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Rail project noise and vibration impact assessment

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ABSTRACT

This paper is a reflection on the state of the art of rail project noise and vibration impact assessment in Australia. It begins with a simple question – "is our system working?". Asking this type of big-picture question leads to discussion on aspects the Australian acoustic industry is doing well, and where there are areas for improvement.

1 INTRODUCTION

When a railway project is proposed in Australia (either a new railway or a redevelopment), our system of governance and regulations requires that the noise and vibration impact is assessed. This assessment initially occurs prior to project approval, with the purpose being (example from New South Wales) "*to help the community, councils, government agencies and the approval authority to get a better understanding of the project and its impact so that they can make informed submissions or decisions on the merits of the project*" (Department of Planning, Housing and Infrastructure, 2024).This is a laudable objective, and it is something Australians can be proud of. We live in a country where the economic, social and environmental impacts of infrastructure projects are considered and assessed, and genuine efforts are made to mitigate adverse impacts of projects. This includes requiring impacts of projects to be revised during the detail design and verified after the commencement of operations.

Generally, a railway project is proposed because it is critical infrastructure that is expected to have a net positive benefit to society. A critical infrastructure railway project that is proposed by a public authority will not be refused development approval – it is more likely that its design will be modified to minimise impacts as far as practicable. In this situation, acoustic practitioners apply the noise and vibration assessment process to ensure that people who are affected by such projects are treated fairly in terms of the mitigation measures that are implemented. This is straightforward for projects such as new urban rail transit systems where the impacts are limited to the project area assessed. The concept of "fairness" in mitigation becomes more challenging for upgrade projects such as freight line capacity improvements that affect train traffic on existing lines outside of the immediate project area. This issue has been discussed by Hanson et al (2023) – in this case taking a project-based approach to impact assessment can limit implementation of the most cost-effective source mitigation measures.

Fundamentally, noise and vibration practitioners / experts undertake railway noise and vibration impact assessments to help others understand what the implications of a project are for acoustic amenity, and to identify what can be done to mitigate these impacts. We expect that the mitigation measures we identify will be implemented throughout all project stages: procurement, design, construction, operation and maintenance of the system.

In practice, rail project noise and vibration impact assessment and reporting methods have evolved over many years and are increasingly becoming standardised. This paper asks: is our typical system of rail noise and vibration impact assessment working, and what could we do better? To answer this question several aspects of the noise and vibration impact assessment process are examined:

1. How do noise assessment guidelines compare across Australia?
2. How well do we really understand rail source noise levels?
3. Are we incorporating best practice prediction tools and modelling algorithms?
4. What does it mean to "validate" a noise model?
5. Does a threshold exceedance indicate an excessive impact?
6. How accurate are the rail noise predictions made before a project is built?
7. How can we communicate rail noise and vibration impacts more effectively?
8. Is the vibration assessment process worthwhile and effective?
9. What projects are coming up in Australia, and what does this mean for noise policies and guidelines?

2 COMPARISON AND DISCUSSION OF AUSTRALIAN RAILWAY NOISE GUIDELINES

Five Australian states apply specific guidelines for the assessment of noise impacts from railway projects. As an example, Table 1 provides a summary of the residential noise assessment thresholds for heavy rail systems.

Table 1: Australian state-specific heavy rail noise residential assessment thresholds (dBA)

State	New railway		Rail upgrade		Comments
	Maximum	LAeq	Maximum	LAeq	
QLD	82	60 (24h)	87	65 (24h)	Single Event Maximum. No relative increase threshold.
NSW	80	60 (day) / 55 (night)	85	65 (day) / 60 (night)	95th percentile maximum. For upgrade projects relative increase thresholds of 2 dB LAeq and 3 dB LAmax apply (either of these along with either of the overall thresholds).
VIC	80	60 (day) / 55 (night)	85	65 (day) / 60 (night)	95th percentile maximum. For upgrades relative increase thresholds of 3 dB apply to the corresponding overall thresholds.
SA	80	60 (day) / 55 (night)	85	65 (day) / 60 (night)	95th percentile maximum. No relative increase threshold.
WA	-	55 (day) / 50 (night)	-	60 (day) / 55 (night)	Consistent objectives for railways and roads, no maximum noise threshold, no relative increase threshold.

