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NOISE CONTROL FOR A BETTER ENVIRONMENT

Environmental Noise Analysis – A Rethink

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ABSTRACT

Objective: To improve current methodologies for the evaluation of environmental noise impact.

Methods: Historical methods of environmental noise analysis have been reviewed and their limitations described. A method of analysis allowing noise impact on a statistical basis has been developed. Records of ambient noise in areas having different land usage have been examined and recent guideline criteria issued by the WHO have been analysed using the statistically based method in the context of those land area uses.

Results: The NSW road noise policy results in traffic noise to exceeding ambient noise levels more than 80% of the time and by more than 25dB(A). New WHO guidelines provide a positive control of traffic noise for residential areas, though will fail to preserve the quiet areas also encouraged by the WHO.

Conclusion: The proposed methodology demonstrates a more intuitively useful measure of noise impact from environmental noise sources than those in current common use and is likely to be understood by both technical and non-technical stakeholders.

Implication: The methodology facilitates a link between noise measurement and research work based on soundscapes, and between regulatory noise management policy and the expectations of the general public.

Keywords: Environmental noise assessment, inverse transformation sampling, modelling, audibility, WHO guidelines, NSW EPA legislation
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1. INTRODUCTION

Environmental noise is commonly evaluated using broad-band A-weighted sound pressure level measurements and predictions. The A-weighted metric has been in common usage for decades, reported [Hohmann, 2013] as early as 1936 and standardised [Beranek, 1960][ASA, 1944] as early as 1944. The original work from which the A-weighting evolved was the development of equal loudness contours for human hearing by Fletcher and Munssen. According to Beranek, the electronic frequency approximation was established as three steps, being the A-weighting for levels less than 55dB, the B-weighting for levels between 55 and 85dB, and the C-weighting for levels above 85dB. While experienced practitioners have noted limitations evident in the practical application of the A-weighted measurement result [Scannel,2003], the continuing and widespread use of the broad-band A-weighted sound pressure level over such a sustained period for this work appears to be reasonable evidence of technical robustness.

Subjective assessment of environmental noise forms an important component explored by researchers working on soundscapes [Lercher, Schulte-Fortkamp, 2003]. Regulatory and predictive procedures must necessarily be based on numerical design and assessment criteria, ideally examined within frames-of-reference that will continue to evolve from soundscape research.

The hypothesis examined by this paper is that the reduction in measurement uncertainty achieved using energy-averaged sound pressure levels is outweighed by the greatly superior findings obtained when assessment is carried out statistically.

2. NOISE IMPACT ASSESSMENT CONCEPTS

The underlying concepts used in noise impact assessment are well known. Briefly, the process involves a measurement assessment of the ambient noise environment, distillation of the background level from that data (originally deemed to be the threshold level to which the ambient regularly descended [AS1055,1973]), identification of an appropriate imposed level characterising the source under review (initially described as the average of regularly occurring maxima [AS1055,1973]), and the relative comparison of the imposed level with the pre-existing background level.

Subjective weightings have been recommended to recognise the subjective aspect relevant to environmental noise – tonal, impulsive and intermittency being the three most common. An oft-noted guidance was a recommendation that the assessment impact value (avge max – avge min) should not exceed zero, noting that exceedances of up to 5dB were considered marginal [AS1055, 1973]. The 5dB-exceedance rule in use today [EPA, 2018] was an outcome of analogue measurements used at the time during which an operator was able to perform both subjective assessment and objective measurement concurrently.

The environmental noise assessment hypothesis is that the contribution from a new source can be characterised by a single variable (the source level), that the ambient noise environment against which the changes and outcomes from that source will be heard can be characterised by a single variable (the background noise level), and that the magnitude of the difference between the future ambient noise environment and the existing environment can be quantified by the simple arithmetic difference between those levels.

Important technical limitations affect this generic procedure. Legislative terminology [DECC,2011;EPA,2017] implies that 'the source' is physically discrete, operationally definable and infer an outcome that will increment an existing ambient environment by some sort of fraction. Assumed is the technical pre-requisite that receivers are physically in the acoustical far-field. In fact, predictions and assessments now commonly involve systems rather than sources, that may be both physically mobile and of larger physical extent than the impact area being examined, may frequently involve multiple sub-sources at least some of which are in the acoustical near-field and for which differing compliance criteria are suggested. Development projects commonly involve outcomes amounting to a major change of land area usage, and not simply to the impact on existing occupants within the development area.

