Environment Protection Authority

# Guidelines for the assessment of noise from rail infrastructure

EPA South Australia

**Guidelines for the assessment of noise from rail infrastructure**

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Disclaimer

This publication is a guide only and does not necessarily provide adequate information in relation to every situation. This publication seeks to explain your possible obligations in a helpful and accessible way. In doing so, however, some detail may not be captured. It is important, therefore, that you seek information from the EPA itself regarding your possible obligations and, where appropriate, that you seek your own legal advice.

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# 1 Introduction

Noise arises from many different types of sources and activities. The simple definition of noise is that it is unwanted sound, and as such, may have both direct physical and psychological effects on people if it is intense or persistent enough; causing sleep disturbance, interfering with normal conversations, or annoyance and stress. Evidence is accumulating that noise has real health effects on people.

The EPA criteria and associated information on noise are based on current knowledge provided by health authorities such as the National Health and Medical Research Council and the World Health Organization (WHO). While there are some basic principles that apply to management of noise from all sources, the character of noise emissions varies widely between railways, roads, domestic sources, industrial activities and wind farms. Noise may be continuous, intermittent, impulsive, containing dominating tones, or may incorporate several of these characteristics. Perception of noise by people can also vary widely and depend on many factors, such as background noise from wind, trees or traffic, weather conditions and building design.

Broad regulation of noise is addressed within the *Environment Protection (Noise) Policy 2007* (Noise Policy), which gives effects to section 25 of the *Environment Protection Act 1993* (EP Act). However, because of the specific nature of noise from different sources such as wind farms and transport corridors, the EPA has developed a range of guidelines that cover the exact requirements for managing noise from these sources.

Together, the Noise Policy and guidelines provide the basis for provision of EPA advice on development proposals and local development plans; and underpin operating conditions for activities licensed under the EP Act. They are predicated on broad principles that communities should be protected from sleep disturbances and be able to carry on normal conversations in their own homes, based in particular on WHO criteria.

The same criteria also form the basis for other Government policy instruments such as the *Minister's Specification SA 78B: Construction requirements for the control of external sound* (DPTI 2013), discussed later in this section, and *Reducing noise and air impacts from road, rail and mixed land use: a guide for builders, designers and the community (DPTI 2012).* Given this, it is important to note that the criteria do not aim for these sources to be totally inaudible, but they are provided to minimise adverse impact of rail operations on amenity in the area.

The South Australian Government has proposed a number of rail infrastructure projects including the electrification of major metropolitan commuter rail lines in order to modernise and extend the passenger rail network. These initiatives aim to develop a modern, transit focused, connected and sustainable city, and will assist in delivering the objectives of the *30-Year Plan for Greater Adelaide* (30-Year Plan) and other government initiatives, by providing:

- an expanded and effective light rail, passenger rail and freight rail system, with improved economic efficiency
- environmental and social benefits including improved safety, fuel efficiency and reductions in greenhouse gas emissions, road congestion and travel time
- long-term mitigation and management of potential adverse impacts from noise and vibration on the health and amenity of nearby communities.

The *Guidelines for the assessment of noise from rail infrastructure* (the *Guidelines*) provide support to the 30-Year Plan by providing clear guidance on the management of potential noise and vibration effects.

The 30-Year Plan incorporates a design philosophy of mixed residential and commercial centres adjacent to major transport nodes providing access to a variety of transport options including mass public transit by rail service or buses, private motor vehicles, walking or cycling. A number of sites designated as transport oriented developments (TODs), and several other major infill developments along existing rail/road corridors are the subject of Structure Plans being developed under the 30-Year Plan. Structure Plans will incorporate guidelines to protect homes along major transport corridors from noise and air pollution, and the *Guidelines* will complement Structure Plans where they include developments near rail corridors.

**The 30-Year Plan for Greater Adelaide**

The 30-Year Plan refers to noise mitigation for residential developments such as transport oriented developments (TODs) and infill developments along major transport corridors.

Several policies relating to management of potential noise issues are enunciated in the Plan:

- Policy 6 – objectives for Structure Plans:
  Structure Plans for greenfield developments, urban infill and transit oriented developments will set objectives and guidelines for the quality of building performance outcomes in terms of … noise attenuation and air quality….
- Target A – building design principles:
  Develop design principles for multi- and mixed-use developments, to be incorporated in Structure Plans…. This work will include … responsive building design on busy corridors (including measures to address noise and air quality).
- Policy 2 – health and wellbeing:
  Ensure health and wellbeing requirements are incorporated into Structure Plans. Structure Plans will … incorporate guidelines to protect homes along major transport corridors from noise and air pollution.

Rail operations can cause noise and vibration effects which may result in nuisance and annoyance for occupants of nearby residential and other sensitive land uses. The *Guidelines* outline approaches for the assessment of noise and vibration from rail operations for both rail infrastructure projects as well as new noise sensitive developments near railway lines.

The *Guidelines* define evaluation distances from rail infrastructure where potential adverse noise and vibration impacts may exist for noise (and vibration) sensitive receivers. These distances are indicative only, and aim to provide guidance for developers of rail infrastructure or new residential areas (or other sensitive uses) on whether investigation of potential impacts will be required. In practice, rail infrastructure and residential areas can be brought closer than the stated evaluation distance by effective mitigation of noise at the source, between the source and the sensitive development, or at the sensitive development itself. Actions such as those below may be used to achieve effective noise reduction in situations where the proposed source–receiver distance is less than the stated evaluation distance:

- Design of developments to minimise risks from noise and vibration. This may include the provision of adequate separation through the creative use of open space or alternatively siting and orienting houses and apartment buildings to minimise penetration of noise into the development. This also may include eliminating corridors between buildings that may funnel noise into a development; or siting community social spaces on the side of buildings away from the railway.
- Engineered acoustic treatments along railway corridor boundaries (such as mounds or barriers).
- Creative architectural design to ensure internal noise amenity, including orientation of windows and balconies away from noise sources, double-glazed windows, acoustic insulation in walls, and adoption of mandated building specifications for noise attenuation.

In practice, a combination of the above measures is likely to result in the optimal solution. It is advantageous to give consideration to these design features at an early stage of the project as the overall costs associated with noise mitigation are likely to be minimised. For example, in a well-designed development, architectural treatment (such as double glazing and acoustically rated insulation) may only be necessary in the first row of houses or apartments.

**Minister's Specification SA78B: Construction requirements for the control of external sound**

The South Australian Government recently released the *Minister's Specification SA 78B* (Minister's Specification) established under the *Development Act 1993*, which aims to ensure that an appropriate level of internal noise amenity is achieved for new sensitive development near major transport routes (including railways and major roads), The Minister's Specification is applicable to certain classes of building, where the site of the proposed or existing building lies within the Noise and Air Emissions Overlay of the relevant Development Plan.

The document aims to simplify for developers the process of achieving an adequate internal amenity through 'deemed to satisfy' provisions, where a specified standard of building construction is deemed appropriate to meet the required internal amenity. For larger developments, the Minister's Specification attempts to encourage innovation by providing latitude for developers to attempt to creatively manage noise and vibration impacts, in addition to minimising construction costs, by engaging an acoustic consultant to develop an innovative design solution which meets the specified internal noise criteria. The *Guidelines* and the Minister's Specification therefore play a complementary role in addressing noise impacts from railways.

The *Guidelines* draw on a review of social survey research, and interstate and international guidelines (refer to the references in the Bibliography). Minimisation of health risks arising from rail noise exposure is considered from both practicability and feasibility perspectives. Recommendations of the WHO (1999, 2009) or the prevention of adverse effects from transport noise are taken into account in the specification of the recommended noise limits.

Underpinning the *Guidelines* are the paramount twin principles of protecting communities against sleep disturbance and providing for speech intelligibility within houses. However, further improvements in amenity are encouraged where practicable. It is important to recognise that it may not be possible to eliminate all noise on urban developments such as those on external amenity, where noise from other transport and normal activities of suburbia already impact on residents.

To assist in understanding of the *Guidelines* content, shaded boxes contain further information and comments.

**General environmental duty**

The Environment Protection Act 1993 (EP Act) has a general duty of care for the environment (section 25) which states:

> A person must not undertake an activity that pollutes, or might pollute, the environment unless the person takes all reasonable and practicable measures to prevent or minimise any resulting environmental harm.

Compliance with guidelines published by the EPA represents the standard of care which should be met to secure compliance with the general environmental duty. Current guidelines have the advantage of flexibility and can be adapted to a range of circumstances.

## 1.1 Objectives

The *Guidelines* outline approaches for minimising and managing noise and vibration impacts from rail activity, including a process to assess potential impacts and to allow for proper environmental management of rail or sensitive developments that may be affected by noise from rail activity. A consistent assessment procedure for rail-related projects will improve regulatory transparency and assist in achieving effective planning processes. As sensitivity to noise varies between individuals, the noise and vibration criteria may not completely prevent adverse impact arising from railway operations for all individuals. However application of the *Guidelines* will assist in minimising adverse impact for the general community and meeting the criteria will demonstrate that reasonable and practicable measures have been taken to prevent or minimise environmental harm.

The noise and vibration criteria are based on a literature review of interstate and overseas regulatory practices and practical experience gained from completed rail-related projects in South Australia. There are several contributing factors to effectively managing rail noise and vibration, of which the *Guidelines* form only one part. In order to effectively manage rail noise impacts from a corridor:

- Proponents of new and upgraded railway line projects should comply with the *Guidelines*. Where EPA's support for the project is required in order to gain development approval for the project, the proponent will be expected to assess the development in accordance with the *Guidelines.*

- Rolling stock operators should ensure that operational rolling stock is maintained to a high standard in order to minimise the likelihood of excessive noise emission.
- The owner (or operator) of tracks constructed to meet the *Guidelines* should maintain rail infrastructure to a high standard to reduce the likelihood of increases in the noise emission from the corridor above and beyond the noise impact predicted prior to construction of the project.
- Where the EPA’s support for a project is sought by the proponent (or required), or a relevant authority chooses to apply the *Guidelines*, proponents of new residential and other sensitive developments near existing railway infrastructure may be required to comply with these *Guidelines*.