In QLD the *Interim Guideline – Operational Railway Noise & Vibration* was published in March 2019. This guideline builds on the historical QLD railway noise code of practice and uses different noise descriptors to those applied in other states. The Single Event Maximum noise parameter is not directly comparable to the 95th percentile maximum level used elsewhere. Defining the LAeq threshold over a 24-hour period means this requirement is more lenient (allows more noise at night) than the separate daytime and night-time LAeq thresholds elsewhere in Australia. However, the QLD guideline also explicitly requires a “worst-case” modelling / prediction approach and requires model predictions to be adjusted upwards if there is any underprediction relative to a measurement. Another notable factor in QLD is that the guideline states that “the track feature adjusted Kilde 67/130 methodology is currently the only accepted methodology for use in Queensland” – this effectively means all QLD assessments use this modelling algorithm. Best practice modelling algorithms are discussed further in Section 4; mandating the use of Kilde is another factor increasing conservatism in the assessment of QLD projects.

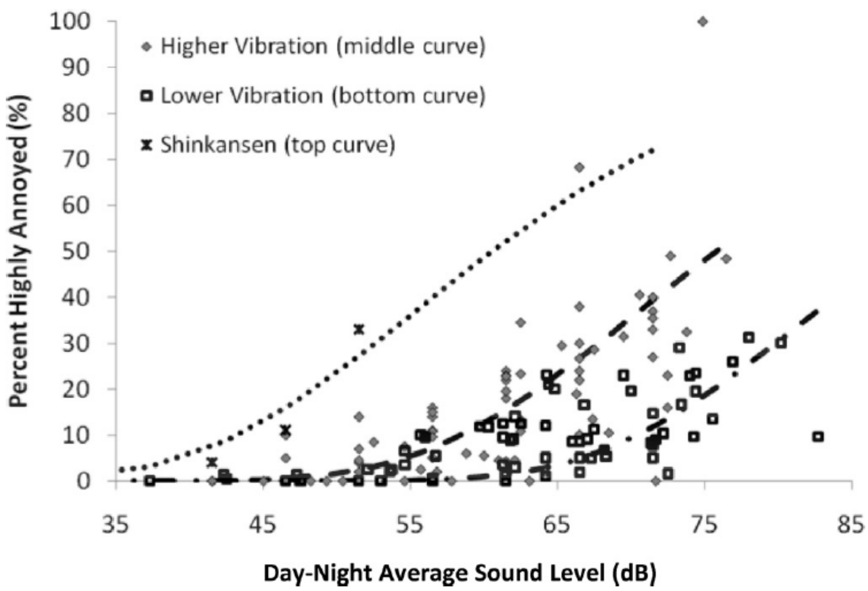
In NSW the Rail Infrastructure Noise Guideline (RING) was published in May 2013. The RING introduced several changes from the 2007 Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects (IGANRIP). One significant change was in the approach to application of relative increase criteria for redevelopment projects. Under IGANRIP, LAeq and LAmax impacts were assessed independently. Under the RING, consideration of noise mitigation is required when there is an increase in either LAeq (day), LAeq (night) or LAmax; in addition to an exceedance of **any** of the overall noise level thresholds (not limited to the parameter that sees the increase in noise). This approach was confirmed by Maddock (2024), clarifying (for example) that an increase of more than 2 dB in any LAeq parameter in conjunction with existing LAmax levels above the threshold triggers consideration of mitigation, even if there is no change in LAmax due to the project and the LAeq levels remain below the absolute thresholds. Although the literal wording of the RING requirement is clear, this change from the IGANRIP approach was not highlighted as a key change to the guideline in consultation materials provided by the regulator at the time (NSW Office of Environment and Heritage, 2012) and was evidently not intuitive to acoustic practitioners. As a result, for over ten years after the RING was published all rail redevelopment projects in NSW incorrectly applied the guideline, beginning with the Epping to Thornleigh Third Track project (ETTT Alliance, 2015) which was subject to particularly intense regulatory scrutiny and oversight due to the level of community opposition. Going forward, the correct implementation of the RING in noise assessments results in more requirements to consider noise mitigation for NSW redevelopment projects but also necessitates improvements in noise model quality and accuracy, discussed in Sections 4, 5 and 6 below.

In Victoria the Passenger Rail Infrastructure Noise Policy (PRINP) from 2013 is the key policy document. This applies the same overall mitigation investigation thresholds as the NSW RING, differing in the approach to relative noise increases for redevelopment projects. The PRINP relative increase approach is aligned with the historical NSW IGANRIP approach, considering LAeq and LAmax effects independently. In Victoria, a 3 dB increase in noise is required in either LAeq or LAmax to trigger mitigation investigation, if the increase results in the same parameter exceeding the relevant overall threshold.