3. ANALYTICAL OBJECTIVES

Many outcomes are of interest when considering an environmental impact due to two concurrent conditions (ambient A and imposed B). These include:

- What is the probability that B will exceed A at any time?
- What are the magnitudes of that exceedance?
- What will be the statistical noise levels of the future ambient levels (A+B)?
- What relative change to any given measurement statistic is expected (e.g. $L_{10,B} - L_{10,A}$)?
- All of the above, but for conditions A, plus numerous $B_1 \ldots . B_N$ future sources of interest.

By extension, the analysis of these parameters provides a powerful basis for the consideration of relative audibility likely to be experienced by a community. This can facilitate an objective basis for cost-benefit analysis of outcomes achieved by alternative mitigation and planning options.

4. PSEUDO-STATISTICAL ANALYSIS

A steady-state, or stationary, noise system is one for which the emission level is constant regardless of the observation period and the associated level manipulations are relatively simple. For a stochastically variable noise system, the objective in using an equivalent energy sound level (L_{Aeq}) is to enable the variable noise system to be considered in the same manner as a stationary noise system. The use of any aggregate noise level statistic alone – L_{Aeq}, L_{A10}, L_{A90}, L_{Amax} etc – stems from a belief that a stochastic system can be examined using the same techniques that can be used for a stationary system.

This assumption is fundamentally flawed, in so far as a sequence of observations at random instants of time for the variable system will not satisfy the conditions defining a stationary system. Any conclusion is unlikely to accurately reflect an observation, and any measurement is unlikely to correlate with a complaint.

5. DATA SAMPLING AND MODELLING

5.1 Inverse Transformation Sampling

Environmental noise varies almost constantly. It is common to survey and report a range of statistical measurement parameters when examining environmental noise. These typically involve the minimum (L_{100}), maximum (L_0), the L_{90}, the L_{10}, frequently the L_1 and usually the L_{eq}. Acoustical convention dictates that a cumulative distribution function derived from a noise measurement sample denotes the probability that the sound level L has a value greater than or equal to b.

$$F(b) = P\{L \geq b\} \qquad 1$$

This is the inverse of the conventional statistical definition for the cumulative distribution function, wherein F denotes a probability that a random variable X has a value less than or equal to b [Ross, p90].

The data obtained from a statistical noise level survey is an array of known data points, representing sample points on a continuous numerical function. Using interpolation between known data points to produce a level probability distribution function, measured data representing a noise generating system can be statistically sampled using inverse transformation sampling based on equation 1. That is, knowing the probabilistic values of L represented by F, randomly selected instantaneous values representing L may be determined using a uniform random number [0,1] selection.

Statistical modelling using inverse transformation sampling involves the conceptually simple process of simultaneously sampling instantaneous levels for two independent conditions of interest – in a simple case an existing ambient noise environment defined by CDF1 into which a new level-varying noise defined by CDF2 will be introduced – and adding the two levels together to produce a resultant instantaneous level outcome [Fitzell,1991]. Using iterative summation, a sequence of instantaneous aggregate level conditions can be compiled, the statistics of which define the outcome aggregate level statistics applicable to the combined noise condition.

5.3 Level Addition

The addition of two instantaneous incoherent sound pressure levels, L_1 and L_2, is straightforward, being determined using equation 2.

$$Lsum = 10\log(10^{\frac{L1}{10}} + 10^{\frac{L2}{10}}) \qquad 2$$

For steady-state noise the probability that the value of L equals b is 1, or where the probability that L has a value greater or less than b equals zero. For steady-state noise, predicting the outcome summation is trivial. In this case, not only will the value of L equal b, the value of Leq will also equal b.