As part of a holistic approach to noise and vibration management; it is important that all new noise sensitive developments are designed and constructed in compliance with building and planning regulations, particularly related to noise and vibration control.

## 1.2 Structure of this document

Sections 1 and 2 of the *Guidelines* provide general information including criteria for rail noise in different cases and define situations where these apply.

Sections 3 and 4 provide technical information about the application of the *Guidelines* including guidance on procedures for collecting and interpreting data, and predicting noise and vibration impacts. Due to the technical nature of this information, it is intended to be primarily used by acoustic engineers engaged in the assessment of rail noise and vibration.

Section 5 provides information for developers, planners and other interested parties on mitigation strategies and design solutions to assist in addressing amenity issues which may arise from rail development, or noise and vibration sensitive development near existing rail lines. This section is not intended to provide solutions for every potential development issue that may arise, but gives a starting point for innovation in meeting amenity criteria through mitigation techniques.

## 1.3 Application of the *Guidelines*

The *Guidelines* are suitable for application to noise and vibration from tram and train line (including passenger and freight rail) operations in the following situations:

- new railway lines
- upgrades to existing railway lines
- new noise and/or vibration sensitive development adjacent to existing railway lines.

Wherever application of the *Guidelines* is appropriate, the mechanism will in most cases be through the development approval system. As such, where a development is of a level of significance such that development approval is required for the project, the planning authority (or other relevant body) is encouraged to apply the *Guidelines* in assessing rail-related noise and vibration impacts of the project. Details of the type of projects requiring development approval are contained in the *Development Regulations 2008*.

The *Guidelines* are **not** applicable to:

- existing railway lines, facilities and stations where no upgrade or new noise and/or vibration sensitive development is taking place
- noise from safety warning devices during rail operations (eg warning horns on locomotives and bells at level crossings)
- noise and vibration during construction of rail infrastructure
- general maintenance of the rail network
- noise from rail-yards, rail freight terminals, intermodal facilities and stations
- occupational noise and vibration due to rail operations, which are governed by the *Work Health and Safety Regulations 2012*.

For information on noise that is not covered by this document including noise from rail-yards, intermodal facilities and railway stations refer to the Noise Policy[1]. Noise that is not managed under the Noise Policy must still meet the general environmental duty required under section 25 of the EP Act.

The *Guidelines* are not applicable to noise from safety devices associated with railway operations, such as warning horns and bells at level crossings, due to the need to ensure public and railway employee safety. However, it is recommended that the design of new and upgraded railway lines include a consideration of noise from safety devices and aim to reduce noise levels from such devices to achieve compliance with the *Guidelines*.

### 1.3.1 New railway lines

A proposed development is considered as a 'new railway line', and as such should meet the relevant noise criteria where:

- A new railway is being constructed in a new rail corridor where nearby noise sensitive receivers are not already exposed to rail noise

or

- An additional railway line is being constructed within an existing corridor, and noise levels generated by existing rail operations in the corridor meet the criteria for new railway lines outlined in Section 2

or

- A substantial realignment of an existing railway within an existing corridor. Normally it involves change of the corridor boundaries or significant alteration of separation distances to the nearest sensitive receivers within the existing corridor.

New railway line developments are subject to more stringent noise criteria (Table 1) as they are able to include cost-effective mitigation measures during the design and planning stages of the project, and are also able to take advantage of modern track design principles which improve operational performance and reduce annoying noise characteristics.

In each of the above cases, it is only intended that rail traffic on the new (or substantially realigned) rail lines within the corridor would meet the criteria outlined in Section 2. It is expected that any post-construction measurements to confirm the rail impact of a project would separate noise impacts from the various railways in a shared corridor accordingly.

### 1.3.2 Upgraded existing railway lines

The noise criteria for upgraded railway lines are intended to be applied where existing rail noise levels at sensitive receivers are at or above the noise criteria for new railway line developments in Table 1. Less stringent criteria are applied in these cases because sensitive receivers adjacent to existing railway lines are already exposed to rail noise and there are often practical limitations to the extent to which noise mitigation measures can be applied to existing infrastructure.

Upgrade works to railway lines would typically involve works within the rail corridor such as extension of the railway line or alteration to the alignment of the rail line. This may include minor widening or realignment of the rail corridor, which would likely result in an increase in noise levels at sensitive receivers. It would not apply to reactivation of a previously non-operational rail line.

Maintenance work on existing lines (including activities such as re-sleepering, electrification and minor track re-alignment) does not generally constitute development and will not be assessed under the *Guidelines*. Such works generally will not increase rail noise or vibration at sensitive receivers, and therefore these activities are not typically considered as upgrade works. In cases where upgrades are considered the *Guidelines* will only apply to the proposed development, not to existing rail operations.

[1] www.epa.sa.gov.au/xstd_files/Noise/Guideline/guidelines_noise_epp.pdf

### 1.3.3 New noise sensitive development adjacent to existing railway lines

The *Guidelines* outline appropriate criteria for planning authorities to assess new noise and/or vibration sensitive development proposed near to existing railway lines. New noise and/or vibration sensitive development that should achieve compliance with the criteria includes residential development (including nursing homes and caravan parks incorporating long-term residential use), educational institutions, places of worship, hospitals and recreational areas. New noise and/or vibration sensitive developments proposed adjacent to existing railway lines should be designed to achieve the noise and vibration criteria outlined in Section 2.

### 1.3.4 Evaluation distances

The impact of noise and vibration should be predicted and considered in the design if noise sensitive developments are proposed within the following *evaluation distances*:

- 35 metres from a tram line[2]
- 180 metres from a train line[3]

If noise sensitive developments are proposed at a sufficient distance from rail lines or vice versa, the *Guidelines* consider that rail noise and vibration impacts will be minimal, and therefore detailed consideration of these impacts during the design of the project is not required.

As noted previously, these distances indicate the need to investigate impacts. Developments proposed within these distances may be acceptable, however a consideration of noise and vibration from rail operations is required, and where necessary appropriate mitigation actions should be implemented. Noise sensitive receivers at distances greater than the above e*valuation distances* from the nearest railway line are deemed to be sufficiently far from the railway such that noise and vibration impacts arising from a modern, well- designed rail system will be minimal.

> In addition to being subject to the provisions of this *Guideline*, buildings constructed as part of noise sensitive developments encroaching upon existing rail corridors may be subject to the provisions of Minister's Specification SA 78B: Construction requirements for the control of external noise. Where the site of a proposed building falls within the Noise and Air Emissions Overlay (which will trigger the specification and identify where it applies) as indicated in the relevant Development Plan for some transport corridors, the provisions of the Minister's Specification are mandatory.

2 See definition in Glossary

3 See definition in Glossary

# 2 Noise and vibration criteria

For rail infrastructure projects involving new or upgraded railway lines, the criteria will apply at existing noise sensitive receivers, as well as at any proposed future sensitive receivers which have already gained development consent under the *Development Act 1993* prior to the announcement of the rail project, the exception is for cases where the development is situated in the previously identified Noise and Air Emissions Overlay in the relevant Development Plan.

For new noise sensitive development proposed near existing railway lines or development which has gained development consent after the announcement of a rail infrastructure project, it is the developer's responsibility to ensure the development is designed with appropriate consideration of noise and vibration impacts, which may be demonstrated by meeting the noise and vibration criteria. For many major transport corridors, the need for certain classes of buildings to consider noise impacts from the transport corridor may be formally identified by the Noise and Air Emissions Overlay in the relevant Development Plan for the area. In such cases, when building rules approval is sought, compliance with the provisions of the Minister's Specification is mandatory.

In some circumstances, the Noise and Air Emissions Overlay may also identify land earmarked for future rail transport routes. In such cases, noise sensitive development proposed within the zone identified by the overlay as well as within the evaluation distances specified in Section 1.3.4 should undertake consideration of potential noise impacts against the noise and vibration criteria.

Sensitive receivers that may be impacted by noise or vibration include:

- residential dwellings and associated private outdoor recreational areas at the ground level (if applicable)
- nursing homes and caravan parks that accommodate existing long-term residential use
- educational institutions
- hospitals
- places of worship
- passive recreation areas, such as parks
- active recreation areas, such as sporting fields.

It is also important to provide a reasonable level of amenity for outdoor areas associated with schools, educational institutions and hospital grounds.

## 2.1 Noise criteria

Air-borne noise from rail pass-bys can have a significant effect on noise sensitive receivers adjacent to a railway line.

Due to the nature of rail operations, noise levels immediately next to a railway line normally consist of relatively short periods of high noise levels throughout the day and night periods, separated by longer periods of quiet. In order to assess potential rail noise effects, it is important to consider both the overall rail noise exposure across a 24-hour day and the noise from individual rail pass-bys.

The majority of air-borne noise from rail pass-bys is generated by a combination of noise from the rail vehicle propulsion system and from interaction at the vehicle–track interface.

The rail propulsion system normally consists of either a diesel or electric locomotive or integral power unit. Diesel locomotives can be a considerable source of engine noise, with significant engine exhaust noise emitted at a height of approximately four metres above the rail, making noise mitigation difficult. Electric locomotives are quieter as they produce less mechanical noise and require no exhaust.

Noise from the vehicle– track interface can be generated through a number of mechanisms based around the continuously welded rail and on tight radius curves where wheel squeal and flanging noise can arise. As wheel-rail noise is generated at a relatively low height, it can often be more practical to reduce through mitigation measures than locomotive noise. Maintaining the condition of the track and the rolling stock is also an important factor in reducing noise from the vehicle–track interface.

Warning horns can be a significant source of maximum noise events from rail corridors, particularly near level crossings. Due to the need to protect the safety of the public and train operators, it is not normally practical to mitigate this noise source. However, the design of new and upgraded railway lines should consider the noise effect of warning horns and aim to reduce the need for them, where possible.

