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HS2

High Speed Rail (Crewe – Manchester) Environmental Statement

Volume 5: Appendix SV-001-00000

Sound, noise and vibration

Sound, noise and vibration methodology, assumptions and assessment

M255

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M255

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1.1.2 The outcomes of the sound, noise and vibration assessments are reported in the relevant Volume 5 sound, noise and vibration appendices for each community area:

- Appendices SV-002 – Baseline and construction sound, noise and vibration reports; and
- Appendices SV-003 – Operational sound, noise and vibration reports.

1.1.3 The outcomes are also summarised in the relevant Volume 2, Community Area reports.

1.1.4 Mapping to support the sound, noise and vibration assessment is presented in Map Series SV-05 (in the Volume 2, Sound, noise and vibration Map Books) and Map Series SV-02, SV-03, SV-08 and SV-09 (in the Volume 5, Sound, noise and vibration Map Book).

1.1.5 This appendix comprises of a number of annexes as introduced below.

1.2 Assessment of impacts, effects and significance

1.2.1 Annex A provides guidance on the more detailed application of the sound, noise and vibration significance criteria set out in Section 18 of the SMR. These significance criteria have been used to facilitate consistent identification of likely noise and/or vibration significant effects arising from construction and operation of the Proposed Scheme.

1.3 Baseline

1.3.1 The Volume 2, Community Area reports, Section 13 Sound, noise and vibration, provide an overview of the baseline sound and vibration conditions pertaining at a local level within each community area, whilst full details of the baseline conditions within the spatial scope of the assessment are included in the relevant Volume 5 Appendices (SV-002).

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1.4.2 For more information, details of the methodologies adopted in the assessment of ground-borne sound and vibration and airborne sound arising from construction, along with relevant assumptions and limitations, please refer to Annex C.

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Annex A: Assessment of impacts, effects and significance

1 Introduction

The assessment of sound, noise and vibration considers the likely significant noise and vibration effects arising from the construction and operation of the Proposed Scheme on:

- people, primarily where they live ('residential receptors') in terms of:
  - on an individual dwelling basis; and
  - on a community basis, including any shared community open areas[1]; and
- community facilities such as schools, hospitals, places of worship, and also commercial properties such as offices and hotels, collectively described as 'non-residential receptors' and 'quiet areas'[2].

In this assessment 'sound' is used to describe the acoustic conditions that people experience as a part of their everyday lives. The assessment considers how those conditions may change through time and how sound levels and the acoustic character of community areas is likely to be modified through the introduction of the Proposed Scheme. Noise is taken as unwanted sound and hence adverse effects are termed noise effects rather than sound effects, and mitigation is, for example, termed 'noise' barriers.

In this assessment, significant noise or vibration effects may be:

- adverse from an increase in sound levels or beneficial from a decrease in sound levels caused by the Proposed Scheme;
- temporary from construction or permanent from the operation of the Proposed Scheme;
- direct, resulting from the construction or operation of the Proposed Scheme, and/or indirect e.g. resulting from changes in traffic patterns on existing roads or railways that result from the construction or operation of the Proposed Scheme; and
- off-route, i.e. caused by the Proposed Scheme outside of the study area around the new railway and associated infrastructure.

[1] 'shared community open areas' are those that the National Planning Practice Guidance – Noise identifies may partially offset a noise effect experienced by residents at their dwellings and are either a) relatively quiet nearby external amenity spaces for sole use by a limited group of residents as part of the amenity of their dwellings or b) a relatively quiet external publicly accessible amenity space (e.g. park to local green space) that is nearby.

[2] Quiet areas are defined in the SMR as either Quiet Areas as identified under the Environmental Noise Regulations or are resources which are prized for providing tranquillity (further information is provided in Section 9).

The assessment is reported in the Volume 2, Community Area reports with more detailed information available in the relevant Volume 5 SV-002 and SV-003 appendices. The assessment of significant off-route noise or vibration effects is reported in Volume 4, Off-route effects.

The approaches to assessing sound, noise and vibration are outlined in Section 8 of Volume 1[3] and the scope and methodology are defined in the SMR (Volume 5, Appendix CT-001-00001). This annex sets out the more detailed technical description and application of the SMR significance criteria.

For sound, noise and vibration it is helpful to differentiate between impacts and effects. Based on the guidance in the National Planning Practice Guidance (NPPG)[4] and the Design Manual for Roads and Bridges[5] the following definitions have been adopted:

- impact: the introduction of a new sound or vibration into an existing environment; and
- effect: the noise effect on the receptor/community subject to an impact. The noise effect is therefore linked to the level of the impact, the sensitivity of the receptor and other key matters such as the existing acoustic environment.

It follows therefore, that:

- an impact is a change in the environment;
- an effect is what results from an impact on a receptor; and is dependent on the receptor and its sensitivity; and
- as an impact increases in level, the effect increases either in terms magnitude (e.g. noise change) or in terms of the number of receptors adversely affected (or both), to a point where either the level of exposure or the number of receptors exposed reach a point where the assessment needs to report the outcome as significant.

[3] See Environmental Statement Volume 1, Introduction and methodology.

[4] Department for Communities and Local Government (DCLG) (2019), *Planning Practice Guidance – Noise*. Available online at: https://www.gov.uk/guidance/noise--2.

[5] Highways Agency (2020), *Design Manual for Road and Bridges (DMRB),* Volume 11 Environmental Assessment, Section 3 Environmental Assessment Techniques, Part 7 Noise and Vibration document LA 111, Highways Agency, London. Available online at: https://www.standardsforhighways.co.uk/dmrb/.

2 Impact criteria

The primary impact criteria are specifically defined for sound, noise and vibration in Section 18 of the SMR.

The impact criteria are further detailed in the following sections.

3 Significance criteria

3.1 General approach

The approach adopted reflects the requirements of the EIA Directive[6], current best practice[7], and Government's noise policy (as defined in Defra's Noise Policy Statement for England (NPSE)[8] and the NPPG).

Consistent with good practice such as that set out in the National Planning Policy Framework (NPPF)[9] and NPPG, the SMR sets out qualitative significance criteria that enable the Proposed Scheme's likely significant noise and vibration effects to be assessed consistently along the line of route whilst responding to local environmental conditions.

The significance criteria set for airborne noise effects on residential receptors consider, for example:

- the number and grouping of adversely effected dwellings and shared community open areas;
- the magnitude of the adverse effects identified (based on noise change);
- the overall level of noise exposure once the scheme is in operation;
- the level and character of the existing sound environment;
- any unique features of the source or receiving environment in the local area;
- combined exposure to noise and vibration;
- the duration of the adverse effect (for construction); and
- the effectiveness of mitigation measures that could avoid or reduce the adverse effects.

The Environmental Impact Assessment process requires that significant adverse effects are defined and the envisaged mitigation to avoid or reduce significant effects (as discussed in the next section) is identified. Given its scale and linearity, the Proposed Scheme extends across many county and local authority areas and includes a diverse range of communities. The role of the number, grouping and magnitude of effects in determining significance is based, where appropriate, on considering communities. This approach forms part of

[6] *Directive 85/337/EEC, as amended by 97/11/EC, 2003/35/EC, 2011/92/EC and 2014/52/EU ('the EIA Directive') of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment.* Strasbourg, European Parliament and European Council.

[7] Including the approach adopted for HS2 Phase One and HS2 Phase 2a.

[8] Department for the Environment, Food and Rural Affairs (2010), *Noise Policy Statement for England*. Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69533/pb13750-noise-policy.pdf.

[9] Department for Communities and Local Government (2021), *National Planning Policy Framework*. Available online at: https://www.gov.uk/government/publications/national-planning-policy-framework--2.

ensuring that mitigation provides reasonable benefit compared to cost and has precedence in the assessment of schemes such as HS2 Phase One, the A14 road scheme, High Speed One[10] (HS1), and the Forth Replacement Crossing. This approach has been refined following review by the HS2 Acoustic Review Group (ARG) (during the HS2 Phase One EIA), the Planning Forum Sub Group-Acoustics (PFSG) and scrutinised through the passage of the HS2 Phase One and HS2 Phase 2a parliamentary processes.

The detailed approach adopted takes account of these reviews and particularly the view expressed by the PFSG that the methodology should identify when significant effects occur on individual receptors as well as communities. The response to the PFSG draws on the requirements of the EIA Directive and the Government's noise policy as discussed in the next sub-sections.

3.2 EIA Directive

The term 'significant effect' is used in undertaking an EIA where the EIA Directive requires the identification of likely significant effects (both positive and negative), and the description of the measures envisaged to avoid, reduce and, if possible, remedy significant adverse effects.

The critical requirement therefore is to identify likely significant effects.

The likely significant effects identified for a project are key because:

- under the EIA Directive, they drive the need to consider mitigation and the efficacy of any mitigation proposed; and
- they are material considerations brought to the attention of the decision makers in the Environmental Statement (ES).

As noted above, the requirements of the EIA process link the identification of significant effects to the identification of mitigation. It may therefore be argued that the definition of significance needs to reflect in part the approach to providing mitigation and the efficacy of the mitigation unless the level of exposure is in itself significant.

Significant effects therefore also need to be identified when the level of noise or vibration is above any threshold above which significant adverse effects on health and quality of life are likely to occur. Guidance on this point can be taken from the Government's noise policy.

[10] High Speed One (HS1) is the rail link between the Channel Tunnel in Kent and St. Pancras International Station in London. Known as the 'Channel Tunnel Rail Link' project during the Project's parliamentary process.

3.3 Government noise policy

The aims of the Government's noise policy[8] are outlined in the box below:

Government Noise Policy Statement for England Aims

Through the effective management and control of environmental, neighbour and neighbourhood noise within the context of Government policy on sustainable development:

1. avoid significant adverse impacts on health and quality of life
2. mitigate and minimise adverse impacts on health and quality of life
3. where possible, contribute to the improvement of health and quality of life.

Note that the terms 'quality of life' and 'wellbeing' are often used interchangeably in the assessment of noise effects.

In its aims the policy uses the key phrases 'significant adverse' and 'adverse'. In clarifying what these mean the policy notes that: '...there are two established concepts from toxicology that are applied to noise effects, for example, by the World Health Organisation (WHO).' They are:

- NOEL – No Observed Effect Level. This is the level below which no effect can be detected. In simple terms, below this level, there is no detectable effect on health and quality of life due to the noise; and
- LOAEL – Lowest Observed Adverse Effect Level. This is the level above which adverse effects on health and quality of life can be detected.

The policy extends these concepts to include SOAEL – Significant Observed Adverse Effect Level. This is the level above which significant adverse effects on health and quality of life occur.

These terms are adopted in the Government's planning guidance[4] on noise. The guidance links them directly, in increasing severity, to four levels of effect:

- effect;
- adverse effect;
- significant adverse effect; and
- unacceptable adverse effect.

This is on the premise that once sound or vibration becomes perceptible, the effect on people and other receptors increases as the level of sound increases. The planning guidance presents example outcomes to help characterise these effects. In general terms, an observed adverse effect is characterised as a perceived change in quality of life for occupants of a building or a perceived change in the acoustic character of an area.

NPPF notes that triggers should be defined for the onset of adverse effects (LOAELs) and significant adverse effects (SOAELs) in terms of total levels of exposure. Also, that these trigger values should reflect the nature of the noise source, the sensitivity of the receptor and local context.

The Government's noise policy notes that it is not possible to have a single objective noise-based measure that defines SOAEL that is applicable to all sources of noise in all situations. Consequently, the SOAEL is likely to be different for different noise sources, for different receptors and at different times. It is for a project to identify relevant SOAEL taking account the different sources of exposure and different receptors.

Adverse and significant adverse noise and vibration effect thresholds are defined for the Proposed Scheme in the later sections of this annex based on national and international standards and guidance, best practice and previous projects.

Where forecast noise or vibration from the Proposed Scheme exceeds the threshold for a significant adverse effect, then a significant noise and/or vibration effect is identified on that individual receptor.

It can be seen that the test of significance in relation to government policy and guidance is therefore a question of degree and that a significant noise and vibration level will be somewhere above a level where the onset of adverse effect might be expected - i.e. SOAEL will always be greater in magnitude than LOAEL and LOAEL are greater than NOEL. In other words, as exposure to a new sound source increases there will start to be some degree of effect on a receptor – the point perhaps at which sound becomes noise – and as the exposure increases, the severity of the effect or effects will rise to a point where the effect becomes significant.

Under the noise policy and guidance, it becomes clear that defining SOAEL for the noise sources under consideration in the EIA is a key step. In addition, any receptor forecast to experience an absolute 'end state' exposure from the source that exceeds the relevant SOAEL should be identified as being subject, in EIA terms, to a likely significant adverse effect. This reflects the aim to avoid significant effects on health and quality of life.

It is also worth noting that the second aim of the NPSE refers to the situation where the effect lies somewhere between LOAEL and SOAEL. The aim is that 'all reasonable steps should be taken to mitigate and minimise adverse effects on health and quality of life while also taking into account the guiding principles of sustainable development. This does not mean that such adverse effects cannot occur.'

The Government's NPPG describes that as exposure increases above the LOAEL boundary, the noise begins to have an adverse effect and consideration needs to be given to mitigating and minimising those effects, taking account of the economic and social benefits being derived from the activity causing the noise. As the noise exposure increases, it will then at some point cross the SOAEL boundary. While the EIA Directive focuses primarily on the identification of likely significant adverse effects, the assessment process also enables the identification of adverse effects between the LOAEL and SOAEL. This provides a basis for considering mitigation measures to reduce and control exposure for communities likely to experience either significant effects or adverse effects.

Each of the following sections of this annex therefore set out how the definitions of LOAEL and SOAEL for the Proposed Scheme have been utilised in determining the significance of noise and vibration effects.

4 Ground-borne sound, noise and vibration

4.1 Introduction

Significance criteria are outlined for sound, noise and vibration in Section 18 of the SMR. The following sub-sections provide more detailed guidance on the application of these criteria to the Proposed Scheme.

In each sub-section, various matters are given codes. These codes are used in the assessment tables of the technical appendices (Volume 5, Appendices SV-002 and SV-003).

Consistent with the SMR, the assessment of ground-borne sound, noise and vibration has considered the likely significant effects arising from the construction and operation of the Proposed Scheme on:

- residential receptors; and
- non-residential receptors.

The following sub-sections consider each of these receptor classifications in turn.

4.2 Residential receptors

The code 'R' is used to designate assessment locations that represent residential receptors. In this assessment, the term residential is applied to permanent dwellings (i.e. houses, apartments etc.). Hotels, hospitals and other buildings where people sleep but are not 'permanent' residences are considered as non-residential receptors.

The assessment of effects has been undertaken at assessment locations that are representative of a number of dwellings.

The number of dwellings represented by an assessment location is recorded in the assessment tables in the relevant appendices in Volume 5.

The following sub-sections consider in turn the application of the qualitative significance criteria set for residential receptors.

The type of effect being considered

For residential receptors, the following codes are used to describe the types of potential effect on occupants as assessed using the criteria defined in the SMR for ground-borne noise or vibration:

- generally, no adverse effect (code 'NA');
- adverse effect (code 'A'); and
- significant adverse effect (code 'S').

The potential for adverse effects on residential buildings themselves, in terms of any risk of cosmetic building damage arising from ground-borne vibration during construction has also been considered. However, the NPPG characterises an exposure level that would cause such an outcome as being unacceptable. Accordingly, NPPG advises that it should be prevented from occurring. Paragraph 18.2.11 of the SMR states the reasons why, with appropriate mitigation and implementation of a Code of Construction Practice (CoCP), it is unlikely that building damage will occur, and therefore it has not been necessary to consider this detail here. However, for completeness criteria is defined in Table A 3.

Each impact criterion defined in the SMR generally takes account of a number of potential effects on a precautionary basis. The basis of the adopted impact criteria is discussed further in the rest of this section.

The number and grouping of impacts

For ground-borne sound, noise and vibration from the construction and operation of the Proposed Scheme, the number and grouping of impacts has been considered in conjunction with the magnitude of the impacts to identify likely significant effects. This is set out in the next section.

The magnitude of the impacts and available dose-response information

For residential receptors (permanent dwellings), the assessment has differentiated between two situations. Firstly, where, despite provision of mitigation measures within the Proposed Scheme, the magnitude of the impact is so great that the absolute noise or vibration level inside dwellings will constitute a significant effect. Secondly where the magnitude of the absolute ground-borne sound or vibration level is not in itself significant inside a dwelling but where it will, when considered in aggregate across a number of dwellings, constitute a significant effect on the general community.

The magnitude of an impact is identified by calculation of the level of ground-borne sound and vibration and the comparison of the calculated levels with the criteria set out in the SMR. The quantitative assessment of impacts and effects (where undertaken) for construction and operation is presented in the assessment tables of the relevant section of the Volume 5 appendices.

In considering the magnitude of an impact and how it informs the identification of significant effects, it is first necessary to establish whether the magnitude of the impact will give rise to any effect at all on the receptor (i.e. the noise or vibration level exceeding the relevant LOAEL). Second it is necessary to identify whether the magnitude of the impact and associated effect is significant itself (i.e. the noise or vibration level exceeds the relevant SOAEL). Third, how the identification of adverse effects between LOAEL and SOAEL provides a basis for considering mitigation measures to reduce and control exposures.

The following sections draw on the impact criteria set out in the SMR and confirm what levels of exposure are considered as LOAEL and SOAEL for the Proposed Scheme.

Ground-borne sound – construction and operation

The SMR defines the LOAEL and SOAEL for ground-borne noise for permanent residential buildings. This information, in addition to the impact classification used in the assessment, is presented in Table A 1.