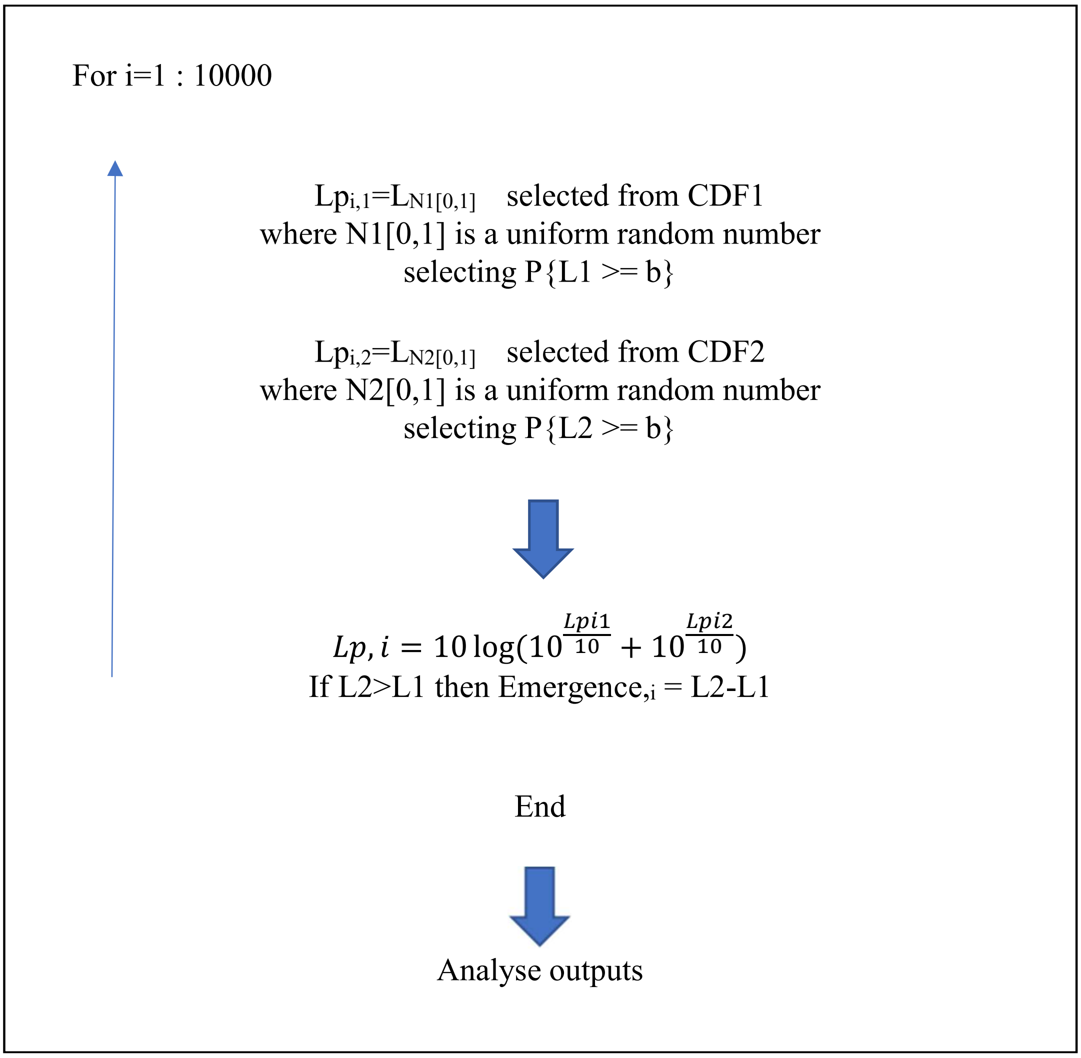
An equivalent energy sound pressure level for each of $L_{eq,1}$, $L_{eq,2}$ and $L_{eq,sum}$ may be calculated using equation 3, which is logically derived from equation 2, calculated over the number of samples representing the measurement or analysis period:

$$Leq = 10\,log\left(\frac{\sum 10^{\frac{Li}{10}}}{n}\right) \qquad for\ i = 1\ to\ n \tag{3}$$

5.4 Proportional Representation and Conditional Probability

When one of two or more components is present only part of the time it is necessary to co-ordinate sampling and summation. This requires a conditional probability function for that component so that sampling of the partially present component is appropriate.

If a component is known to operate one-third of any given period, summation modelling could simply sample for that component at each third *Lsum* iteration. More practically, a set of N presence functions will be required for a noise system involving N contributing components. Each presence function is simply a fraction representing the probability of 1 for the condition present, and zero for the condition absent, applied at each summation using a uniform random number [0,1]. For environmental applications the probability that ambient noise is present is always 1, though this may often not be the case for the components to be imposed.



