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Noise impact and its magnitude

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ABSTRACT

This paper researches and proposes criteria for the assessment of environmental noise impact. Limitations in current methods of assessment are particularly evident when considering moving and stochastically varying noise systems, and when considering impact from development that may be a cause of, or related to, change to land usage. The paper proposes a statistically based method of impact prediction and assessment based on Emergence and benchmarks the findings against long-established principles of impact assessment. The paper demonstrates that Emergence, and therefore impact, is a complex parameter unable to be simply evaluated using stationary noise level metrics. The paper identifies important aspects of noise impact that are omitted by current noise impact assessment procedures and recommends both a methodology and associated acceptance criteria for a more rigorous impact assessment method, considering both active and passive aspects of impact.

1 INTRODUCTION

In the judgement handed down by Justice Moore AJ (NSW LEC, 2015), overturning a development consent granting approval for temporary use of a structure as a function centre, important considerations arose concerning "the fundamental nature of the test required" when considering impact. That test, imposed by a Local Environment Plan clause drafted from the NSW Model LEP (NSW Govt, 2006) and replicated in numerous NSW local government area examples, referred to application to <u>temporarily carry out an otherwise prohibited land use</u>, for which the LEP requires that development consent must <u>not</u> be granted unless the consent authority is satisfied the use will not adversely impact on any adjoining land or the amenity of the neighbourhood. In precis, professional acoustic reports had been compiled in the context of the assessment criteria promulgated by familiar authorities – EPA, Department of Liquor and Gaming. Council, in turn, had utilised various of the recommendations to formulate conditions of consent. Justice Moore, however, concluded that the nature of the investigations did not constitute a correct test satisfying the requirements of the LEP sub-clause.

The specific plea upheld by Justice Moore was that the acoustical assessments did not address the fundamental test that there be <u>**no**</u> adverse impact (Judgement, cl 69, cl 116, cl 125, cl 126) instead concluding that the predicted impact was considered acceptable. Justice Moore determined that technical standards derived from those applied by an external regulator – OLGR in that case – envisage "*merely an acceptable impact rather than absence of impact*" (Judgement, cl 119). In a further qualification (Judgement, cl 97, cl 102) Justice Moore noted that "*mitigation measures*" do not constitute elimination. There is, however, a broad question raised by Justice Moore's ruling – how does environmental noise assessment quantify the magnitude of an impact and what quantifies an impact that can be deemed satisfactory?

2 THE NATURE OF NOISE IMPACT

Surprisingly, the term "impact" is undefined in NSW legislation, NSW case law and, apparently, in international law. The Oxford definition (Oxford, 2019) of impact refers to "a marked effect or influence", and in the context of the environment the term impact management generally refers to management of a negative effect. The Federal Parliament adopted (Commonwealth of Australia, 1995) a more holistic and fundamental working definition (Hede, 1993) being:

> *The environmental impact of an action is the difference between the state or condition of the environment which occurs as a result of that action being taken or withheld, and the state or condition which would otherwise occur.*

This is a clear and objective description of impact. The intent is unambiguous and considering impact in such a way may overcome the obstruction to communication arising from the arcane nature of acoustical measurement metrics. If adverse impact is deemed a necessary cost to allow economic development, how much impact is reasonable and can that be explained to stakeholders who incur that cost in a framework they can understand? Considering amenity, the term identifies “a desirable or useful feature or facility of a building or place”, and in aggregate to “the pleasantness or attractiveness of a place” [Oxford]. It is possible that a comparison of ambient noise level may help distinguish differences affecting the amenity for two fundamentally similar auditory environments, but level of amenity is not a noise level.

A prediction of noise impact, therefore, requires the identification of the characteristics representing the existing (ambient) auditory environment and identifying which of those characteristics may be at risk of change. Despite members of the community expecting that protection of the environment involves recognition of valuable environmental assets, researchers in Soundscapes (Lercher & Schulte-Fortkamp, 2003) (Brown, 2010) observe that the asset value of an acoustical environment is recognised almost exclusively in the context of building acoustics and rarely in relation to environmental acoustics.

Noise impact, particularly in quieter areas, is complex. Stationary measures – e.g. the L_{Aeq} – L_{A90} - are insensitive to the dynamic conditions associated with acoustical environments and can not describe how stochastically varying noise from a source will rise above the stochastically varying ambient sound. The term emergence (or emergent noise) more effectively describes impact than the common current descriptor of intrusion (or intrusive noise). Intrusion suggests that impact will occur only from louder events and that impact can only be negative - The call of a lyrebird emerged? Or intruded? Noise emergence, and impact, may occur passively - in the quieter passages of the recital, the sound of air conditioning emerged”, or as a flock of birds drifted away, the drone of the freeway emerged. The negative impact of the residual sound is its undesirability in the audible environment and in neither example does the impacting sound rise above the background level.