SA's Guidelines for the Assessment of Noise from Rail Infrastructure were published in April 2013. These apply the same overall LAeq and LAmax trigger levels as NSW and VIC, however there is no relative increase criterion for redevelopment projects. This means that the absolute thresholds apply to all projects with noise mitigation considered simply based on the absolute level of impact with the project.

WA combines guidelines for road and rail noise impact assessment in WA State Planning Policy 5.4 – Road & Rail Noise (SPP 5.4, 2019). This guideline applies consistent impact assessment thresholds for road and rail projects, without a maximum noise level threshold or a relative increase threshold.

The LAeq thresholds for consideration of mitigation of rail noise in both NSW and SA are 5 dB higher than the corresponding thresholds for road traffic noise (other states use L10 descriptors to assess road traffic noise impacts). This more lenient approach to railway noise is linked to the historical "railway noise bonus", where a different approach to railway noise impact assessment is justified by research into annoyance due to noise exposure from different transportation sources. Croft and Hemsworth (2018) reviewed research into the railway noise bonus, concluding that annoyance due to noise associated with diesel freight trains or other noise sources such as curve squeal may not be well represented even by the "high vibration" categories in ISO 1996-1 (2016). Data supporting this conclusion is reproduced in Figure 1. The same considerations apply to noise from high-speed trains. Of all the Australian approaches, only the WA guideline reflects the current understanding that the railway noise bonus is only applicable to limited particular modes of rail traffic, so that allowing more noise from freight or high-speed railways than from road traffic is not justified.



Source (Schomer et al, 2012)
Figure 1: Effective loudness functions overlaid on corresponding rail noise survey data

Figure 2 summarises the relative level of protection provided to residential receivers in each state by the impact assessment guidelines for heavy rail noise, based on LAeq thresholds. QLD is least protective in allowing higher night-time noise despite mandating conservatism in prediction. NSW is more protective than VIC for redevelopment projects due to differences in approach to project noise increase. SA is more protective than both NSW and VIC for redevelopments due to the lack of any exemptions to consideration of mitigation based on minimal noise increase. WA is most protective based on LAeq approach with lower targets and no relative increase, although this may be somewhat countered by the lack of any maximum noise level threshold.

Figure 2: Relative noise protection for residences affected by heavy rail noise by state, from least to most protective considering LAeq thresholds for consideration of mitigation.

3 RAIL NOISE SOURCE LEVELS

It is normal for rail noise source levels used in noise prediction models to be derived from measurements of comparable systems. In NSW recent research by Pandey (2021) has highlighted the importance of using a sufficiently large data set of measurements to derive source levels, particularly for freight where there can be considerable variation in operational parameters (speed, engine notch setting) in addition to the fundamental differences in rolling stock. Pandey investigated noise measurements of almost 3000 freight train passbys, comparing locomotive and wagon noise emissions (including curve noise) with the reference source levels documented in the Transport for NSW Asset Standards Authority Stage III Rail Noise Database (RND). Pandey identified measured in-service freight locomotive source levels measured for trains travelling both uphill and at grade 5 dB higher than the RND levels. For downhill trains the difference was less pronounced, but still measurements indicated noise levels 2 dB higher than indicated by the RND. Subsequent work supporting the Inland Rail Project has confirmed that use of the RND source levels for freight locomotives may underestimate impacts in some circumstances.

The RND (SLR, 2015 and Transport for NSW, 2015) contains a limited dataset of freight measurements (213 passbys in total), with locomotives measured travelling through urban areas on shared passenger tracks with closely spaced signals. Verification of actual engine notch settings was not possible in compiling the RND, which relied on an assumption that the measurements reflect typical traction and braking scenarios. The original intent of the RND was that it would be updated as more measurement data was collected elsewhere, but this has not occurred. It is now increasingly clear that the RND may not reflect actual operating conditions particularly for intercity freight operations through rural areas.

Often it is assumed by practitioners that the source levels applied in previous assessments are safe and reliable to implement. For new railway projects there is no alternative than to rely on experience of noise emissions of similar systems. For redevelopment projects, measurement of sufficient existing train passby events is always required to confirm source levels, and to validate noise models (see also Section 5).

4 BEST PRACTICE NOISE MODELING ALGORITHMS

Europe has always been a world leader in developing and improving railway noise prediction models and algorithms. The European Commission’s Environmental Noise Directive (END) from 2002 required member states to prepare and publish noise maps and noise management action plans every five years, for cities and for major transportation noise sources including railways. For over 20 years the END noise mapping process has enabled the identification of the number of people affected by noise in Europe, including assessment of implications for the health and well-being of populations. Another factor driving improvements in noise modelling is the European Green Deal (European Union Agency for Railways, 2020) – in order to meet climate objectives a modal shift to railways is required.

