indicate or any valuable information it may relate.

Annoyance associated with chipper noise has often been reported for receptors located many kilometres from the chipper and so it appears that the absolute intensity is not particularly important. The chipper clearly offers no threat to a listener located several kilometres away. Thus it seems that there are other issues that can lead to annoyance.

WHAT DO WE REALLY HEAR

The brain appears to have the capacity to translate things seen or heard into conceptual equivalents that are split into source characteristics and the distance to the object. Visually, this could be perceiving a piece of paper not in terms of it angular size but as a piece of A4 paper at a perceived distance and orientation. This can only be achieved if there is some suitable evaluation of the distance to the object. Experience with spatial location and binocular vision provide significant help in making estimates of distance to visual objects. Similarly, there are aural and visual queues that provide estimates of the distance to audible objects. This effect is referred to as constancy and aural aspects of constancy have been studied by Zahorik and Wightman [4] who suggest that arrival time of echo signals in reverberant spaces is one method for aural-only determination of distance to the particular sound source. Other subtle acoustic effects, such as the air's preferential absorption of high frequencies, could also provide an indication of distance. This work and the discussion on loudness constancy by Schlauch [5] indicate that listeners have the potential to estimate the emitted sound power of a sound source.

Mono recordings completely lack angular resolution and also tend to lack distance depth, apart from what can be gleaned from signal strength. This indicates that, although the ears are not highly directional, the human binaural hearing system greatly increases the awareness of spatial aspects of sound sources. The value of binaural recordings over mono recordings for subsequent evaluation of sound sources within a soundscape has been strongly supported by Genuit and Fiebig [6].

Thus, it is likely that we, and many other animals, perceive sound as identified sources at estimated distances, rather than a set of separable signals of estimated signal strength. This is certainly what occurs for visual objects and it appears that, where possible, sound objects are treated similarly.

The interesting consequence of loudness constancy is that sound from sources such as industrial activities may be preferably perceived in terms of the identified source and its emitted acoustic energy. This would indicate that a loud source is not necessarily loud at the listening location and the full description of the perception is ‘the chipper is surprisingly loud considering that it is 2 kilometres away’.

THE BUILDING BLOCKS OF REAL SOUNDS

There is no doubt that frequency analysis has provided an enormous assistance to understanding practical acoustic signals. The use of spectrograms, the display of high resolution frequency spectra as a function of time, allows for the identification of signals that have resolvable tonal components that may or may not be changing with time. Frequency modulated signals, warbles, bird chirps, insect noises, the doppler frequency shift of passing aircraft and the gear shifts of passing vehicles are all detected with good clarity. There are, however, some sounds that are clearly discernible by the human ear but don't show particularly identifiable or detectable patterns when subjected to spectrogram analysis. Sounds like growls fit this category; they are obvious to the human ear and give us a clear message but their spectrograms can be insipid when imbedded in normal outdoor sound.

When considering the various audible stimuli that we mentally package into discrete sounds, we don't necessarily hold pure tonal components as particularly important nor do they hold, above other components, the main information imparted by the sound. Most of the important everyday sounds are not particularly tonal and it is possible that our auditory system has a particular ability at decoding these types of sounds. Non-tonal sounds can be very important, particularly if they are grunts and growls produced by predatory animals that can move much faster than us.

The penalties for tonality and modulation used for the evaluation of industrial noise may, thus, be a little bit too specific and should probably be treated as special cases of a more general attention-attracting descriptor.

LESSONS FROM PSYCHOACOUSTICS

There are two clear aspects of psychoacoustics that have relevance to the understanding of human reaction to environmental noise. The study of psychoacoustics within the laboratory has provided an amazing range of detail regarding the human auditory system's response to various types of sound stimuli, together with the implications of degraded sensitivity through disease and poor listening environments. For practical reasons, the listening experiments of classical psychoacoustics intentionally excluded much of the real-world context of normal auditory experience. Even so, it has demonstrated that being able to audibly identify the source of a specific sound has a relatively minor significance when evaluating its loudness but can strongly influence its annoyance [7]. Psychoacoustic research has also shown that it is possible to construct a loudness meter that consistently shows good agreement with subjective evaluation but that A-weighted measurements can give poor agreement with subjective evaluation [7].

Thus, loudness, annoyance and the A-weighted sound pressure level at the listener’s ear can be independently influenced by sound characteristics.

In recent years there has been increased focus on the real-world context of the evaluation of sound under the title of Ecological Psychoacoustics [8]. There is an indication that the perception of dynamic, real-world sound stimuli does no necessarily align with that of static stimuli. This is not particularly surprising given the response of animals in general, and humans in particular, to acoustic or visual stimuli that are indicative of potentially threatening situations. This would suggest that evolutionary processes have influenced the development of the human auditory system, possibly to a very significant degree, and may also suggest that sounds that are more attention-attracting tend to be of a type that is significant for evolutionary advantage.

