Audibility of Transportation Noise

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Abstract

A lack of information as to why noise created by transportation may be "loud but acceptable" compared to "audible and annoying" to an individual is creating problems in resolving noise issues. For example, people complain about tire noise, but what is tire noise and why is it "noisy"? Traditionally, land-based transportation noise has been described using a range of dB(A) descriptors; many of them are variations on a theme (Leq, L10 and so on). By contrast, aircraft noise has more sophisticated perceived noise level criteria. Common dose-response data tends to describe noise that affects the community rather than individual sensitivity and annoyance. Developing a methodology to measure and assess audible intrusive noise and correlating to individual sensitivity and response is part of a continuing research program at Massey University, Wellington, NZ. The Paper presents a snap-shot of the aims and methodologies of the research, plus some of the problems found.

Introduction

Where noise is a problem it makes good sense that the noise should be measured and assessed in such a way that a person can be confident that his or her concern is being properly addressed. Finding the tools to do both for noise that is just audible or is part of some other significant noise source has been a major problem as nearly all methodologies in standards or legislation are refined towards "loud" noise rather than "quiet" noise. The research program outlined in this Paper had to initially establish some goal posts and rules for the game. That is, to develop a methodology to measure and assess low-levels of intrusive noise and to better understand the relationship of people to such noise.

Goalposts

In the recent past the common theme of environmental noise management methodologies, standards and regulations is that noise criteria, social surveys and assessment procedures support the "dose-response" relationship model where an average level in dB(A), or similar, is all that is needed to describe the effect of noise on people. A considerable range of variations to the theme have been introduced over the last 20 years but the dB(A) theme endures. By and large noise assessment, especially for transportation noise where some situations may require "model only" assessments (airport noise, for example), has become concerned with measuring only noise "levels" above certain criteria, or something that could be clearly heard and defined by some form of independent assessor.

This is clearly not satisfactory for a significant minority of the population. What is true is that many people are not satisfied with being told that the noise they hear is below "the criteria" and therefore no problem exists. This largely ignored group is significant; from between 5% to 20% of the population, depending on the attitude of people who report they have severe or moderate annoyance from 'noise'. Perhaps worse, for some, is when an independent assessor cannot hear or measure the noise in question and concludes that the noise does not exist. There are two significant issues not clearly identified by existing environmental noise assessment methodologies-

The first issue concerns noise that is clearly audible but just below the assessment criteria or which has an identifiable character that is difficult to assess. This is termed "low-level" noise in this Paper. For example, aircraft noise heard inside a dwelling but below a maximum level of 45 dB(A) is within the generally accepted WHO [1] noise criterion for acceptable interior noise amenity, yet can be disturbing to recipients due to the fact the noise is always overhead and cannot be avoided. That is, an emotional or sensitivity element is creating or enhancing a noise issue.

The second issue is noise that just intrudes into a person's consciousness. The noise may be distinctly audible or have definable character or it may be almost inaudible to anyone except the person. At this point it may be near of below the nominal threshold of hearing. This is termed "intrusive" noise in this Paper. By definition "intrusive noise" is sound that is audible to a person and which has distinctive characteristics that make it annoying or disturbing. For example, to the author at least, engine noise (fan belt squeal?) and air pressure release valve purging from Brisbane City buses.

Rules for the Game

Continuing our “Goalposts” theme, we need to get some “Rules for the Game”. Low levels of intrusive noise, that is, noise that is only just audible, is a very real problem to many people. This problem is increased by a general lack of knowledge on how to handle, assess or describe what the noise or problem actually is.

Some of the “rules” considered in the research program are definitions of what is to be measured or assessed and why. After considering these points the ‘how’ of measurement is considered.

Individual response to noise

When an individual responds to "noise", the person is responding to a stimulus that is noticeable within the general sound environment in which that person is living. The environment is made up of a variety of sound sources continuously varying in level and over time with only a few sources, relatively speaking, actually causing noise. Noise in this context means sound that is unwanted as it is out-of-character with the environment that the individual finds acceptable.

An individual may react differently to noise from a combination of sources than to noise from a single source at the same level. Equally, other persons in the vicinity may not be disturbed by the so-called noise. Traditional noise management control is often based on predicting the effects of a given sound level exposure from all sources on a community. The potential for an individual to be disturbed is then estimated from the overall exposure. That this approach is not satisfactory on an individual basis has been widely reported.

