Unexpectancy in environmental noise assessment

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In this paper, we report a new hypothesis that indicators of environmental and community noise which take the relative unexpectancy or unpredictability of a sequence of environmental noise events into account could offer additional greater explanatory power compared to than any of the various forms of A-weighted equivalent level (L_{Aeq}) that are becoming increasingly adopted into existing regulations. This hypothesis is based on two key observations; a) that even though the relationship between L_{Aeq} and overall disturbance or annoyance is known to be relatively weak, there are at present no alternative frequency weighting schemes (for example, the B, C and D-frequency weightings, or the so-called equal loudness level weightings based on ISO 226 or ISO 532b) which can reliably discriminate between different noise sources with known differences in annoyance response at the same long term average equivalent levels; and b) that many noise exposed residents report that they 'get used to' or even pay no attention to the noise for most of the time and only become properly aware of the noise or are most annoyed by it when disturbed by particular events which are more noticeable than the rest for some reason or another. Most of the information contained within short term variations in the sound level time history is completely ignored by all forms of energy equivalent averaging.

More specifically, we propose that increased unexpectancy is likely to be associated with increased noticeability thereby leading to increased levels of reported disturbance and annoyance. In this paper, we propose a generic format for expressing unexpectancy in mathematical form and we report some preliminary tests of the discriminatory capabilities of this new class of indicator.

1 Introduction

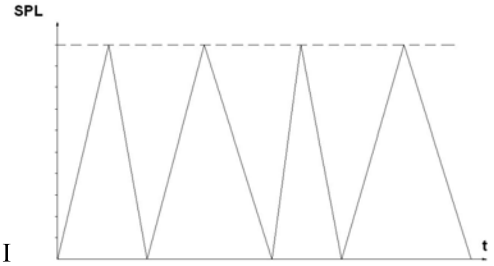
Most countries in Europe are increasingly using some form of A-weighted equivalent level to assess environmental and community noise. However, because the overall relationship between L_{Aeq} and overall disturbance and annoyance is relatively weak, this has stimulated continuing debate about alternative indicators. In previous research [1] the authors investigated similarities and differences between the standard A-frequency weighting; the equal-loudness level weighting (ISO 226); and the ISO 532b version of Zwicker's loudness calculation method using large 1/3rd octave band noise monitoring databases of both general airport noise and single vehicle pass-by events. The results suggested that, contrary to Schomer's earlier findings [2,3], the small differences which were found might not in practice provide sufficient discriminatory power to justify the adoption of any of these alternative schemes. For this paper, we assume that the problem could have as much to do with the method of averaging over time as with the method of frequency weighting adopted. Noting that transportation and community sounds tend to differ more in terms of event profiles over time than they differ in time averaged frequency content [4], we propose a new theory, that indicators which reflect the 'unexpectancy' of separate events could a) distinguish between different noise sources in ways that conventional indicators cannot, and that if a) is true, then b), that unexpectancy could explain some differences in reported disturbance and annoyance which are not explained by more conventional indicators.

2 Theoretical background

Single number indicators such as L_{Aeq} (or L_{den}) have many advantages from the regulatory and administrative point of view but any such advantages are diminished in importance where differences in reported disturbance and annoyance do not conform to differences in the indicated values. To construct any single number indicator, it is necessary to average or aggregate across actual variation which exists in all environmental sounds. For L_{Aeq} and L_{den}, while the method of aggregating across the audible frequency range (the A-frequency weighting) could be important where significant differences in frequency content exist, the method of averaging out across variations in the time domain (so-called equal energy averaging) could be of equal or greater importance, particularly in the case of known differences in reported disturbance and annoyance between different transportation noise sources [5-8]. It is well-known that conditions with marked differences in sound level profiles over time could have the same L_{Aeq} or L_{den} even where reported disturbance and annoyance is different.