Dinohobl (2025) discusses that although there are recommended noise exposure limits for health, a consistent European impact analysis or standard for a noise-related cost-benefit analysis including climate benefits and costs as well as noise annoyance and health effects is not yet established. Nevertheless it is clearly important that rail noise models are as accurate as possible. Overprediction of impacts or excessive conservatism results in distortion of the understanding of health effects, whilst also acting as a constraint on the necessary expansion of railways to meet climate objectives. Noise as a constraint on rail expansion is a key reason that rail noise modelling in Europe is continuously being challenged and improved, an example is the improvements to CNOSSOS-EU published by the Netherlands National Institute for Public Health and the Environment (RIVM, 2019).

In Australia the railway noise impact assessment thresholds outlined in Section 2 have all been developed by state regulatory authorities considering the balance of adverse impacts and benefits to society of rail projects. They acknowledge that the thresholds do not represent “no impact”. However, unlike Europe, Australian guidelines for rail noise impact assessment have historically discouraged the adoption of new or improved modelling algorithms. There are several possible reasons for this:

1. Regulators are rarely experts in rail noise algorithms – this is entirely understandable since this role typically requires generalist knowledge of many disciplines. However, lack of regulatory understanding of the limitations of particular modelling algorithms has led to resistance to change. It is easier to approve something that is done the same way it has been done before, than to risk a change that is not fully understood.

2. Most Australian states (except WA) apply maximum noise level thresholds in addition to equivalent average noise thresholds. Mainland Europe uses equivalent average noise thresholds only, therefore the most widely used models such as CNOSSOS-EU do not include maximum noise level prediction capability.

3. There is a view that European models may not be applicable to Australian track and rolling stock. While this last concern is valid, it applies to the models that have historically been applied in Australia just as much as it does to more sophisticated models, so this barrier is clearly surmountable.

The most commonly used rail noise modelling algorithm across Australia is Kilde 130 which was developed in 1984, over 40 years ago. Kilde is one of the few algorithms that allows for calculation of both LAeq and LAmax impacts and has a reasonably low computational cost. However, as an accurate predictor of railway noise levels it has limitations:

- It represents broadband noise only, with no consideration of frequency dependent effects.
- It applies a binary representation of ground conditions as either hard or soft which is a critically limiting simplification in rural areas where long distance propagation effects determine prediction accuracy.

In addition to its inability to represent frequency dependent effects, the simplistic ground and propagation models of Kilde 130 tend to result in increasingly conservative (high) predictions of rail noise if hard ground is modelled as distances from the source increase. Since using Kilde 130 with the alternative fully soft ground conversely may result in even more unacceptable underpredictions, hard ground is commonly assumed and in fact is the specified default assumption called for by the NSW RING[1].

In NSW, the need to consider noise mitigation for a rail redevelopment project prior to the RING was typically controlled by the relative increase in addition to the absolute noise level for the same parameter (either LAmax or LAeq). In this case the conservatism of Kilde 130 in predicting overall levels was manageable because the relative increase in the same parameter could be accurately predicted. Under the RING, scenarios are possible where the relative increase is in daytime LAeq but the triggering overall level is the LAmax. The Kilde 130 algorithm can predict the relative increase in both LAeq and LAmax but will typically overpredict absolute noise levels at increasing distances, unrealistically increasing the number of properties triggered for consideration of mitigation and forming a constraint on necessary rail expansion projects.

The recent clarification of the application of the RING (Maddock, 2024) effectively means that Kilde 130 should not be used to model rail noise projects in NSW going forward, except perhaps in limited specific circumstances where the only affected receivers are immediately adjacent to the rail line, trains are passenger only (no low-frequency exhaust impacts) and the default assumption of fully hard ground is reasonable. The same concerns with overconservative modelling should apply in other states. There is a tendency for regulators to apply guideline investigation thresholds as hard limits in project Conditions of Approval, rather than as intended as trigger levels for investigation of reasonable and feasible noise mitigation. This leads to an expectation that any identified exceedance of the trigger levels should be mitigated, by barriers or property treatments if not by other means, increasing the costs of rail projects without driving implementation of more cost-effective source control measures (Hanson et al, 2023).

The Nord 2000 rail noise modelling algorithm is more sophisticated than Kilde 130 retaining the ability to calculate both LAeq and LAmax but with improved frequency-dependent representation of noise propagation factors including terrain, ground impedance, screening, reflection, air absorption and scattering effects. With appropriate selection of source noise levels and model validation, there is no reason not to apply more advanced modelling algorithms in Australia. Although Nord2000 is itself 25 years old, research into improvements into the model is continuing, for example the work of Ratay (2024).