For i=1 : 10000

$Lp_{i,1}=L_{N1[0,1]}$ selected from CDF1
where N1[0,1] is a uniform random number
selecting P{L1 >= b}

$Lp_{i,2}=L_{N2[0,1]}$ selected from CDF2
where N2[0,1] is a uniform random number
selecting P{L2 >= b}

$$Lp, i = 10\log(10^{\frac{Lpi1}{10}} + 10^{\frac{Lpi2}{10}})$$

If L2>L1 then Emergence,$_i$ = L2-L1

End

Analyse outputs

Figure 1: The reverse transformation modelling algorithm

Conditional probability is an important element in the assessment of multiple-component noise systems, allowing for multi-stage sources, intermittently operating sources, and overall influence factors that may be present such as systematic diurnal variation. The underlying assumptions described by conditional probabilities should be documented and provide an unambiguous framework describing the noise impact assessment for the project.

5.5 Interpolation Issues

Uncertainty can be aggravated by the acoustical measurement convention where the percentile statistic describes the probability that the value of a randomly selected sample from that population will exceed the value of that statistic. As this contrasts with the statistical convention where a percentile describes the probability that such a sample will be less than the reported value, understanding the origin of any data being used is fundamental.

Increasingly non-linear level increment occurs with environmental noise sources as percentiles of interest approach the extremes, affecting the sampling process. A useful improvement to accuracy achieved by sampling based on simple linear interpolation was found to be the addition of triangular median value interpolation points between each pair of statistical metrics. Two interpolation test statistics were used to validate data interpolation techniques, based on raw data statistics of L_{max}, L_1, L_{10}, L_{50}, L_{90} and L_{min}:

1. The predicted equivalent energy level calculated from interpolated datasets were compared with the measured equivalent energy levels, and
2. Statistical parameters for a one-hour measurement period, compiled by merging of interpolated arrays from sequential short statistical periods – 15 minute and 1 minute were compared with directly measured metrics for the same one-hour periods.

Survey data (N=54) expanded by linear interpolation to a dataset produced a mean outcome calculated Leq vs measured Leq error of +1.4dB(A) with a standard deviation of 1.62dB(A). Adding triangular interpolation for the same data reduced mean Leq error to +0.4dB(A), with a standard deviation of 1.52dB(A).

Considering shorter periods and larger data sets using median triangular interpolation, N=226 and N=670, for 15 minute measurement period data, produced mean Leq error of -0.12dB(A) and -0.16dB(A) respectively, with standard deviations of 0.77 and 0.29dB(A) respectively. That is, using a median triangular interpolation is likely to result in a systematic calculated Leq error of the order of +/-0.2dB.

The largest error due to interpolation effects was found to occur for the metrics between L_{10} and L_{max}. While this suggests further smoothing using multiple triangular median interpolation points may lead to improvement, the mean error due to interpolation can be seen to be less than 1dB and almost certainly sufficient for most practical applications.

5.6 Level Subtraction

A problem frequently affecting the measurement of noise immission at a measurement point due to a specific source is the uncertain contribution to that measurement from ambient noise. Considering environmental noise on a statistical basis without discussion of statistical level subtraction, for which opportunities are limited, would be incomplete.

Inverse transformation summation can be used to iteratively estimate the contribution from concurrent level-varying sources, in some cases reliably, if something is known of the statistical levels describing the contribution of at least one source. Initial estimates can be benchmarked using the parameter relationships that are frequently known – Lmax, Lmin and Leq, however if only the Leq contribution from either the source or ambient is known, no additional statistical contribution data can be derived.

6. ANALYTICAL OUTCOMES

The following summarises the outcomes using reverse transformation sampling addition based on three case studies assuming a typical, relatively quiet, residential area. This is described by the statistical levels shown in Table 1.

Table 1: Example ambient noise level data

	$L_{A,max}$	$L_{A,01}$	$L_{A,10}$	$L_{A,50}$	$L_{A,90}$	L_{Amin}	$L_{A,eq}$
Sound Pressure Level, dB	67.3	57.6	49.4	43.3	40.0	37.3	47.7

Three different source data arrays are examined based on data summarised in Table 2.