An impact from any sound source is likely to occur when the level of sound from that source exceeds the ambient sound. Classifying the risk of adverse noise impact, therefore, involves consideration from two potentially different perspectives, one being the protection from changes to aspects of an existing ambient noise environment that are considered valuable, and the other being protection from changes that do not fundamentally alter the ambient environment, but may bring about an undesirable increase in audible noise events. Conceptually, these impacts evolve from passive and active effects respectively and, in this paper, consideration of both “Passive Impact” and “Active Impact” is suggested. Both can be quantified. The magnitude of passive impact is the complement of the probability that the ambient noise will be retained and is the form of impact relevant to locations where conservation or preservation is a priority. For other areas, where annoyance or interference are the primary risks, magnitude of active impact can be estimated as the probability that the imposing source, or sources, will be emergent. In both cases impact commences at zero percent and rises to 100 percent, and in both cases the form of impact considered dominant is a clear basis for communication of the perceived risk.

3 THE CURRENT NOISE IMPACT ASSESSMENT PARADIGM

Over decades, assessment of environmental noise has evolved to a methodology where the noise of a source or activity of interest is quantified as an energy equivalent A-weighted noise level, with the background being quantified as the 10^{th} percentile (or L_{A90}) of the range of A-weighted sound pressure levels occurring within the ambient environment (NSW EPA,2017).

Equivalent energy level metrics have widespread application in regulatory documents. The equivalent energy sound pressure level is a measurement metric, nothing more, nothing less. It requires definition of a duration over which the measurement is determined, and conclusions using that level can have relevance only to aspects of an environment able to be referenced to that same duration. Most assessments relating to environmental noise are carried out over durations rarely less than 15 minutes, frequently an hour, and equally frequently over periods of 24 hours. Where subjective aspects are considered relevant – impulsive noise, tonality etc – the addition of adjustment factors to the observed equivalent energy level are applied. These aspects are not contentious, though their method of application can appear arbitrary.

Background noise refers to the specific 10th percentile metric determined from measurement sampling of the ambient sound at a location. The L_{A90} also applies to a specific measurement period, the most commonly used of which are, probably, 15 minute and 1-hour sample periods, from which it is obvious that between 24 and 96 statistical values can be obtained for any given day of measurement.

4 DISCUSSION

Environmental noise impact assessment involves almost exclusively measurement. However some assessments might need no noise measurement at all, instead identifying the risks of impact and their management. For example, if a proposed activity will attract 30 motor vehicle movements to a site, can 30 compensating current motor vehicle movements be removed from access routes by management? This type of approach is rarely employed.

People react to sound quickly and may remember the effects and impacts for a long time. For critical listening, interference from background sound is reported to commence from as low as 7dB below the signal of interest (Chappel et al, 2016), however it is generally accepted, and research into hearing aids has concluded, that a change of 3dB is a threshold above which reliable auditory outcomes can be expected (McShefferty et al, 2015). Consideration of active impact should include allowance for a just noticeable difference threshold (JND) of 3dB.

As regards measurement useful for noise impact assessment, as the number of concurrent incoherent sources in an acoustical system increases, so the statistical repeatability of measurement metrics converge – in the limit this reaches a steady-state for which all metrics will be equally reliable. Similar effects can apply to subjective aspects and multiple-source systems typically diminish the likelihood that subjective level adjustment factors will apply. These limits, and dominant steady-state sources, represent stationary acoustical systems. Current NSW regulations do invoke consideration of both noise amenity and noise intrusion, however the metrics used, L_{Aeq} and L_{A90}, are suited to stationary systems and provide little insight into emergence in a stochastically varying acoustical environment. In measuring impact as an index equal to L_{Aeq}-$L_{A90,}$ the index is perceived to convey the same information regarding impact whether applied to acoustically pristine land, or to a CBD building.

4.1 Source level measurement issues

The measurement of an equivalent energy level for a steady-state, or stationary, noise event is straightforward and repeatable. However an energy equivalent metric is insensitive to discrete but significant events, increasingly so as the duration of the averaged-sample period is increased. These aspects are examined considering a randomly chosen environmental noise dataset of property boundary sound pressure levels over a 6.5 hour period, during which a number of vehicles parked on a site, a trio jazz concert was held inside a building on the site, a number of periods of outdoor socialising occurred adjacent to the building and the attendees then departed. The latter portion of the sample comprises, primarily, ambient sound from unrelated distant sources.