Table A 1: Ground-borne sound impact criteria for permanent residential buildings

Impact classification	Ground-borne sound level L_{pASmax} (measured indoors, near the centre of any dwelling room on the ground floor)	Effect	
Negligible	< 35	Generally no adverse effect	LOAEL
Low	35 – 39	Potential significant effect when assessed on a community basis	
Medium	40 – 44		SOAEL
High	45 – 49	Significant effect	
Very high	>49		

Ground-borne vibration: occupants and users of buildings – construction and operation

The SMR defines the LOAEL and SOAEL for ground-borne vibration for permanent residential buildings. This information, in addition to the impact classification used in the assessment, is presented in Table A 2.

Table A 2: Vibration impact criteria for occupants and building users of permanent residential buildings

Impact classification	In the absence of appreciable existing levels of vibration[11,12]		Effect	
	VDV $m/s^{1.75}$ Daytime (0700 - 2300)	VDV $m/s^{1.75}$ Night-time (2300 – 0700)		
Negligible	≤0.2	≤0.1	Generally no adverse effect	LOAEL
Minor	> 0.2 – 0.4	>0.1 – 0.2	Potential significant effect when assessed on a community basis	
Moderate	> 0.4 – 0.8	> 0.2 – 0.4		SOAEL

[11] Highest impact category used, daytime or night–time.

[12] Determined at the worst location on a normally loaded floor (usually the centre of the floor).

Impact classification	In the absence of appreciable existing levels of vibration[11,12]		Effect
	VDV $m/s^{1.75}$ Daytime (0700 - 2300)	VDV $m/s^{1.75}$ Night-time (2300 – 0700)	
Major	>0.8	>0.4	Significant effect

Ground-borne vibration: buildings – construction and operation

The NOELs for ground-borne vibration with regard to risk of building damage, Table A 3.

Table A 3: Vibration impact criteria for buildings (criteria below which there is no risk of cosmetic damage)

Category of building	Impact criterion: (Peak Particle Velocity - PPV - at building foundation)	
	Transient[13] vibration	Continuous[14] vibration
Potentially vulnerable buildings[15]	≥6 mm/s	≥3 mm/s
Structurally sound buildings	≥12 mm/s	≥6 mm/s

The background and evidence for these criteria is set out in the Report 'Impacts of Tunnelling in the UK'[16].

Residential direct effects – individual dwellings

Construction and operation of the Proposed Scheme: Ground-borne noise

Residential receptors (dwellings) forecast to experience ground-borne noise levels (measured indoors, near the centre of any dwelling room on the ground floor) greater than SOAEL (>45 dBL_{pASmax}) have been identified as being likely to experience a significant adverse noise effect from construction or operation of the Proposed Scheme.

[13] Transient vibration relative to building response such as impulsive vibration from percussive piling.

[14] Continuous vibration relative to building response such as vibrating rollers.

[15] BS7385 highlights that the criteria for aged buildings may need to be lower if the buildings are structurally unsound. The standard also notes that criteria should not be set lower simply because a building is important or historic (listed). Where information about these structures is not currently known, the significance criteria for these receptors has been set at a lower level on a precautionary basis.

[16] High Speed Two Ltd (2013), *Impacts of Tunnels in the UK*, Department for Transport. Available online at: https://webarchive.nationalarchives.gov.uk/20131203120858/http:/assets.hs2.org.uk/sites/default/files/inserts/Impacts%20of%20tunnels%20in%20the%20UK.pdf.

Ground-borne vibration

Occupants of dwellings forecast to experience ground-borne vibration (measured indoors, near the centre of any dwelling room on the ground floor) greater than SOAEL, as defined in Table A 2, have been identified as being likely to experience a significant adverse vibration effect from construction or operation of the Proposed Scheme.

Residential direct effects – communities

Construction and operation of the Proposed Scheme

Where the level of noise or vibration caused by the Proposed Scheme exceeds the relevant LOAEL value, but is less than the relevant SOAEL value people's perception of the effect is generally indicated by the increase in noise or vibration. This is the increase compared to the environment without the Proposed Scheme.

Consistent with best practice and guidance, the magnitude of the adverse effect on people due to vibration has been indicated as being negligible, low, medium and high for ground-borne noise and negligible, minor, moderate or major for vibration.

For residential receptors, effects likely to be considered significant on a community basis will also be determined where the calculated ground-borne noise and or vibration level exceeds the relevant LOAEL but is less than the relevant SOAEL values in the SMR by taking into account:

- the type of effect being considered (e.g. annoyance);
- the magnitude of the effect (i.e. the calculated noise or vibration level compared the relevant LOAEL and SOAEL values and available dose response information);
- the change in vibration level, where relevant;
- the number and grouping of residential receptors affected;
- the potential combined effect of airborne sound, ground-borne noise and ground-borne vibration;
- any unique features of the Proposed Scheme's noise and vibration in the area being considered (which may require secondary acoustic indicators/criteria);
- the frequency and duration over which temporary construction impacts may occur; and
- the effectiveness of mitigation through design or other means.

The assessment is evidence based but also calls on professional judgement. As examples, the assessment methodology could consider the following combinations of magnitude of exposure and number of adversely effected receptors as significant on a community basis:

- a large number of dwellings subject to minor ground-borne vibration and/or low ground-borne noise adverse effects that are grouped closely together forming a residential community; and

- a small number of dwellings subject to major ground-borne vibration and/or high ground-borne noise adverse effects that are grouped closely together forming a residential community area.

For the purposes of the assessment, 'considered significant on a community basis' refers to residential community areas defined as a group of residential dwellings situated close to each other. Such residential community areas will usually be part of a named city, town, village or hamlet, in which case the name of the village etc. is used to help describe the significant effect. Each significant effect has been given a unique identification (ID), for example MA01-O-C02. As an example, this ID refers to community area MA01 (Hough to Walley's Green), where an operational sound and vibration effect (O) is predicted and this is the second significant effect identified on a community basis (C02). These ID are provided to navigate the reader between the text in Volume 2 and Volume 5 reports, their tables and maps.

There may be unique circumstances where secondary criteria are required to assess the significance of a potential effect arising. These are considered later in this section.

The potential combined impacts of airborne sound, ground-borne sound and ground-borne vibration

Where significant effects from more than one source are identified at the same assessment location then an additional significant combined effect is reported.

Where effects from more than one source are identified at the same assessment location (i.e. levels of exposure greater than the relevant LOAEL) an assessment is undertaken to determine whether cumulatively a significant combined effect should be reported, even if taken individually the effects will not be classified as significant. The cumulative assessment, where appropriate, makes use of available dose-response relationship information.

Any unique features of the Proposed Scheme's sound or vibration impacts in the area being considered (which may require secondary impact indicators/criteria)

Any unique features are identified, in so far as is practicable, and described in the relevant CA reports (Volume 5, Appendices SV-002).

The assessment of any unique feature identified based on the best available information, including the consideration of secondary impact criteria, is presented in the relevant sound, noise and vibration CA reports.

Unique features of the Proposed Scheme that could influence the assessment of effects from airborne sound and noise could include, for example, construction activities such as impact driven piling.

Unique features of the local receiving environment that could influence the assessment of effects from ground-borne noise or vibration could include, for example:

- receptors with piled or other foundations at a location relative to the railway, where the form of foundation could give rise to an increase in the magnitude of resulting noise or vibration inside the property; and
- where condition surveys demonstrate that a receptor is structurally unsound and is therefore more vulnerable.

The frequency and duration over which temporary construction impacts may occur

Where effects are identified for a period exceeding one month, then the effect will be considered to be significant provided that other criteria (e.g. number of impacted receptors) are also met.

The effectiveness of mitigation through design or other means

In assessing residual effects, the effectiveness of the envisaged mitigation options will be taken into account. In taking forward additional mitigation to reduce or avoid a significant effect, consideration will be given to the reduction in the magnitude of the noise or vibration impact provided by the envisaged mitigation option, the number of receptors that will benefit and sustainability considerations such as use of resource and cost.

4.3 Non-residential receptors: direct effects

In the assessment, the term residential is applied to permanent dwellings (i.e. houses, apartments). Hotels, hospitals and other buildings where people sleep but are not 'permanent' residents are, along with other buildings having specific noise and vibration sensitive resources, considered as non-residential receptors.

The effect of noise or vibration on a non-residential receptor is dependent on:

- the exposure, and change in exposure compared to the baseline, due to the Proposed Scheme;
- the receptor's generic sensitivity to noise or vibration (i.e. dependent on the use of the receptor with for example, a school being more sensitive than an office); and
- the receptor's specific sensitivity to noise or vibration (for example: the location of layout of a school and whether the most sensitive parts of the school are closest to and face the Proposed Scheme or are located further from the route and are on the opposite side of a building; and the sound insulation performance of the building and hence whether sensitive indoor activities are insulated from change in outdoor noise).

The assessment considers the noise and vibration exposure at each receptor and the receptor's generic sensitivity. With regard to specific sensitivity the assessment in on a worst-case basis, assuming that the receptor is the most sensitive it can be (for example, assuming that for a school the teaching spaces are at the closest point to the Proposed Scheme, facing the route with windows partially open).

Where significant effects are forecast on this basis, HS2 Ltd will continue to seek reasonably practicable measures to further reduce or avoid these significant effects. In doing so HS2 Ltd will continue to engage with stakeholders to fully understand the receptor, its use and the benefit of the measures. The outcome of these activities will be reflected in the Environmental Minimum Requirements.

The assessment has been undertaken at assessment locations that are representative of each non-residential receptor defined, wherever practicable, at the building, part of the building or open space associated with the receptor and which is closest to the Proposed Scheme. The following sub-sections consider in turn the application of the qualitative significance criteria set for non-residential receptors.

The type of effect being considered

For non-residential receptors, including resources such as hospitals and hotels where people sleep, the types of potential effect on occupants and activities considered in the ES arising from ground-borne noise or vibration and the codes used to identify them are:

- generally, no adverse effect (code 'NA');
- adverse effect (code 'A'); and
- significant adverse effect (code 'S').

The potential for effects on non-residential buildings themselves, in terms of any risk of cosmetic building damage arising from ground-borne vibration is assessed. NPPG characterises an exposure level that will cause such an outcome as being unacceptable. Accordingly, NPPG advises that it should be prevented from occurring.

The use and sensitivity of the receptor

Table A 4 and Table A 5, (derived from the SMR), identify the different non-residential receptor and land use categories for ground-borne sound and vibration respectively and the associated impact (screening) criteria. The criteria apply to construction and operation of the Proposed Scheme unless specifically stated in Table A 4 and Table A 5.

Table A 4: Ground-borne sound impact criteria for non-residential receptors

Category of building		Impact (screening) criterion dB L_{pASmax} [dB]	Potential effect
Code	Description		
G1	Theatres/large auditoria; and concert halls	25	Adverse 'A'
G2	Sound recording/broadcast studios	30	Adverse 'A'

Category of building		Impact (screening) criterion dB L_{pASmax} [dB]	Potential effect
Code	Description		
G3	Places of meeting for religious worship/courts/cinemas/ lecture theatres/museums/small auditoria or halls	35	Adverse 'A'
G4	Offices/schools/colleges/hospitals/hotels/libraries	40	Adverse 'A'

Table A 5: Ground-borne vibration impact criteria for non-residential receptors

Category of building		Impact (screening) criterion		Reference	Potential effect
Code	Description	VDV_{day} $[m/s^{1.75}]$	VDVnight $[m/s^{1.75}]$		
V1	Vibration sensitive research and manufacturing (e.g. computer chip manufacture); hospitals with vibration sensitive equipment/ operations; universities with vibration sensitive research equipment/operations	Risk assessment will be undertaken based on the information currently available for the relevant equipment/ process, or where information provided by the building owner or equipment manufacturer[17].		SMR. ISO 14837-1[18] FRA, FTA[19]	Adverse 'A'
V2	Hotels; hospital wards; and education dormitories	0.2	0.1	BS6472-1[20] FRA, FTA	Adverse 'A'
V3	Offices; schools; and places of worship	0.4	n/a	BS6472-1 FRA, FTA	Adverse 'A'
V4	Workshops	0.8	n/a	BS6472-1	

The assessment of effects on non-residential receptors has been undertaken on a reasonable worst-case basis taking account of public available information about each receptor. The assessment is considered worst-case because in many cases, for example:

- the location of the sound sensitive area within the receptor may be subject to lower exposure from the Proposed Scheme than calculated at the selected assessment location; and
- the design of the receptor may offer greater reduction of ground-borne sound or vibration.

[17] The assessment will be based on all information available to the project but it is accepted that it will not be possible to identify every potentially vibration sensitive process or item of equipment. The assessment methodology provides a basis for assessing and mitigating if necessary any vibration sensitive process or equipment at the time the project becomes aware of it.

[18] ISO 14837-1 (2005), *Mechanical Vibration: Ground Borne Noise and Vibration Arising from Rail Systems. Part 1: General Guidance International Standards Organisation*.

[19] U.S. Department of Transportation, Federal Railroad Administration (2005), *High-Speed Ground Transportation Noise and Vibration Impact Assessment*, Office of Railroad Development.

[20] British Standards Institution (2008), *BS6472-1, Guide to Evaluation of Human Exposure to Vibration in Buildings.* Part 1: Vibration Sources other than Blasting.

The magnitude of the effects

The magnitude of any exceedance of the forecast exposure compared to the screening criteria set in Table A 4 and Table A 5 or the exceedance over the existing baseline is used to inform the identification of significant effects. The identification of any significant effects is described on a case-by-case basis in the relevant Volume 5 appendices, as required.

The design of the receptor affected

Any relevant design features will be identified in so far as is practicable at this stage, based primarily on desk top studies. Design features of the receiving receptor that could influence the assessment of effects from ground-borne noise or vibration include, for example:

- receptors with piled or other foundations at a location relative to the railway, where the form of foundation could give rise to an increase in the magnitude of resulting noise or vibration inside the property;
- receptors with large span, lightweight floors;
- where condition surveys demonstrate that a receptor is structurally unsound and is therefore more vulnerable; and
- mitigation (e.g. base isolation) designed into the receptor to protect it from existing ground-borne noise or vibration sources.

Assessments are undertaken on a receptor-by-receptor basis as necessary to support construction planning and detailed design of the Proposed Scheme and ensure that relevant measures are implemented to avoid or reduce any significant noise effect.

Typical building design is identified as 'T' and special as 'SP' and further information regarding the 'special' building design is presented in Volume 5, Appendices SV-002.

The existing ambient sound and vibration levels in the receptor affected

Likely significant effects are identified on a 'worst-case' basis using the screening criteria in Table A 4 and Table A 5. The screening criteria assume that the existing sound and vibration levels at the receptor are low and hence any level of sound or vibration greater than the screening criteria could give rise to a noise or vibration significant effect.

Any unique features of the Proposed Scheme's sound or vibration impacts in the area being considered (which may require secondary impact indicators/criteria)

Any unique features are identified, in so far as is practicable, during the screening assessment.

The treatment of any unique feature, including the consideration of secondary impact criteria, will be considered as part of assessments undertaken to support the construction planning, detailed design and implementation stages of the Proposed Scheme as necessary and as described for residential receptors above.

Unique features of the Proposed Scheme that could influence the assessment of effects from ground-borne noise or vibration include, for example, construction activities: impact driven piling.

5 Airborne sound and noise

5.1 Introduction

Significance criteria are outlined for sound, noise and vibration in Section 18 of the SMR for the ES. The following sub-sections of this report provide more detailed guidance on the application of these criteria for the ES.

The assessment of sound, noise and vibration considers the likely noise and vibration significant effects arising from the construction and operation of the Proposed Scheme on:

- people, primarily where they live ('residential receptors') in terms of a) individual dwellings and b) on a wider community basis, including any shared community open areas; and
- community facilities such as schools, hospitals, places of worship, and also commercial properties such as offices and hotels, collectively described as 'non-residential receptors' and 'quiet areas’.

The following sub-sections consider each of these receptor classifications in turn.

5.2 Residential receptors

The code ‘R’ is used to designate assessment locations that represent residential receptors. In this assessment, the term residential is applied to permanent dwellings (i.e. houses, apartments). Hotels, hospitals and other buildings where people sleep but are not ‘permanent’ residents are considered as non-residential receptors. Typical building design is identified as 'T' and special as 'SP' and further information regarding the 'special' building design is presented in Volume 5, Appendices SV-002 and SV-003.

The assessment of adverse effects has been undertaken at assessment locations that are representative of a number of dwellings. The number of dwellings represented by an assessment location is recorded in the assessment tables in relevant Volume 5 appendices.

The following sub-sections consider in turn the application of the qualitative significance criteria set for residential receptors.

The type of effect being considered

For residential receptors, the following codes are used to describe the types of potential effect on occupants as assessed using the criteria defined in the SMR for airborne noise:

- generally, no adverse effect (code ‘NA’);
- adverse effect (code ‘A’);
- significant adverse effect (code ‘S’); and
- unacceptable adverse effect (code ‘U’).

The criteria defined in the SMR generally allow the assessment of effects to be undertaken on a reasonable worst-case basis, taking account of public available information about each receptor. The basis of the adopted criteria is discussed further in the rest of this section. Technical supporting information is presented in the Volume 5 appendices.

The number and grouping of effects

For airborne noise from the construction and operation of the Proposed Scheme the number and grouping of effects has been considered in conjunction with the magnitude of the effects to identify likely significant effects. This is set out in the next sub-section.