Table 2: Source noise level arrays

	L_{Amax}	L_{A01}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Aeq}
A source matching the ambient	67.3	57.6	49.4	43.3	40.0	37.3	47.7
Steady state source L90 + 5dB	45.0	45.0	45.0	45.0	45.0	45.0	45.0
Freeway traffic at LAeq 55dB	70.0	62.5	58.6	53.1	48.2	41.1	55.0

The data of Table 1 depicts a typical average statistical ambient level in a relatively quiet residential area. The data in Table 2 for sources 1 and 2 are arbitrary, while source 3 uses raw survey measurement data. The values used for source 3 reflect a daytime traffic noise design aim considered stringent by the current NSW Road Noise Policy [DECC,2011]. Using inverse transformation sampling and the summations discussed above, outcome noise levels set out in table 3 can be predicted.

Table 3: Outcome area noise levels – ambient noise plus the imposed source noise

	L_{Amax}	L_{A01}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Aeq}
A source matching the ambient	69.0	60.8	52.4	46.9	44.6	40.4	50.7
Steady state source $L_{A,90}$ + 5dB	67.3	58.1	50.8	47.2	46.2	45.7	49.6
Freeway traffic at $L_{A,eq}$ 55dB	70.0	63.9	58.9	53.7	49.6	41.8	55.7

In addition to predicting outcome statistical metrics reported in Table 3, powerful measures of relative and intra-statistical parameters can be identified. These include the objective assessment of:

- Probability that noise from the imposed source will be higher than the ambient level
- Measures of emergence or exceedance
- Intra-statistical metrics – e.g. $L_{A,1}$-$L_{A,90}$

It is also evident that there is no simple relationship between the statistics of outcomes in Table 3 compared with those of the input statistics, apart from L_{max}, L_{min} and L_{eq}.

6.1 Noise Emergence and Audibility

Potential to consider audibility is one of the most powerful outcomes. Audibility is a complex issue affected by many parameters, many of which are not in common use in environmental noise assessment or planning. These include frequency content, signal stability, tonality, signal to noise and coherence. Notwithstanding, an A-weighted signal that exceeds that of the surrounding ambient, therefore producing a signal-to-noise greater than zero, is more likely to be audible than one producing a signal-to-noise of zero or less.

Using the examples from Table 2, the probability that the sound pressure level from each of the introduced sources will be higher than that of the ambient at any instant has been calculated and shown, using the term Emergence, in Figure 2. Considering the concept that an "intrusive' noise up to 5dB higher than the average background is subjectively marginal, Figure 2 provides clear insight into the likely audibility of each of the introduced noise sources.