Generally speaking, for a sound to become noise, it must cause annoyance or distress to a person. The psychological mechanism for this transformation of sound to noise varies widely from person to person. Annoyance has been defined (WHO) [1] as "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them".

Noise sensitivity and individual attitudes

Individual noise sensitivity is a personality trait covering attitudes towards a wide range of environmental sounds (Ellermeier et al, 2001)[2]. Noise sensitivity is a major precursor to individual noise annoyance (Job 1988) [3], second after noise exposure.

Conceptually, *noise sensitivity* is clearly distinguishable from *noise annoyance*. Measures of annoyance show a clear positive correlation with indices of noise exposure, whereas noise sensitivity measures are independent of exposure. Noise sensitivity modifies various effects of noise including reaction and sensitivity to particular noise sources. Sensitivity to a particular noise source may influence reaction to a different noise source to some extent, such that reaction to a combined noise source would involve a complex interplay of noise sensitivities.

Attitudinal and social surveys have come under intensive review [4] over the last few years and standardised surveys for community response and individual noise sensitivity have been widely published. The same intensity of review has not been given to the physical measurement and assessment of the intrusive nature of noise. The quantification of 'intrusive' noise, or 'nuisance' noise, is subject to an assessment of individual sensitivity to the noise in question (that is, *why* is the sound *noise*) and measurement of the physical characteristics of the noise in combination with all other sound sources. There is no consensus on a model for assessing low levels of intrusive noise. Negative reactions to noise may include dissatisfaction, annoyance, anger, frustration, disappointment, anxiety, helplessness and/or distress. Reaction is generally regarded as an important effect of noise exposure and has been examined in many community surveys, most of which have focussed on the relationship between annoyance and sound pressure level. These surveys generally identify a relatively high positive correlation between sound exposure and grouped reaction, independently of which noise source was considered.

Annoyance

The current analysis of annoyance response to sound from combined sources can be summarised as belonging to measures of sound exposure (most often time-average Leq levels), loudness, noisiness or some form of 'noise and number' assessment. Annoyance commonly signifies an individual's reactions to sound based on its physical nature and its emotional content and novelty (Kryter) [5]. Kryter has defined two general classess of "unwantedness" - one in which the information conveyed is unwanted and one in which annoyance is from the physical content of the sound and not the because of the 'meaning', if any, of the noise. He considered that even though the absolute level of noisiness or unacceptability of the noise from a given source may differ somewhat among people, variations in the frequency content, duration, and spectral complexity have the same relative effect of the noisiness perceived by each individual. His concept of noisiness excludes the emotional content and novelty aspects of annoyance and identifies only the physical nature of the unwanted sound. Stevens [6] summed up the response of people in a more succinct form: "..the public has a four letter word for unwanted sound. It is L-O-U-D." But he also commented that there is little hope that acceptability (of noise) can be measured in any useful sense when meaning and context are allowed to change. Noise can produce many social and behavioural effects, often complex, subtle and indirect, as well as annoyance. These effects are assumed to be the result of the interaction of physical characteristics of sound, including sound pressure level, spectral characteristics, and variations of these properties of noise with time, with non-acoustic factors. The impact of a reaction may range from a minor disturbance, to a substantial loss of life quality, to profound debilitation.

Frustration, Stress and Anxiety

While difficult to assess, the emotional attributes of noise must be considered as it is these attributes that lead to complaint and hence, a noise-affected person. Some persons responding to intrusive noise have reported high levels of frustration, stress and anxiety. By anxiety, its meant the unpleasant emotion characterised by terms like *"worry", "apprehension", "dread"*, and *"fear"*. If initial attempts at coping are unsuccessful, anxiety intensifies and the individual becomes more rigid in his or her efforts and less able to perceive alternative solutions to the problem. Individuals cope with anxiety by focussing on the problem (finding ways to change or avoid the anxiety-producing situation) or by focussing on the emotion (finding ways to reduce anxious feelings rather than attempting to deal directly with the anxiety-producing situation). Either way the individual feels stressed. How much stress a person feels depends on-

Predictability: being able to predict the occurrence of the stressful event, even if the individual cannot control it, usually reduces the severity of the stress.

Control over duration: having control over the duration of a stressful event reduces the severity of the stress. A person's belief that he or she can control the duration of an aversive event appears to lessen anxiety, even if the control is never exercised or the belief is erroneous.