For example, work by Meidema and others [6-9] shows that aircraft noise can be generally more disturbing or annoying than road traffic noise and road traffic noise can be generally more disturbing or annoying than railway noise when present (separately) at the same L_{Aeq} or L_{den}. Both aircraft and railway sound level profiles over time generally have much wider variation than typical road traffic sound level profiles over time. While this suggests that the range of variation from the highest to the lowest sound levels could be important, it does not account for the finding that aircraft noise is generally considered to be more disturbing or annoying than railway noise. An additional factor which may be important here is that except for receiver locations right at the end of the main runway in use aircraft noise events are generally much more random than railway noise events which generally follow one another according to a regular timetable. For railway noise, there is often little variation in maximum sound levels and event durations from one train to another (See also table 1.). A succession of railway noise events is likely to be much more predictable than a succession of aircraft noise events when both are present (separately) at the same L_{Aeq} or L_{den}. In the general situation, typical railway noise could therefore be described as having lower unexpectancy than typical aircraft noise at the same L_{Aeq} or L_{den}.

Figures 1a and 1b below illustrate this point. Figure 1a shows a succession of four events with high regularity or expectancy. Figure 1b shows a similar succession with the same overall L_{Aeq} but with lower regularity or expectancy.



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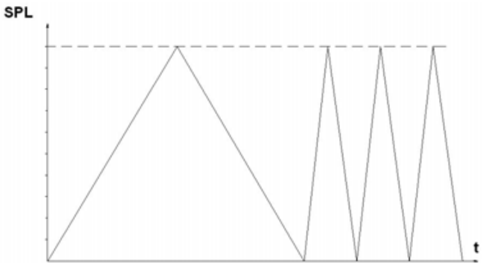

Figure 1 a,b Four consecutive noise events having the same overall L_{Aeq}, but potentially contributing different amounts of reported disturbance and annoyance

Comparing the likely disturbance or annoyance associated with either sequence; in Figure 1a we might assume that a typical listener would be more likely to habituate to repeated events which are all similar to the first event; whereas in Figure 1b we might assume that a typical listener might be surprised by the change in character from the first event to the final three events and report higher disturbance or annoyance accordingly.

3 Statistical analysis of the time history of different noise sources

Ignoring variation in the frequency domain as being outside the scope of this paper, variation which exists between different noise sources in the time domain can most conveniently be described in terms of the following indicators:

$\mathbf{L_{Aq}}$	equivalent level
$\mathbf{L_{max}}$	Maximum Level
$\mathbf{t_e}$	Event time,
$\mathbf{t_r, t_f}$	rise and fall times at the beginning and ending of each separate event
N 24	Number of events (in this example counted over 24 hours)
$\mathbf{t_p}$	time between events

For this paper, a number of 24-hour sound level recordings were collected for the statistical analysis reported below. Road traffic noise recordings were made in various locations around Budapest to collect representative samples of passenger cars, HGV-s and passenger coaches in town single-lane traffic, rural highways (speed limit 80 km/h), and motorways (speed limit 130 / 80 km/h). In addition to this various engine conditions have been investigated such as hill climbing, hill descent, acceleration and braking. For railway noise, several different types of passenger-, freight trains and single locomotives were recorded, at speeds varying from 50 to 130 km/h. For aircraft noise, recordings were carried out close to the take off and landing routes of a major Continental European airport. The noise recording location is exposed only to aircraft noise depending mainly on the runways in use at the time and on the direction of the wind. The types of aircraft recorded ranged from the larger Boeing 767 to the smaller Fokker 70, the recordings also included ATR 42 type turboprop aircraft. The recordings were evaluated using a Larson Davis 2900B analyser.

Depending on the distance from the road to the receiver and on the amount and type of traffic, and particularly at the higher levels of exposure, road traffic noise generally has short event times with associated short rise and fall times and a relatively narrow range from the equivalent to the maximum level. (Figures 2. - 4.) The range of variation from the equivalent to the maximum level is generally quite small because successive events generally overlap in time with correspondingly short times between successive events. Railway noise typically has many fewer events than typical road traffic noise with longer event, rise and fall times and a much narrower range of variation between successive events. When operating to a timetable, there is much less variation in the time between successive events than in the case of random traffic flows such as on roads. Aircraft flyovers tend to be the most variable because of differences in traffic and weather conditions from one day to the next and also because older and larger aircraft tend to be much noisier than more modern and smaller aircraft which can all be operating within the typical mix of aircraft types at each airport.