To assess rail noise, criteria are provided for:

- $L_{Aeq,15h}$ and $L_{Aeq,9h}$ equivalent noise levels, addressing the average noise exposure of a sensitive land use across the day or night period respectively.
- $L_{Amax}$ levels, addressing the maximum noise levels at a sensitive land use due to individual pass-by events.
- $L_{Aeq,1h}$ equivalent noise levels, addressing the worst-case average noise exposure of non-residential sensitive receivers during their hours of operation.

Separate $L_{Aeq}$ criteria are provided for the day and night periods with more stringent criteria applied for the night period. This reflects the increased effect of rail noise during night-time. The 15-hour day period is defined from 7 am to 10 pm and the nine-hour night period from 10 pm to 7 am.

Table 1 outlines the noise criteria at noise sensitive receivers for new railway lines and upgraded existing lines, and for new residential development adjacent to existing rail corridors. The noise criteria represent external noise levels at the most exposed sensitive façade at the ground level. The aim of the *Guidelines* is to protect internal living areas and external recreation areas.

**Table 1 Noise criteria for residential receivers**

| Period | Noise criteria, dB(A) | | |
|---|---|---|---|
| | Rail infrastructure developments | | New sensitive developments near existing railway line |
| | New railway line | Upgraded existing railway line | |
| Day, 7 am to 10 pm | 60 $L_{Aeq,15h}$<br>80 $L_{Amax}$ | 65 $L_{Aeq,15h}$<br>85 $L_{Amax}$ | 60 $L_{Aeq,15h}$<br>80 $L_{Amax}$ |
| Night, 10 pm to 7 am | 55 $L_{Aeq,9h}$<br>80 $L_{Amax}$ | 60 $L_{Aeq,9h}$<br>85 $L_{Amax}$ | 55 $L_{Aeq,9h}$<br>80 $L_{Amax}$ |

The criteria outlined in Table 1 are also applicable for nursing homes, aged care facilities and for caravan parks accommodating long-term residential use.

If private or community outdoor recreation areas associated with the sensitive noise receiver are provided, the residential noise criteria in Table 1 should be met in at least one of these locations to enable residents to enjoy a place of quiet amenity.

Table 2 outlines the noise criteria for non-residential sensitive receivers near proposed new railway lines and upgraded existing lines, and for new sensitive development adjacent to existing rail corridors. The noise criteria represent external $L_{Aeq}$ noise levels at the most exposed sensitive façade for the hours of operation of the land use unless otherwise stated. Noise assessment in recreational areas should be conducted at the most exposed boundary of the area.

For new noise sensitive developments, it is advisable to refer to the relevant Development Plan applicable to the locality of interest. The development plan may indicate that special provisions regarding protection from rail noise apply in the development zone, or that the subject site lies within the Noise and Air Emissions overlay. In such cases, the provisions of the Minister's Specification are mandatory for building rules approval to be granted for certain classes of buildings on the land.

**Table 2 Noise criteria for non-residential sensitive receivers during hours of operation**

| Landuse | Noise criteria, dB(A) | | |
|---|---|---|---|
| | Rail infrastructure developments | | New sensitive developments near existing railway line |
| | New railway line | Upgraded existing railway line | |
| Educational institutions | 65 $L_{Aeq,1h}$ | 65 $L_{Aeq,1h}$ | 65 $L_{Aeq,1h}$ |
| Hospitals | 60 $L_{Aeq,1h}$ | 60 $L_{Aeq,1h}$ | 60 $L_{Aeq,1h}$ |
| Places of worship | 60 $L_{Aeq,1h}$ | 60 $L_{Aeq,1h}$ | 60 $L_{Aeq,1h}$ |
| Passive recreation areas* | 60 $L_{Aeq,15h}$ | 65 $L_{Aeq,15h}$ | 60 $L_{Aeq,15h}$ |
| Active recreation areas such as sporting fields* | 65 $L_{Aeq,15h}$ | 65 $L_{Aeq,15h}$ | 65 $L_{Aeq,15h}$ |

* Level to be assessed at most affected location of the recreation area.

$L_{Amax}$ noise criteria have not been specified for the sensitive receivers in Table 2 as the focus for these receivers is considered to be speech interference and interference with general activities.

### Technical notes to Tables 1 and 2

- When noise levels due to a new or upgraded rail development are predicted, noise impact from the development should meet the noise criteria both on project opening and for expected rail volumes over an indicative period into the future (eg 10 years after project opening). Future growth in rail vehicle volumes should be taken into account if noise monitoring to verify the accuracy of predictions is conducted upon completion of a project.
- Where the noise criteria are specified as $L_{Aeq,T}$ levels (for the time period T), the levels refer to noise from rail operations only and do not include noise from other sources that may affect the general ambient environment at a receiver, such as noise from road traffic and industrial areas or noise from other rail infrastructure not considered under the guidelines (eg rail-yards).
- $L_{Aeq,1h}$ levels are to be assessed for the typical worst-case rail noise period during the hours of operation of the sensitive receiver.
- Where $L_{Amax}$ levels are specified, the criteria refer to the maximum noise level from rail operations only not exceeded for 95% of rail pass-by events.
- For residential receivers, educational institutions, hospitals and places of worship, external noise levels should be assessed at a distance of one metre from the window of the receiver most exposed to noise from the rail corridor, at a height of 1.2-1.5 metres above floor at the ground level. The noise criteria for these receivers include an allowance for noise reflected from the building facade, assumed to be +2.5dB.
- If an assessment requires prediction or measurement of external noise levels at a free-field location away from building façades and other reflecting surfaces, then the noise level should be adjusted by +2.5dB to account for reflections from a building facade. This will ensure that the comparison of measured and predicted noise levels against the noise criteria is consistent.

- The noise criteria for all recreation areas do not allow for noise reflection from a facade, and noise levels at these locations should be measured and predicted for free-field conditions. For outdoor areas associated with schools, educational institutions, places of worship, etc, the relevant passive or active recreational categories apply.
- The EPA recognises that in some situations meeting the external noise criteria may not be practicable. In these cases it is appropriate to provide protection to internal areas of the receiver in order to achieve compliance with the design sound levels indicated in the Minister's Specification. Noise sensitive areas in educational institutions and places of worship would generally be areas designated for study or prayer, or where speech recognition is important.
- All rail noise levels should be measured in accordance with the procedures outlined in Section 4.1.

## 2.2 Ground-borne noise criteria

Ground-borne noise from rail operations can be generated when ground-borne vibration produced by a rail vehicle pass-by is re-radiated as noise inside a building by the building structure. The causes of ground-borne noise from rail operations are therefore the same as those of ground-borne vibration, discussed in Section 2.3.

In the majority of situations, ground-borne noise is not normally noticeable as it is at a much lower level than the level of air-borne noise from rail pass-bys. However, ground-borne noise may cause annoyance when there is no significant air-borne noise affecting a residence, such as where noise sensitive receivers are located above underground railways, in a mixed-use building integrating rail infrastructure or in close proximity to the railway. While these situations are currently uncommon in South Australia, the increasing focus on high-density development around public transport infrastructure and TODs mean that a method for assessing the effect of ground-borne noise is required.

Table 3 presents the ground-borne noise criteria for noise sensitive receivers. These criteria are only to be applied where the level of ground-borne noise from rail pass-bys is higher than the level of air-borne noise from the pass-by.

**Table 3 Ground-borne noise criteria for sensitive receivers**

| Landuse | Time period | Ground-borne noise criteria, dB(A) |
|---|---|---|
| Residential | Day, 7 am to 10 pm | 40 $L_{Amax}$ (slow) |
| | Night, 10 pm to 7 am | 35 $L_{Amax}$ (slow) |
| Educational institutions & places of worship – quiet areas | When in use | 40 $L_{Amax}$ (slow) |
| Educational institutions & places of worship – other areas | When in use | 45 $L_{Amax}$ (slow) |
| Hospitals – sleeping areas | When in use | 35 $L_{Amax}$ (slow) |
| Hospitals – other areas | When in use | 40–45 $L_{Amax}$ (slow) |

The $L_{Amax}$ (slow) criteria outlined in Table 3 refer to the maximum noise level not exceeded for 95% of rail pass-by events, measured using the 'slow' response setting on the sound level meter. The criteria are applicable to ground-borne noise from rail pass-bys only and measurement should exclude contributions from other noise sources. The ground-borne noise levels are to be measured and predicted near the centre of the most exposed sensitive room, with measurements conducted in accordance with the procedures outlined in Section 4.2.

Note that quiet areas in educational institutions and places of worship would generally be areas set aside for study or prayer, or where listening is important. For hospitals, the ground-borne noise level from rail pass-bys in wards used for sleeping is to be less than 35dB(A) $L_{Amax}$ (slow). For other areas of hospitals, the lower criterion of 40dB(A) would normally be applicable for more noise sensitive areas, with a higher criterion of 45dB(A) adopted for less sensitive spaces[4].

## 2.3 Vibration criteria

As well as generating air-borne and ground-borne noise, rail operations also generate ground-borne vibration that can affect sensitive receivers. Vibration effects from rail movements may include annoyance, discomfort and interference with typical activities. At higher levels of vibration, effects can also include disturbance to building contents although this is unlikely in the majority of rail pass-by situations.

Ground-borne vibration from rail movements is created by the interaction between the wheels and the rail, where irregularities in either surface can generate considerable vibratory energy. These irregularities may include variations in the roundness and smoothness of wheels, or in the flatness and smoothness of the rail itself. Vibration can also result where the track contains expansion joints, which incorporate regular gaps to allow the track to expand in warmer weather conditions. The support system of the railway line is also an important determinant of the level of vibration, and can contribute to higher levels of vibration where the rail is supported at fixed points by a rigid support system rather than on track ballast.

In order to minimise the vibration generated by rail operations, the track and rolling stock should be kept in good condition. Tracks may be constructed using continuous welded rail and a support system that provides vibration isolation to reduce transmission through to the ground.