The analysis used rolling samples, each commencing 1 second apart, of 15-minute, 1-hour and 4-hour LAeq metrics each, shown in Figures 1 and 2. This analysis simulated a sequence of independent analyses that, by chance, commenced one second apart and was designed to show the significance of a chosen assessment period, the influence of the instantaneous commencement time, and the lack of sensitivity of the metric. The method of analysis is not suggested as an assessment technique but is informative in describing the insensitivity of the L_{Aeq} unit. Considering the findings shown in figure 1:

1. All three L_{Aeq} period metrics are strongly influenced by the presence of a short period of relatively loud events (within the first 15 minute period). However, valid L_{Aeq} period level maxima could be reported as 55dB, 60dB or 66dB depending on the choice of the assessment period.
2. If the marked effect of the initial period is excluded from the analysis, the presence of substantial and regular level maxima remaining throughout the first 60% of the data, and their absence in the last 40%, is not distinguished by the rolling energy equivalent metrics shown in Figure 1 – for the 15 minute data perhaps to a small degree but for 1-hour and 4-hour data essentially not at all.

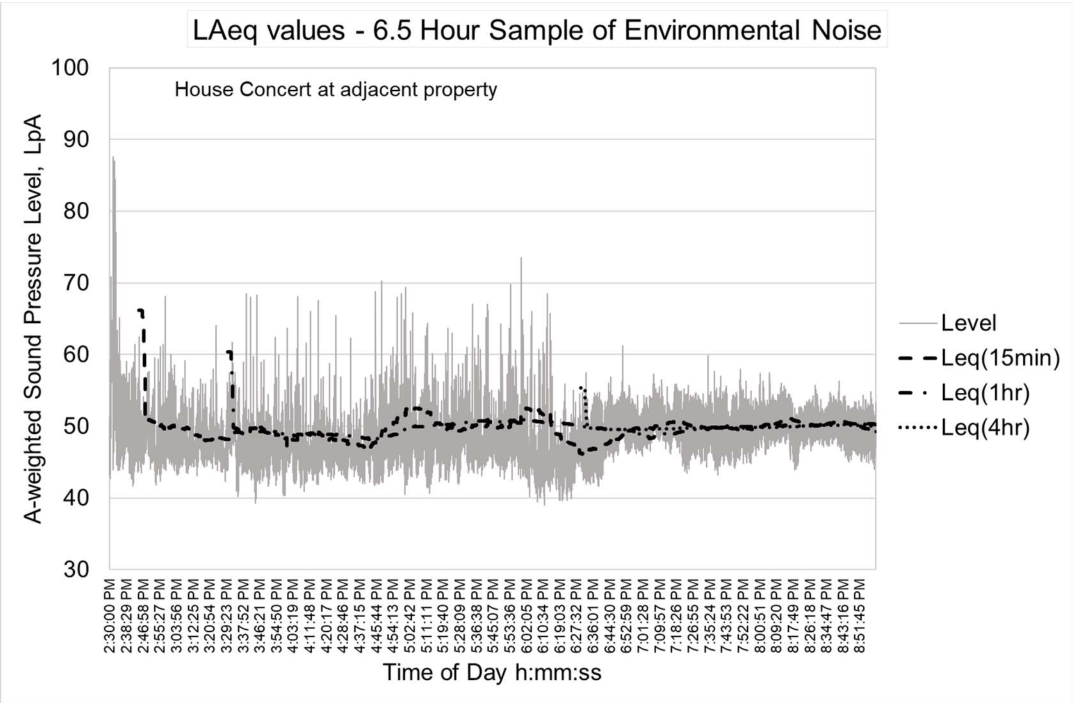

Figure 1: Environmental noise levels and survey L_{Aeq} metrics

Figure 1 demonstrates a systemic problem affecting an energy-equivalent measurement – the optimum assessment interval can only be determined retrospectively having knowledge of the instantaneous noise level variance. While Figure 2 does show that 15-minute period statistically based sound level measurements do respond to the variance of the underlying level waveform. Figure 2 also demonstrates the insensitivity to variance of the L_{Aeq}.