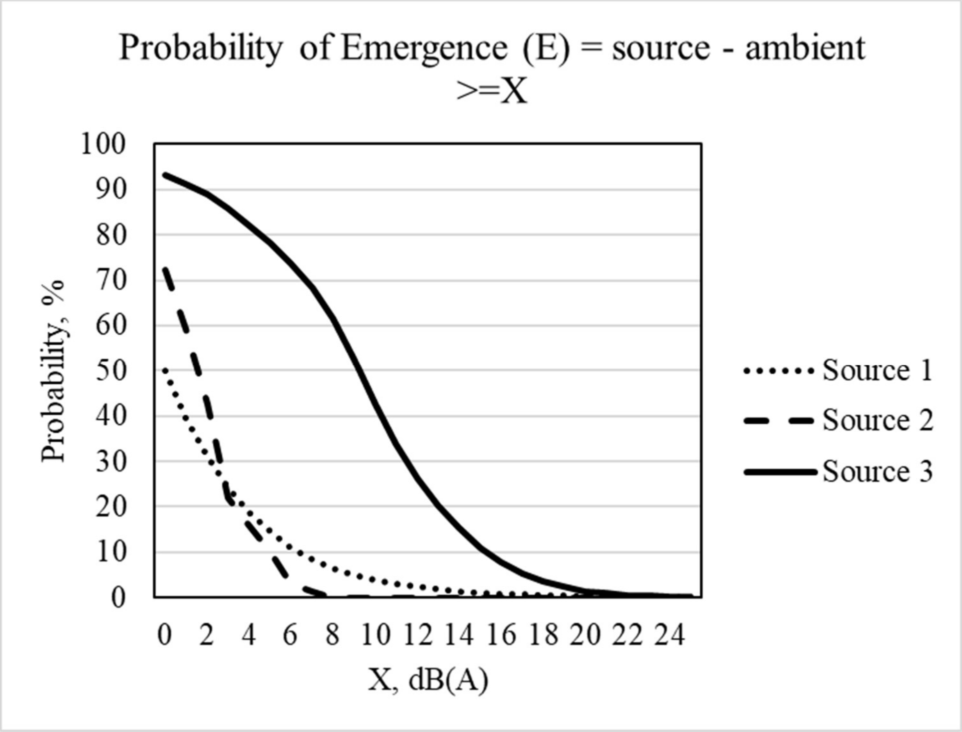


Figure 2: Probability of Emergence [L2 (imposed) greater than L1 (ambient])]

The outcomes shown in Figure 2 are not apparent from any simple inspection of the input level statistics, emphasising the higher level of information able to be achieved using an Emergence assessment compared to analysis based on stationary metrics.

Multiple operating sources occur frequently, for example all three of those of Table 2 in addition to the ambient, and an outcomes test that considers the probability of each individual component dominating the running threshold created by concurrent noise from the aggregate of the others can be applied. This enables an investigation to determine conclusions such as those of Table 4:

Table 4: Outcome noise level dominance

Component	Portion of time dominant by, say, 5dB(A) or more
Existing ambient	1 percent
A source statistically matching the ambient	1 percent
Steady state source $L_{A,90}$ + 5dB	0 percent
Freeway traffic at $L_{A,eq}$ 55dB	31 percent

The inclusion of conditional operating probability to the above examination can further refine the sophistication of findings such as those of Table 4.

Examining correlation coefficients between Emergence and outcome statistical noise metrics suggests that no single statistical measurement parameter is an obvious surrogate producing similar findings to those based on Emergence.

6.2 Application to Road Traffic Noise

The outcomes described in Figure 2 with respect to the road traffic noise example for a suburban area are instructive and it is useful to consider how road traffic noise standards in general might be considered in the context of different land use areas.

WHO have published recent guidelines [WHO,2018] giving recommended criteria proposed for regulatory road traffic noise policy, as well as for other major sources. In the Australian context, adoption of the WHO criteria as policy for road noise design criteria would constitute a substantial improvement (~5dB(A)) to the current standards adopted for road noise impact control.

Table 5: WHO recommended criteria for road traffic noise

	WHO	WHO	Implied	
Recommended WHO metric	L_{night}	L_{den}		
Approximate Australian equivalent metric	$L_{Aeq,9hr}$	N/A	$L_{Aeq,15hr}$	$L_{evening}$
Recommended / required compliance level	45	53.0	51.1	46.1

The WHO recommendations have been considered using the inverse transformation sampling technique to predict likely traffic noise Emergence during daytime and night. This involved superimposing average value statistical metrics based on the WHO guidelines set out in Table 5 above, compared with similar mean metric data obtained by analysis of survey records from Australian locations, sorted by land area usage and generally referring to 15 minute periods.

Table 6: Typical mean statistical levels for traffic complying with WHO guidelines

Description	L_{Amax}	L_{A1}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Aeq}
WHO Day Traffic Guideline	65.7	58.9	53.7	49.3	44.8	39.6	51.1
WHO Night Traffic Guideline	59.4	53.5	47.9	41.2	35.8	31.8	45.0