The magnitude of the effects and available dose-response information

For residential receptors (dwellings), the assessment has differentiated between two situations:

- where the magnitude of the impact is so great that the absolute noise inside dwellings will give rise to a significant adverse effect; and
- where the magnitude of the absolute sound level is not in itself significant inside a dwelling but where the change in sound level outside dwellings will, when considered in aggregate across a number of dwellings and their shared community open areas[1], constitute a significant adverse effect on the acoustic character of the area such that there is a perceived change in the quality of life.

Residential receptors: direct effects – individual dwellings

Construction of the Proposed Scheme

Residential receptors (dwellings) forecast to experience a noise level from construction activities that is greater than the following (LOAEL) criteria for any period exceeding one month have been identified as being likely to experience a significant adverse noise effect from construction of the Proposed Scheme; Noise outside dwellings from the Proposed Scheme at the facade: 75 dB $L_{pAeq,T}$ during the day; 65 dB $L_{pAeq,T}$ during the evening; or 55 dB $L_{pAeq,T}$ during the night, or above the existing ambient if this is higher.

Above these thresholds there will be a significant observed adverse effect. These significant effects are identified receptor-by-receptor.

For daytime, the widely used[21] outdoor 75 $L_{Aeq,12hr}$ daytime noise threshold used for category 'C' of the ABC impact criteria Table A 6 has been taken to be a SOAEL.

[21] Large infrastructure projects including HS1, the Forth Replacement Crossing and Thames Tideway Tunnel.

Table A 6: Airborne sound from construction: impact criteria at dwellings (construction sound only) (from SMR)

Period	Assessment category		
	A	B	C
Day: T=12hr, Weekdays, 07.00-19.00, T=6hr, Saturday, 07.00-13.00	>65 $L_{pAeq,T}$	>70 $L_{pAeq,T}$	>75 $L_{pAeq,T}$
Evenings and weekends: T=as defined by time period (e.g. for 19.00-23.00 T is four hours), Weekdays 19.00-23.00, Saturdays 13.00–23.00 and Sundays 07.00-23.00	>55 $L_{pAeq,T}$	>60 $L_{pAeq,T}$	>65 $L_{pAeq,T}$
Night: T=8hr, Every day 23.00–07.00	>45 $L_{pAeq,T}$	>50 $L_{pAeq,T}$	>55 $L_{pAeq,T}$

Note, all sound levels are defined at the façade of the receptor:

- Assessment Category A: impact criteria to use when baseline ambient sound levels (rounded to the nearest 5) are less than these values;
- Assessment Category B: impact criteria to use when baseline ambient sound levels (rounded to the nearest 5) are the same as category A values; and
- Assessment Category C: impact criteria to use when baseline ambient sound levels (rounded to the nearest 5) are higher than Category A values.

If the ambient sound level exceeds the Assessment Category C threshold values given in the table (i.e. the ambient sound level is higher than the above values), then an impact is deemed to occur if the total $L_{pAeq,T}$ sound level for the period is greater than the ambient sound level.

It should be noted that the SOAEL assumed for construction is, as is the norm, higher than the SOAEL for operational noise from the Proposed Scheme. This reflects that construction noise is temporary (in that daytime construction noise varies substantially in level and character on a month-by-month basis).

For night-time, the WHO Night Noise Guidelines for Europe[22] has been used for noise measured outdoors. The WHO Environmental Noise Guidelines[23], although published later, reports in some cases slightly higher levels, however it also identifies that it is complimentary to the Night Noise Guidelines and that use of the Night Noise Guidelines forms a precautionary approach, which is aimed at protecting the whole population. The Night Noise Guideline Interim Target of 55dB $L_{pAeq,8hr}$ has been adopted as the noise

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[22] World Health Organization (2010), *Night Noise Guidelines for Europe*, Available online at: http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf.

[23] World Health Organization (2018), *Environmental Noise Guidelines for the European Region*. WHO Regional Office for Europe.

threshold used for Category 'C' of the ABC impact criteria at night (refer to section 18 of the SMR) and again can be taken to be a SOAEL.

For the evening the SOAEL is set 10dB lower than the daytime SOAEL consistent with the ABC criteria and the accepted criteria that date back to the Advisory Leaflet (AL)72 - Noise Control on Building Sites[24].

Above these SOAELs, noise levels inside properties will lead to significant adverse effects. This is why HS2 Ltd will offer noise insulation to properties where it is not reasonably practicable to further reduce noise exposure outside the properties due to construction. This is consistent with other major projects (e.g. HS2 Phase One, HS1, Crossrail, the A14 road scheme, Thames Tideway Tunnel etc.) and is consistent with BS5228-1[25].

Noise insulation will mitigate the significant effect arising from internal noise levels exceeding the relevant SOAEL.

Operation of the Proposed Scheme

Residential receptors (dwellings) forecast to experience a noise level greater than the following criteria have been identified individually as being likely to experience a significant adverse noise effect from operation of the proposed scheme - Noise outside dwellings (free-field) from the Proposed Scheme only: 65dB $L_{pAeq,0700\text{-}2300}$ during the day; or 55dB $L_{pAeq,2300\text{-}0700}$ during the night.

Above these thresholds there will be a significant observed adverse effect.

During the daytime, the free-field level of 65dB $L_{pAeq,0700\text{-}2300}$ is considered a SOAEL. This is consistent with the daytime trigger level in the UK Noise Insulation (Railways and other guided systems) Regulations[26]. The assessment of noise levels inside dwellings is undertaken assuming that windows are open. In this respect, it differs from the approach employed for the assessment of construction noise. This is on the basis that operational noise is permanent.

For night-time, following NPPG, where the noise from the operation of the Proposed Scheme (i.e. the use of new or additional railways authorised by the Bill) measured outside a dwelling exceeds the Interim Target defined by the WHO Night Noise Guidelines for Europe[22], residents are considered to be significantly affected by the resulting noise inside their dwelling.

The WHO Night Noise Guidelines for Europe set the Interim Target at 55dB $L_{Aeq,8hr}$ measured outdoors. This noise threshold has been taken to be a SOAEL, as described earlier. Again,

[24] Department for the Environment (1976), *Advisory Leaflet (AL) 72 (1976), Noise control on Building Sites,* first published 1968, Third edition, HMSO.

[25] British Standards Institution (2009), *BS5228-1-2009 (+A1: 2014), Code of practice for noise and vibration control on construction and open sites – Part 1: Noise*.

[26] *The Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996*. HMSO.

this criterion is based on the assessment of internal noise levels with windows assumed to be open.

In addition to the SOAEL for night noise from the Proposed Scheme as described above, significant adverse effects are reported on dwellings where, during the night (2300 – 0700), the forecast maximum sound level from the Proposed Scheme at the façade of the dwelling is above 85dB L_{pAFmax} (where the number of train pass-bys exceeding this value during the night is less than or equal to 20) or 80dB L_{pAFmax} (where the number of train pass-bys exceeds 20). This is based on the objective evidence in published research[27,28,29].

The Interim Target is a lower level of noise exposure than the Regulations trigger threshold for night noise. In these particular circumstances, following the methodology set out in the Regulations and where night-time noise levels are predicted to exceed 55dB[30], or the maximum noise level (dependent on the number of train passes) as a train pass exceeds the criterion[31], noise insulation will be offered for these additional buildings.

Residential direct effects - communities

Construction and Operation of the Proposed Scheme

Where the level of noise or vibration caused by the Proposed Scheme is greater than the lowest adverse effect threshold but is lower than the significant adverse effect threshold, people's perception of the effect is generally indicated by the increase in noise or vibration. This is the increase compared to the environment without the Proposed Scheme.

Considering airborne noise, people living in the local community when a change in noise occurs may consider it as an adverse effect on the acoustic character of the area and hence may perceive it as a change in the quality of life. People who only experience the sound of the Proposed Scheme once it is established will consider noise based on the absolute levels, not the change in levels. The proportion of these people annoyed by the absolute level of noise is likely to be lower than for people who experience the change when the Proposed Scheme is introduced. However, this assessment has assumed as a reasonable worst-case that all people living in the community experience the change when the Proposed Scheme is introduced.

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[27]Elmenhorst, E.M et al. (2012), *Examining nocturnal railway noise and aircraft noise in the field: sleep, psychomotor performance and annoyance*. Science of the Total Environment, 424.

[28] Basner, M., Muller, U. and Elmenhorst, E.M. (2011), *Single and Combined Effects of Air, Road, and Rail Traffic Noise on Sleep and Recuperation*. Sleep, 34, 11-23.

[29] Rice, C.G. and Morgan, P.A. (1982), *A synthesis of studies on noise-induced sleep disturbance*. ISVR Memorandum No. 623.

[30] Equivalent continuous level, $L_{pAeq,23:00-07:00}$ measured without reflection from the front of buildings.

[31] During the night (23:00-07:00) a significant effect is also identified where the Proposed Scheme results in a maximum sound level at the façade of a building at or above: 85 dB L_{pAFmax} (where the number of train pass-bys exceeding this value is less than or equal to 20); or 80 dB L_{pAFmax} (where the number of train pass-bys exceeding this value is greater than 20).

Consistent with best practice and guidance, the magnitude of the adverse effect on people due to noise change has been indicated as being negligible, minor, moderate or major.

Based on noise change, a number of adversely effected dwellings may be considered to be significant for the purposes of this assessment when considered collectively on a community basis taking account of the local context. This is even though the final noise levels with the Proposed Scheme in operation do not exceeded the significant adverse effect level. In considering adverse effects to be significant on a community basis the following criteria have been taken into account:

- the number and grouping of adversely effected dwellings and shared open areas;
- the magnitude of the adverse effects identified (based on noise change);
- the overall level of noise exposure once the scheme is in operation;
- the level and character of the existing sound environment;
- any unique features of the source or receiving environment in the local area;
- combined exposure to noise and vibration;
- the duration of the adverse effect (for construction); and
- the effectiveness of mitigation measures that could avoid or reduce the adverse effects.

The assessment is evidence based. As examples, the assessment methodology could consider the following significant on a community basis:

- a large number of dwellings subject to minor adverse effect due to noise change in a quiet existing environment that are grouped closely together forming a residential community; or
- a small number of dwellings subject to major adverse effect due to noise change in an existing environment that is currently either quiet or moderately noisy that are grouped closely together forming residential community area.

For the purposes of the assessment, 'considered significant on a community basis' refers to residential community areas defined as a 'group of residential dwellings situated close to each other, including any shared open space'. Such residential community areas will usually be part of a named city, town, village or hamlet, in which case the name of the village etc. is used to help describe the significant effect. Each significant effect has been given a unique ID, for example MA01-O-C2. As an example, this ID refers to OSV, in community area MA01 and this is the second significant effect identified on a community basis (C2). These ID are provided to navigate the reader between the text in Volume 2 and Volume 5, their tables and maps.

There may be unique circumstances where secondary criteria are required to assess the significance of a potential effect arising. These are considered later in this section.

Construction of the Proposed Scheme

As outlined in Section 3 of this annex, the second aim of the Government's NPSE refers to the situation where an effect lies somewhere between LOAEL and SOAEL. The aim is that 'all reasonable steps should be taken to mitigate and minimise adverse effects on health and quality of life while also taking into account the guiding principles of sustainable development. This does not mean that such adverse effects cannot occur.'

Therefore, Government policy in essence requires that 'all reasonable steps' are taken to mitigate noise, i.e. Best Practicable Means (BPM) should be applied between LOAEL and SOAEL. The requirement to employ BPM to minimise noise is embedded in the draft CoCP.

The consideration of noise exposure between LOAEL and SOAEL is aligned with the ABC assessment methodology identifying potential significant effects where forecast noise levels exceed Categories A and B. These categories consider the impact of construction in locations with lower existing noise levels. Where construction noise levels are predicted to exceed the A or B Categories, but are less than the Category C threshold, then this is assessed as potentially significant in quieter areas. At these levels of exposure there is limited internal impact inside properties affecting people or their activities. However, outside the properties the construction noise is sufficiently prominent relative to ambient levels that this will be an effect on the external acoustic character of the area. Mitigation of such effects is therefore about mitigation at source. Noise insulation is not an appropriate mitigation measure as it can only control noise levels inside a property.

The increase in noise levels identified by construction levels exceeding category A or B (but being below category C) and the resulting effect on the overall amenity and general community annoyance can be significant when considered collectively for groups of dwellings and their shared community open areas.

In these circumstances a significant effect is identified on each group of dwellings, including their shared community open areas, where the A or B noise category is exceeded at generally five or more dwellings for a continuous duration of one month or longer and where the dwellings concerned are in close proximity to one another and form a community or part of a community.

Operation of the Proposed Scheme

Again with reference to the second aim of Government's noise policy, free-field absolute sound levels of 50 $L_{pAeq,day}$ and 40 $L_{pAeq,night}$ or a maximum absolute sound level of 60 L_{pAFmax} at the façade from the Proposed Scheme are considered LOAEL and hence generally no effect on communities is likely. The LOAEL of 40 $L_{pAeq,night}$ is considered likely to be precautionary for high speed rail.

For the daytime level, the WHO Guidelines for Community Noise[32] identifies guideline values to assess typical community annoyance with 50 or 55 dB L_{pAeq} (outdoor noise level), representing 'daytime levels below which a majority of the adult population will be protected from becoming moderately or seriously annoyed, respectively.' On this last matter, page 144 of the Community Noise guidelines states that 'Available data indicate that daytime sound pressure levels of less than 50 L_{pAeq} cause little or no serious annoyance in the community'. The dose response curves on page 100 of the same document suggest about 5% of the population is annoyed at 55' i.e. the majority referred to in the annoyance guideline value is about 95% of the population.

In the WHO's Night Noise Guidelines for Europe the night noise guideline, 40 $L_{pAeq,2300\text{-}0700}$ outdoors, is set explicitly at the lowest observable adverse effect level (LOAEL). As stated in Section 5.1 of this annex, this level is considered likely to be precautionary for high speed rail.

The WHO Guidelines for Community Noise also identify 60 L_{pAFMax} outside as the guideline value for sleep disturbance with windows open. For this reason, sound levels of 60 L_{pAFMax} at the façade is also considered the LOAEL for operational railway noise at night[33].

The threshold of 50 $L_{pAeq,0700\text{-}2300}$ represents the onset of the lowest observed community noise effects during the day (annoyance) and 40 $L_{pAeq,2300\text{-}0700}$ and 60 L_{pAFMax} represents the onset of the lowest observed community noise effects during the night (risk of sleep disturbance) consistent with guidance such as the WHO Guidelines. No adverse effects are therefore generally likely below these absolute levels of sound exposure.

Forecast operational sound levels from the Proposed Scheme of between 50 and 65 daytime, or 40 and 55 night-time (i.e. between the respective LOAELs and SOAELS) may be perceived as a change in quality of life for occupants of dwellings or a perceived change in the acoustic character of an area. When considered collectively for groups of dwellings and their shared community open areas, such effects may be significant.

The impact arising from a change in sound levels is evaluated in accordance with the SMR, reproduced below as Table A 7.

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[32] Berglund, B., Lindvall, T. and Schwela, D.H. (1999), *Guidelines for community noise*, in World Health Organization and Environmental Health, Geneva: World Health Organization.

[33] The maximum sound level LOAEL at night accounts for self-reported sleep disturbance. Although it should be noted that a study looking at objective measures of sleep disturbance from high speed railways (Marshall T, et al. *Evaluating the Health Effects of Noise from High Speed Railways*, ICBEN 2014) identifies a sound level where the model predicts a zero probability of additional noise induced awakenings of 67dB L_{pAFMax} at the façade from the operation of HS2 Phase 2b.

Table A 7: Airborne sound from operational train or road movements - impact criteria (from SMR)

Long term Impact Classification	Short term Impact Classification	Sound level change $L_{pAeq,T}$ (positive or negative) T = either 16hr day or 8hr night
Negligible	Negligible	≥ 0 and < 1
	Minor	≥ 1 and < 3
Minor	Moderate	≥ 3 and < 5
Moderate	Major	≥ 5 and < 10
Major		≥ 10

The identification of a significant effect will therefore depend on:

- the magnitude of the impact (impact classification and maximum absolute sound level at the façade from the Proposed Scheme);
- the number of dwellings experiencing the impact magnitude (generally the higher the impact magnitude the smaller the number of dwellings receiving the impact required to identify a significant effect, which at increasing absolute exposure converges to one dwelling when the SOAEL is reached); and
- the grouping of the dwellings subject to an impact. The identification of significant effects at these sound levels (between LOAEL and SOAEL) generally being weighted to clusters of dwellings in close proximity that form a community or part of a community. This ensures that mitigation in the Proposed Scheme provides a reasonable level of benefit compared to cost (see later in this section).

The existing sound environment in terms of the absolute level and the character of the existing soundscape

The results of the baseline surveys are presented in the relevant Volume 5 Appendices (SV-002).

Based on the baseline data, the following are taken into account as additional evidence when assessing the significance of the effect caused by the introduction of the Proposed Scheme into an existing sound environment:

- the identification by a competent and qualified surveyor that based on their professional listening and completion of a survey record, the existing sound environment has a 'unique feature' (in terms of soundscape). The potential effect of sound from the Proposed Scheme on the unique feature is qualitatively assessed based on the reported character of the feature as discussed in the next sub-section;
- for operational rail sound, greater weight is given to a sound level change between 1 and 3 if the area is already exposed to levels of noise that exceed the criteria contained in the Noise Insulation (Railway and Other Guided Transport Systems) Regulations 1996; and
- others (as identified in CA reports).