Cognitive evaluation: what the event means to a person. The same stressful event can be perceived quite differently by two people, depending on what the situation means to the individual. The objective facts of the situation are less important than the individual's appraisal of them.

Feelings of competency: a person's confidence in his or her ability to handle a stressful situation is a major factor in determining the severity of the stress.

Social supports: the availability of emotional support and concern of other people can make stress more bearable.

Correlating the above attributes into a valid assessment regime is a significantly part of the research.

Measurement of Sound and Noise

My original assessment was that intrusive noise is very similar in character to a "bum-note" or someone off-key in music; easily heard and has a describable affect on the listener. The "bum-note" may not be noticed by anyone but a person who was actually interested in the music or it may be so bad even a tone-deaf person would hear it. The concept, I believe, is readily translated into all forms of environmental sound. The only problem is in actually recording and measuring the sound, and then assessing its effect on individuals. So, what are tools currently available and how useful are they?

A Short Overview

Kryter [5] identified six significant, measurable physical aspects of a sound most likely to control its noisiness: (1) frequency spectrum; (2) sound level (3) spectrum complexity (concentration of energy in pure tones or narrow frequency bands within a broadband spectrum; (4) duration of the total sound; (5) duration of the increase in level prior to the maximum level of non-impulsive sounds; and (6) the increase in level of impulsive sounds within an interval of 1 second. He also differentiates between 'loudness' and 'noisiness'. Kryter developed the PNdB methodology for calculation of perceived noisiness but, apart from the EPNdB method for aircraft noise, the methodology has not gained wide acceptance. This is possibly due, in large part, to the fact that the instrumentation to implement the methodologies have, until recently, been expensive and difficult to implement. The methodologies for loudness have enjoyed a better degree of acceptance, with Zwicker's method being implemented by various sound level meter manufacturers. But again, the instruments are expensive and uncommon in comparison to sound exposure methodologies and instruments.

Young [7] in an evaluation of transportation noise presented a comprehensive analysis of the measurement of noise level and exposure. This evaluation has been expanded upon by Schultz [8] with a large number of measurement methodologies being reviewed. However, published works in recent years appear to have "lost" this earlier research and instead concentrate on the use of dB(A) sound levels as the sole measure of "noise". The work in early years tended to concentrate on noise from transportation, which is of a relatively defined nature, whether from aircraft, rail traffic or road traffic. Environmental noise consists of these sources plus noise from industry, neighbours, loud music, discrete events, and so on.

What human listeners are most interested in is the type of source and what it means to them, and they are not directly interested in tonal or impulsive content, as such. Hence measurement alone is not sufficient to assess noise.

Research instrumentation

The traditional methods to assess noise have been to either take noise measurements in the field or to take a recording and then analyse the data back at the office. The noise data would then be assessed against some legislation or arbitrary standard or guideline and the person told if he or she was deemed to have a problem. Rarely, if ever, is the person affected by the noise actually interviewed in detail about his or her reaction to the noise. That this approach is flawed is evident but to date has been the only practical approach to most noise assessments.

In preparing for this research, a different approach has been taken. Instrumentation is used in its broad sense and includes traditional noise measurement instrumentation, as well as more detailed instrumentation to analyse sound signals and automated templates for socio-acoustic analysis (individual sensitivity vs community dose-response assessment).

The "traditional" measurement instrument is a type 1 integrating-averaging sound level meter to provide the "traditional" time-average Leq and statistical data. The instrument includes FFT and digital filter signal processing, a wide range of automatic templates for ratings or procedures (loudness, noisiness, tone, impulsiveness and so on) and audio files. There are only a few systems on the market that can do this type of analysis and none of them are inexpensive. All systems require extensive manual intervention in order to be used properly and are highly time consuming to use. Instrumentation to measure complex sound environments does not exist in a relatively inexpensive commercial form. Instrumentation to assess the meaning of the measured levels and to link with human reaction to an identified noise source does not exist.

Work to date has concentrated on developing a high quality and inexpensive sound recording system that will operate with home computers. The system consists of a two channel high quality soundcard, high-quality microphones and preamplifiers, calibration routines and two channel recording software. Two channels are used: one for interior recording and one for exterior recording. Audio files are compressed with lossless compression, rather than lossy compression such as MP3. Using compressed audio has resulted in some tonal elements being lost as the compression routine decides the information is not important and discards it. Another significant problem was recording audio data as separate tracks onto recording media (CD disks). This is an issue with the burning software. Instrumentation to record sound must be of a high-quality. For this research a range of only 60 dB (nominally 10 dB to 70dB) is required but the noise-floor of the instrumentation is close to the lower levels that are of interest in this research. The noise floor is also close to the minimum audible field for sounds below 200 Hz.