Table 7: Mean statistical levels for ambient noise in different land use areas

Land Area Usage	L_{Amax}	L_{A1}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Aeq}
Daytime							
Wilderness	60.2	48.5	40.0	31.6	26.5	23.0	38.5
Rural	66.2	55.8	48.0	42.7	39.5	36.3	46.7
Quiet Suburban	69.0	61.4	53.7	46.9	43.7	41.9	50.9
Suburban	77.2	69.1	62.2	55.9	51.7	48.5	59.6
Urban Fringe	73.8	65.6	60.5	56.1	53.0	50.1	58.2
CBD	81.9	73.9	68.7	64.8	61.3	58.0	66.4
Industrial	71.4	64.3	60.3	56.7	54.1	51.6	58.2
Night							
Wilderness	44.6	31.9	26.0	21.7	19.5	17.4	25.2
Rural	55.4	47.5	41.9	36.8	33.2	30.5	39.8
Quiet Suburban	54.3	48.7	43.7	40.1	38.3	36.9	41.7
Suburban	69.5	61.6	54.7	50.0	47.8	45.6	52.9
Urban Fringe	67.7	60.5	55.0	50.9	48.4	46.0	53.1
CBD	76.3	69.1	63.5	58.3	55.0	52.5	61.1
Industrial	65.6	60.5	56.4	53.4	51.8	49.9	55.1

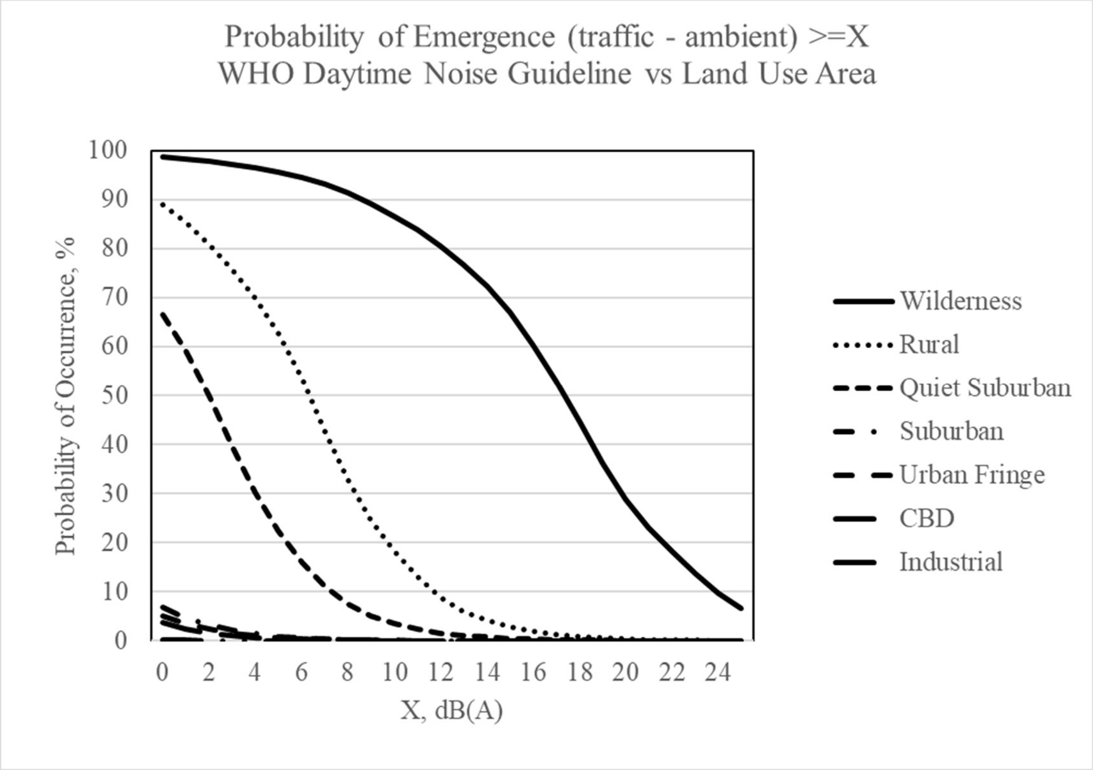


Figure 3: Probability of Emergence, WHO daytime road traffic guideline

The Emergence values of Figures 3 and 4 obtained clearly show the WHO guidelines provide excellent conditions for residential and commercial areas, though not for rural or wilderness areas. These outcomes suggest that policy based on the WHO noise level criteria alone will not preserve quiet areas, encouraged by both the WHO [2018] and of interest to soundscape researchers [Lercher and Schulte-Fortkamp, 2003].

Reviewing correlation coefficient for Emergence vs statistical noise level metrics, for this example of road traffic noise, suggest that changes to the L_{A1} noise level metric is the most useful parameter on which to base design of road traffic noise mitigation.