Any unique features of the Proposed Scheme's sound or impacts in the area being considered (which may require secondary acoustic indicators/criteria)

By exception, effects may also be identified following consideration of any unique features of the sound impact from the Proposed Scheme and/or the character of the existing soundscape. Any unique features are identified, in so far as is practicable, and described in the relevant Volume 5 appendices.

The assessment of any unique feature, including the consideration of secondary impact criteria, are presented in the relevant Volume 5 appendices.

Unique features of the Proposed Scheme that could influence the assessment of effects from airborne sound and noise include, for example:

- construction activities such as impact driven piling or others (as described in the relevant Volume 5 appendices); and
- existing sound features, for example, where the existing baseline environment in an area is subjectively very quiet, (substantially less than 50 daytime and/or 40 night-time) and the existing environment is characterised by little or no appreciable man made sound sources. Such environments are rare[34] (in the national context) and hence it is considered a unique feature. Specific assessment of any such environment calls on additional secondary criteria as required and as presented in the relevant Volume 5 appendices. Effects identified for such an environment will be effects on the unique feature as a resource.

The potential combined impacts of airborne sound, ground-borne sound and ground-borne vibration

Where significant effects from more than one source are identified at the same assessment location then an additional significant combined effect is reported.

The assessment tables in the relevant Volume 5 appendices identify where a receptor is forecast to experience simultaneous adverse effects from vibration and noise. Where the nature of the adverse effect is in terms of general amenity and increased community annoyance as described earlier in this section, then additional weight is given to combined impacts of simultaneous noise and vibration in the identification of significant effects. This is set out as required in the relevant Volume 5 appendices.

[34] Building Research Establishment (2002), *UK National Noise Incidence Study 2000/2001*, DEFRA.

The frequency and duration over which temporary construction impacts may occur

For construction, only impacts occurring for a period exceeding one month are considered in respect of identifying likely significant construction noise and/or vibration effects.

The effectiveness of mitigation through design or other means

In assessing residual significant effects, the effectiveness of the envisaged mitigation options is taken into account.

For construction, the effectiveness of further mitigation options to reduce or remove likely residual temporary effects is considered with regard to the principles of BPM as defined by the Control of Pollution Act 1974[35]. Consideration of further mitigation is presented on a case-by-case basis in the relevant Volume 5 appendices.

For the operation of the Proposed Scheme, as described in the relevant Volume 5 appendices, further mitigation options have been considered in respect of the following criteria:

- benefit compared to cost;
- benefit has been evaluated by calculating the reduction in WebTAG 'willingness to pay' provided by the further mitigation. The WebTAG monetised noise impact values are 60 year costs (base year 2011);
- cost has been estimated based upon indicative costs for noise fence barriers. It has been assumed that the design life of a noise fence barrier is 40 years;
- engineering practicability;
- impacts on other environmental disciplines, including landscape and visual; and
- consultation and stakeholder engagement responses.

5.3 Non-residential receptors and land uses

In this assessment, the term residential is applied to permanent dwellings (i.e. houses, apartments). Hotels, hospitals and other buildings where people sleep but are not 'permanent' residents are, along with buildings having other specific noise and vibration sensitive resources, considered as non-residential receptors.

The assessment of adverse effects has been undertaken at assessment locations that are representative of each non-residential receptor defined, wherever practicable, at the

[35] *Control of Pollution Act 1974.* Her Majesty's Stationery Office, London.

building, part of the building or open space associated with the receptor and which is closest to the Proposed Scheme.

The following sub-sections consider in turn the application of the nine qualitative significance criteria set for residential receptors.

The type of effect being considered

For non-residential receptors, including those where people sleep, such as hospitals and hotels, the types of potential effect on occupants and activities considered in the ES arising from airborne noise and the codes used to identify them are:

- generally, no adverse effect (code 'NA');
- adverse effect (code 'A');
- significant adverse effect (code 'S'); and
- unacceptable adverse effect (code 'U').

The basis of the adopted criteria is discussed further in the rest of this section. Technical supporting information is presented in the technical appendices in Volume 5.

The use and sensitivity of the receptor

Table A 8 identifies the different non-residential receptor and land use categories for airborne noise and the associated impact (screening) criteria. The criteria apply to sound arising from both construction and operation of the Proposed Scheme unless specifically stated in the table.

The assessment of effects on non-residential receptors has been undertaken on a reasonable worst-case basis taking account of public available information about each receptor. The assessment is considered worst-case because in many cases, for example:

- the location of the sound sensitive area within the receptor may be subject to lower exposure from the Proposed Scheme than calculated at the selected assessment location;
- the design of the receptor may offer greater reduction of ground-borne sound or vibration; or
- the existing environment and design of the building may mean that existing sound levels already exceed the absolute screening criteria adopted or that ambient internal noise or vibration have some masking effect.

The design of the receptor affected

Any design features that can be practicably identified by 'desk top review' are considered in the assessment. In instances where further assessment is required, it will be undertaken as described in the foregoing sub-section.

The existing sound environment in terms of the absolute level and the character of the existing soundscape

The results of the baseline sound level survey information available at the time of writing have been taken into account as part of the assessment. In instances where further assessment is required, it will be undertaken as described in the foregoing sub-section.

The magnitude of the impacts

The magnitude of an impact and potential adverse effect is evaluated by the increase in sound levels over and above the relevant screening criterion defined in Table A 8, categorised using the impact criteria descriptions presented in the SMR.

The assessment informed by these indicators is set out as required in the relevant Volume 5 appendices.

Table A 8: Airborne sound impact criteria for non-residential receptors, construction and operation

Category of building		Impact (screening) criterion		Potential effect	Reference
Code	Description	Day 0700 - 2300	Night 2300 - 0700		
A1	Large and small auditoria; concert halls; sound recording and broadcast studios and theatres	60[1] L_{pAFmax} or 50[1] $L_{pAeq,T}$ and Not > than existing		'Q' deterioration of acoustic Quality	FRA/FTA, BS8233[36]
A2	Places of meeting for religious worship; courts; cinemas; lecture theatres; museums; and small auditoria or halls	50[2] $L_{pAeq,T}$ and a change > 3	-	'D' Disturbance	BS8233, EFA's Acoustics Performance Standards[37], HTM 08-01[38], WHO Guidelines
A3	Schools; colleges; hospitals*;	50[2] $L_{pAeq,T}$ and a change > 3	45*[3] $L_{pAeq,T}$ and a change > 3	'DSd' Disturbance and Sleep disturbance	

[36] British Standards Institution (2014), *BS8233, Guidance on sound insulation and noise reduction for Buildings*.

[37] Department for Education/Education Funding Agency (2014), *Acoustic design of schools: Performance standards*, Building Bulletin 93.

[38] Health sector buildings (2011), Health sector buildings: acoustic design requirements, *Health Technical Memorandum 08-01: Acoustics*. Available at https://www.gov.uk/government/publications/guidance-on-acoustic-requirements-in-the-design-of-healthcare-facilities.

Category of building		Impact (screening) criterion		Potential effect	Reference
Code	Description	Day 0700 - 2300	Night 2300 - 0700		
	hotels*; and libraries				
A4	Offices and amenity spaces	ABC[4] / 55 [5] [6] $L_{pAeq,T}$ and a change > 3 [5]	-	'D' Disturbance	BS8233, BCO guidance[39]

• *Based on an internal level of 25 $L_{pAeq,T}$ consistent with BS8233 and 25 L_{pASmax} consistent with FRA/FTA guidance for the operation of the railway and specific construction activities such as percussive piling. To require these criteria the internal sound levels due to existing sources (internal and external) must already be reduced to these criteria or lower. Given typical environments this suggests any such receptor will have a level of sound insulation from the building shell (including windows and ventilation penetrations) that will reduce external levels by at least 25 to 30. Also allows for façade correction and conversation from slow to fast time response.*

• *Based on an internal level of 35 $L_{pAeq,T}$ consistent with Building Bulletin 93 and BS8233 etc. Equivalent external level assuming 15 for a partially open window.*

• *Based on an internal level of 30 $L_{pAeq,T}$ consistent with BS8233, WHO guidelines etc. Equivalent external level assuming 15 for a partially open window.*

• *For construction assess using A and B categories from ABC method consistent with AL72.*

• *Based on an internal level of 40 $L_{pAeq,T}$ consistent with BS8233, BCO guidelines etc. Equivalent external level assuming 15 for a partially open window.*

• *Based upon guidance from World Health Organization 'Guidelines for community noise'.*

The potential combined effects of airborne sound, ground-borne sound and ground-borne vibration

Where significant effects from more than one source are identified at the same assessment location then an additional significant combined effect is reported.

The assessment tables in the relevant Volume 5 appendices identify where a receptor is forecast to experience simultaneous adverse effects from vibration and noise. Additional weight is given to combined effects of simultaneous noise and vibration in the identification of significant effects. This is set out as required in relevant Volume 5 appendices.

Any unique features of the Proposed Scheme's sound or effects in the area being considered (which may require secondary acoustic indicators/criteria)

Any unique features are identified, in so far as is practicable, during the screening assessment.

[39] British Council for Offices (2014), *Guide to Specification*.

The treatment of any unique feature, including the consideration of secondary impact criteria, will be considered as part of assessments undertaken to support the construction planning, detailed design and implementation stages of the Proposed Scheme as necessary and as described in the foregoing sub-sections.

Unique features of the Proposed Scheme that could influence the assessment of effects from airborne noise include, for example, impact driven piling during the construction.

The frequency and duration over which temporary construction effects may occur

Where a qualifying effect is identified for a period exceeding one month, then the effect is considered to be a significant effect.

The effectiveness of mitigation through design or other means

Mitigation options are considered in respect of the following criteria:

- benefit (of noise reduction to stakeholders) compared to cost;
- engineering practicability;
- impacts on other environmental disciplines, including landscape and visual; and
- consultation and stakeholder engagement responses.

6 Quiet areas

'Quiet areas' are defined in the SMR as:

- areas designated under Local Plans as being prized for their tranquillity;
- areas designated under Local Plans or Neighbourhood Development Plans as Local Green Spaces; and
- areas identified as Quiet Areas through implementation of the Environmental Noise Regulations[40, 41].

Tranquillity assessment is multi-disciplinary and has been led for this ES by the landscape and visual team. The methodology employed is set out in the SMR and is centred on assessing tranquillity on designated Landscape Character Areas (LCA). As discussed in Volume 1, the sound, noise and vibration assessment has considered, on a case-by-case basis, each LCA that has been identified by the landscape and visual team as currently exhibiting high tranquillity. It is only when considering high tranquillity that the assessment methodology identifies sound, or more importantly the absence of man-made sound, as a potentially material consideration.

The assessment of effects has been undertaken at assessment locations that are representative of each quiet area identified. The results are reported in the relevant sound, noise and vibration assessment tables of the relevant Volume 5 appendices; however, evaluation of these impacts in terms of the tranquillity assessment is reported in the relevant Volume 5 appendices of the landscape and visual assessment.

The following sub-sections consider in turn the application of the six qualitative significance criteria set for quiet areas.

6.1 The type of effect being considered

For quiet areas, the types of potential effect considered in the ES arising from airborne noise and the code used to identify them in the assessment tables in the Volume 5 of the ES is: Deterioration of Acoustic Quality (code 'Q').

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[40] Environmental Noise (England) Regulations 2006 (SI 2006/2238). Available online at: https://www.legislation.gov.uk/uksi/2006/2238.

[41] Environmental Noise (England) (Amendment) Regulations 2009 (SI 2009/1610). Available online at: https://www.legislation.gov.uk/uksi/2009/1610.

6.2 Criteria set out in the Noise Action Plans in England for 'Quiet Areas'

Local authorities are responsible for identifying quiet areas. The location of Quiet Areas in each relevant local authority jurisdiction has been confirmed in discussion with each authority.

Identified Quiet Areas have been assessed using the criteria set out in either Local Plans or Neighbourhood Development Plans under the NPPF or the relevant Action Plan under the Environmental Noise Regulations. The criteria and assessments are set out in the relevant landscape and visual appendices.

6.3 Tranquillity indicators

As advised in the Government's NPPG, there are no precise rules, but for an area to be protected for its tranquillity it is likely to be relatively undisturbed by noise from human sources that undermine the intrinsic character of the area. Such areas are likely to be already valued for their tranquillity and are quite likely to be seen as special for other reasons, including their landscape. For this assessment, the term tranquillity is defined in the assessment of LCAs (through applying the general methodology set out in the landscape and visual section of the SMR (Section 15.5)).

As part of the dialogue with local authority Environmental Health Practitioners, the location of any areas in each relevant local authority jurisdiction identified by the authority as being 'prized' for their tranquillity has been confirmed.

Once identified, the effect of the sound level arising from the Proposed Scheme on the tranquillity for each LCA is assessed qualitatively using the sound change impact categories identified in the SMR.

The magnitude of any impact and the area of the LCA subject to the impact has been used to inform an assessment of the significance of the effect on tranquillity undertaken by the landscape and visual team.

6.4 Any unique features of the Proposed Scheme's sound or effects in the area being considered (which may require secondary acoustic indicators/criteria)

Any unique features are identified, in so far as is practicable, and described in the Volume 2 CA reports.

The assessment of any unique feature, including the consideration of secondary impact criteria, is presented in the relevant landscape and visual assessment CA report in Volume 5.

Unique features of the Proposed Scheme that could influence the assessment of effects from airborne sound and noise could include, for example:

- construction activities such as impact driven piling or others (as described in the relevant Volume 5 appendices); and
- existing sound features, for example, where the existing baseline environment in an area is subjectively very quiet, (substantially less than 50 daytime and/or 40 night-time) and the existing environment is characterised by little or no appreciable man made sound sources. Such environments are rare[34] (in the national context) and hence it is considered a unique feature. Specific assessment of any such environment calls on additional secondary criteria as required and as presented in the relevant Volume 5 appendix. Effects identified for such an environment will be effects on the unique feature as a resource.

6.5 The frequency and duration over which temporary construction effects may occur

A qualitative assessment has been undertaken of the potential impact of construction noise on identified quiet areas and LCA on a case-by-case basis.

The qualitative assessment establishes the likely presence of a significant noise effect based upon a range of factors including:

- the timing of the construction noise compared to the timing of typical usage of the LCA;
- the proportion of regularly used public rights of way (PRoW) within the LCA affected by construction noise including regular 'stopping points'; and
- the availability of other unaffected parts of the LCA for users during the relevant construction period.

6.6 The effectiveness of mitigation through design or other means

LCA are generally environmentally sensitive in many respects. Additional weight therefore is given to the adverse effects of noise mitigation on other environmental disciplines where the weighting applied is steered by the baseline tranquillity assessment undertaken by the landscape and visual team.

Annex B: Baseline

1 Assessment locations

The assessment of airborne sound and ground-borne sound and vibration significant effects for both construction and operation has been undertaken at assessment locations that are considered representative of a number of dwellings or other sensitive receptors.

Baseline assessment locations and measurement locations used in the baseline sound surveys are shown on the Map Series SV-02 (for operation) and Map Series SV-03 (for construction) contained within Volume 5, Sound, noise and vibration Map Book. These are labelled with an assessment location or measurement location reference code to enable cross-reference to each of the relevant Volume 5 appendices (Appendices SV-002).

The use of representative assessment locations in this manner means that the assessment covers all sensitive receptors, subject to the screening distances identified for airborne sound and ground-borne sound and vibration. Where a receptor has multiple uses, the assessment has been made based on the most sensitive use.

Building receptors potentially sensitive to sound or vibration were initially identified using Ordnance Survey (OS) Address Point data, which lists the postal addresses of all properties within the spatial scope of the study area. Using these data residential dwellings were identified, along with other sensitive non-residential building use categories.

Non-residential sensitive receptor categories considered for airborne sound and ground-borne sound and vibration are identified in Annex A, along with the relevant assessment criteria.

Engagement with stakeholders at community forums and with local and county authorities along the line of route have been used to identify any additional potentially sensitive receptors.

2 Local authority discussions

Discussions were held with environmental health practitioners from the relevant county and local authorities. These discussions included the following:

- selection of appropriate locations for sound and vibration assessments;
- baseline sound monitoring protocols and the selection of monitoring locations;
- identification of any areas designated under Local Plans as Local Green Spaces prized for their tranquillity, where the soundscape is deemed to be a significant factor;
- identification of quiet areas defined by (or to be defined by) the local authority through implementation of the Environmental Noise Regulations;
- identification of any new developments which should be considered as noise sensitive receptors; and
- review of baseline data.

3 Approach to data collection

3.1 Vibration

It has been assumed that there is no appreciable vibration baseline along the Proposed Scheme. In some areas this may not be the case, for example where receptors are located in close proximity to existing major railways or where non-residential receptors contain equipment which is particularly sensitive to vibration. Therefore, in general, no baseline vibration monitoring has been carried out.

Potential impacts arising from any ground-borne vibration generated by the construction or operation of the Proposed Scheme have therefore normally been assessed on a worst-case basis against specific thresholds, below which receptors will not be affected by vibration.

This approach will tend to overestimate the number and magnitude of impacts and effects. Consideration of measured existing baseline is likely to result in fewer or lower impacts being identified.

3.2 Airborne sound

Baseline sound levels have been established for each assessment location in order to characterise the existing baseline environment. The baseline information is a key part of the airborne sound assessments for both construction and operation of the Proposed Scheme.

Baseline sound levels have been established through a combination of sound monitoring and sound modelling. Modelling has been undertaken where existing sound levels at assessment locations are dominated by transport sources which can be reliably modelled. These levels have been verified using results from sound monitoring.