Vibration levels from 95% of rail pass-bys at adjacent sensitive receivers should achieve compliance with the evaluation criteria for intermittent vibration sources provided in Annex A of Australian Standard AS 2670.2–1990: *Evaluation of human exposure to whole-body vibration, Part 2–Continuous and shock-induced vibration in buildings (1 to 80Hz)*.

Rail vibration levels should be measured and predicted at the worst-case location within a building which represents a typical position for building occupants. Measurement of vibration from rail pass-bys is to be conducted in accordance with the procedures outlined in Section 4.3.

4 Refer to Bibliography – New South Wales Department of Environment and Climate Change 2007 and WHO Health Organization 1999.

# 3 Rail noise and vibration assessments

This section describes the typical steps that would be undertaken as part of a rail noise and vibration assessment, as well as an indication of what should be prepared as part of the assessment documentation. It is intended that an assessment would be carried out by an appropriately qualified acoustic engineer [5] or an officer authorised under the EP Act.

Depending on the type of development, the following steps would normally be addressed in the assessment:

- measurement of existing rail noise and vibration
- prediction of rail noise and vibration
- noise and vibration mitigation procedures
- measurements to verify the accuracy of noise and vibration predictions.

Note that, while the first three steps would be presented in a single assessment report, post-construction verification measurements would normally be conducted some time after the initial rail noise and vibration assessment and presented in a separate report.

## 3.1 Measurement of existing rail noise and vibration

Measurements of the existing rail noise and vibration at or near sensitive receiver locations would normally be expected for the assessment of an upgrade of an existing railway line or of a new noise sensitive development adjacent to an existing line. The purpose of the measurements is to characterise the existing exposure of sensitive receivers or the existing exposure of the site of a proposed sensitive development. The measurements will also allow rail noise and vibration predictions to be validated to ensure an acceptable level of accuracy.

Where a large number of sensitive receiver locations are adjacent to the rail corridor and need to be included in the assessment, it will not be practical to measure existing rail noise and vibration at every location. In these cases, the existing conditions at all sensitive receiver locations should be predicted based on measurements conducted at a number of representative sites. For example, the nearest residential location to the railway line among a group of residences would normally provide a suitable monitoring site. The exact number of representative locations will depend on the project area, and monitoring for projects involving large rail corridors should be discussed with the EPA to confirm the number and location of monitoring sites. Rail noise and vibration prediction methodologies are discussed in Section 3.2.

All measurements of existing rail noise and vibration are expected to be conducted in accordance with the procedures outlined in Section 4.

For new railway corridors, measurements of existing rail noise and vibration are not required if there is no existing railway line in the general vicinity of sensitive receivers. However, measurements of existing rail noise and vibration from other rail corridors may still be useful to provide validation of noise and vibration prediction methodologies.

## 3.2 Prediction of rail noise and vibration

As part of any assessment of rail noise and vibration, it will be necessary to carry out predictions to assess the noise and vibration levels at sensitive receivers due to new or upgraded railway lines, or at a new noise sensitive development adjacent to an existing railway line. Predictions should be carried out for both the project opening situation and, in the case of projects involving new or upgraded rail infrastructure, for an indicative future situation of the railway line, eg 10 years after opening. Predictions should show that noise and vibration levels are projected to meet the relevant criteria for both situations, with appropriate 'reasonable and practicable' mitigation measures identified where necessary.

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5 See definition in Glossary.

### 3.2.1 Rail noise prediction

Rail noise levels should be predicted using a three-dimensional model in an appropriate computer noise-modelling software package that correctly implements the chosen rail noise prediction method. The method or methods will normally need to be capable of predicting $L_{Aeq}$ and $L_{Amax}$ noise levels for comparison with the criteria.

> There are a number of computer noise modelling software packages for implementing rail noise propagation models. These include the SoundPLAN software, produced by Braunstein + Berndt GmbH, and the CadnaA software produced by DataKustik GmbH. Any software package would normally be considered acceptable as long as it correctly implements an appropriate noise propagation model.

A number of specific rail noise prediction algorithms that calculate noise at identified receiver locations are in use around the world. One commonly employed model is the Nordic Rail Prediction Method, which predicts both $L_{Aeq}$ and $L_{Amax}$ noise levels. Other models, such as the United Kingdom Calculation of Railway Noise (CoRN), only predict $L_{Aeq}$ noise levels and may need to be used in conjunction with other prediction methods during an assessment.

While the Nordic Rail Prediction Method and CoRN models would be considered acceptable, it is important to realise that each model has been developed from measurement data compiled in the country of origin based on their specific rolling stock fleet and track construction. Should either model be used, it should be validated for the specific project based on existing rail noise measurements in South Australia or another Australian state where rolling stock noise has similar characteristics.

> In addition to the Nordic Rail Prediction Method and CoRN models, a number of other rail noise models are in use in Europe. The European Union (EU) is currently working to harmonise these methods and to develop a rail noise prediction method, largely based on the Dutch SRMII method.
>
> The use of any rail noise prediction models should be discussed with the EPA prior to use, and it may be necessary for the predictions to be validated for South Australian conditions.

Whatever prediction algorithm is utilised in the modelling process, it is critical that all input data and validation information be clearly stated in the noise assessment report. Where relevant, the documentation should clearly state how noise due to turnouts, diamond crossings, mechanical joints, curve squeal and the like have been accounted for.

Standard modelling factors that should be conservatively adopted for rail noise prediction are:

- predict noise levels in octave bands from at least 31.5 Hz to 4 kHz
- use worst-case weather conditions[6] [7]
- use atmospheric conditions at 15°C and 70% humidity
- assume hard ground between the rail line and noise sensitive receivers.

Where alternative modelling factors are used, justification is to be given for the selection of the alternative factors.

> The standard modelling factors presented have been selected to provide a conservative prediction of rail noise from typical propagation models. However, they will not necessarily be appropriate or applicable for all assessment situations. Alternative factors for specific situations or for different propagation models will normally be acceptable as long as reasonable justification can be provided.

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6 In accordance with the *Guidelines for the use of the Environment Protection (Noise) Policy 2007* (pg 48) worst-case weather conditions should correspond to CONCAWE meteorological category 6 at night, and 5 during the day.

7 Weather patterns are considered significant when they occur for greater than 10% of the year, or greater than 30% of any one season. In cases where worst case conditions are different from the default conditions, justification must be provided.

### 3.2.2 Ground-borne rail noise and vibration predictions

There is no widely used and accepted model for the prediction of ground-borne noise and vibration from railway operations. International Standard ISO 14837–1:2005 *Mechanical vibration–Ground-borne noise and vibration arising from rail systems* provides a discussion on different types of prediction models and reference should be made to this standard for further information.

Broadly speaking, there are two types of models used for predictions of vibration:

- **empirical models:** measurements gathered at a site or series of sites are used to predict ground-borne noise and vibration levels at the sites in question based on simple extrapolation functions or regression and trend analysis
- **parametric models:** algebraic or numerical models that predict ground-borne noise and vibration based on a specific set of input data.

Empirical models are most commonly used and would normally be considered acceptable as long as the situations in which the measurements were taken are representative of the prediction situation. It is important that the measurements used to predict the ground-borne noise and vibration levels are included in the noise assessment report.

The accuracy of parametric models is highly dependent on the quality of the input data which can make accurate predictions difficult if determinants of vibration and re-radiated noise at the prediction site are not accurately known. The use of any parametric model should be discussed with the EPA beforehand, with input data included in the documentation.

Reference may also be made to the US Federal Transit Administration *Transit noise and vibration effect assessment* (2006) for information on the assessment of ground-borne noise and vibration from rail operations.

## 3.3 Rail noise and vibration mitigation procedures

In situations where the predicted rail noise and vibration levels exceed the criteria, it is expected that the assessment recommends reasonable and practicable mitigation measures. In these cases, the assessment should detail the mitigation measures, the predicted noise and vibration levels with and without the measures implemented, and the overall reduction achieved.

Note that, for new and upgraded rail lines, mitigation measures installed at the source and along the transmission path should always be considered in preference to measures installed at noise sensitive receivers. Where mitigation measures at the receivers are proposed, the justification for this decision will be expected.

Refer to Section 5 for a discussion of typical noise and vibration mitigation measures for rail operations, the definitions of ‘reasonable’ and ‘practicable’, and an outline of the responsibility for the implementation of mitigation measures.

## 3.4 Post-construction measurements

The EPA may request measurements to demonstrate that noise and/or vibration levels meet the noise and vibration criteria upon completion of the development. Generally, this would be requested where a significant new or upgraded rail project has been completed or where significant mitigation measures have been implemented to achieve the criteria.

Under normal circumstances post-construction monitoring should be conducted at the external facade of noise sensitive receivers nearest to the railway line. Where a large number of sensitive receivers exist adjacent to a new or upgraded rail corridor, conducting compliance monitoring at every location is unlikely to be practical. In such situations, the existing conditions at all sensitive receiver locations should be predicted based on measurements conducted at a number of representative sites in a similar manner to measurements of existing rail noise discussed in Section 3.1. Note that, when selecting a representative number of monitoring sites, preference is to be given to any receivers that have been provided with rail noise or vibration mitigation as part of the project.

All verification measurements are to be conducted in accordance with the procedures outlined in Section 4, and should account for expected future rail volumes at least 10 years into the future. Future rail volume predictions will not be required where post-construction monitoring is undertaken at the completion of noise sensitive development near to an existing rail line.

In situations where post-construction monitoring indicates that the noise and/or vibration levels are exceeded at sensitive receiver sites, the EPA may request additional information in order to assess whether a noise or vibration reduction plan should be implemented. Refer to Section 3.5 for further information on such situations.

## 3.5 Non-compliance situations

Post-construction noise monitoring at the completion of a project may demonstrate that rail noise levels have exceeded the criteria specified during the design stage, or may deviate significantly from the predicted noise levels. In such situations, the EPA may require a noise reduction plan to be adopted that will implement appropriate mitigation measures in a specified time period.