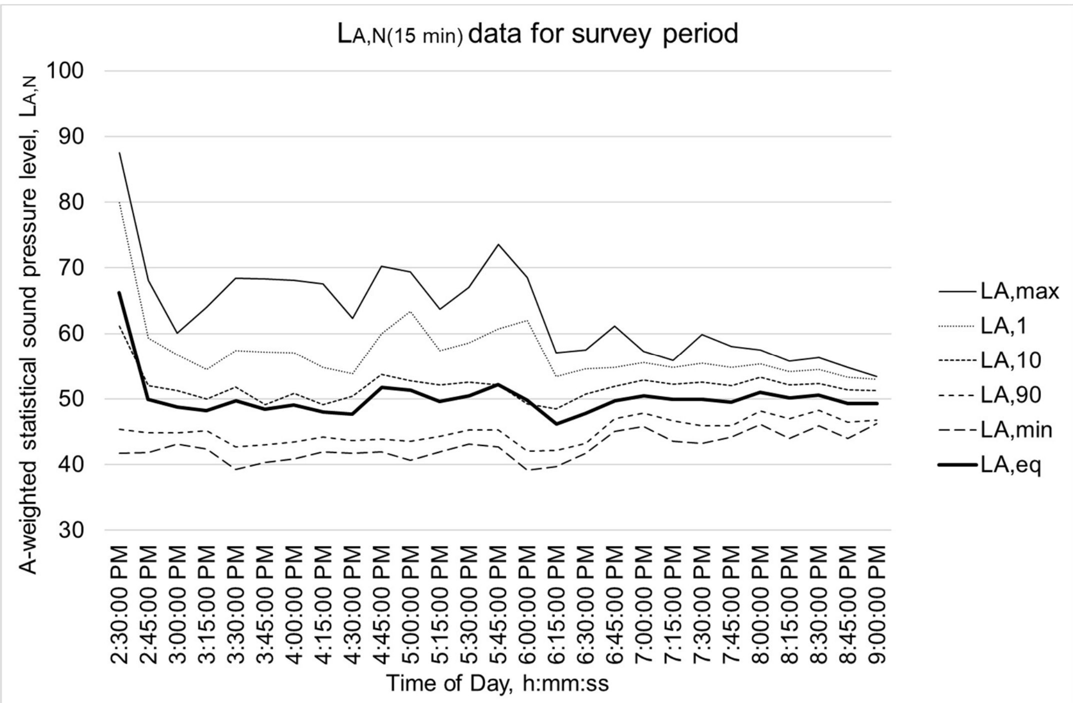

Figure 2: Statistical survey levels

A second analysis considered a dataset from approximately 5 days of road traffic noise surveying. The range of equivalent-energy-level based metrics derived from that second dataset is summarised in Table 1 and simply confirms the mathematically obvious expectation that the L_{Aeq} for stochastically varying noise over progressively longer periods is de-sensitised. These two examples demonstrate the magnitude of this effect. An inappropriate assessment period for an energy equivalent metric can render a noise impact assessment meaningless.

Table 1: Equivalent Energy Metrics, Road Noise Survey Example T=15min

	Day	Night
Overall Lday	64.9	
Overall Lnight		57.2
Highest Lday or Lnight	66.2	57.9
Lowest Lday or Lnight	64.4	55.7
Highest LAeq15min	74.2	66.5
Highest LAeq1hr	70.4	65.1
Lowest LAeq15min	39.9	26.5
Lowest LAeq1hr	58	32.2

4.3 Noise Impact Assessment

While the data from Figures 1 and 2 do not reflect a typical project assessment period, a background noise rating level determined from 15-minute statistical data would be reasonably estimated as 43dB(A). The mean L_{Aeq} over the concert period from Figure 2 is 51dB, or if the assessor had missed the initial sample period a mean value of 50dB. An intrusive noise impact assessment would therefore indicate an exceedance of 7-8dB(A) or if assessed from a full-day perspective, less. If the EPA Noise Policy for Industry were relevant to the site, which it is not, these outcomes would trigger consideration of mitigation, though only marginally so.

The manipulation of equivalent energy metrics is quite simple, with values and outcomes being readily added and subtracted. This has encouraged their use in regulatory procedures, however it should be recognised that procedures based on longer periods are procedures that de-sensitise the discrimination of the assessment. Desensitising is aggravated as the level instability of the system rises. Additionally, subjective weighting factors may be more numerically significant to an assessment finding than the predicted emergence. This inhibits planning stage predictions compared with post-completion measurement. The inability of noise intrusion assessment to distinguish between land use areas where a small number of subjectively different sources create unstable stochastic variance, from those involving a stationary system comprised of many sources, is a fundamental issue.