Sounds often have tonal character. Much discussion has been made about what is tonal and how it is to be measured, as well as the "penalty" that should be given to sound that has "tonality". It is fair to say that this is still not resolved even with the latest revision of the International Standard dealing with environmental noise assessment. This Standard [9] suggests an analysis method as shown in Figure 1. To do this is not easy and requires a sophisticated sound level meter supported by equally sophisticated software. Additionally, to date the research to support the tonality assessment and associated "penalty" is not readily available.

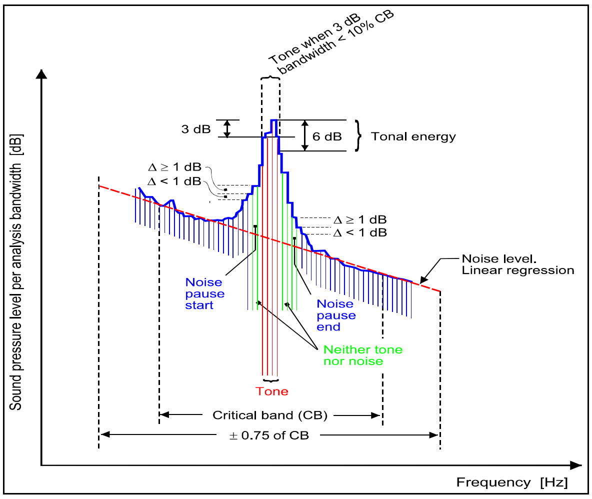

Figure 1. Identifying a tone (ISO 1996-2003-2 draft).

My research indicates that there are other alternatives to the ISO approach. The alternatives are well known in the transportation quality assessment world. The assessment methods are not simple and are more solidly grounded in psychoacoustics research than in attitudinal survey response data.

Methodology

The methodology of the research consists of three broad, interlinked strands.

The first strand adapts published benchmark community attitudinal survey questions and individual noise sensitivity questions to develop a new set of "intrusive" noise survey questions. The new questions investigate individual reaction to noise and noise annoyance, attitude to the noise source, noise sensitivity and personality factors.

The second strand utilises published procedures for measuring sound. [9] This includes standard measures such as the time-average level (Leq), maximum and statistical levels, third octave levels for calculation of various ratings, critical bands and perceived noisiness, FFT spectrum (nominally 1Hz per line) over the range 20Hz to 20,000Hz. FFT is calculated with a Hamming window and 66% overlap. The analysis methodologies are published in standards or benchmark reports and guidelines (from the USEPA, for example). Interior and exterior sound levels are recorded as the fabric of the building and room design can modify the sound immission. The sound recordings are taken in 10 minute blocks of time in order to characterise the environment, interior and exterior. The interior levels are further analysed to characterise identified intrusive noise.

The third strand integrates published psychoacoustic procedures [10] for sound quality and individual human response. The intrusive noise elements identified in the interior sound recordings are analysed for standard measures such as audibility, loudness, pitch, timbre, tone to noise ratio, prominence ratio, dissonance, sharpness, fluctuation strength, roughness, unbiased annoyance, tonality, threshold in quiet and just noticeable differences in amplitude and frequency. The person's responses to the identified intrusive events are tabulated, analysed and described. The response and measurement variables are correlated to provide a relevance matrix.

"Ordinary" software implementations (such as from Artemis™ and 01dB™ systems) and Psysound [11] are essential for analysis procedures but they unfortunately are only part of the tools needed. The biggest problem found to date has been the time needed to analyse a 10 minute file. At present it takes about 1 hour, which is too long. The essential part of the file analysis is representation through waterfall and sonograph / spectrogram visualisation of sound file. This makes the noise events easier to conceptualise.

Conclusions

Research is in progress at Massey University, Wellington, NZ, for a new methodology to measure and assess "low-level" intrusive noise, as it affects individuals. New measuring instrumentation, analysis methodologies and assessment protocols have had to be developed to do this. The outcome desired is a single number representing noise sensitivity-response and a single number representing noise exposure. Combined, the two numbers represent an intrusive noise rating (INR). The research has direct application to assessing the audibility of transportation noise and, in particular, levels and types of noise that currently difficult to assess.

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