5 NOISE MODEL VALIDATION

It is usual for Australian rail noise impact assessment reports to include a section titled “Noise Model Validation” or similar. These typically include a tabular comparison of model results with measurements, followed by a comment such as “*Comparison of measured versus predicted noise levels indicates the difference is generally within the acceptable range of ±2 dB at most locations. Therefore, the model is considered to be valid for predicting rail noise levels*.”

[1] When using commercial modelling software, practitioners who are not aware of this limitation of the Kilde algorithm can be caught out. The software allows the user to input intermediate ground absorption values between fully hard and fully soft, without any notification that the algorithm will round that value to use a binary 0 or 1 value for calculation.

It is not unusual for a few locations to show higher noise predictions than was measured – these deviations are normally accepted on the basis of conservatism. Often an overall average or median difference value is also reported, to suggest that on the whole the model is fit for purpose.

Some aspects of this rather casual approach to model validation that deserve more attention are:

1. Usually, measurements for validation purposes are collected close to the tracks, so they can "verify the source level assumptions". While verification of the source levels by measurement close to the tracks is necessary, these same locations should not be the sole measurements used to validate the whole model. Using measurements close to the tracks does not validate the model's ability to predict noise at increasing distances from the source. If exceedances of the assessment thresholds are predicted 200m from the tracks, then the accuracy of the model should be validated out to those distances.

2. In locations with mixed freight and passenger traffic, the model must be validated for both traffic types independently. This is particularly important when modelling 95th percentile maximum noise levels – source levels are defined independently for the 95th percentile freight and 95th percentile passenger trains, so combining these for overall level validation can distort the results – the model will show only the 95th percentile maximum for the single noisiest train type, which should not be directly compared to the 95th percentile event in combined traffic.

3. In QLD, allowing "model calibration" by simply adding a correction factor to an underprediction does not require any investigation of why the model might be underpredicting or which of the many possible modelling inputs or assumptions should be adjusted to give a more accurate result. If the source of inaccuracy is not identified, the model is not a useful tool for investigating the effects of mitigation measures.

Model validation is an area where the industry in Australia can improve. As a minimum, validation should include confirmation of source levels by measurement close to the tracks in addition to validation of propagation effects at greater distances from the tracks. Validation distances should correspond to the range of distances at which thresholds are predicted to be exceeded. This is of course intrinsically linked to the need to shift to models that are capable of improved representation of noise propagation effects.

6 DOES AN EXCEEDANCE OF A THRESHOLD EQUATE TO AN IMPACT?

The various railway noise guidelines used in Australia are all intended to identify levels of noise from rail project operations that warrant investigation of reasonable and feasible noise mitigation options. None of the guidelines state that the assessment thresholds should be applied as hard limits / noise criteria that must be met. However, it is increasingly common for project conditions of approval to require projects to meet the assessment thresholds at all receivers or undertake property treatments for any residual exceedances of the assessment thresholds. One possible reason for this may be that the guidelines are typically developed by regulators, whereas project conditions are set by development authorities / agencies, i.e. a different department of government.

A rigid application of the assessment thresholds as criteria is contrary to the intent of the guidelines and creates a significant constraint on projects that are proposed in the context of the greater public good. It means that rail noise assessments become simply a process of deciding where noise barriers are built, or who gets property treatments, rather than considering the bigger picture of how government funds could be used most cost-effectively to benefit the greatest number of people.

In jurisdictions where there is a relative increase threshold, rigid application of the assessment thresholds also has the potential to lead to perverse outcomes. This is particularly the case in NSW under the RING. For example, the actual impacts of a freight capacity increase project can be minimised if it is possible to schedule additional freight traffic during the daytime period rather than the night-time period. However, this may exceed the daytime LAeq relative increase threshold. If the maximum noise levels from existing freight is already above the overall threshold, consideration of mitigation of impacts is required. Because the additional train movements are during the day it could be argued that the actual impact has been minimised by the schedule, so that construction of a barrier is not warranted. However, it would also be possible in this case to schedule some of the additional freight traffic at night instead of during the day, which may avoid an exceedance of either day or night relative increase threshold and hence avoid any requirement to consider mitigation, although the actual impact of the night-time traffic when sleep disturbance is considered is far greater.