The human auditory system has surprisingly fine frequency resolution, typically 0.7% of the frequency above 500 Hz for detection of pitch modulation [5]. There also seems to be a strong recognition of repeated sounds, the closer the repeated sound is to the first occurrence the stronger the subjective impression. These types of sensitivities may have evolutionary-advantage origins but appear to play a part in increasing our awareness of sounds that contain features such as mild pitch modulation and temporal repetitions. As a consequence, these features are often present in alarm and warning sounds.

The chipper example contains some of these mild sound components, even though it may not contain strong, clearly identifiable components.

IMPLICATIONS OF LIVING IN A SOCIETY

Freud, in Civilization and Its Discontents [9], identifies some of the advantages and disadvantages for an individual living within society. In particular, the individual benefits from protection and support but suffers the loss of freedom and the need to conform. Within an ordered, civilized suburb an individual no longer has the freedom to make as much noise as they may desire. The choice of a place to live, sufficiently removed from all other activity, so as to provide assured peace and quiet, is only available to those who are prepared to accept reduced services, subsequent higher building costs and greater time and cost travelling to and from work.

Not only does the individual have to suffer the moral restrictions placed upon them by the community at large, along the lines of treat your neighbour as you would like to be treated, but the State will generally pass laws to achieve some agreed level of both acceptable living standards and general order. Lord Devlin, in The Enforcement of Morals [10], considers issues such as moral and alternative justification for various parts of the law, freedom of the individual versus the security of the State, safety, order, moral welfare, the need for the law to change as civilization advances, and the level of good behaviour expected relative to that enforced by the statutes.

The issue here is a community's justification to formulate particular laws to control noise. Protection of basic health an welfare, with its clear moral justification, is certainly consistent with the need to prevent high noise levels that are likely to lead to hearing damage. The control of noise by statute at lower levels really becomes an environmental protection action with its own justifications, moral or otherwise. Environmental noise, at moderate to low intensity, does not have a consistent and definite point at which it is clearly undesirable. Thus, there is some latitude to balance the noise from a project against the benefits to the community at large, and nearby neighbours in particular. This balance can change with time.

Sometimes there is a behavioural dimension where the noise in question was produced by an inappropriate action. This tends to be more common for the individual noise maker than for large corporations. It would seem reasonable to treat these situations as behavioural problems rather than noise problems.

CHANGING CODES FOR THE RATING OF INDUSTRIAL NOISE

British Standard BS4142, Method of rating industrial noise affecting mixed residential and industrial land, has undergone an interesting change since its first publication in 1967 [11]. The original edition stipulated measurements made using a meter set to A-weighting and slow time response and included corrections for tonal character, impulsive character and a correction covering intermittency and duration. The standard then goes on to briefly describe the measurement of the 'background or ambient noise level' and to how to establish an alternative to this measurement using basic and corrected criteria. Situations, based on the relative magnitude of these levels, are then identified where complaints are to be expected and where complaints are not expected. The criteria are based on a basic criterion of 50 dB(A) with adjustments for type of installation (old but in character, newish but out of character or new activity), type of district (industrial area, general industry, urban/light industry, urban, suburban or rural residential), time of day (day, evening and night) and season.

The most recent edition or this standard, BS4142 : 1997 [12], also includes a measurement protocol for background noise level determination, based on the L_{90} in the absence of the noise in question, but no longer includes the alternative criteria scheme. The industrial noise level, corrected for attention attracting features, is called the rating level. In line with the original 1967 edition, the 1997 edition bases its assessment on the likelihood of complaints – when the rating level is about 10 dB or more above the background noise level complaints are likely, a difference of 5 dB is considered of marginal significance.

Both the 1967 and 1997 editions BS 4142 include a rating correction, referred to as a 'tonal character correction' in 1967 and 'the noise contains a distinguishable, discrete, continuous note' in 1997, described as 'whine, hiss, screech, hum etc'. These descriptions may not be identified as 'tonal' in other codes of practice on the assessment of environmental noise and is an example of the flexibility of language that can occur in these types of document.

Both versions include a comment to the effect that if the rating level is more than 10 dB below the measured background noise then this is a positive indication that complaints are unlikely. This is highly likely but the comment would seem to be somewhat at the extreme low end of practical reality, particularly if 5 dB above the measured background is expected to be acceptable.

The 1967 edition provides some indication of expectation for levels of background noise in different land use types against which the level of noise from industrial activities can be compared. In the latest edition the variation of background noise level with area type is not present and the actual, measured background is the only basis for a performance criterion. A variation of expectation with land use is present in the New South Wales Industrial Noise Policy [13] where acceptable levels of noise from industrial activities vary as a function of land use type.