In determining whether additional mitigation measures are required and the timeframe for implementing them, the following would normally be assessed:

- whether the criteria are exceeded, and by what margin
- the times of occurrence of the rail noise
- any component of the ambient noise environment that has a noise level similar to or greater than the rail noise
- any annoying character of the rail noise source, eg wheel or brake squeal
- any benefits of the project in reducing rail noise levels from previous existing levels
- the number of people affected by higher noise levels
- whether noise levels are likely to considerably increase in the future, due to increased rail movements
- the landuses and Development Plan zoning existing in the vicinity of the railway line
- whether mitigation measures are reasonable and practicable
- any other matter determined to be relevant by the EPA or required to be taken into account under section 25 of the EP Act.

Where post-construction monitoring indicates that the ground-borne noise and/or vibration criteria are exceeded, a similar process will also be undertaken to determine whether a noise or vibration reduction plan is required.

## 3.6 Documentation

This section outlines the information typically required in the documentation for rail noise and vibration assessments when reviewed by the EPA.

### 3.6.1 Rail noise and vibration assessment

1. the location of rail corridor and of all relevant sensitive receivers, preferably depicted on aerial imagery or an appropriately scaled and detailed site plan
2. project extents (for new or upgraded railway lines only)
3. type of sensitive receivers and a description of the land use
4. details of any existing rail noise and vibration measurements, including measurement location, time, duration, weather conditions, equipment used, type/number of rail vehicles measured and operating conditions of vehicles during measurements
5. measured or predicted existing rail noise and vibration levels at sensitive receivers
6. noise and vibration criteria for sensitive receivers
7. predicted noise and vibration levels at the sensitive receivers, as well as noise contour maps for relevant assessment periods
8. details of methodology/algorithm used to predict noise and vibration levels, including weather conditions and other input data, with details of the validation carried out, and justification of weather conditions and input data used.

9 rail vehicle volumes, vehicle types and any vehicle specific noise and vibration mitigation measures assumed in the predictions

10 comparison of predicted levels to the criteria, in particular highlighting any non-compliance with the criteria

11 any expected noise events of annoying character, such as wheel and brake squeal, and appropriate design measures undertaken to mitigate the likelihood of these events

12 details of recommended noise and vibration mitigation measures required to achieve the criteria at sensitive receivers, if required, including predicted reductions due to mitigation measures

13 reasons why mitigation measures at the source or along the transmission path have been discounted, if relevant.

### 3.6.2 Post-construction monitoring results

1 location of rail corridor and all relevant sensitive receivers, preferably depicted on aerial imagery or an appropriately scaled and detailed site plan

2 project extents (for new or upgraded railway lines only)

3 type of sensitive receivers and a description of the zone category for receivers as outlined in the appropriate Development Plan, if relevant

4 criteria at sensitive receivers, determined during rail noise and vibration assessment

5 measurement locations, time, duration, equipment used, type/number of rail vehicles measured and operating conditions of vehicles during measurements

6 weather conditions during the noise monitoring

7 details of any predictions made based on post-construction noise or vibration measurements (if measurements not conducted at all sensitive receiver locations), including prediction methodology used and assumed rail movement volumes

8 comparison of measured/predicted noise levels to criteria, indicating any exceedences of the criteria based on current or future train volumes

9 any measured noise events of annoying character, such as wheel and brake squeal, including event duration and percentage of pass-bys during which they occurred

10 details of any additional noise or vibration mitigation measures required to achieve criteria.

# 4 Measurement procedures

This section describes appropriate procedures for measuring rail noise and vibration. Measurement may be required as part of a development application for a number of reasons, including:

- to characterise the existing rail noise and vibration levels at a sensitive landuse
- to validate a rail noise or vibration prediction methodology
- post-construction monitoring to assess whether noise and vibration levels at a sensitive landuse meet the criteria.
- It is intended that any measurements carried out as part of a rail noise and/or vibration assessment be undertaken by an acoustic engineer[8] or an officer authorised under the EP Act.

## 4.1 Rail noise measurement

The measurement of air-borne noise from rail vehicles may be conducted through either attended or unattended noise monitoring. Each method has advantages and disadvantages that will make it more suitable for certain situations.

Attended measurements of rail noise have the advantage that someone is present for each rail pass-by to identify factors such as the speed and type of train, the cause of maximum noise events and any annoying characteristics of the noise (eg due to wheel or brake squeal). However, attended measurements require at least one person to be present at all times and it is impractical to undertake such measurements for a long period of time or over a large number of pass-bys. Attended measurements are to be carried out for a period to obtain sufficient data to adequately characterise the noise impact at the measurement location.

Unattended measurements, using a noise logger or sound level meter left at a measurement site for a period of time, are able to be conducted over a period of a few days with relative ease. This allows the noise from a large number of rail pass-bys to be measured. However, unattended measurements can be affected by other noise sources, such as road traffic pass-bys, which may appear similar to rail noise when measurement data is reviewed. Additionally, it may be difficult to ascertain if the noise from rail pass-bys has an annoying character and what the cause of the maximum noise events may be. If unattended monitoring is being conducted, the noise monitoring equipment is to incorporate triggered monitoring and recording to improve the relevance of the data obtained. The trigger level should be set appropriately to capture all necessary rail vehicle movements.

> Unattended monitoring of rail noise using equipment that does not incorporate triggered monitoring and recording capabilities is not preferred, but may be acceptable in some situations. Equipment with continuous recording capability, for example, would be acceptable as long as the recording and monitoring data can be used to assess for annoying characteristics of the noise. Continuous monitoring equipment would also be acceptable as long as the noise from rail vehicle pass-bys can be accurately differentiated from extraneous noise sources. In some cases identification of the rolling-stock may be necessary to correlate the noise data with a particular type of rail movement. This information may be obtained from the track operator.

To provide rail noise measurements of appropriate accuracy:

- sound level meters and noise loggers are to be of at least Class 1 certification as defined by Australian Standard AS IEC-61672.1–2004: *Electroacoustics–Sound level meters–Part 1: Specifications*
- meters or loggers must be calibrated on site before and after measurement periods using a calibrator, suitable for a Class 1 instrument, that complies with Australian Standard AS IEC–60942–2004: *Electroacoustics–Sound calibrators*
- all microphones are to be protected with windshields on site

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[8] See definition in Glossary.

- any measurements obtained during periods when the wind speed at the measurement height exceeds 5 m/s or where the measurements have been affected by rain, are to be discarded, unless it can be demonstrated, through certificate of warranty from the windshield manufacturer, that data above 5 m/s is not adversely affected by wind noise.

Class 1 certified monitoring equipment is required by Australian Standard AS 2377–2002: *Acoustics–Methods for the measurement of rail bound vehicle noise*. However, in some rail noise measurement situations, Class 2 certified monitoring equipment may provide measurements of sufficient accuracy.

### 4.1.1 Measurement location and height

The appropriate selection of rail noise measurement locations is critical to the accuracy of any rail noise assessment. Generally, it is recommended that rail noise measurements be conducted at the sensitive receivers considered as part of the assessment. However this may not always be appropriate, particularly where the ambient noise environment at the measurement site is significantly affected by other sources, and noise from rail operations is only audible for short periods of time.

The general principles to follow in selecting rail noise measurement locations are:

- The ambient noise environment at the measurement locations, excluding noise from rail operations, should be relatively quiet and rail noise measurements conducted at the sites should not be affected by extraneous noise sources such as road traffic, construction, air conditioning noise and the like.
- The locations should have a clear, relatively unobstructed view of the railway line, unless being measured at a specific sensitive land use to quantify rail noise at that location. Obstructions may include barriers such as buildings, fences, sheds or mounds.
- The selected locations should be representative of worst-case noise levels from the railway line and should be of sufficient number to quantify the rail noise levels due to each track section considered as part of the assessment. This could include straight sections of track, curves, turnouts, level crossings and transitional speed areas.
- Where there may be a significant number of sensitive receivers exposed to rail noise as part of an assessment, it will normally be sufficient to conduct monitoring at a representative number of locations and then use the measurements as a basis to predict noise levels at other sensitive receivers. The number of monitoring locations will need to be sufficient to accurately quantify the rail noise levels at all sensitive receivers for the purpose of the assessment.

If measurements are being conducted at a land use incorporating a sensitive building, the measurements are to be taken at a distance of one metre from a ground floor window of the building that serves a sensitive internal area and is most exposed to noise from the rail corridor. In these cases, the noise level is affected by reflections from the facade which are assumed to increase the measured noise level by +2.5dB. The measurement location is not to be beneath a balcony or verandah.

In situations where measurements at the building facade are not possible, due to the presence of a balcony or verandah or other practical limitations, then measurements may be taken at other free-field locations on the sensitive land use. This may also be the case where measurements are being taken at a future sensitive lan duse site, on a recreation area or in representative locations where no sensitive buildings are nearby. For the purposes of this document, free-field locations are defined as any location at least five metres from any reflecting surface (other than the ground). Other than for passive and active recreation areas, rail noise levels measured at free-field locations are to be adjusted by +2.5dB to account for the facade reflection factor and allow comparison with the noise criteria. The correction is not applicable to noise measurements in private and communal outdoor recreation areas.

All rail noise measurements are to be conducted at a height of 1.2–1.5 metres above ground or floor level.

In certain situations, it may be necessary to conduct internal noise measurements within a sensitive building to assess noise from a railway line. This may occur where compliance monitoring is being conducted at a multi-storey building that has had architectural acoustic treatments applied to improve noise reduction across the facade.

Where internal noise measurements are being undertaken, the measurements should be conducted at the worst-case location within a room that represents a typical occupancy position or at the centre of the room if this is not clear. The measurements are not to be affected by extraneous noise sources, either internal or external to the building.

### 4.1.2 Determining $L_{Aeq,T}$ and $L_{Amax}$ due to rail operations from measured data

The measurement of noise over the duration of a rail vehicle movement should provide the following noise metrics:

- $L_{Aeq,p}$ over the duration of the audible vehicle pass-by (p)
- $L_{Amax}$ for the pass-by.