Another argument against rigid application of investigation thresholds in NSW is a comparison between the impacts of adding additional traffic to an existing busy freight line vs a lightly trafficked line, each with existing maximum noise levels above the LAmax threshold. Busy freight lines may see hundreds of trains a day, but a project adding 50 trains to this will not trigger an LAeq relative increase threshold. Whereas on a lightly trafficked line doubling the number of trains from 3 trains to 6 trains per day will trigger consideration of feasible and reasonable mitigation under the RING, although the noise impacts are unquestionably much lower than on the busy line.

If regulators do determine that assessment thresholds are to be applied as hard limits this should apply only to the overall assessment levels, to avoid perverse outcomes. However, any application of the assessment thresholds as hard limits risks implying that there is no impact unless there is an exceedance, by conflating an exceedance of an investigation threshold with the actual impact. This type of approach has the potential to force the construction of mitigation measures that are not the most cost-effective way of using project funds. It also means that noise mitigation costs are likely to be incurred by projects that do not have the greatest absolute impact when the number of noisy train passby events is considered.

7 ACCURACY OF NOISE PREDICTIONS LONG TERM

It is usual in Australia for compliance measurements to be required after commencement of operation of rail projects. These are intended to verify that the actual impacts of the project are as expected, and the mitigation measures that have been installed are appropriate. In the case of the Epping to Thornleigh Third Track project, compliance measurements were required at 1 year, 5 years and 10 years after opening (ETTT Alliance, 2015) – to date two of these rounds of measurements have been completed.

Compliance measurements after opening of Australian rail projects generally indicate noise levels are within predictions – this could mean that practitioners are very good at predicting noise impacts accurately, or alternatively that the tendency to conservatism in assessment means that actual impacts tend to be less than predicted.

One area where the accuracy of noise predictions can be challenging is situations where wheel/rail interface issues and maintenance state of a railway can lead to considerably higher noise emissions than predicted. Croft et al (2021) provides an example of this issue. It is usual for environmental impact assessments to assume that railways will be perfectly maintained, but in practice once systems are built there may not be any effective regulatory requirement to ensure that noise during operations is minimised. In particular where railways (usually light rails or metros) are operated and maintained by a private entity under contract to the government transport agency, the terms of their contract determine what is required of them. Once the initial set of compliance measurements is “passed” then there may be no effective requirement to minimise noise thereafter.

8 COMMUNICATING IMPACTS EFFECTIVELY

“Fundamentally, noise and vibration practitioners / experts undertake railway noise and vibration impact assessments to help others understand what the implications of a project are for acoustic amenity, and to identify what can be done to mitigate these impacts.” (Quote from Introduction).

The reports that document railway noise and vibration impact assessments are increasingly lengthy and formulaic. The audience is typically the regulator, the approval authority, and also the people and businesses in the project area who may be affected. These reports are also used to inform the design of new developments near the railway. The outcomes of noise and vibration impact assessments need to be summarised in a form that is accessible to the intended audience of the report. This includes describing the impacts of the project in terms of how it may affect people and businesses, not just in terms of the number of exceedances of assessment thresholds.

It is worth considering if the noise and vibration impacts of a project are communicated effectively by a lengthy report. Sometimes even the address of individual properties is obscured in report result tables for privacy reasons, replaced by a “unique property ID” that requires additional effort for an affected resident to translate into a particular location of interest. Some impact assessment reports are tending towards mindless compliance with requirements at the expense of effectively communicating the implications of a project for acoustic amenity.

Visual communication is key – noise contour plots have traditionally been used in impact assessment reports. Advances in electronic reports and GIS capabilities now allow for even more effective communication of impacts. Ideally, a resident or business owner affected by a project should now be able to navigate to their property on an online map to find information specific to them, alongside an explanation of the various noise descriptors. It should be straightforward to include additional details such as the number of trains, and to give an idea of typical passby maximum noise levels (not just the 95^{th} percentile event).

9 THOUGHTS ON VIBRATION AND GROUND-BORNE NOISE

Vibration impact assessments for rail projects are similarly intended to help others understand the implications of a project, but are also used to inform the trackform design, which is the primary means of vibration control at source. Path and receiver vibration mitigation measures are not practical for existing receivers, whereas future developments can incorporate vibration isolation into their design where necessary.

In practice the mitigation requirements are usually controlled by ground-borne noise, but assessments must also consider tactile vibration. Noting that the outcome of these impact assessments drives the track design, the conclusion of vibration and ground-borne noise impact assessments for projects is almost universally that compliance with guideline levels will be achieved with careful attention in the detail design phase.