The following specific sound level indicators have been evaluated for each assessment location:

- 16 hour daytime A-weighted energy average sound level, $L_{pAeq,16hr\ (07:00\text{-}23:00)}$[42];
- 8 hour night-time A-weighted energy average sound level, $L_{pAeq,8hr\ (23:00\text{-}07:00)}$;
- night-time A-weighted arithmetic average sound level, $L_{pAmax,5min\ (23:00\text{-}07:00)}$; and
- night-time A-weighted highest sound level, $L_{pAFmax,5min\ (23:00\text{-}07:00)}$.

All baseline data are free-field sound pressure levels.

[42] The daytime ($L_{pAeq,12hr\ (07:00\text{-}19:00)}$) and evening ($L_{pAeq,4hr\ (19:00\text{-}19:00)}$) sound level used in the construction assessment is determined using the same process as defined for the 16 hour daytime.

3.3 Existing baseline sound modelling

Baseline sound levels have been predicted where existing sound levels at assessment locations are dominated by transport sources which can be reliably modelled.

Road traffic modelling has been undertaken using the Calculation of Road Traffic Noise[43] including the additional procedures described in the Design Manual for Roads and Bridges[5] (LA 111 from DMRB Volume 11). TRL Method 2[44] has been used to convert predictions of road traffic noise to $L_{pAeq,T}$ sound levels in the time periods required for the assessment. For roads with an 18 hour flow of less than 1,000 vehicles the methodology set out in the Noise Advisory Council measurement and prediction guide[45], for predicting road traffic noise has been used.

Railway noise modelling has been undertaken using the Calculation of Railway Noise [46] and the additional library of source terms published by DEFRA[47].

Modelled predictions assume downwind sound propagation. In order to account for the variation in wind directions that normally occur, a correction has been applied, adopting the methodology advocated within the Yamamoto study[48] on the effect of wind propagation on monitored sound levels.

3.4 Existing baseline sound measurement

Baseline monitoring has been carried out to establish representative sound levels at assessment locations as well as to verify the baseline sound model. Monitoring has comprised:

- long-term measurements – unattended measurements of several days' duration;
- short-term measurements – unattended measurements typically of 24 hours' duration, and attended measurements typically of several hours; and
- verification measurements – typically over a durations of three hours (attended) or 24 hours (unattended), to assist in verifying the baseline sound model.

[43] Department for Transport Welsh Office (1998), *Calculation of Road Traffic Noise*. London, Her Majesty's Stationary Office.

[44] Abbott, P.G. and Nelson, P.M. (2002), *Converting the UK Traffic Noise Index LA10, 18h to EU Noise Indices for Noise Mapping*, TRL Limited.

[45] The Noise Advisory Council (1978), *A guide to measurement and prediction of the equivalent continuous sound level Leq*. London, Her Majesty's Stationary Office.

[46] Department for Transport (1995), *Calculation of Railway Noise*.

[47] Department for the Environment, Food and Rural Affairs (2007), *Additional railway noise source terms for Calculation of Railway Noise 1995*. A report produced for Defra by AEAT.

[48] Yamamoto, K. (2010), *Road traffic noise prediction model 'ASJ RTN-Model 2008': Report of the Research Committee on Road Traffic Noise*, Acoustic Science and Technology, 31 (1), pp 2-55.

Monitoring has been carried out using Class 1 sound level meters located in free-field conditions where possible (i.e. at least 3.5m from acoustically hard, reflective surfaces). During monitoring, windshields have been used to minimise the effect of wind on the microphone.

Sound level measurements likely to have been affected by wind or rain have been discarded. Meteorological data from nearby weather stations were used to inform this process.

3.5 Future baseline

Construction

The assessment of noise from construction activities assumes a future baseline year of 2025. As a conservative assumption it has been assumed that no change in baseline sound levels will occur between the existing baseline (2018/19) and the future baseline year of 2025.

Operation

Changes in road and rail traffic between 2018/19 and 2038 may result in changes in baseline sound levels at receptors. For modelled transportation sources, future baseline sound levels (2038) have been predicted.

Roads in Important Areas identified in Defra's Noise Action Plan[49], likely to be resurfaced under future routine maintenance programmes, before the opening of the Proposed Scheme, are assumed, on a precautionary basis, to have a low noise thin surface in 2038. Following engagement with Highways England, it is assumed all trunk roads, except those that currently have a concrete surface, will be resurfaced with a low noise thin surface before the opening of the Proposed Scheme. Concrete surfaces have a high durability and are therefore replaced significantly less often. Assuming a low noise thin surface in the future 2038 baseline will result in a lower baseline, sound level than that predicted for other road surface types. Decreases will be larger for most other road surfaces. Decreasing the baseline will have the effect of increasing predicted adverse airborne noise effects during operation.

Airborne noise from railways in Important Areas identified in Defra's Noise Action Plan[49] is assumed, on a precautionary basis, to be controlled to a level of 65 dB $L_{Aeq,18h}$, where they are predicted to exceed this level. This is assumed to be the lowest level of airborne railway noise where mitigation would be considered within an Important Area, based upon the following, taken from the Defra's Noise Action Plan report: 'Nothing further needs to be done

[49] Department for the Environment, Food and Rural Affairs (2019), *Noise Action Plan: Roads*. Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/813666/noise-action-plan-2019-roads.pdf.

as the noise level at each dwelling in the Important Area is below 65 dB(A), $L_{Aeq,18h}$, ignoring the effect of reflection from the facade of the relevant dwelling'.

3.6 Methods used to derive baseline sound levels

A number of methods have been used to characterise existing baseline sound levels. Data for each assessment location have been coded to indicate how the data have been assigned and how the baseline sound level has been derived. These codes are shown for each assessment location in the relevant Volume 5 reports for each community area (Appendices SV-002).

There are four codes relating to the derivation of baseline sound levels, each of which has been given a number or letter, for the day and night-time periods:

- source of data, code reference 1 – 7;
- method of assigning data to assessment locations (including any corrections applied to data), code reference A – C;
- distance from measurement location to assessment location, code reference i – iii; and
- uncertainty associated with data at assessment locations, code reference a) – c).

Each of these codes is described in more detail in the sub-sections below. For each assessment location, a site-specific code has been generated comprising these four components.

At some assessment locations, it was appropriate to utilise a different data source for the daytime and night-time periods. Codes contained within brackets in Volume 5: Appendix SV-002-0MA01 to SV-002-0MA08 relate to the derivation of night-time baseline noise levels where they are different to the daytime levels.

Some examples of site specific codes are provided below.

Source of data, code reference 1 - 8

Baseline data have been derived using a number of methods or sources, as appropriate to define representative baseline sound conditions across the study area. These methods are described in Table B 1 below.

Table B 1: Methods and sources of data derivation

Code	$L_{pAeq,T}$	L_{pAFmax}
[code 1] Long-term measurement location	Long-term measurements were undertaken at representative locations typically for a period of around 7 days. The $L_{pAeq,T}$ baseline sound levels used in the operation and construction assessments have been derived based on the long-term measurements using the following process: • values of $L_{pAeq,5min}$ have been measured throughout the survey period; • values affected by adverse meteorological conditions, such as rainfall or high wind speeds, have been removed from the data set; • noise measurement data have been reviewed and excluded where they are likely to have been affected by extraneous sound sources which do not form part of the typical sound environment; and • energy averages have been calculated for the time periods relevant to the assessment.	For L_{pAFmax} sound levels, the following process has been followed: • the L_{pAFmax} indicator has been calculated as the arithmetic average of all calculated L_{pAFmax}, 5 min values during the night-time period; and • the maximum L_{pAFmax} indicator has been calculated as the maximum of all night-time L_{pAFmax}, 5 min values.
[code 2] Short-term measurement location	Measurements have been taken at a representative location, typically for a period of around 24 hours unattended or several hours attended. Short term measurements were typically selected in locations where predicted train noise from the Proposed Scheme is lower than the operational airborne noise effect threshold for a significant observed adverse affect level The short-term measurements have been used to define $L_{pAeq,T}$ sound levels for time periods relevant to the assessment using the same process as for the long-term measurement data.	As used for code 1
[code 3] Specific road traffic validated prediction	Road traffic sound predictions of the $L_{pAeq,T}$ sound levels for the time periods relevant to the assessment have been undertaken for assessment locations. Road traffic levels are checked for dominance[50] against rail traffic predictions (where available). Where necessary, models produced for these purposes have also been validated by means of measurements of sound levels.	Where $L_{pAeq,T}$ baseline sound levels have been derived by modelling noise, L_{pAFmax}, levels have been estimated based on the predicted sound level and sound levels from the relevant validation measurement.
[code 4] Specific rail traffic validated prediction	Rail traffic sound predictions of the $L_{pAeq,T}$ sound levels for the time periods relevant to the assessment have been undertaken for assessment locations. Rail traffic predictions are checked for dominance against road traffic predictions (where available). Where necessary, any model produced for these purposes has also been validated by means of measurements of sound levels.	As above

[50] Road traffic noise is deemed to be the dominant source of noise when it is 10dB higher than rail traffic noise.

Code	$L_{pAeq,T}$	L_{pAFmax}
[code 5] Specific combined road and rail traffic validated prediction	Where modelled road traffic and rail traffic levels are within 10dB of each other, the predicted sounds levels are combined by means of an energy summation to give combined predicted $L_{pAeq,T}$ sound levels for the time periods relevant to the assessment Where necessary, any model produced for these purposes has also been validated by means of measurements of sound levels.	As above
[code 6] Baseline levels adopted from nearby assessment location	Where there is an absence of suitable data, baseline levels have been taken from a nearby assessment location for which information has been attributed using code 1-5. This is generally in instances where modelled predictions are not considered representative or where access for monitoring could not be arranged.	
[code 7] Predictions from other sources (e.g. Defra noise maps)		As for code 3 above

Method of assigning data to assessment locations – code reference A - C

One or more of the following four approaches has been used when applying the derived baseline sound data to each assessment location.

Code A. Data from above source applied directly

Measured or predicted sound levels have been applied directly to the assessment location.

Code B. Correction applied based upon location of assessment location

Measured sound levels have been corrected to account for differences between the measurement location and assessment location.

Code C. Minimum level cut-off applied

A minimum likely baseline value has been applied where it has not been possible to derive a realistic sound level. Where any such cut-off has been applied, it is identified against the relevant assessment location in the baseline data presented in the relevant Volume 5 Appendices (SV-002).

Distance from assessment location to measurement location - code reference i - iii

Each assessment location has been attributed to one of the following categories according to the location of measurements from which data have been assigned.

- Code i. Data applied from a measurement/prediction at or very close to the assessment location;
- Code ii. Data applied from a local measurement location at a greater distance but noted to have equivalent acoustic climate; and
- Code iii. Data applied from a distant measurement location where sound levels would be expected to be similar.

Uncertainty - code reference a - c

Baseline sound levels for each assessment location have been given an overall rating of uncertainty, following the scale set out below.

- Code a. Data are considered highly representative of the prevailing sound climate;
- Code b. Data are considered representative of the prevailing sound climate, but uncertainties and/or variations in measured levels indicate that there may be a higher degree of uncertainty than for (a); and
- Code c. Data are considered to be an estimate of the sound climate due to assumptions made.

Examples of assessment location codes

For example, an assessment location coded as ‘1, A, i, a’, indicates that baseline sound levels for daytime and night-time have been allocated directly from a long-term measurement very near to the assessment with no corrections applied. Resulting uncertainty is considered to be classification 'a', i.e. data are considered highly representative of the prevailing sound climate.

An assessment location coded as ‘3, (4), A, b’, indicates that the baseline sound level for daytime is from a validated road traffic prediction and a validated rail traffic prediction for the night-time. Both predicted levels been applied directly to the assessment location (with no correction made for distance). Resulting uncertainty is considered to be classification 'b', i.e. data are considered to be an estimate of the sound climate due to assumptions made.

Annex C: Construction assessment methodology

1 Introduction

This annex presents further detail on the methodology employed to assess firstly ground-borne sound and vibration and secondly airborne noise generated by the construction of the Proposed Scheme.

2 Ground-borne sound and vibration

2.1 Assessment methodology

Temporary direct effects due to ground-borne sound and vibration could potentially be caused by significant construction activities such as tunnelling, using tunnel boring machines (TBM) and the supporting temporary construction railway, demolition, some types of piling and vibro-compaction. Temporary indirect effects may potentially arise from construction traffic on the existing road network.

In accordance with Section 18 of the SMR (see Volume 5, Appendix CT-001-00001), a quantitative assessment has been undertaken for all receptors within the following areas:

- residential and non-residential receptors (except as defined below) - whichever is the greater of either 85m from the nearest construction activity or the area within which impacts from ground-borne sound and/or vibration from the Proposed Scheme are forecast; and
- non-residential receptors/land uses where low ambient vibration or sound is critical to operations, for example, very sensitive laboratory equipment such as nanotechnology laboratories, sound recording/broadcast studios, large auditoria/theatres or concert halls – 200m from the nearest construction activity.

Building receptors potentially sensitive to vibration were initially identified using OS AddressPoint data, which lists the postal addresses of all properties within the spatial scope of the study area. For each residential receptor, an assessment location was defined which was considered representative of a number of dwellings.

Non-residential sensitive receptor categories considered for ground-borne sound and vibration are identified in Annex A of this document, along with the relevant assessment criteria.

Engagement with stakeholders at community forums and with local and county authorities along the line of route has been used to identify any additional potentially sensitive receptors.

Vibration – human response

The ground-borne vibration potentially generated by construction activities has been calculated using the guidance in Transport Research Laboratory (TRL) Report 429[51],

[51] Transport Research Laboratory (2007), *Transport Research Laboratory Report 429 - Groundborne vibration caused by mechanized construction works*.

TRL Report 53[52] and guidance in BS5228-2:2009 (+A1: 2014)[53]. These sources of guidance primarily define empirical prediction methods for various construction activities in terms of the resultant peak particle velocity (PPV).

Construction vibration levels considering human response have been predicted for a daytime (07:00 - 23:00 hours) and, if applicable, night-time (23:00 - 07:00 hours).

For perceptible vibration, predictions are required in terms of the vibration dose value (VDV) parameter, with the unit m/s$^{1.75}$ at the centre of the worst-affected floor. Consequently, the VDV has been estimated from the predicted PPV using the following equation[54]:

$$VDV_{free-field} = CF \times FF \times PPV \times t^{0.25}$$
$$FF = 2 \times \pi \times f \times W_b$$

- where 'CF' is the crest factor, 'FF' is the frequency factor, 't' is the time in seconds over which the PPV is expected during construction activities, 'f' is frequency and 'W_b' $^1/_3$ octave band weighting correction.

In the absence of any specific frequency information for the construction activity being assessed a frequency factor of 99.3 should be adopted. To ensure consistency across the ES assessment the following crest factors have been adopted:

- vibratory piling – crest factor = 4;
- tunnel boring machine – crest factor =4; and
- vibratory rollers – crest factor = 2.

Vibration – building damage

The ground-borne vibration potentially generated by construction activities has been calculated using the guidance in TRL Report 429, TRL Report 53 and guidance in BS5228. These sources of guidance primarily define empirical prediction methods for various construction activities in terms of the resultant PPV.

Construction vibration impacts on buildings have been predicted assuming the activity is on-going at the closest approach to the receptor. The predictions have been made using the PPV parameter with the unit mm/s at the foundation of the receptor.

[52] Transport Research Laboratory (1986), *Transport Research Laboratory Report 53 - Ground vibration caused by civil engineering works*.

[53] British Standards Institution (2009), *BS5228-2-2009 (+A1: 2014), Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration*.

[54] Based upon estimation provided in *'ANC Guidelines: Measurement and assessment of groundborne noise and vibration'*, corrected for W weighting b.

Indirect impacts

The indirect impacts of vibration from construction road traffic can potentially arise from two sources:

- ground-borne vibration produced by the movement of heavy vehicles over irregularities in the road surface; and
- airborne vibration arising from low frequency sound emitted by vehicle engines and exhausts.

A qualitative assessment of indirect impacts has been carried out route-wide (refer to Annex G).

2.2 Assumptions and limitations

Tunnel boring machine (TBM)

To excavate the tunnels TBM will be used, which can generate ground-borne noise and vibration as the rotating head of the TBM 'cuts' through the ground. TBM can therefore give rise to ground-borne noise and vibration impacts, albeit only for short periods of time (generally a matter of days) at any individual receptor.

The material cut away by the TBM (excavated material) is generally carried to the surface by conveyors, which in themselves generate no significant ground-borne noise or vibration outside of the tunnel. It has been assumed that materials (including tunnel lining segments), people and equipment will be transported from the surface to the TBM by temporary construction trains, which will travel at relatively low speeds. Other methods of material movement maybe employed; however, these will result in lower levels of ground-borne sound and vibration. It has also been assumed that where two TBMs are to be used to drive adjacent HS2 tunnels, the two drives will be staggered in time.

Ground-borne noise and vibration have been estimated using the prediction methodologies in TRL 429. Details of the outcome of the route-wide assessment are provided in Annex G.

Temporary construction railway

It has been assumed that materials (including tunnel lining segments), people and equipment are likely to be transported from the surface to the TBM using a temporary railway. It should be noted that other methods of moving material and people are available, but the temporary railway is the most likely and is also the method which represents a reasonably foreseeable worst-case in terms of ground-borne noise or vibration impacts. Supply trains can also be used to transport spoil from the TBM to the surface. This temporary railway can generate ground-borne noise and vibration in the same way as the permanent railway.

The trains and track used for these temporary operations are generally different from permanent rail systems.