5 QUANTIFYING IMPACT BY EMERGENCE

Environmental noise varies almost constantly. A powerful dynamic assessment technique is the calculation of statistically based emergence based on sampling the variance of both the impacting source noise and the impacted ambient noise (Fitzell, 1991) using the reverse transformation algorithm shown in Figure 3. Emergence can be quantified by determining the probability that the sound pressure levels from a source, if appropriate including the addition of subjective weightings relevant to that particular source, will be higher than the ambient sound pressure levels. The ability to selectively add subjective weightings to source components is, alone, a major impact discrimination benefit.

Interpolation between known statistical data points produces a cumulative level distribution function (CDF) for each of the ambient sound and the imposed sound. The interaction between two incoherent or independent noise systems can be statistically modelled using iterative inverse transformation sampling. This involves the conceptually simple process of randomly sampling cumulative distribution functions to obtain concurrent instantaneous levels representing each condition of interest – the ambient sound (CDF1) and the imposed source (CDF2) – and computing the instantaneous aggregate outcome for each sample (Fitzell, 2019). Through iterative summation, the statistics of the outcome aggregate level – e.g. L_{A1}, L_{A10} etc – can be determined, though more important are the statistics of the differences between L1 and L2 at any instant of time. Cases such as a high level but short duration emergence are distinguished from a longer duration lower level emergence using this method, when an energy averaged metric will assume that they are identical.