9.1 Tactile vibration

In NSW, tactile vibration has been assessed in accordance with Assessing Vibration: a Technical Guideline (AVaTG, Department of Environment and Climate Change, 2006) since its publication. AVaTG is also adopted in other states and territories in Australia. This document uses frequency-weighted Vibration Dose Values (VDVs) to assess vibration, which is a time dependent metric that accumulates based on vibration amplitude and exposure duration. The AVaTG criteria are based on the now superseded 1992 version of BS 6472-1. The guideline notes that "*As BS 6472–1992 is due to be revised, this guideline can be considered interim until the revision is published*."

BS 6472-1 was updated in 2008, incorporating more recent guidance. The 1992 version used the W_g weighting for vertical vibration, which is now known to result in calculated VDVs from rail induced vibration that are around half the magnitude of equivalent VDVs applying the currently endorsed W_b weighting. This was demonstrated by Allan et al. (2010) and confirmed using two large datasets by Miller et al. (2021).

Additional research has been undertaken since the 2008 issue of the British Standard. Whitlock (2011) undertook an equivalency study comparing international standards including BS 6472-1:2008 and the Norwegian Standard NS 8176.E:2005 to determine their applicability in New Zealand. He notes that:

> *"NS 8176.E:2005 has been successfully implemented in a number of major Auckland projects, and aligns well with the rating criteria of ISO 2631-2:1989. Furthermore the straightforward calculation procedure and data relating to population annoyance are beneficial. It is more stringent than BS 6472-1:2008 but has shown to be practicable in New Zealand applications."*

Persson-Waye et al. (2014) provide an overview of the CargoVibes project, including examining the proportions of people annoyed by vibration from freight passby events when various international standards and guidelines are applied. The results from several representative guidelines are summarised in Table 2.

Table 2: People annoyed by vibration in residences at standard limits, from Persson-Waye et al. (2014)

Standard	Limit	Highly Annoyed	Annoyed	Slightly Annoyed
BS 6472:2008	Night-time VDV limit of 0.1 $m/s^{1.75}$	26%	46%	67%
NS 8176.E:2005	New residential building limit (Class C V_w, 95% = 0.3 mm/s)	10%	22%	41%
US FTA manual	Vibration impact criteria > 70 events per 24h day	3%	9%	21%
German DIN 4150:2 1999	Night-time impact criteria of KBFmax = Au 0.1 mm/s (lower threshold)	3%	9%	21%

The thresholds within the various standards ultimately correspond to nominated thresholds of annoyance, which reflect local context and expectations. The VDV tactile vibration criteria in AVaTG are more lenient than the criteria applied elsewhere, particularly when accounting for the use of the outdated W_g frequency weighting (Table 2 reflects the updated BS 6472 W_b weighting). Anecdotally, complaints about vibration are often raised at levels that are much lower than those required to trigger the AVaTG criteria.

The NS 8176.E method seems to be a potentially more appropriate metric for freight train assessment, since it is based on a statistical maximum value from as few as 15 measured events and is more stringent than BS 6472 for infrequent high amplitude events. It also has practical synergies for evaluation of both human comfort and ground-borne noise. However, this method may not be appropriate for passenger trains with more frequently occurring events. The findings in both Whitlock (2011) and Persson-Waye et al (2014) were applicable to intermittent and infrequent freight events. People may be more tolerant to passenger train vibration than to freight vibration (eg Sharp et al. 2014).

Vibration dose is only one possible vibration metric that can be applied to passenger train events. Waddington et al. (2014) note that root-mean-square, root-mean-quad, root-mean-hex, root-mean-oct, VDV, standard deviation, peak particle acceleration, LMax, Leq and SEL are all equally effective predictors of annoyance, and that marginal improvement of magnitude and significance of correlation can be observed when appropriate frequency weightings are applied, or if velocity is used instead of unweighted acceleration. VDV as an assessment criterion is often not practical to implement whereas single-event metrics have a lot of advantages: the use of Lmax,slow velocity would also have practical synergies with the assessment of ground-borne noise.

Further research is required to develop vibration limits incorporating a readily calculable single-event metric for freight and passenger train passbys that correspond to the desired thresholds of annoyance. Until this occurs, railway impact assessment reports in Australia will continue to include lengthy sections that are difficult for the intended audience to understand, describing highly technical details of tactile vibration criteria and predictions, yet almost always concluding that there are no exceedances of the assessment thresholds for residential receivers since the tactile vibration limits are lenient and the design can readily be adjusted to ensure compliance.

9.2 Ground-borne noise

Ground-borne noise generally controls the need to mitigate vibration impacts and therefore drives the track design. Vibration source levels and ground propagation can usually be estimated with reasonable accuracy during the planning and design stages of a project through measurements on existing systems and on-site testing. What is usually largely unknown at these stages is the responses of individual buildings and rooms, specifically:

- The coupling losses to individual buildings.
- Internal amplification of vibration on suspended floors.
- How efficiently the vibration will be re-radiated into ground-borne noise.