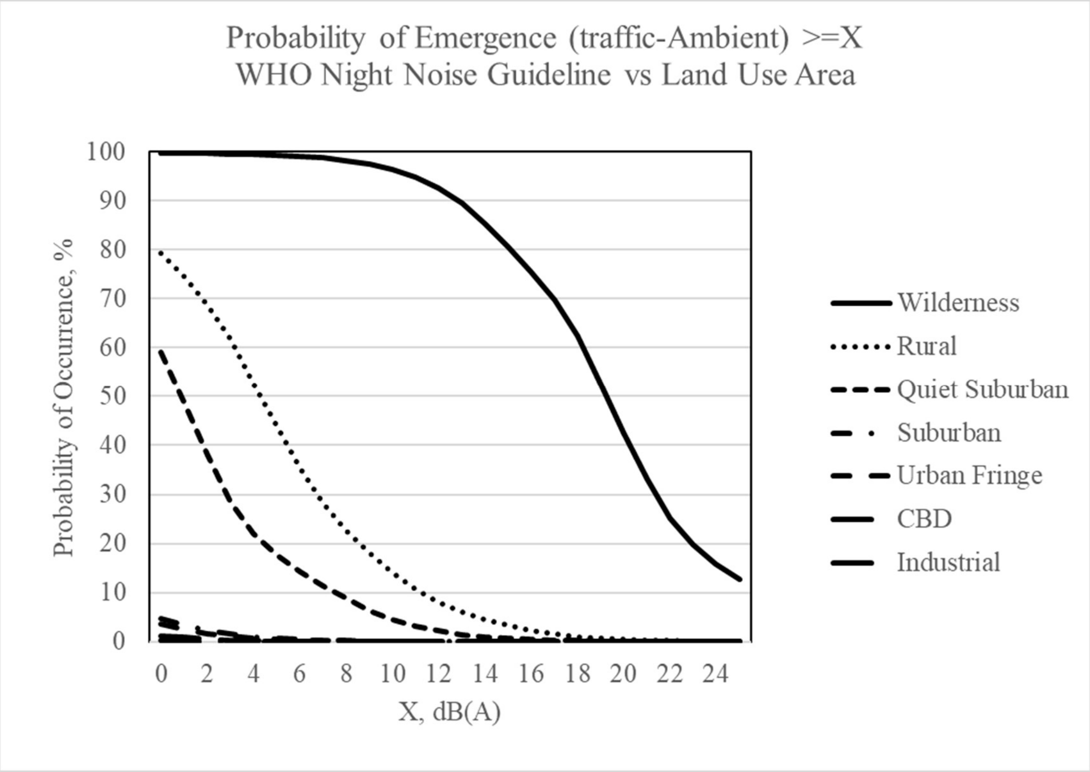


Figure 4: Probability of Emergence, WHO night road traffic guideline

7. CONCLUSIONS

Studies of multi-factorial noise environments have experienced limitations due to the use of quasi-stationary noise metrics. The use of the equivalent energy level to assess management strategies is not sensitive to changes that occur statistically, particularly as regards loud noise events, nor able to identify fundamental changes that will affect the subjective nature of an area. Stationary metrics provide no effective basis for understanding properties relevant to quiet areas. The equivalent energy level is not understood, intuitively, by laymen who represent the stakeholder community adversely affected by environmental noise.

Regulators have included statistical noise level design criteria, supplementing equivalent energy criteria, despite the fact that no procedure has existed for the prediction of those statistical levels. Such criteria can only be applied retrospectively and are of little or no planning benefit.

The reverse transformation modelling procedure proposed by this paper does enable the prediction of outcome statistical noise levels and, more importantly, a prediction of the probability that an introduced noise source, or a collection of sources, will exceed the ambient at any instant of time. These principles can be applied to the analysis of any stochastically varying noise source or system. The outcomes provide a useful guide to the probability that a new source will be audible to occupants of an area impacted by a proposed development project. These analytical outcomes will provide an improved level of certainty for regulators, planners and the stakeholders to any development proposal.

An important legacy of the process is foreseen to be unambiguous documentation of the operating basis describing a development proposal, increasing both transparency and accountability in the assessment work carried out by a designer and in the undertakings made by a development proponent.

8. ACKNOWLEDGEMENTS

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