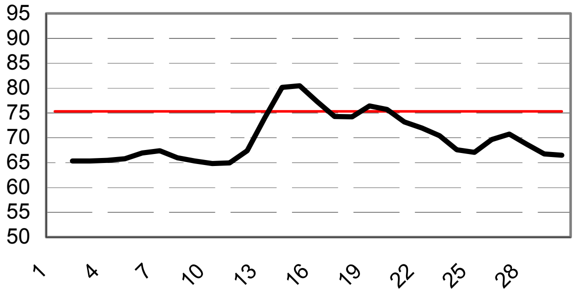

Figure 2. Representative road traffic pass-by

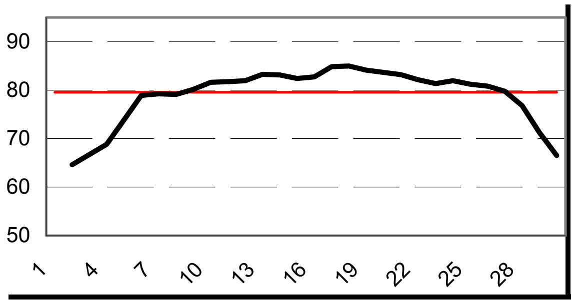

Figure 3. Representative rail traffic pass-by

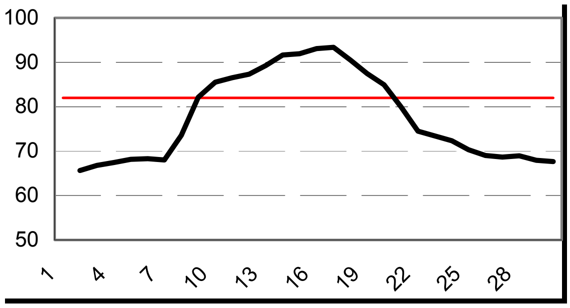

Figure 4. Representative aircraft flyover

Table 1. A statistical summary of representative single pass-by measurements

		average	var.	
Road traffic	L_{Aeq}	78	3,3	dB
	L_{max}	83,5	4	dB
	Te	4	1	s
	t_r, t_f	2	0,3	s
	N24	-	-	
	Tp	1	-	s
	L_{max}- L_{Aeq}	5,5	2	dB
Rail traffic	L_{Aeq}	82,9	2,4	dB
	L_{max}	89,9	3,1	dB
	Te	25	4	s
	t_r, t_f	10	2	
	N24	220	30	
	Tp	1800	380	s
	L_{max}- L_{Aeq}	7	2,6	dB
Air traffic	L_{Aeq}	84,1	4,1	dB
	L_{max}	94,2	7,1	dB
	Te	11	3	s
	t_r, t_f	4	0,4	s
	N24	198	17	
	Tp	850	1900	s
	L_{max}- L_{Aeq}	10	3,4	dB

Table 1 summarises the results of a statistical analysis of a large database of in-field measurements of road, railway and aircraft noise.

4 Theory of unexpectancy

L_{eq} is logarithmically proportional to the averaged sound intensity (measured in watts per square metre) at a defined receiver point over a defined period of time. The average sound intensity can be calculated from the aggregate total sound energy per square meter (measured in joules/per square metre) divided by the time, which can in turn be calculated from the separate energy per square meter per event, multiplied by the number of events and then divided by the overall time.

This leads to the following relationship:

$$L_{eq} = 10 \log N + 10 \log M - 10 \log T + c \qquad (1)$$

Where

N is the number of events

M is the separate energy per square metre per event

T is the overall time

c is a constant (effectively a scaling factor) which is required when taking the various decibel reference quantities into account but is not important for this theory.