These factors are usually estimated based on empirical data from sources such as the FTA manual and broadly applied to various categories of receivers. They are subject to considerable uncertainty.

Once the train line is operational, if there are exceedances of the ground-borne noise criteria, options to rectify these are limited to addressing any maintenance issues such as discrete defects or replacing the trackform with a lower-vibration alternative. In practice, replacing track is rarely feasible or reasonable and would only occur if significant exceedances are observed and attempts at implementing maintenance practices are exhausted.

Assessing ground-borne noise compliance by measurement in strict accordance with guidelines is extremely challenging. Residents are usually reluctant to provide internal access to their home, particularly overnight. Ambient and occupant noise during the day is often significantly higher than the night-time criterion. Consequently, compliance with the ground-borne noise criterion is often estimated based on an indirect method, whereby the vibration levels are measured on the floor and an assumption is made regarding how efficiently the vibration is re-radiated into sound (perhaps validated in a small number of one-third octave bands where the trains are observable above the background).

Unlike airborne noise, where measurements at a particular location can be considered representative of the general area, indoor ground-borne noise measurements are only relevant to that particular room. Compliance in one room does not preclude significant exceedances in other rooms of the house or neighbouring properties, due to the underlying variabilities in coupling loss, internal amplification and reradiation as sound. It is not practical to try and establish compliance at every potentially affected receiver, or to design with conservatism such that there are no exceedances in any room.

A more practical approach to measure compliance with ground-borne noise criteria is simply measuring vibration externally to the building. The estimated coupling losses, internal amplifications and efficiency of vibration re-radiating as sound that were used in the planning and design stages can then be subtracted from the internal predictions, verifying that the vibration levels in the ground that formed the basis of the design are in compliance. This would provide an indication of likely ground-borne noise compliance, and is more applicable to understanding if vibration and ground-borne noise across a general area are within expected ranges than a measurement inside a building which is affected by the response of that specific building.

10 UPCOMING PROJECTS AND HOW THESE MAY INFLUENCE ASSESSMENT APPROACHES

Several major projects are in the pipeline across Australia that may influence modelling methods and further encourage improvements in the art of railway noise impact assessment. Urban passenger projects are underway in many areas; the impacts of these projects are being assessed using existing guidelines and approaches and generally it is expected that the design of these projects can adequately manage noise and vibration emissions to within acceptable levels.

Two specific projects with the potential to influence assessment approaches are the currently under construction Inland Rail project, and the potential for high-speed rail. These are projects that will cross state boundaries – Inland Rail has already generated considerable discussion about the need for unified assessment methods across Australia (SLR Consulting, 2023).

In relation to high-speed rail, eventually a national high-speed rail network may become a reality, or at least connect Brisbane, Sydney, Canberra, and Melbourne. While the first phase of this network is focusing on Newcastle to Sydney, now is the time to consider if current rail noise and vibration impact assessment approaches are suitable for the task. There is potential for noise impacts from high speed trains at considerable distances from the tracks. Yet high speed rail would represent a seismic shift in the areas where it is constructed, and it would be expected that considerable new development would occur around stations and other areas close to the alignment.

These projects represent an opportunity for big picture thinking, including assessing and addressing noise and vibration impacts wholistically alongside the other impacts and benefits of the projects to ensure outcomes are protective of affected receivers, but also are cost-effective and maximise the value to society that these types of projects can provide.

11 CONCLUSIONS

This paper poses a two part question, “is our typical system of rail noise and vibration impact assessment working?” and “what could we do better?”.

Across Australia, generally our system of rail noise and vibration impact assessment is working reasonably well in achieving the objectives of protecting those affected by adverse noise and vibration impacts from railway projects. Most projects open with general community acceptance. However, there are many areas where we can do better, highlighted in this paper. Key areas for improvement are:

- Consolidating freight noise emission data to ensure that appropriate source levels are used to assess projects.
- Incorporating best practice noise modelling algorithms and prediction tools to avoid excessive conservatism.
- More rigorous noise model validation, including validation of noise propagation over relevant distances.
- Avoiding application of noise investigation thresholds as rigid criteria that must not be exceeded.
- Contractual requirements for operation and maintenance to promote long-term impact minimisation.
- Improvements in effective communication of impacts.
- Revisiting tactile vibration assessment approaches and criteria to better reflect human annoyance responses.
- Focussing on external vibration measurement for general ground-borne noise project compliance.

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