Land use planning is relatively dynamic, meaning that planning practice does not always place particular types of activity within appropriately zoned areas. Thus, there may be some discrepancy between the land use zoning of an area and the activities within the particular area. This raises the added complexity as to whether the noise criteria for an area should align with the land use zoning or the actual existing land uses.

SOME ANALOGIES FROM VISUAL ASSESSMENT

In some recent projects involving visual assessment [14], people were asked to rate a series of photographed scenes. The inclusion of open water in a scene significantly increased the perceived value of the view, almost irrespective of the amount of water that was visible. On the negative side, any long shed that had similar dimensions to chicken sheds tended to decrease the value of the view disproportionately when compared with scenes that included different shaped sheds. It is assumed that this latter effect was related to adverse publicity relating to battery hens. These influences suggest that the observer is not particularly driven by the angular extent of objects in their view and allows preconceived values to flavour his or her acceptance of visually similar objects.

The opinions of professionals and stakeholders regarding the rating of scenes did not always align with those of the general public. This difference of opinion related to both specific items in the scene and the spatial proportions and distribution of different object types.

There are certainly some similarities between these visual perceptions and auditory perceptions, which indicate that the mechanism of contemplated acceptance may be similar for visual and sound scapes. The ability of people to rate different visual scenes suggests that a similar approach may operate for rating different acoustic environments.

DISCUSSION

Several discrete considerations can be identified from the foregoing sections:

- A certain amount of noise can generally be considered to be normal and reasonable. Thus, it is not necessary or appropriate to attempt to aim for no audible sound at noise sensitive receptors such as dwellings, hospitals etc. resulting from the operation of noise generating activities such as factories, construction, entertainment and the like. On the other hand, there is potential for significant annoyance, loss on acoustic amenity and general interference from inappropriately elevated levels of noise.

- When determining appropriate noise levels it is necessary to achieve a balance between the expectations of the individual, and this may be a specific individual, and the workings of the community. Part of this is the determination of an appropriate level for a given noise within a particular setting and part is the management of expectations.

- Specific noises can contain attention-attracting features that significantly increase the potential for complaint. Several such features have been recognised in most codes of practice for the assessment of noise impact. Typically these features are included as a correction or penalty of between 5 and 10 dB on top of the measured or predicted A-weighted sound pressure level.

- There are other issues, such as the sensitivity to sound source power and sensitivity to textured, subtle components, which should become part of the management of environmental noise. Ideally, these issues can be incorporated into an objective, dB(A) noise limit style framework.

There is, in the case of discrete industrial activities, an argument for regulating the sound power rather than the resulting sound pressure level at noise sensitive receptors. The loudness constancy effect would be addressed by this approach. This approach would also eliminate the need to incorporate meteorological influences into the evaluation of compliance; they would, however, remain part of the initial assessment process. Compliance could be evaluated at close range with significantly greater certainty. For the chipper, it would be necessary to establish an appropriate sound power level for the operation having regard to proximity of houses, background noise conditions, identified and expected meteorological influences on propagation, land use and sound qualities of the source. A measurement strategy using nearby measurement locations would be used to establish compliance.

CONCLUSIONS

"There are things which cannot be encapsulated by any finite collection of rules or procedures. Beauty, simplicity, ugliness, and truth are all prospective properties. There can be no magic formula that can generate all possible examples of attributes like these, even in an infinite lifetime. They are inexhaustible. No program or formula can generate all examples of beauty or ugliness; nor can any program recognize them all when it sees them, and nor can we, in the ways that the romantics imagined." - John Barrow [15].

This probably means that there can never be a totally definitive way to manage environmental noise. And although it is unlikely that these words were written with environmental noise in mind, they do seem to ring true when considering the variety of sounds, both anthropogenic and otherwise, around us and the variety of responses that we exhibit as individuals.

Even so, some success has been achieved over the years. Given the real-world reactions to environmental noise and the results from both traditional and ecological psychoacoustics, it would seem appropriate to revisit some of the underlying assumptions of contemporary environmental noise assessment and regulation legislation, particularly:

- those surrounding the use of A-weighted frequency response measurements,
- noise limits set at background plus 5dB – probably without any knowledge of the pre-existing background noise level,
- the importance of the sound power level of a noise source compared with the resulting sound pressure level at the listener's ear, and
- the importance of difficult-to-measure but attention-attracting characteristics.

This may not be easy due to a perceived loss of certainty in the minds of project managers, environmental consultants, assessors and regulators. Ideally, certainty in establishing realistic expectations needs to be managed first. The more technical aspects, including acoustic engineering, numerical prediction and psychoacoustics can then be used to achieve these established expectations.

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