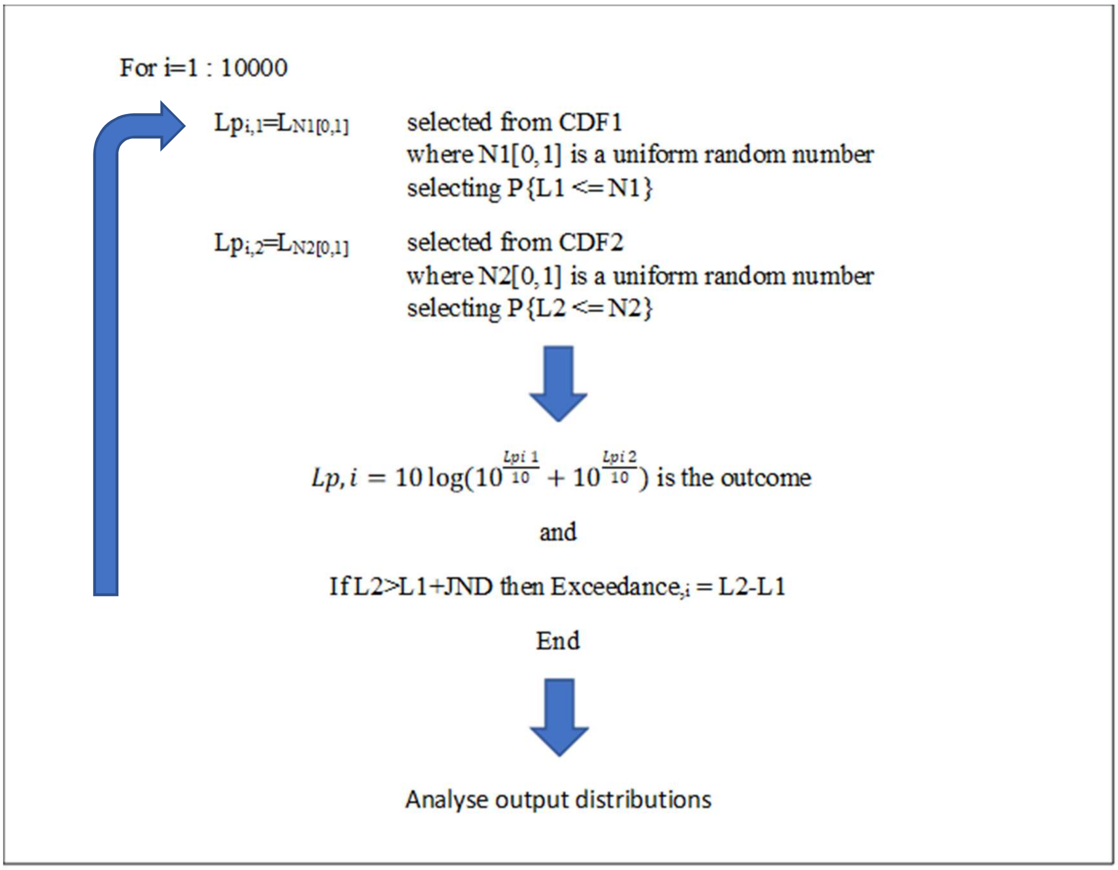

Figure 3: Reverse transformation algorithm

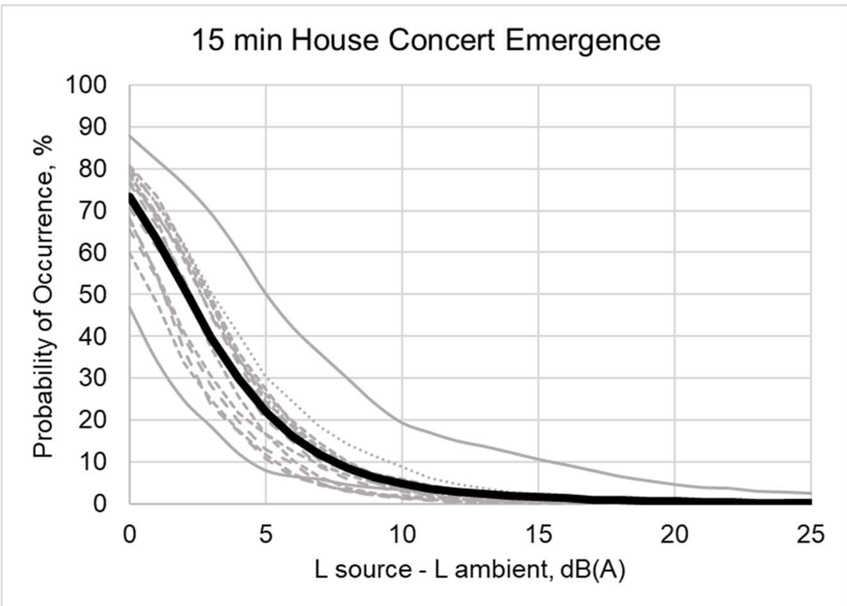

Figure 4: House Concert Source Emergence

Active impact is equal to the probability that noise from the new source will exceed the ambient sound by more than 3dB so as to qualify as “noticeable”. Analysis of the overlay of results charted in Figure 4, describing each 15 minute sample over the period of the concert together with the average emergence in bold, shows that the average level of active impact is 40%, but as high as 70 percent for the loudest period sample. To a layman, this means the activity associated with the source would, on average, be identifiable 40 percent of the time. Noise from the concert was more than 5dB(A) higher than the ambient for only 20 percent of the time, but did exceed the ambient noise by up to 25dB(A) very briefly.

Passive impact magnitude is the probability that the instantaneous imposed level will be higher than the ambient level, thereby concealing the ambient sound. For this same period, average passive impact is 73% and, again to a layman, this means that for 73 percent of the time the existing ambient environment would be concealed. It could be argued that a true threshold of interference affecting existing ambient sound commences 7-10dB below the ambient levels, the effect of which could be analysed should it be so deemed. The magnitude of passive impact will always be higher than the active, or intrusive, impact level. The choice of which type of impact is prioritized is determined by which aspect of potential change to the ambient environment is considered relevant.

6 MAGNITUDE OF IMPACT

Historical benchmarks can provide insight into what is a reasonable magnitude of impact. A data study using three commonly encountered conditions for a relatively quiet ambient area into which each of three new sources are to be alternatively introduced is described in Table 2. The three new “sources” are a steady state noise such as an air-conditioner, generating a noise level 5dB(A) higher than the ambient L_{A90}, the second a new freeway generating a road traffic noise L_{Aeq} level of 55dB(A), and a third new stochastically varying source generating the same minute-to-minute variance as the ambient noise but at an L_{Aeq} level 5dB(A) higher than the ambient L_{A90}. That is, two are consistent with the 5dB emergence limit principle and one is a current NSW road design target. Table 3 are the outcome statistical levels for the existing ambient and new sources combined. One observation worth noting is that the relationship between the input and outcome statistics is not trivial.

Table 2: Input data, statistical levels at recipient

	$L_{A,m}$	$L_{A,1}$	$L_{A,10}$	$L_{A,50}$	$L_{A,90}$	L_{Amin}	$L_{A,eq}$
Ambient noise levels	67	58	49	43	40	37	48
Steady State Source LAeq = L_{90}+5dB	45	45	45	45	45	45	45
Freeway traffic 55dB L_{Aeq}	69	62	58	53	48	40	55
Stochastically varying L_{eq}=L_{90}+5dB	65	55	47	41	37	35	45

Table 3: Outcome noise levels, ambient plus sources operating individually

	$L_{A,m}$	$L_{A,1}$	$L_{A,10}$	$L_{A,50}$	$L_{A,90}$	$L_{A,mi}$	$L_{A,eq}$
Steady State Source LAeq = L90+5dB	67	58	51	47	46	46	50
Freeway traffic 55dB LAeq	69	64	59	54	50	42	56
Stochastically varying Leq=L90+5dB	68	60	52	46	43	39	50