It is not reasonably practicable for the temporary track laid for construction to provide the same level of ground-borne sound and vibration control as the permanent track laid for operation. Firstly, the temporary track needs to be installed quickly and in short rail lengths as the TBM advances. Secondly, the temporary track is at a different level and line than the permanent track as the concrete tunnel invert is not in place and cannot be put in place as the tunnel is bored. Thirdly, the temporary track doesn't have to be designed to the same standards as the permanent track, for example the permanent track has to remain safe for public operation and have low maintenance requirements over a long design period, e.g. 60 years.

Temporary track is therefore fundamentally different from permanent track and has to be installed and removed. The economics and sustainability of this process need to be considered and this often results in track components being recycled between tunnelling projects. Additionally, the rolling stock for the construction and permanent stages is very different, with the permanent railway incorporating more ground-borne sound and vibration control.

Details of the outcome of the route-wide assessment are provided in Annex G.

Vibro-compaction

Vibration from the use of rollers to compact material has been predicted for structural earthwork activities and ballast laying activities. The prediction method in BS5228-2:2009(+A1: 2014) for start-up and run down has been used to predict the worst-case PPV to assess the risk of building damage. For the assessment of annoyance, the steady state prediction method in BS5228-2:2009(+A1: 2014) has been used. The predictions are based on typical manufacturer's data for a range of sizes of vibratory rollers.

It is considered that the use of vibratory rollers for minor works, such as road surfacing, reinstatement after utility diversions etc. will generate perceptible vibration. However, as noted in the SMR 'the Phase One construction design and EIA showed that with due warning and the other mitigation measures committed to in the CoCP, they will not result in significant adverse effects due to the limited nature and short duration of such works'.

Piling

The majority of piling required to construct viaducts and bridges is bored piling, which is not a significant source of vibration. In some situations, other forms of piling (including vibratory, sheet or impact piling) are considered likely to be necessary. The relevant prediction method for the proposed type of piling as detailed in BS5228-2:2009(+A1: 2014) has been adopted.

Pneumatic breakers

Pneumatic breakers are commonly required to break up existing concrete structures during demolition works. The use of such equipment can generate perceptible vibration. However, any adverse effects are generally limited to receptors in very proximity of the equipment. As noted in the SMR, 'the Phase One construction design and EIA demonstrated that based on the limited extent and duration of such works, and with due warning and the other mitigation measures committed to in the CoCP, any adverse vibration effects are considered unlikely to be significant'.

Road traffic: ground-borne noise or vibration

Based on the commitment given in the CoCP that the surface of temporary and permanent access roads and temporary haul routes for the Proposed Scheme will be maintained through the construction of the Proposed Scheme, the effects of ground-borne noise or vibration from construction road traffic are not considered to be significant. The Phase One construction design and EIA demonstrated how any residual ground-borne noise or vibration effects can be mitigated by a CoCP.

Vibration: construction rail traffic

Changes to train movements on existing rail lines has the potential to affect vibration levels at receptors in very close proximity that are already subject to appreciable existing levels of vibration. The SMR identifies a 25% change in Vibration Dose Value (VDV) as the onset of minor impacts, which will require more than a doubling of the existing train movements. Construction related train movements on this scale are not currently anticipated, therefore, a more detailed quantitative assessment is not considered to be required.

3 Airborne sound

3.1 Assessment methodology

Direct impacts

Without mitigation, temporary direct impacts due to airborne sound may be caused by significant construction activities such as tunnelling, demolition, earthworks, viaducts, bridges, road realignments, station construction, utility works and track works. These activities will be supported from construction compounds close to the structure/tunnel being constructed, or larger worksites from where activities are coordinated.

In accordance with Section 18 of the SMR airborne sound arising from construction has been considered within the spatial scope of 300m from any construction activity or the area within which sound levels from the Proposed Scheme are predicted to give rise to potential impacts, whichever is the greater.

The assessment of noise from construction activities assumes a baseline year of 2025 which represents the period immediately prior to the start of the construction period.

The assessment of airborne sound impacts for construction has been undertaken at assessment locations that are considered representative of a given number of dwellings or other sensitive receptors. The use of representative assessment locations in this manner means that the assessment covers all sensitive receptors, subject to the screening distances identified. Where a receptor has multiple uses, the assessment has been made based on the most sensitive use.

Building receptors potentially sensitive to sound or vibration were initially identified using OS Address Point data, which lists the postal addresses of all properties within the spatial scope of the study area. Using these data, residential dwellings were identified along with other sensitive non-residential building use categories. Non-residential sensitive receptor categories considered for airborne sound are identified in Annex A of this document, along with the relevant assessment criteria.

Engagement with stakeholders at community forums and with local and county authorities along the line of route has been used to identify any additional potentially sensitive receptors.

The airborne sound generated by construction activities has been calculated using the method set out in BS5228-1: 2009 (+A1: 2014)[25], using suitable and verified sound prediction software. The influence of topography, ground type and shielding by barriers, buildings etc. has been taken into account.

Construction sound levels have been predicted as the average over a calendar month as an $L_{pAeq,T}$. The time periods for the predictions are as presented in the SMR (see also Annex A), depending on which time periods are relevant to the works proposed in the vicinity of each receptor. The predictions consider the variation in the programme and the working area for the period assessed.

The predictions are presented as façade levels relating to a position 1m from the building. The assessment considers noise on a month-by-month basis. Noise levels will vary day-to-day. Highest daily levels may sometimes be around five higher than the monthly level but could also be substantially lower on other days. Predictions at multiple floor buildings have been made at all floors, the results are presented for the worst-affected floor.

Indirect impacts

Indirect impacts of airborne sound could be caused by temporary changes to road or traffic patterns on the existing road network during construction. The assessment of noise from construction road or rail traffic assumes a baseline year representative of the period just before the commencement of construction. Further information can be found in the Transport Assessment Part 1, see Volume 5, Appendix TR-001-00000. A quantitative assessment has been completed for local and strategic roads in the vicinity of the scheme used for the movement of materials.

For roads with an 18-hour flow of 1,000 vehicles or more, the methodology set out within the Calculation of Road Traffic Noise (CRTN)[55] has been used to predict the change in sound level resulting from the change in road traffic sound due to indirect impacts associated with construction of the Proposed Scheme. For roads with an 18-hour flow of less than 1,000 vehicles the methodology set out in the Noise Advisory Council measurement and prediction guide[56] has been used.

For both prediction methods, the baseline and with construction traffic noise level has been predicted as a free-field $L_{pAeq,16hr}$ level at a reference distance of 10m from the kerb.

With regard to changes in rail traffic on existing lines, the assessment is based on the principles of the methodology set out within the Calculation of Rail Noise (CRN)[57] to determine the magnitude of the resulting change in rail noise along affected lines.

3.2 Assumptions and limitations

The Proposed Scheme has been split into a number of design elements including bored tunnels, green tunnel, viaducts, earthworks, embankments, cuttings, ventilation and intervention shafts, head houses, access roads, road/rail over/under bridges, depot and stabling facilities loading/unloading operations at road/rail heads and utility diversions.

[55] Department for Transport (1988), *Calculation of Road Traffic Noise*, HMSO.

[56] The Noise Advisory Council (1978), *A guide to measurement and prediction of the equivalent continuous sound level*.

[57] Department for Transport (1996), *Calculation of Rail Noise*, HMSO.

Associated works including works to the conventional rail network and road diversions are also included in the assessment.

Construction works and assumptions forming the basis of the assessment at a local level are presented in the relevant Volume 2 Community Area reports.

To ensure a consistent approach to site assumptions across the route, engineers have provided assumptions on a 'modular' basis using the design element types and where practicable, standard assumptions for use along the entire line of route. Construction assumptions for each of the main construction activities include:

- plant assumptions:
  - type of equipment;
  - number of equipment;
  - percentage on-times for relevant assessment time periods; and
  - activity working hours;
- material and equipment haul along the route;
- programme; and
- site plans illustrating working locations, compound locations and haul routes.

The assessment assumes the implementation of the principles and management processes set out in the draft CoCP (see Appendix 5, CT-002-00000) which are:

- best practicable means (BPM) as defined by the Control of Pollution Act, 1974 (CoPA) and Environmental Protection Act 1990 (EPA) will be applied during construction activities to minimise noise (including vibration) at neighbouring residential properties;
- as part of BPM, mitigation measures are applied in the following order:
  - noise and vibration control at source: for example, the selection of quiet and low vibration equipment, review of construction methodology to consider quieter methods, location of equipment on site, control of working hours, the provision of acoustic enclosures and the use of less intrusive alarms, such as broadband vehicle reversing warnings[58]; and then
  - screening: for example, local screening of equipment or perimeter hoarding;
- where, despite the implementation of BPM, the noise exposure exceeds the criteria defined in the draft CoCP, noise insulation or ultimately temporary re-housing will be offered in accordance with the draft CoCP's noise insulation and temporary re-housing policy;
- lead contractors will seek to obtain prior consent from the relevant local authority under Section 61 of CoPA for the proposed construction works. The consent application will set out BPM measures to minimise construction noise, including control of working hours,

[58] Warning signals that consist of bursts of white or pink noise, rather than traditional two-tone reversing sirens.

and provide a further assessment of construction noise and vibration including confirmation of noise insulation/temporary re-housing provision;

- contractors will undertake and report such monitoring as is necessary to assure and demonstrate compliance with all noise and vibration commitments;
- monitoring data will be provided regularly to and be reviewed by the nominated undertaker and will be made available to the local authorities; and
- contractors will be required to comply with the terms of the draft CoCP and appropriate action will be taken by the nominated undertaker as required to ensure compliance.

Track laying

Track laying, power system and signalling installation works move quickly along the route. They are therefore considered unlikely to result in significant construction noise effects, given the short duration in adjacent to any individual receptor or residential community area. Any adverse noise effects will be of short duration and will be controlled and reduced by the management processes set out in the CoCP. Hence any effects are therefore considered to be not significant.

Utilities

Current information on likely utility diversions is included within the construction noise predictions. The exact utility diversion requirements will be refined in conjunction with the various utility providers as the design progresses. However, the impact of changes to utility diversion works is likely to be limited (i.e. less than one month). Such works do not generally require large quantities of plant, are limited to the daytime and progress at a reasonably rapid rate, therefore the duration of the impact at any one receptor will be limited. Any adverse noise effects will be controlled and reduced by the management processes set out in the CoCP and hence the effects are therefore considered to be not significant.

Work during short-term road or rail possessions

It is anticipated that there may be some night-time working during works to cross or tie into existing roads and rail lines. In these situations, it is assumed that the duration of the night-time works will be limited. Any noise exposure will be short-term and will be controlled and reduced by the management processes set out in the CoCP. The effects are therefore considered to be not significant.

Annex D1: Operational assessment ground-borne noise and vibration

1 Assessment methodology

Permanent direct effects due to ground-borne noise and vibration could potentially be caused by the passage of high speed train services associated with the Proposed Scheme, and to a lesser extent other rail systems, such as depots. This section should be read in conjunction with Section 18 of the SMR (see Volume 5, Appendix CT-001-00001).

Without mitigation, vibration from the Proposed Scheme may propagate through the ground to surrounding buildings where it might result in the vibration of floors, walls and ceilings, which could also be heard as a low frequency 'rumbling' sound; the latter is referred to as ground-borne noise. For the operational railway, significant ground-borne noise and vibration effects will be reduced or avoided through, for example, the performance specification and design of the rolling stock and infrastructure (especially the track system). Mitigation measures are set out in Volume 1, Section 9 and the Volume 2, Community Area reports.

A quantitative assessment of ground-borne noise and vibration has been undertaken for all receptors within the following areas:

- residential and non-residential receptors (except as defined below) - whichever is the greater of either 85m from the centreline of the route or the area within which impacts from ground-borne noise and/or vibration are forecast; and
- non-residential receptors/land uses where low ambient vibration or sound is critical to operations, for example, very sensitive laboratory equipment such as nanotechnology laboratories, sound recording/broadcast studios, large auditoria/theatres or concert halls - 200m from the centreline of the route.

The effects of noise and vibration from operation of the Proposed Scheme have been assessed based on the train flows as described in Section 4 of this annex. Trains are expected to be mix of 200m and 400m long trains.

Building receptors potentially sensitive to vibration were initially identified using OS Address Point data, which lists the postal addresses of all properties within the spatial scope of the study area. For each residential receptor, an assessment location was defined which was considered representative of one or more dwelling(s).

Non-residential sensitive receptor categories considered for ground-borne noise and vibration are identified in Annex A of this document, along with the relevant assessment criteria.

2 Calculation methodology

The calculation procedures described in this section are used to support the assessment of ground-borne noise and vibration effects and potential effects upon the use of resources. Calculation procedures have been developed for the prediction of:

- perceptible vibration and ground-borne noise in buildings arising from trains on surface and green tunnel sections of railway; and
- perceptible vibration and ground-borne noise in buildings arising from trains using bored tunnelled sections of railway.

Calculation procedures for the Proposed Scheme are based upon the verified calculation methods that were developed for HS1[59]. The verified HS1 methods are empirical and were developed from over 3,000 measurements. The HS1 method has been further tested, validated and scrutinised at public inquiry on many urban mass transit systems around the world. For application to the Proposed Scheme the method has been further developed and verified to allow for assessment of vibration sources at speeds over 300kph (225mph).

Calculation procedures for the Proposed Scheme are consistent with ISO 14837[60] and take account of all key parameters, including train design, train speed, track design, tunnel design, tunnel depth, ground conditions, receiving building foundations and receiving building type.

The calculation procedures are summarised in the flow chart shown on Figure D1 1. A summary of the procedures follows. Specific characteristics of the individual calculation procedures are also provided in Table D1 1.

The calculation procedures generally consist of three stages as follows:

- source terms;
- propagation; and
- building response.

[59] Greer, R. J. (1999), *Methods for predicting ground-borne noise and vibration from trains in tunnels*, Proceedings of the LARIF and IoA Conference.

[60] International Standards Organization (ISO) (2005), *14837 Mechanical vibration – Ground-borne noise and vibration arising from rail systems – Part 1: General Guidance*.

Figure D1 1: Flow chart summary of the HS2 high speed rail ground-borne noise and vibration model

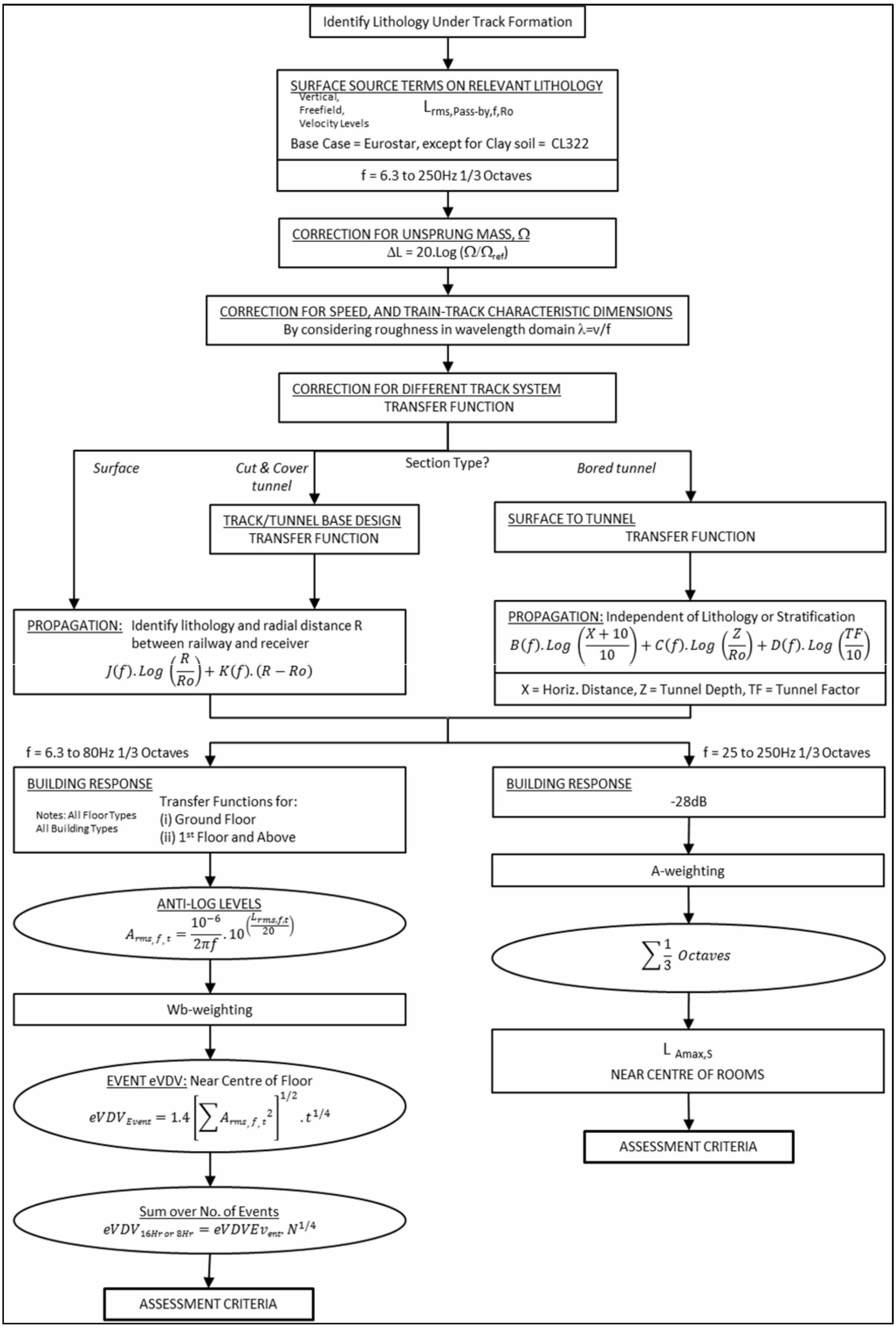


Table D1 1: Summary of individual elements of calculation procedure

Alignment	Surface and green tunnel		Bored tunnel	
Impact	**Perceptible vibration**	**Ground-borne noise**	**Perceptible vibration**	**Ground-borne noise**
Source term form	Vertical root mean squared (rms) particle velocity third octave bands 6.3-250Hz, 10m from track			
Source term derived from	Trains on ballasted track – surface sections: Eurostar (Class 373) on chalk, sand or sand and clay lithology or Stansted Express (Class 322) on clay lithology			
Adjustments	✓	✓	✓	✓
Train type				
Speed	✓	✓	✓	✓
Unsprung mass	✓	✓	✓	✓
Surface-tunnel	n/a	n/a	✓ *	✓ *
Track-form	✓	✓	✓	✓
Train length	✓	n/a	✓	n/a
Train flows	✓	n/a	✓	n/a
Propagation terms	Function of radial distance from rail head Lithology dependent		Function of tunnel depth, horizontal distance to track and tunnel form and width Lithology independent	
Propagation model derived from	Variety of trains in UK, France and Germany on ballasted track – surface sections		Variety of trains in tunnels in UK, France and Germany	
Building response	x4 from exterior to first floors (worst-case)	BBN/Kurzweil equation applied to free field levels	x4 from exterior to first floors (worst-case)	BBN/Kurzweil equation applied to free field levels
Level predicted	Daytime (07:00 - 23:00) and night-time (23:00 - 07:00) Vertical Vibration Dose Value (VDV) near the centre of the floor of the room	L_{pASmax} near the centre of the room due to the passage of a train	Daytime (07:00 - 23:00) and night-time (23:00 - 07:00) Vertical VDV near the centre of the floor of the room	L_{pASmax} near the centre of the room due to the passage of a train