To determine the $L_{Aeq,T}$ level for comparison with the relevant criterion for a site, the measured $L_{Aeq,p}$ across the entire period (T) are logarithmically summed and the result averaged across the duration of the period. If the complete number of pass-bys across the whole period have not been measured, then it will normally be acceptable to calculate the $L_{Aeq,T}$ level based on a representative measured number of pass-bys during the period.

If a rail corridor is used by different types of rail vehicles (eg freight rail and passenger rail), then it is necessary to measure pass-bys from all types of vehicle. In these cases, the $L_{Aeq,T}$ level from each type of vehicle should be calculated and logarithmically summed to give the overall level. If tracks within the corridor are managed by different entities, it may be necessary to present $L_{Aeq,T}$ levels for different vehicle types/rail lines individually to assist in determining practicable and reasonable measures to reduce the environmental impact.

Measured $L_{Amax}$ levels from different rail vehicle pass-bys can vary significantly due to changes in carriage condition and the way that the wheels interact with the rail. When determining $L_{Amax}$ levels to report as part of an assessment, the $L_{Amax}$ level from the 95$^{th}$ percentile of pass-bys should be determined and presented. Measurement of a sufficient number of pass-bys is required to ensure a robust statistical analysis to determine this percentile.

An example demonstrating the calculation of $L_{Aeq,T}$ and $L_{Amax}$ from rail noise measurements is provided in Appendix A.

For the assessment of low-volume rail lines, such as rural freight corridors, it may be impractical to obtain $L_{Amax}$ and $L_{Aeq}$

exceeded for 95% of pass-bys. In these cases, the EPA will accept measurement results from a smaller number of pass-bys. An assessment of noise levels conducted in this manner should clearly state the reasoning for the selection of the particular rail pass-by or pass-bys.

### 4.1.3 Annoying characteristics

Some annoying characteristics are a common part of noise from rail operations, occurring even where well-maintained rolling- stock is operating on well-maintained rail lines, and have been taken into account when developing the noise criteria. However, it is also important that any annoying characteristics of rail noise above and beyond what would reasonably be expected are identified and managed.

During the measurement of rail noise, any particularly annoying characteristics of noise from rail movements are to be identified and included in the assessment documentation. Identification of annoying characteristics may be undertaken by an acoustic engineer or by an authorised officer (under the EP Act). Annoying characteristics of rail noise will be taken into account by the EPA when considering noise mitigation requirements.

Annoying characteristics of rail noise could include:

- tonality (eg wheel squeal on tight curves)
- low frequency noise (eg locomotive noise intrusion into a sensitive room)

- impulsive noise (eg wheel flat noise from repetitive impacts of flat spot on wheel or rail joint noise as the wheels pass discontinuities in the track)
- modulating noise (eg hunting noise which is the cyclically modulating noise from wheel flange contact with the rail).

It is important to recognise that the criteria presented in this document may not adequately assess all types of noise from rail operations where there is a specific annoying characteristic associated with the noise. For example, the noise generated by idling locomotives located near sensitive receivers for considerable periods of time may comply with the criteria but still cause significant annoyance due to its low frequency content, particularly in areas of low background noise levels. For situations such as this, under section 25 of the EP Act (general environmental duty), the EPA reserves the right to apply alternative criteria to indicate an appropriate standard of care.

## 4.2 Ground-borne rail noise measurement

Ground-borne rail noise levels at a site should only be measured where the level of ground-borne rail noise is higher than that of air-borne noise from the rail pass-bys.

To provide ground-borne noise measurements of appropriate accuracy:

- sound level meters are to be of at least Class 1 certification as defined by AS IEC–61672.1–2004
- meters or loggers must be calibrated on site immediately before and after any measurement period using a calibrator which is suitable for the class of the instrument and complies with AS IEC–60942–2004
- $L_{Amax}$ levels should be measured using the ‘Slow’ response setting on the meter or logger.

Measurements should be conducted near the centre of the most affected sensitive room, and at a height of 1.2–1.5 metres above floor level. Note that measurements should not be conducted at the centre of the room due to possible influence from acoustic standing waves on the result. Where there may be a significant number of sensitive receivers exposed to ground-borne noise, it will normally be sufficient to conduct monitoring at a representative number of worst-case locations. Worst-case locations are generally those that are closer to the railway line, as ground-borne vibrations (and therefore ground-borne noise) will typically decrease with increasing distance.

In some situations, noise from rail operations within a sensitive receiver room may consist of a combination of ground-borne and air-borne noise (eg near the opening of a railway tunnel). Discerning the relative contributions of ground-borne and air-borne noise to the overall noise level in a room in these situations can be difficult and will usually rely on predictive methods. An indicative methodology that could be used in this situation is:

- measure the air-borne rail noise at representative external location near the sensitive receiver room
- predict the internal air-borne noise level in the room based on the external noise level and on the building facade
- measure rail vibration levels on relevant vibrating surfaces within the room, using the result to predict the ground-borne noise generated inside the room from the radiating surfaces.

As the ground-borne noise level from rail vehicle pass-bys will vary from vehicle to vehicle due to changes in carriage conditions, ground-borne $L_{Amax}$ levels are to be determined and reported from the 95$^{th}$ percentile of pass-bys. Measurement of a sufficient number of pass-bys is required to ensure a robust statistical analysis to determine the percentile.

Further information on the measurement of ground-borne noise from rail operations is provided in ISO 14837–1.

## 4.3 Ground-borne rail vibration measurement

Ground-borne vibration levels from rail pass-bys at a site are expected to be measured in the most affected sensitive room of a receiver. Measurements should be conducted at the worst-case location which represents a typical position for building occupants. This may require measurement at a number of locations around a room in order to remove any potential error due to variations in vibration levels across the room.

Where there may be a significant number of sensitive receivers exposed to ground-borne vibration from rail operations, it would normally be sufficient to conduct monitoring at a representative number of worst-case locations. Worst-case locations are generally those that are closer to the railway line, as ground-borne vibrations will typically decrease with increasing distance.

The vibration levels from rail pass-bys should be measured along three orthogonal axes (ie x-, y- and z-directions as defined by AS 2670.2) in terms of RMS (root–mean–square) velocity or acceleration across the frequency range of 1 to 80Hz. Typically, measured third-octave band vibration levels will be required to allow direct comparison with the vibration criteria. However, the EPA will consider measurement of overall RMS values acceptable provided that the overall value is below the criterion for each octave band.

Mounting of vibration transducers (ie accelerometers or geophones) to the floor or surface of a room is to be conducted in general accordance with Australian Standard AS 2775–2004: *Mechanical vibration and shock–mechanical mounting of accelerometers*.

Further information on the measurement of ground-borne vibration is provided in both AS 2670.2 and ISO 14837–1.

# 5 Rail noise and vibration mitigation

This section outlines typical mitigation measures that can be implemented to reduce noise and vibration effects from rail operations and provides basic guidance for the effective implementation of the measures. It also provides information on the responsibility for implementing and maintaining noise and vibration mitigation measures.

It should be noted that the *Guidelines* refer to possible noise mitigation measures that may be implemented only for the part of railway corridor (the ‘footprint’) affected by an upgrade project or an encroaching sensitive development. On the one hand, this may include existing residential areas adjacent to and within the evaluation distance from the part of a railway being upgraded. On the other hand, developers may need to consider noise mitigation for houses when planning new residential developments that encroach upon existing railway corridors; that is, they are likely to be built within the relevant evaluation distance from the railway. Refer to Section 1.3.4 for recommendations on evaluation distances, where sensitive receivers may be adversely affected by the rail noise.

Generally, rail noise and vibration mitigation measures can be grouped into one of the following categories:

- mitigation at the source
- mitigation along the transmission path
- mitigation at the receiver.

Of these, mitigation measures installed at the source are preferred as they typically provide the greatest protection to sensitive receivers, provide benefit to a greater number of receivers, are generally more cost effective and can remove or reduce the need for mitigation measures along the path or at the receivers themselves.

Mitigation along the transmission path, such as the installation of a noise barrier, is preferable to mitigation at the receiver as it will provide protection to both outdoor and indoor areas of sensitive receivers, and to a greater number of receivers. Mitigation at the receiver is normally the least desirable option, especially where the treatments consist of upgrades to the building facade as protection is only provided to indoor areas.

When determining the appropriate noise and vibration mitigation measures, if required as part of an assessment, it is important that consideration is given to how reasonable and practicable the proposed mitigation measures are. Although mitigation at the source is always preferable, in many situations measures such as altering the design of the track may not be reasonable and/or practicable. Similarly, noise barriers to provide mitigation along the transmission path may not always be practical and mitigation measures installed at the receiver may need to be considered as an alternative or additional solution in some situations.

Where treatment at receivers is recommended for a new or redeveloped railway line project, justification should always be given for this decision.

To determine whether noise and vibration mitigation measures are reasonable and practicable the following factors should be considered:

- the noise or vibration reduction achieved, and number of receivers benefited
- the cost of the measure, including a comparison of the various mitigation measures and a comparison of the cost to the noise or vibration reduction
- other benefits of the mitigation measure, eg improvement in ride quality on passenger trains or improved safety provided by noise barriers
- any undesirable effects of the measure, eg reduced track safety through design alterations, aesthetic and overshadowing effects due to barriers, safety and security issues associated with trackside barriers
- community views and perceptions regarding the measure.

For new noise sensitive developments adjacent to railway lines, appropriate planning of the development is an important factor in noise and vibration mitigation. If additional noise or vibration reduction is still required after appropriate planning of the development has been undertaken, then mitigation treatments at the receiver are generally the only option as there is no control over the railway line and its operations or over the rail corridor.

## 5.1 Mitigation at the source

Mitigation of rail noise and vibration at the source is typically only relevant for new or upgraded railway lines, as control over the track design, construction and maintenance requirements is possible.