From the relationship given by equation (1) above it can be easily seen, that the L_{eq} increases up to the L_{max} (the maximum sound level during each separate event) as the number of events within the overall time increases or as the separate energy per square metre per event increases. This is consistent with the assumptions underlying the use of L_{eq} as an indicator of community and environmental noise in many situations but not in all. In many situations, reported disturbance and annoyance does indeed appear to increase as the number of events and/or the separate energy per square metre per event increases, but there are also situations where reported annoyance and disturbance appears to increase as the difference between L_{max} (the maximum sound level during each separate event) and L_{eq} increases. This situation can arise where the duration of each separate event is quite short or where there are relatively few events within the overall time period. In addition, reported disturbance and annoyance appears to be influenced by the regularity of the sequence of separate events, possibly because it is harder for listeners to habituate to more irregular sequences of separate events.

For this paper, we define unexpectancy as the opposite of predictability, and note that unexpectancy can be defined both objectively and subjectively. Subjective unexpectancy depends not only on the characteristics of the noise events themselves but also on the state of mind of the individual concerned and might be affected by the degree of absorption in a distracting task. For regulatory and administrative purposes we are much more concerned with objective unexpectancy, which if it turns out to be useful when predicting reported disturbance and annoyance, might be amenable to regulation and control whereas subjective unexpectancy would not be. Objective unexpectancy describes the extent to which future events can be predicted from the recent time history. For example, an event which precisely conforms to a regular pattern set up by previous recent events has low objective unexpectancy whereas an event which stands out from any regular pattern previously experienced has high unexpectancy. The following separate statistical indicators can be combined to derive an overall indicator of objective unexpectancy;

var {L_{max}}	variance of the maximum level of the single events in a sequence
var tp	variance of the time between the maximum levels of single events in a sequence
var dt_p	variance of the differences of tp from the expected average
var N/T	variation of event numbers per time unit
T	total measurement time

For this paper we ignore the additional unexpectancy associated with possible differences in frequency spectra or short term time history between the separate events occurring in an overall sequence. We define objective unexpectancy U as a function of the variance in maximum levels and in the time between separate events in two possible ways as follows;

A) Formula (2), consists of two parts; the variation of the maximum levels and the logarithmic value of the variation of the time differences over a total period are added together. The constants x and y are influencing the weight these two parts take on the total index.

$$U = x * \mathrm{var}\{L_{\max}\} + y * \log\left(\frac{\mathrm{var}\{t_p\}}{T}\right) \qquad (2)$$

B) The second formula (3) represents the effect of variation over time slightly differently, in that it is the variation of event times before and after the times they would be expected if they were all equally spaced in time which is taken into account rather than the variance in actual times from each event to the next.

B) $$U = x * \mathrm{var}\{L_{\max}\} + y * \log \mathrm{var}\{dt_p\} \quad (3)$$

Both formulae use easy measurable parameters; the maximum levels L_{max} and the variance over time can be recorded and evaluated with simple statistical algorithms.

By the time of submitting this paper the detailed subjective testing of the formulae has not been finished. The relative advantages and disadvantages of the two formulations will only become apparent after those further tests whether or not this type of analysis can contribute additional explanatory power to the analysis of existing databases of reported disturbance and annoyance.

5 Conclusion

Previous analysis [1] suggested that whereas the standard A-frequency weighting might have a number of deficiencies when applied to certain kinds of environmental noises, such as sounds with high levels of low frequency content and sounds with both higher and lower sound levels than the average, it was unlikely that adopting either of the more complicated equal loudness level based indicators over and above the standard A-frequency weighting for environmental noise measurements would solve the problem. Because the overall frequency spectra of typical aircraft, road and railway noise sources are often much more similar than they are different, there are limited opportunities for alternative frequency weighting schemes to be able to discriminate between them. However, differences between the typical time histories of these different noise sources are often much more significant than any small differences in frequency content and seem much more likely to be able to provide additional explanation for observed differences in reported disturbance and annoyance. We have therefore proposed an additional indicator of unexpectancy which takes differences in the predictability of a noise event sequence into account based on the variance in event maximum sound levels (L_{max}) and the variance in the time of each event or the variance in the time between successive events.

Future work will consist of comparing the results of those formula with large scale social survey data for traffic (land or air) noise annoyance.

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