** Assumes surface with continuously welded rail (CWR) on ballast to tunnel with CWR on unmitigated paved concrete track (PACT)*

2.1 Source terms

The source terms have been derived from measurements of vibration due to the passage of relevant rolling stock running on the surface on good quality ballast track in France and the UK. The source terms define the levels of vibration, 10m from the nearest rail, for each of the four generic classifications of lithology (sands, mixed sands and clays, and chalks) to be found along the alignment of the route. The source terms, L_{Source}, are expressed as root mean square particle velocity in one-third octave frequency bands, $ƒ$. The source terms used for the prediction of ground-borne noise and vibration for the Proposed Scheme are provided in Table D1 2.

The surface source terms are adjusted in level in by a factor ΔL in each one-third octave band frequency band to reflect the source levels of the high speed trains. ΔL is given by the following equation:

$$\Delta L(ƒ) = L_{Source}(ƒ) — \Delta IL(ƒ) + \Delta R_{eff}(ƒ, r, r_{Source}) + 20.\log(\Omega/\Omega_{Source})$$

The terms to the right of the equation are described in more detail below.

Track-form correction - ΔIL(f)

The track-form correction corresponds to the difference between the vibration insertion loss, IL, of the reference track-form of the source term and the proposed track-forms. The reference track-forms for each source term are provided in Table D1 3.

The insertion loss of a track system is a measure of the change in ground-borne vibration at 10m the track that will occur if one track system was replaced with another. The vibration insertion losses used in the calculations for the Proposed Scheme are provided in Table D1 3. These insertion losses have been expressed in decibels with reference to a hypothetical 'highly' stiff reference track.

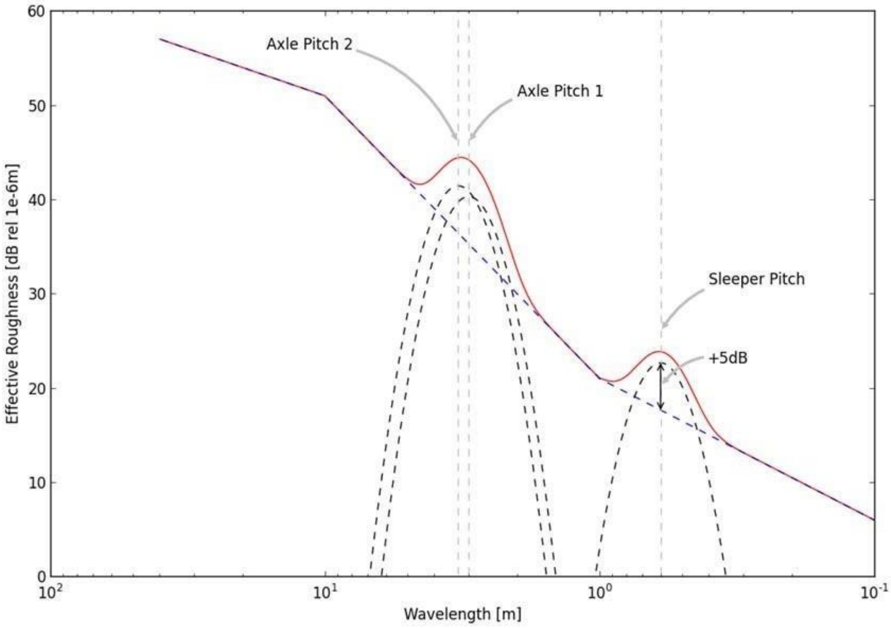
Speed correction - $\Delta R_{eff}(ƒ, r, r_{Source})$

The speed/track-form correction in the HS1 calculation procedures has been revised to allow for trains travelling at speed above 300kph. The revised module is based on the assumption that the vibration spectrum measured 10m from the rail and the effective roughness of the wheels and rail are directly related. The speed correction is required to account for differences in the following parameters between the source term train/track and the proposed high speed trains/track:

- the spacing between sleepers or rail fastening;
- the spacing between axles on a train; and
- the change in the dynamic forces generated by the combined surface roughness of the rails and train wheels when the speed is changed.

In the calculation procedures for the Proposed Scheme, these differences are accounted for with a forcing function that is fixed in wavelength. This function has been termed the effective roughness R_{eff}. The effective roughness is defined from the combination of a curve that represents the combined roughness of the wheels and rails and curves to represent parametric excitation from the passage of sleepers and axles. An example curve representing the roughness of the wheels and rails is presented in Figure D1 2. The curves used to predict ground-borne noise and vibration for the Proposed Scheme are given numerically in Table D1 4. The curves representing the parametric excitation from sleepers and axles are super-imposed on to the term representing wheel-rail roughness to give the term R_{eff}.

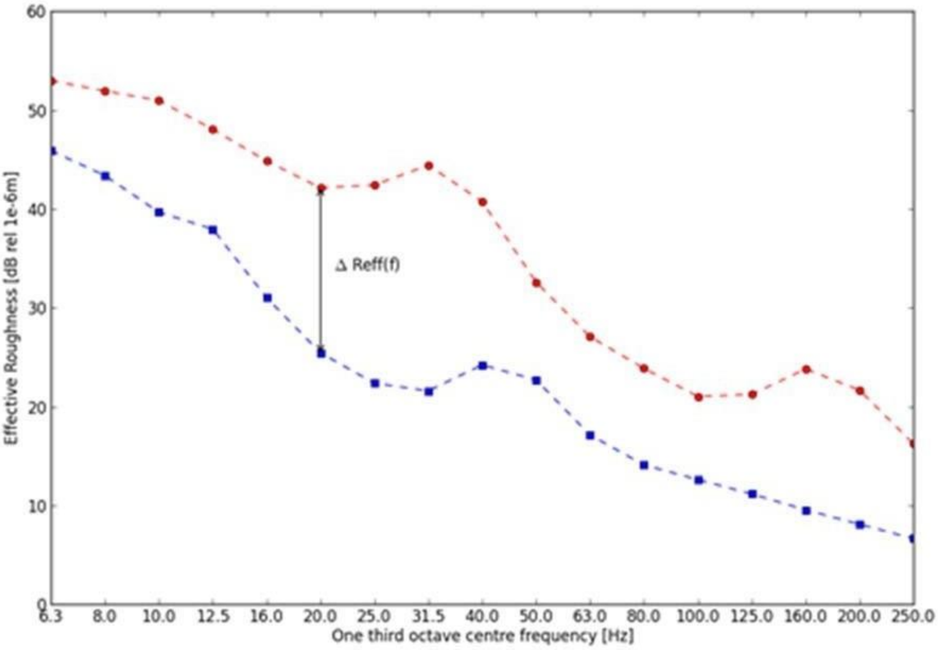
Figure D1 2: Effective Roughness (R_{eff})



In Figure D1 2, the combined roughness of wheels and rails is denoted by the light blue checked line. Parametric excitation from axles is denoted by the dark blue checked line. The effective roughness term used in the speed correction is denoted by the red line.

The effective roughness is defined in each frequency band, f, for the source train travelling a speed r_{Source} and for the high speed trains travelling at speed r. The source term is then corrected by the difference between the two effective roughness terms. This is presented in Figure D1 3.

Figure D1 3: Example of ΔR_{eff} calculated from the effective roughness of a Stansted Express (Class 322) travelling at 100kph (blue line); and high speed train travelling at 320kph (red line)



The reference roughness levels for the source terms and for the track-form were not available. Generic roughness levels have been derived from a known rail roughness that is representative of high speed ballast track. For wavelengths less than 1m the combined wheel-rail roughness spectrum has been derived from the combination of a roughness spectrum measured on ballast track on a high speed railway in Italy[61] and measurements of wheel roughness on disc-braked wheels[62]. For longer wavelengths roughness measured with Network Rail's New Measurement Train on ballast track on HS1 was used to derive the shape of the roughness term. To represent slab track on the Proposed Scheme the same roughness has been used for wavelengths less than 1m while at long wavelengths roughness measurements made on tunnelled slab track on HS1 have been used. The levels are provided in Table D1 4 and Table D1 5.

Unsprung correction - 20. log(Ω/Ω_{Source})

The unsprung mass of a train is defined as the mass of the wheels, axles and any equipment mounted on the axles. The dynamic forces generated at the wheel - rail interface during the passage of a train are proportional to the unsprung mass. In the calculation procedures for the Proposed Scheme the unsprung mass source level is corrected according to the relationship shown above, where Ω is the average unsprung mass per axle of the proposed high speed train and Ω_{Source} is the average unsprung mass per axle of the source term train.

[61] Grassie, S. L. (2012), *Rail irregularities, corrugation and acoustic roughness: characteristics, significance and effects of reprofiling*, Journal of Rail and Rapid Transit, 226 (5).

[62] Squicciarini, G. et al. (2013), *Statistical description of wheel roughness*, Proceedings of the 11th IWRN, Uddevalla, Sweden.

The HS1 calculation procedures included an overall mass correction in addition to the unsprung mass correction. The frequency bands where the two corrections were applied were defined by the secondary suspension natural frequency. In modern trains this natural frequency is very low. Consequently, the unsprung mass correction has been applied to all frequency bands and no overall mass correction has been applied.

2.2 Propagation

Vibration from surface and green tunnelled section of railway

The propagation model for the prediction of ground-borne noise from surface and green tunnelled sections of railway has been derived from the analysis of vibration due to the passage of TGV (Train à Grande Vitesse) and other trains on surface sections of ballasted track in France and the UK. The calculation procedure contains terms for both geometric dispersion of vibration and absorption by the medium. The attenuation terms are governed by the nature of the main sub-surface lithological layer between the receiver and railway and are provided in Table D1 6.

Vibration from bored tunnelled sections of railway

The propagation model for ground-borne noise and vibration bored from tunnelled sections of railway has been derived from a statistical analysis of the results of measurements of ground-borne noise and vibration from a variety of train types in tunnels both in the UK and France. Separate aspects of the transmission path are addressed by three specific terms to account for:

- absorption and geometric dispersion of the bulk waves from tunnel to surface (a function of depth from railhead to surface);
- absorption and dispersion of the surface wave (a function of horizontal distance from tunnel centre); and
- the effect of tunnel width.

Analysis of the available data for ground-borne noise from trains in bored tunnels indicated that differences in lithology do not have a major influence upon the propagation characteristics. The term for the calculation of propagation losses is accordingly lithology independent and is presented in Table D1 7.

2.3 Building response

Ground-borne noise

Ground-borne noise levels (L_{pASmax}) near the centre of ground floor and basement rooms are calculated from rms third octave band vertical particle velocities (evaluated for the period whilst a train is passing) outside the building of interest. The conversion to internal ground-borne noise levels is based on the equation proposed by Bolt Beranek and Newman (BBN)/Kurzweil[63], validated and adjusted through an analysis of measurements carried out during validated and adjusted through an analysis of measurements carried out during a collaborative study between British Rail and London Underground Limited (LUL)[64].

Perceptible vibration

Analysis of measurements of vibration from trains carried out during the collaborative study between British Rail and LUL indicated that vertical VDVs measured near the centre of wooden floors of ground floor rooms in brick-built residential properties are twice those measured on the ground immediately outside the property of interest. The vertical VDV values for the first floor were found to be around four times the level measured on the ground immediately outside the property of interest. The analysis of building response in the collaborative study was limited to brick-built residential properties with wooden floors and strip foundations.

The application of this approach to other building construction types is considered to be cautious, i.e. result in worst-case estimates of vibration levels. Therefore, for the purpose of assessment at all residential properties, vibration levels on the first floor and above due to the passage of trains, are considered to be four times the vibration level immediately outside the property. For assessment at non-residential properties, the same approach has been applied where the building construction is unknown, again based on a worst-case estimate of vibration levels. Where the building construction is known to include concrete floors, appropriate spectral building corrections from the Transport Noise Reference Book[65] have been applied to calculation vibration on first floor and above. These building response factors are considered to be more representative for known concrete building constructions.

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[63] Wilson Ihrig and Associates (1983), *State of the Art Review: Prediction and Control of Ground borne Noise and Vibration from Rail Transit Trains*, Final Report, UMTA-MA-06-0049-84-4, DOT-TSC-UMTA-83-3.

[64] Greer, R. J. (1993), *Methodology for the Prediction of Re-radiated Noise in Residential Buildings from Trains Travelling in Tunnels*, Proceedings of Internoise.

[65] Nelson, P. M. (1987), *Transportation Noise Reference Book*, Butterworth.

Table D1 2: Vertical V_{rms} surface source terms (dB re. 1e-6 mm/s, defined over pass-by period)

Train Type (Lithology)	Reference			One-third octave centre frequency [Hz]																
	Speed (kp/h)	Distance (m)	Track	6.3	8	10	12	15	20	25	31.5	40	50	63	80	100	125	160	200	250
Eurostar (sand)	268	10	SNCF Ballast	74.5	88.4	89.1	93.8	102.3	106.0	108.7	104.7	101.0	105.7	98.2	93.9	81.2	75.3	-	-	-
Eurostar (sand and clay	250	10	SNCF Ballast	85.6	86.0	83.4	87.3	89.5	106.2	101.7	108.6	107.3	106.1	103.1	94.6	84.2	79.7	72.0	-	-
Eurostar (Chalk)	285	10	SNCF Ballast	69.0	78.2	74.2	75.9	85.8	93.6	98.9	96.6	91.2	96.0	93.2	92.3	87.0	87.7	77.6	66.7	59.2
CL322 (Clay)	100	10	BR Ballast	54.8	68.3	76.1	76.6	76.5	82.5	86.1	90.2	92.2	91.1	80.2	73.3	67.1	61.5	62.3	54.7	46.9

Table D1 3: One-third octave band insertion losses for source term reference and high-speed rail track systems

Track	Sleeper spacing	One-third octave centre frequency [Hz]																
		6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250
SNCF Ballast	0.55m	0.0	0.0	-0.1	-0.2	-0.5	-1.1	-2.3	-4.1	-6.0	-7.5	-8.6	-10.3	-9.5	-5.5	2.1	5.1	17.5
BR Ballast	0.65m	0.0	-0.1	-0.2	-0.7	-1.5	-3.0	-6.0	-10.0	-10.0	-7.8	-4.7	-0.6	4.6	9.6	5.3	3.8	3.8
Base case track	0.6m	-0.6	-0.5	-0.4	-0.5	-0.8	-1.2	-2.0	-3.3	-6.0	-10.2	-8.7	0.0	6.3	11.5	16.6	21.5	32.1

Table D1 4: Effective roughness – reference train

Wavelength [m]	25	20	16	12.5	10	8	6.3	5	4	3.15	25	2	1.6	1.25	1	0.8	0.63	0.5
Levels [dB re 1e-9m]	49.7	48.8	43.8	46.5	46.4	48.7	45.8	43.1	40.3	36.1	34.9	31.5	21	17.6	16.9	16.7	14.1	6.7
Wavelength [m]	**0.4**	**0.315**	**0.25**	**0.2**	**0.16**	**0.125**	**0.1**	**0.08**	**0.063**	**0.05**	**0.04**	**0.0315**	**0.025**	**0.02**	**0.016**	**0.0125**	**0.01**	**-**
Levels [dB re 1e-9m]	5.6	3.5	3	3.7	0.9	5.2	1.9	-2.0	-0.1	-3.3	-3.7	-7.3	-8.1	-8.3	-9.1	-9.4	-10.1	-