An assessment of noise impact using the current assessment paradigm can be determined from the results of Table 3 compared to Table 2, while assessment based on emergence is evaluated using the same algorithm as the summation producing Table 3. The magnitude of impact determined using emergence, compared with conventional assessment, is summarised in Table 4. Considering emergence outcomes, shown in Figure 6 and Table 4, these three cases demonstrate very different outcomes. The impact of road traffic is very large, dominating the existing ambient noise environment for 93 percent of the time. Active impact, the closest parallel to current conventional impact assessment is 22 percent for a steady-state source – for example heavy industry – but for a stochastically varying source at the same equivalent energy level only 12 percent. The disparity in magnitude of passive impact is even more significant, with a steady-state noise dominating the ambient for over 70 percent of the time and approaching the magnitude of impact imposed by traffic. Conventional noise impact assessment would, however, consider two sources to be equivalent, and very substantially less than the third.

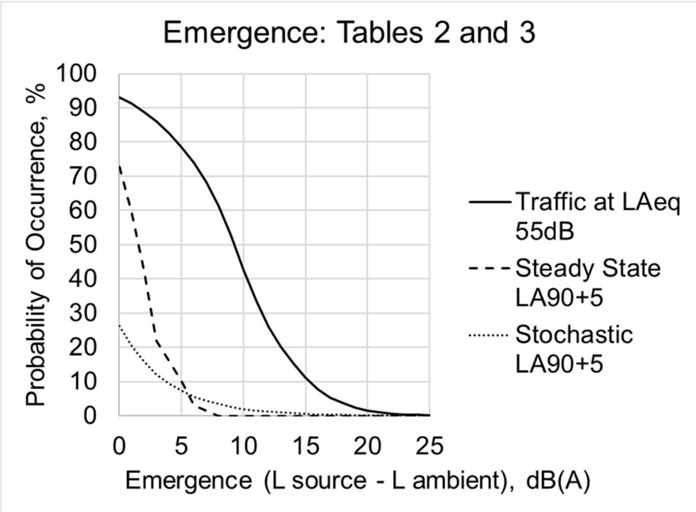

Figure 6: Comparison emergence-based noise impact

Table 4: Conventional Impact Assessment compared with Passive and Active Impact

	L_{Aeq}-L_{A90}	Passive Impact	Active Impact
Steady state source LA,90 + 5dB	5 dB	72%	22%
Freeway traffic at LA,eq 55dB	15 dB	93%	86%
Match ambient variance but Leq=L90+5dB	5 dB	26%	12%

Notwithstanding the disparities reported in Table 4, these examples do suggest that an “acceptable” magnitude of active impact is probably between 10 and 20 percent. Historically, passive impact has not been recognised, so a concept of change is necessary to identify an acceptable magnitude of impact where passive impact is the priority. This concept is that land begins as one type of land area and is changed progressively to a different type of land area by a sequence of individually “acceptable” changes, or impacts – the entropy of acoustics. All land commenced as acoustically pristine and/or uncontaminated land and has progressively evolved to the land use types now commonly accepted, at least as far as land occupied by humans is concerned. Examining expected ambient noise levels in different land use areas therefore enables the overall magnitude of impact required to change the land classification. That is, the difference is the aggregate change that means the existing land use characteristics are effectively lost and the land is now fundamentally different.

Table 5: Average daytime statistical noise levels vs Land Area Usage

	L_{Amax}	L_{A1}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Aeq}
Acoustically Pristine	60	49	40	32	26	23	39
Rural	66	56	48	43	39	36	47
Quiet Suburban	69	61	54	47	44	42	51
Suburban	76	67	61	56	52	49	59
CBD	82	74	69	65	61	58	66

Table 5 shows average daytime statistical sound pressure level measurements obtained from an ambient noise study (Fitzell, 2019). The aggregate impacting noise required to be imposed on each land type, so as to result in an area of land having ambient statistical sound pressure levels equivalent to the next higher category, has been investigated using inverse transformation sampling, and in turn the magnitudes of passive impact associated with such a change is able to be evaluated. Table 6 shows that a passive impact of 90% sufficiently changes land that it would be classified differently. Because this method of impact assessment uses a linear scale, iterative application of "acceptable" magnitudes of change can be calculated, benchmarked to the findings of Table 6. A reasonable planning strategy ought to recognise that a number of development approval changes will occur in developing areas, so policy should make provision for multiple impacts from current and future developments.