Where new railway lines are being constructed or significant realignment of an existing railway line is being undertaken, careful route selection and design are important factors in reducing noise and vibration levels. The further a railway line is from a noise sensitive location, the lower the noise and vibration levels will be at that location as long as the track shape does not change significantly. Doubling the distance between a stretch of straight track and a sensitive receiver will typically bring about a 3dB reduction in $L_{eq}$ noise levels and a 6dB reduction in $L_{max}$ noise levels.

It is also important that any track be designed to avoid tight radius curves wherever possible, particularly adjacent to noise sensitive receivers. Sharper curves increase the likelihood of events such as wheel squeal and flanging which can cause higher noise levels of annoying character. In order to reduce the chance of wheel squeal occurring, the radii of curves should be maximised.

General track design should also include a consideration of:

- avoiding turnouts, diamond crossings and transitional speed areas near sensitive receivers
- the use of continuously welded rail rather than jointed rail
- reducing the gradient of the track as much as possible to reduce engine and brake noise
- avoiding level crossings near sensitive receivers to reduce disturbance from warning horns and bells
- locating idling locomotives away from sensitive receivers.

Maintaining the track in good condition is also a factor in reducing rail noise and vibration as source levels from a track can increase over time as the rail wears. Grinding and friction modification of tracks can reduce train pass-by noise and vibration levels, and should be considered as part of an ongoing maintenance program if noise or vibration from a section of track is an issue.

For rolling stock operators, it is also critical that rolling stock is selected and maintained to achieve relevant noise and vibration emission standards. Rolling stock should be regularly monitored to ensure that any potential issues are quickly identified and rectified, through replacement or maintenance measures such as wheel truing and grinding. The operation of well-designed railway lines can still have a significant noise and vibration effect on receivers if poorly maintained rolling stock is operated.

## 5.2 Mitigation along the transmission path

The mitigation of noise from rail operations along the transmission path is most commonly achieved through the installation of noise barriers along the rail corridor. Noise barriers can take a variety of forms, ranging from walls or fences through to earth mounds and cuttings for the railway line, and are most effective when installed as close as possible to the noise source or to the receiver. To provide noise reduction of a source, a barrier must at least break the line-of-sight between the source and the receiver.

Noise barriers can be relatively costly to install, and should normally achieve a minimum noise reduction of 5dB(A) to be considered cost effective. If a barrier provides a reduction of less than 5dB(A), occupants of sensitive receivers shielded by the barrier are unlikely to perceive a noticeable change in noise levels. The selection of an appropriate barrier material is also important, and the material should be dense enough to sufficiently reduce noise transmission. In situations where barriers are installed on either side of a rail corridor or where receivers are located directly across from a barrier, absorptive materials should be considered so that noise levels do not increase due to reflections from the barrier.

Barriers are also a highly visual form of noise mitigation and consideration of community acceptance and urban design aspects is critical. It is important to realise that these are not always negative effects of barriers, and appropriately designed barriers can enhance the visual appeal of a project as well as improve community acceptance.

The reduction of ground-borne noise and vibration along the transmission path is generally more difficult but can be achieved, if required, through the use of resilient rail clips, baseplate pads or ballast mats. Resilient rail clips and baseplate pads are installed between the rail and the support system and provide a reduction in transmitted vibration. The installation of these measures should be considered for rail bridges where the rail is directly fixed to the structure as transmitted vibration can be radiated by the bridge structure as air-borne noise. Ballast mats, made from resilient material, can be installed under ballasted track to reduce vibration transmission into the ground.

Ground vibrations from rail operations can also be reduced through the installation of trenches between the line and the receivers in a similar manner to noise barriers. Although this is not current practice in South Australia and is a relatively high-cost approach, it has been implemented with varied success in other countries. Trenches can be either left open or filled with an alternative material if open trenches are considered undesirable. Note that trenches would only be effective in reducing vibration from above ground (surface) rail operations and will not typically have any effect on vibration generated by underground railways.

## 5.3 Mitigation at the receiver

In situations where all appropriate track design measures have been undertaken and where noise barriers have been deemed unreasonable or do not provide the total noise mitigation required, it would normally be considered acceptable for noise mitigation to be provided at a sensitive receiver as part of a new or redeveloped railway line project. New noise sensitive developments may also implement mitigation measures at the receiver but should first apply appropriate planning measures as outlined in Section 5.4.

Noise mitigation at the receiver can be achieved by either installing a fence on the property or by upgrading the facade of a building to provide a greater degree of noise reduction to internal areas. Of these options, installing a fence is preferable as it will provide protection to both outdoor and indoor areas. However, in certain cases (such as multi-storey buildings) acoustic treatments to the building facade will be the only feasible option.

The noise reduction provided by a fence will be highest when the fence is installed as close as possible to the receiver location or to the noise source, depending on the situation. As for barriers in the rail corridor, fences should at least break line-of-sight to the noise source and would normally need to achieve a minimum noise reduction of 5dB(A) to be considered reasonable.

Acoustic treatments to a building facade could include a combination of upgrading windows with thicker or double glazing, providing solid core doors and installing seals to windows and doors. Acoustic treatments for internal living areas of classes 1–4 and 9c buildings should comply with the ‘deemed to satisfy’ provisions or be designed to reduce internal noise levels to achieve the internal noise criteria as required by the Minister’s Specification.

It is important to note that if acoustic treatments to a building are proposed assuming that windows and doors are to be closed for noise reduction, alternative ventilation will need to be supplied to internal areas of the building that require noise treatment in accordance with the Building Code of Australia.

Where new or upgraded track infrastructure is proposed, providing vibration mitigation at existing receiver locations is normally not practical and vibration mitigation should be achieved through a combination of track design and transmission path measures. Where a new noise sensitive development is proposed, compliance with the vibration criteria should be achieved through appropriate land use planning measures as discussed in Section 5.4.

## 5.4 Mitigation through land use planning

For new noise sensitive development adjacent to rail corridors, appropriate planning measures should be implemented prior to any other mitigation measures, such as fences and building treatments, being considered.

Consideration should be given to locating sensitive buildings as far from the rail corridor as possible within the property boundary, as well as locating sensitive rooms on the furthest side of the building from the rail corridor to provide shielding and reduce noise impacts to these areas. For example, bedrooms should be located away from rail corridors where possible, while less sensitive areas such as garages, kitchens, bathrooms and laundries may be located on the facade facing the railway line.

Buildings that are not noise sensitive may also be able to be used to shield areas which are noise sensitive on a development. For example, sheds or garages could be positioned between the rail corridor and a residence to provide a reduction of noise levels. Similarly, less sensitive areas of educational institutions such as toilets, change rooms or workshops could be used to shield classrooms and study areas. Mixed-use developments may place commercial land uses adjacent to the rail corridor, which would also have additional positive effects (such as creating vibrancy near railway stations and encouraging passive surveillance).

Reducing ground-borne noise and vibration from rail operations may also be achieved by using heavier forms of building construction or by isolating parts of the building structure from the foundations. However, this is a relatively high-cost approach to mitigation and would not be reasonable for most developments.

If all of these measures have been examined and additional mitigation is still required, then receiver treatments could be considered as outlined in Section 5.3.

## 5.5 Responsibility for mitigation

The responsibility for compliance with the noise and vibration criteria will depend on the type of project proposed. This responsibility may include the design, implementation and maintenance of mitigation measures where these are required to meet the criteria.

It is not possible to address all scenarios that may be encountered in practice such as multi-line corridors belonging to different owners where upgrade takes place or new line is proposed. It is recommended to discuss potential issues if they arise with administering authorities and relevant track owner(s).

### 5.5.1 New and upgraded railway line projects

Where new and upgraded railway line projects are proposed and being constructed, the design and implementation of mitigation measures required to meet noise levels in the *Guidelines* are the responsibility of the proponent, generally the track owner.

The long-term effectiveness of noise mitigation strategies and measures is likely to be dependent on implementation of an effective ongoing maintenance and management plan. The responsibility for ongoing maintenance and management of mitigation measures will vary depending on the nature of the measure and the management of the railway line. Typical responsibility for maintenance and management are:

- Fixed noise mitigation features installed within the rail corridor (such as noise mounds and barriers) – track owner or operator (if they are different)
- Fixed noise mitigation measures installed on private property outside the rail corridor (such as noise mounds, barriers, or architectural façade treatments such as double-glazing) – generally the owner of the property on which the mitigation measure is installed will be responsible. However; in some cases the railway operator may agree to undertake ongoing maintenance

### 5.5.2 Rolling stock maintenance

Ongoing maintenance and management of mitigation measures may vary depending on the nature of the measure and the management of the railway line, but generally the rolling stock operator is responsible for maintaining their own assets and the track owner is responsible for the railway and relevant infrastructure.

In some situations, it may be determined that a railway line has been designed in general compliance with the noise and vibration criteria but that noise levels due to individual pass-bys of poorly maintained rolling stock occasionally exceed the criteria. This may be demonstrated by post-construction monitoring following completion of a project or by monitoring conducted due to a number of complaints adjacent an existing corridor.

While the rolling stock owner/operator may differ from the track owner, the responsibility to demonstrate that any noise and/or vibration issues are caused by specified third-party rolling stock rests with the track owner. In these circumstances the responsibility to ensure rolling stock maintenance or design issues are corrected will rest with the rolling stock operator in accordance with the conditions of their EPA environmental authorisation.

### 5.5.3 New noise sensitive developments adjacent to rail corridors

For new noise sensitive developments, the responsibility for mitigation rests with the developer. This responsibility includes the design, implementation and maintenance of any mitigation measures. Once the development has been completed, responsibility for ongoing maintenance of noise mitigation measures passes to the owner, occupier or site manager/strata corporation (where appropriate) of noise sensitive premises.

The only exception to this is where a project has been granted development consent prior to the announcement of a new or upgraded railway line project. In these cases, the rail project proponent needs to provide mitigation to the future development with the developer responsible for any existing rail noise and vibration mitigation requirements that would exist without the proposed project.