Table 6: Magnitude of impact based on percentage of preserved ambient noise

Land change	Passive Impact
Acoustically pristine land to rural land	93%
Rural land to quiet suburban land	70%
Quiet suburban land to suburban land	90%
Suburban land to CBD	91%

The aggregate of a sequence of impacting changes can be calculated using equation 1.

$$x = (1 - i)^n \quad (1)$$

where
x is the residual portion of the ambient environment
i is the passive impact $[0,1]$ *imposed at each stage, and*
n is the number of sequential stages

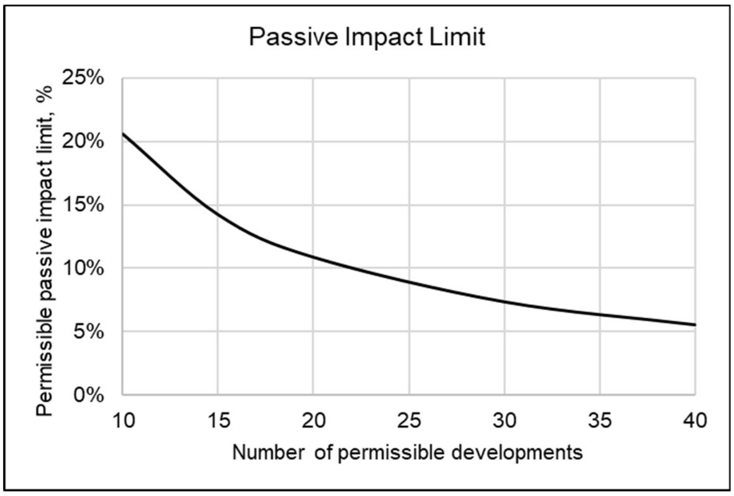

Figure 6: Permissible passive impact limit vs provision for future planning approval changes

Equation 1 and its application summarised in Figure 6 can be used to describe an "acceptable" magnitude of permissible impact. Figure 6 defines a sequence of impacts, each of magnitude i=20%, that will result in an aggregate impact of 90 percent. Using Figure 6 as a guide will allow a regulator or planner to implement a consistent development consent policy and, in turn, the identification of a magnitude of impact has wider application. For example, where a large development is proposed and is shown to result in a nett change to the surrounding land type by the magnitude of impact, this approach allows the infrastructure or environmental costs necessary to support that changed land use to be properly identified as a cost due to that development proposal. Where no impact is a requirement, such as the introductory case, a required limit to passive impact is zero percent.

7 CONCLUSIONS AND RECOMMENDATIONS

The risks of adverse noise impact from a development proposal likely to affect nearby land should be considered from different perspectives depending on whether the auditory events associated with that development represent features already present in the nearby land, or they are new features contributing to encroaching change. An environmental noise impact assessment must identify acoustical attributes of potentially affected lands and be able to express the risks to that land in the context of the operating features comprising the development proposal. Where there is risk that the proposal will erode attributes of the impacted land, control of passive impact is likely to be the priority. Where the risk is that the proposal will undesirably add to ambient noise already present in the auditory environment, control of active impact is likely to dominate.

Passive impact is a parameter unrecognised by current methods of noise impact assessment, despite generating more demanding management requirement than active impact and being more critical to increasing areas of lands affected by expanding development.

Passive impact cannot be measured using equivalent energy metrics. Significant limitations are also perceived in the use of equivalent energy metrics where non-stationary acoustical systems are involved, potentially eroding the effectiveness of active impact assessment. Frequently, equivalent energy based assessment is unable to discriminate between markedly different environmental circumstances, eroding the basis of otherwise well-intended planning.

A method enabling both active and passive impact levels to be quantified has been described. Apart from providing a superior measurement description, a planning benefit is that assessment requires clear functional descriptions of a development proposal. This enables the inclusion of subjective penalty weightings for only those elements to which they should be reasonably applied. The impact outcomes can be compared on a linear scale so are more likely to be understood by a wide range of development stakeholders, whilst also providing a foundation for coherent long-term planning policy. Limit magnitude of impact criteria of Table 7 are proposed:

Table 7: Proposed environmental noise impact acceptance criteria

Characteristics compared with ambient noise	Impact criterion	Acceptable magnitude of impact
New characteristics involved	Passive	20% (or Figure 6)
Similar to or already existing in the environment	Active	20 %

Impact is determined at, and experienced by, the impacted. In most eco-systems the impacted entities are unable to object to the loss of their habitat, or worse. Noise is ephemeral and is not a “serious” environmental impact, however it is a precursive symptom of environmental degradation. The strategy described in this paper is an opportunity for acoustical practitioners, managers and planners to adopt a position consistent with environmental impact assessment leadership.

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