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Environment Protection Act 1993

Environment Protection (Noise) Policy 2007

Work, Health and Safety Regulations 2012

# Glossary

| | |
|---|---|
| **A-weighted** | Frequency weighted as specified in Australian Standard AS IEC 61672–2004: Electroacoustics–Sound level meters or its replacement. |
| **acoustic engineer** | An engineer who is eligible for full membership of both the Australian Acoustical Society and the Institution of Engineers Australia. |
| **authorised officer** | A person appointed to be an authorised officer under Division 1 of Part 10 of the *Environment Protection Act 1993*. |
| **ambient noise** | The total noise in a given environment, in the absence of the noise under investigation. |
| **brake squeal** | High-pitched, tonal noise generated by brake shoes rubbing on wheels. |
| **dB(A)** | The noise level in decibels, obtained using the 'A' weighted network of a noise level meter as specified in Australian Standard AS IEC 61672–2004: Electroacoustics–Sound level meters or its replacement. |
| **diamond crossing** | Level junction of two separate railway lines. |
| **equivalent noise level** | The equivalent (energy averaged) continuous A-weighted sound pressure level obtained over the measurement time interval. Expressed as $L_{Aeq,T}$, where T refers to the measurement time interval, eg $L_{Aeq,15h}$. This measure is commonly used by legislation when setting limits for environmental noise. |
| **extraneous noise** | This includes noise temporary in nature, such as aircraft flying over head, a passing truck or occasional dog bark. Continuous distant traffic noise is not extraneous noise. Local passing traffic is extraneous noise. |
| **flanging noise** | Sharp, sometimes tonal noise created where wheel flange strikes the side of the rail as it moves around a curve. |
| **ground-borne rail noise** | Internal noise radiated by the building structure due to ground-borne vibration produced by rail vehicle movements. |
| **Guidelines** | Guidelines for the assessment of noise from rail infrastructure |
| **hunting noise** | Cyclically modulating noise from wheel flange contact against the rail as the carriage moves from side-to-side. |
| **IEC** | International Electrotechnical Commission |
| **impulsive noise** | Noise with a dominant characteristic consisting of a single pressure peak, or sequence of such peaks, or a single burst with multiple pressure peaks whose amplitude decays with time, or a sequence of such bursts. |
| **level crossing** | The crossing of a railway line by a road or pedestrian path at a single level. |
| **low frequency noise** | A noise with perceptible and definite content in the audible frequency range below 250Hz. |
| **maximum noise level** | The maximum A-weighted sound pressure level during a measurement time interval. Obtained using the 'Fast' time weighting and expressed as $L_{Amax}$ for rail noise. For ground-borne rail noise, it is obtained using the 'Slow' time weighting and expressed as $L_{Amax}$ (slow). |
| **measurement location** | Location at or near a sensitive land use where rail noise is measured. |

| | |
|---|---|
| **modulating noise** | Noise which varies significantly and cyclically in frequency, character or amplitude. |
| **new noise sensitive development** | Proposed noise and/or vibration sensitive developments that are subject to any development conditions relating to rail noise or vibration. |
| **new railway line project** | A project that introduces rail noise to noise and/or vibration sensitive receivers not previously exposed to it. Would normally involve the construction of a new railway line or the significant realignment of an existing line. |
| **passenger rail** | A rail system used for transportation of passengers. |
| **railway** | A guided system designed for the movement of rolling stock. |
| **rail infrastructure** | Infrastructure associated with the operation of a railway. |
| **rail joint noise** | Noise created as wheels pass by joints (discontinuities) in the rail. |
| **rail noise** | Any air-borne noise generated by the operations of rail vehicles as part of a light rail, passenger rail or freight rail system. |
| **rail vibration** | Vibration generated by rail vehicle movements, propagated through the ground. At high enough levels, rail vibration can shake structures and cause discomfort to building occupants. |
| **'reasonable and practicable' measures** | Has the same meaning as in section 25 of the Environment Protection Act 1993. Specifically noise mitigation measures which are reasonable given the financial implications of employing such measures, and the current state of technical knowledge regarding such measures. |
| **rms (root mean square)** | This is a statistical measure of the magnitude of a varying quantity. |
| **rms velocity or acceleration** | Root–mean–square of the velocity or acceleration signal, used for the measurement and assessment of vibration from rail operations. |
| **rolling stock** | Vehicle (whether or not self- propelled) that operates on or uses a railway track |
| **sensitive receiver** | Premises that may be affected by noise and vibration from rail operations. |
| **tonal noise** | Noise with perceptible and definite pitch or tone. |
| **train line** | Rail infrastructure and its associated rolling stock that operates in dedicated rail corridors for passenger and/or freight transportation which may be electrified or hauled by diesel locomotives/railcars. Normally train lines operate at higher speeds and have a higher carrying capacity than tram lines. Train lines may also be referred to as 'heavy rail' in the relevant Development Plan, or other regulatory documents. |
| **tram line** | An electrified passenger transport system which may operate in dedicated corridors or on shared roadways with other road vehicles. Tram lines may also be referred to as 'light rail' in the relevant Development Plan, or other regulatory documents. |
| **turnout** | A mechanical installation of rails, switches and crossings that allow two tracks to converge and allow rolling stock to change tracks. |
| **upgraded railway line project** | An infrastructure project that increases noise levels at sensitive receivers already exposed to rail noise. |
| **wheel flat noise** | Impulsive, repetitive noise created by worn, flat areas of wheels. |
| **wheel squeal** | High-pitched, tonal noise generated by interaction between the wheel and the rail on tight curves where the wheel cannot pass freely through. |

# Appendix A Example $L_{Aeq,T}$ and $L_{Amax}$ calculation

This example demonstrates how to calculate $L_{Aeq,T}$ and $L_{Amax}$ noise levels from a series of measurement results at a specific location.

**Table 4 Example set of measurement results**

| Measurement | Time | Pass-by duration (seconds) | Measured noise levels, dB(A) | |
|---|---|---|---|---|
| | | | $L_{Aeq}$ (for pass-by) | $L_{Amax}$ |
| 1 | 6.22 am | 33 | 70 | 77 |
| 2 | 6.51 am | 31 | 71 | 79 |
| 3 | 7.30 am | 30 | 71 | 78 |
| 4 | 7.43 am | 30 | 69 | 78 |
| 5 | 7.51 am | 35 | 72 | 81 |
| 6 | 8.12 am | 31 | 67 | 75 |
| 7 | 8.50 am | 33 | 72 | 82 |
| 8 | 9.47 am | 32 | 71 | 80 |
| 9 | 11.25 am | 30 | 69 | 77 |
| 10 | 1.50 pm | 28 | 70 | 79 |
| 11 | 2.31 pm | 34 | 69 | 77 |
| 12 | 3.49 pm | 33 | 71 | 82 |
| 13 | 4.35 pm | 29 | 70 | 78 |
| 14 | 5.14 pm | 30 | 68 | 76 |
| 15 | 5.29 pm | 31 | 73 | 86 |
| 16 | 5.37 pm | 32 | 72 | 80 |
| 17 | 5.54 pm | 31 | 70 | 79 |
| 18 | 7.38 pm | 30 | 71 | 79 |
| 19 | 8.50 pm | 34 | 67 | 76 |
| 20 | 10.24 pm | 33 | 71 | 81 |

To calculate the $L_{Aeq,T}$ for a period based on measurements of all pass-bys during that period the following equation should be used:

$$L_{Aeq,T} = 10 \times \log_{10}\left(\frac{\Sigma p_i \times 10^{0.1 \times L_i}}{Tp}\right)$$

Where:

- $p_i$ is the duration of each pass-by, in seconds
- $L_i$ is the $L_{Aeq}$ noise level of the pass-by over that duration
- $T_p$ is the duration of the total assessment period (T) in seconds.

So the $L_{Aeq,15hr}$ from 7 am to 10 pm for the above set of measurements would be:

$$L_{Aeq,15hr} = 10 \times \log_{10}\left(\frac{30 \times 10^{7.1} + 30 \times 10^{6.9} + \cdots + 34 \times 10^{6.7}}{15 \times 60 \times 60}\right) = 50\ dB(A)$$

In situations where not all pass-by noise levels during an assessment period have been measured, then the LAeq,T for the period is able to be conservatively approximated by assuming a typical worst-case pass-by noise level and duration. For example, the set of measurements only contains three pass-bys during the night-time period. If there were actually ten pass-bys during the night time period, then the $L_{Aeq,9hr}$ for the night time period could be approximated by assuming a typical worst-case pass-by level of 72dB(A) and duration of 34 seconds (based on all measurements taken). The $L_{Aeq,9hr}$ level can then be calculated by time correcting the pass-by noise level:

$$L_{Aeq,9hr} = 72 + 10 \times \log_{10}\left(\frac{10 \times 34}{9 \times 60 \times 60}\right) = 52\ dB(A)$$

The worst-case $L_{eq,1hr}$ for the example set of measurements could be for either the 7.30 am to 8.30 am period or for the 5 pm to 6 pm period as in both periods there were four pass-bys. The measured $L_{Aeq,1hr}$ levels are:

$$L_{Aeq,1hr}(7{:}30\ to\ 8{:}30) = 10 \times \log_{10}\left(\frac{30 \times 10^{7.1} + 30 \times 10^{6.9} + 35 \times 10^{7.2} + 31 \times 10^{6.7}}{1 \times 60 \times 60}\right) = 56\ dB(A)$$

$$L_{Aeq,1hr}(5{:}00\ to\ 6{:}00) = 10 \times \log_{10}\left(\frac{30 \times 10^{6.8} + 31 \times 10^{7.8} + 32 \times 10^{7.2} + 31 \times 10^{7.0}}{1 \times 60 \times 60}\right) = 57\ dB(A)$$

Based on the set of measurements, the worst-case $L_{Aeq,1hr}$ level is 57dB(A) during the period from 5 pm to 6 pm.

The relevant $L_{Amax}$ level for comparison with the criteria is the $L_{Amax}$ level not exceeded for 95% of rail pass-bys. For the presented set of measurements it would be 82dB(A).