Table D1 5: Effective roughness – Proposed Scheme train

Wavelength [m]	25	20	16	12.5	10	8	6.3	5	4	3.15	25	2	1.6	1.25	1	0.8	0.63	0.5
Levels [dB re 1e-9m]	43.9	45.2	43.6	42.5	43.2	43.6	42.4	40.3	36.2	33.1	30.8	28.2	21	17.6	16.9	16.7	14.1	6.7
Wavelength [m]	**0.4**	**0.315**	**0.25**	**0.2**	**0.16**	**0.125**	**0.1**	**0.08**	**0.063**	**0.05**	**0.04**	**0.0315**	**0.025**	**0.02**	**0.016**	**0.0125**	**0.01**	**-**
Levels [dB re 1e-9m]	5.6	3.5	3	3.7	0.9	5.2	1.9	-2.0	-0.1	-3.3	-3.7	-7.3	-8.1	-8.3	-9.1	-9.4	-10.1	-

Table D1 6: One-third octave band surface – bored tunnel transfer function

Transfer function	One-third octave centre frequency [Hz]																
	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250
Surface - bored tunnel	-18.2	-12.7	-15.5	-19.7	-18.9	-29.1	-26.8	-15.3	-6.0	-3.1	2.0	6.4	6.5	3.2	-3.1	-8.7	-7.4

Table D1 7: Vibration propagation terms for surface and green tunnel sections

Soil	Coefficient	One-third octave centre frequency [Hz]																
		6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250
Chalk	J	2.5	-2.5	-0.6	3.0	2.5	-8.1	-7.3	-9.6	-21.4	-29.4	-26.6	-28.5	-32.1	-38.9	-40.3	-	-
	K	-0.14	-0.09	-0.11	-0.15	-0.16	-0.1	-0.19	-0.22	-0.06	0	-0.02	0	0	0	0	0	0
Sand	J	-4.2	-9.3	-16	-11	-9.9	-8.7	-24.1	-26.4	-32.1	-29.4	-34.2	-26.8	-22.3	-17.9	0	0	0
	K	-0.02	0.02	0.03	-0.02	-0.06	-0.17	-0.02	0	0	-0.05	0	0	0	0	0	0	0
Sand and Clay	J	-6.6	6	8	6.4	15.3	-14.1	-8	-48.8	-37.8	-38.1	-42.8	-34.8	-31.6	-25	-29.6	0	0
	K	-0.14	-0.21	-0.25	-0.28	-0.42	-0.22	-0.26	0	-0.09	-0.06	0	0	0	0	0	0	0
Clay	J	-9.53	-9.53	-9.53	-9.53	-9.53	-9.53	-28.6	-38	-37.5	-25.4	-42.8	-34.8	-31.6	-25	-29.6	0	0
	K	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	0	0	0	0	0	0	0	0	0	0	0

Propagation model for frequency f, = J(f). Log10 (R/10)+K(f) (R-10), where R is radial distance from track (m)

Table D1 8: Transfer function between green tunnels with earthen base and concrete slab base

Propagation coefficient	One-third octave centre frequency [Hz]																
	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250
B	-9.0	-12.8	-13.7	-12.8	-12.0	-12.3	-5.6	-169.0	-21.3	-19.4	-20.4	-22.3	-20.6	-18.1	-14.2	-5.7	-3.1
C	-22.1	-24.4	-16.0	-7.2	-12.0	-9.0	0.0	-13.7	-26.1	-16.7	-15.0	-19.2	-23.4	-16.9	-6.1	-1.0	-10.0
D	-52.8	-36.6	-45.7	-50.0	-47.4	-78.2	-76.1	-63.2	-27.5	-27.1	-10.9	20.6	13.4	-7.4	-48.2	-72.9	-87.7

Propagation model for frequency f, = B(f). Log10 ((X+10)/10)+C(f) Log10 (Z/10)+D(f) Log10 (TW/10), where X is horizontal distance (m), Z and TW are tunnel depth and width, respectively(m)

2.4 Accuracy of the procedures

An indication of the accuracy of the ground-borne noise and vibration procedures for bored tunnels is shown in Figure D1 4 and Figure D1 5 respectively. These figures show the results of the calculation procedures plotted against measured, or in the case of ground-borne noise pseudo-measured, values (pseudo-measured ground-borne noise values are calculated by applying the ground-borne noise building response function to measured vibration values). A perfect model will result in all points on these graphs lying upon a diagonal line (i.e. predicted = measured). However, it can be seen that there is considerable inter-site and inter-train variability so the measured results alone exhibit a degree of scatter.

Figure D1 4 compares three datasets and two prediction methods. The monochrome symbols are the prediction-measurement pairs used to demonstrate the accuracy of the original HS1 procedures in the 1990s. The dataset includes measurements from LUL, Deutsche Bahn ICE trains in Germany, SNCF TGV in France and intercity trains on the East Coast Mainline (ECML) in the UK. In addition to presenting the scatter plots a straight line regression to fit the original dataset is presented to enable inferences to be drawn with regard to trends in prediction errors. The slopes of these regressions are less than 1 implying that the calculation procedures tend to overestimate low levels (which may occur relatively distant from the track). At the time, the models were adjusted to ensure that they were most accurate in the critical ranges (i.e. around the levels used in the impact criteria).

The figure also shows prediction-measurement pairs (also using the original HS1 procedures) for three railway schemes constructed after the procedures were developed. The datasets include measurements from Metropolitan Rapid Transit (MRT), Singapore, Manchester MetroLink and Tangara Trains, Sydney, Australia. The prediction accuracy for these schemes fall within the expected accuracy of the prediction method.

Figure D1 4 also shows prediction measurement pairs for trains operating on the HS1 in 2012. This time the predictions have been made using the calculation procedures for the Proposed Scheme described here. The datasets include measurements made above the HS1 London Tunnels at Islington and Hackney and measurements made above the North Downs Tunnel. Again, the data falls within the expected limits for accuracy of the original procedures.

Figure D1 4: Accuracy of the Proposed Scheme ground-borne noise procedures compared to the accuracy of the original HS1 procedures

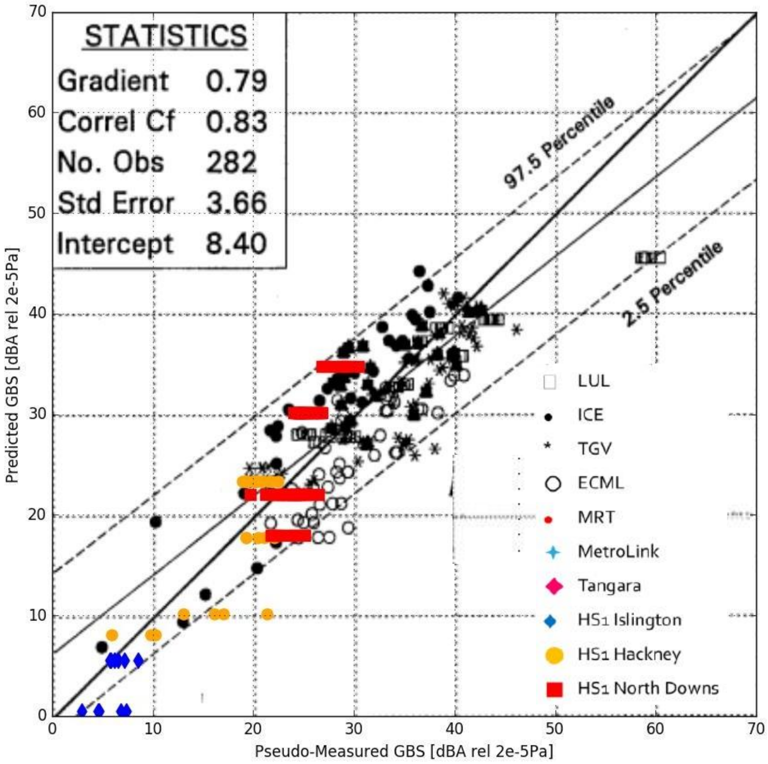
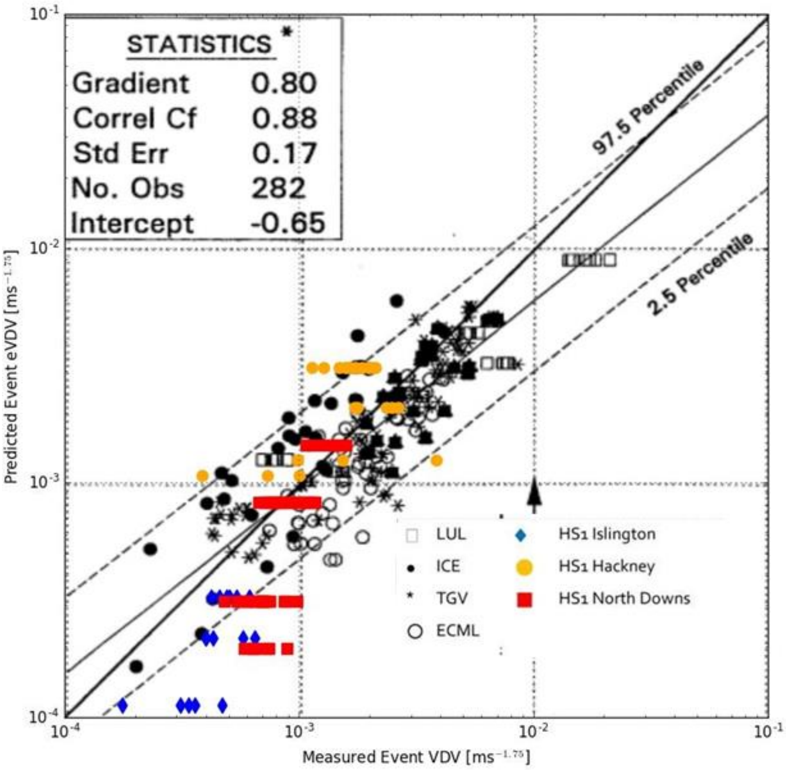


Figure D1 5 shows the equivalent results for the calculation procedures for perceptible vibration. Again, the monochrome prediction measurement pairs were used to verify the HS1 prediction method. The perceptible vibration data for MRT, Metrolink and Tangara were not available. The prediction measurement pairs for data obtained on the HS1 and predicted with the HS2 method are also shown.

Figure D1 5: Accuracy of the Proposed Scheme ground-borne vibration procedures compared to the accuracy of the original HS1 procedures



3 Assumptions and limitations

The assessment procedures have assumed that the level of operational train vibration transmitted to the ground along sections of HS2 on viaduct will be negligible.

As described above, adjustments are made to the source term to account for the type of track systems proposed for the Proposed Scheme. Standard slab track is assumed for all surface sections. A resilient track system is assumed in the Manchester Tunnel. On a precautionary basis, standard slab track is assumed in Crewe Tunnel as known resilient track systems are not currently proven to be effective or safe for train speeds through the tunnel.

The calculation procedures use the vertical component of vibration only. Ground vibration is a three-dimensional phenomenon and is more fully described by three orthogonal components. However, the ground-borne noise model is a prediction of ground-borne noise level based on a correlation between ground-borne noise and vertical vibration, so there is no need to consider the other components of vibration in this context. The vertical component of vibration is considered to be adequate for the prediction of perceptible vibration effects upon the use of resources because:

- in general, people and equipment potentially affected by vibration are floor-standing or seated and, generally (and particularly in low or medium-rise buildings and at the frequencies of interest), vertical vibration is the dominant component of floor vibration; and
- in the frequency range associated with perceptible vibration from trains, people are most sensitive to vibration in the vertical (feet to head) direction.

4 Train flows

The assessment of operational sound, noise and vibration from rail sources associated with the Proposed Scheme are based upon the train flows presented in Volume 1, Section 8. In addition to the HS2 train services, these flows include Northern Powerhouse Rail services which are anticipated to operate on the Proposed Scheme.

In the event that the Northern Powerhouse Rail services do not use the Proposed Scheme, it is envisaged that HS2 only services would include train flows as described in the Volume 1, Section 4.3. This scenario includes the fewer trains operating on some parts of the Proposed Scheme. An assessment has been undertaken to determine the potential changes in likely significant effects and mitigation as a result of these reductions. The alternative flows described would not result in any change to the assessment of likely significant effects due to ground-borne noise and vibration.

Annex D2: Operational assessment airborne sound

1 Assessment methodology

During operation, permanent direct effects due to airborne sound could be generated by the operational railway and its supporting systems (e.g. stations/interchanges, rolling stock and infrastructure maintenance depots (IMD), vent shafts, and other line side equipment). The Proposed Scheme may also cause long term changes in road and rail traffic patterns on the existing road and rail networks - these are considered as indirect effects.

The spatial scope for the direct effects of operational airborne sound assumes a screening distance of 500m or 1,000m from the centreline of the line of route of the Proposed Scheme in urban and rural areas, respectively, or the area within which sound levels from the Proposed Scheme are forecast to give rise to potential impacts, whichever is greater.

The effects of operational airborne sound arising from the Proposed Scheme have been assessed on the basis of the highest likely train flows within the first 15 years of operation, including the Phase Two services, where this results in higher noise levels than the operation of Phase One services only. The assessment considers the baseline anticipated at Year of Opening (2038) in the absence of the Proposed Scheme.

The assessment of airborne sound impacts for operation has been undertaken at assessment locations that are considered representative of a number of dwellings or other sensitive receptors.

The use of representative assessment locations in this manner means that the assessment covers all sensitive receptors, subject to the screening distances identified. Where a receptor has multiple uses, the assessment has been made based on the most sensitive use.

Building receptors potentially sensitive to sound or vibration were initially identified using OS Address Point data, which lists the postal addresses of all properties within the spatial scope of the study area. Using these data residential dwellings were identified, along with other sensitive non-residential building use categories.

Non-residential sensitive receptor categories considered for airborne sound are identified in Annex A, along with the relevant assessment criteria.

Engagement with stakeholders at community forums and with local and county authorities along the line of route have been used to identify any additional potentially sensitive receptors.

2 Operational railway sound - implementation

In order to evaluate the potential direct impacts of sound emissions from railway rolling stock operating on the HS2 infrastructure proprietary environmental acoustic modelling software (NoiseMap) has been used. The software directly implements the HS1 method for prediction of airborne railway sound which forms the basis of the adopted prediction methodology (as detailed in the following section), and each of the source terms have been defined for the rolling stock anticipated to operate on the infrastructure of the Proposed Scheme. The same methodology was adopted for the assessments presented in the HS2 Phase One and HS2 Phase 2a Environmental Statements (ES).

A 3-dimensional model of the study area has been created, incorporating geo-referenced topographical features such as terrain contours, building outlines and other structures that might screen or reflect noise, ground cover types, source lines etc.

Where available, the Digital Terrain Model (DTM) implemented in the software has been based upon LiDAR data obtained by the HS2 Ltd, subsequently re-sampled to a horizontal resolution of 1m and a vertical resolution of 0.2m. Outside of the corridor along the route for which this information is available the DTM has been based upon Geostore data at a 5m grid.

Building heights have been derived from the LiDAR data. Where Geostore data has been used to define the DTM it is assumed that buildings comprise two storeys, extending to a height of 8m above the ground plane.

The route alignment, engineering earthworks, noise barriers and other features of the Proposed Scheme have been imported directly from models provided by the engineering design teams. In addition, speed profiles along the entire line of route have been defined for each of the HS2 service stopping scenarios, based upon data provided by the railway systems engineers.

The acoustic model has then been used to predict the resultant free-field sound level due to the Proposed Scheme at each of the identified assessment locations. As described, the assessment of operational airborne sound has been undertaken at assessment locations that are considered representative of one or more dwellings or other noise sensitive receptors. Predictions have been made at each storey of a building (assuming a ground floor receptor height of 1.5m and a further 2.5m for each additional storey) and the highest resultant sound level taken to represent the assessment location.

The results of the acoustic modelling have subsequently been exported to a Geographical Information System (GIS) to provide resultant free-field sound pressure levels for the Proposed Scheme at each of the identified assessment locations for each of the parameters considered within the assessment i.e. $L_{pAeq,16hr}$, $L_{pAeq,8hr}$ and L_{pAFmax}.

These data have then been combined with the baseline and other ancillary data to populate the impact and effect tables for each community area Volume 5 Sound, noise and vibration operation assessment appendix (Appendices SV-003).

3 Assumptions and limitations

3.1 Operational assumptions

Train flows

The effects of operational airborne sound arising from train services on the Proposed Scheme have been assessed in the long term on the basis of the maximum service patterns within the first 15 years of operation. The assessment considers the baseline anticipated at Year of Opening (2038) in the absence of the Proposed Scheme.

For the purposes of the sound, noise and vibration assessment assumptions regarding train flows have therefore been developed for each of the following:

- Proposed Scheme at Year 15 with HS2 services only; and
- Proposed Scheme at Year 15 with HS2 services and Northern Powerhouse Rail services.

A simplified representation of these assumptions is presented in Volume 1[3].

The foregoing passenger services comprise train rakes of various lengths and compositions, including individual 200m units, coupled 200m units, and 400m trains. The service patterns have therefore been converted into equivalent numbers of 200m trains for use as the input to the modelling i.e. a 400m train is equivalent to two 200m trains.

At night, there will be regular line inspections and planned maintenance work at some locations along the route. It is assumed that at any one location on the route maintenance is likely to be very occasional. Given the irregularity of the activity and short duration at any one location, maintenance work is considered unlikely to give rise to significant noise or vibration effects.

A small number of diesel-powered specialist engineering trains will travel on most nights from the Infrastructure Maintenance Depot (IMD) to either inspect the line or to a location of planned maintenance. It is assumed that planned maintenance movements are likely to leave the IMD as soon as possible after passenger services finish at 24:00 and return to the IMD shortly before passenger services start again at 05:00.

Train speed

Trains on the Proposed Scheme will operate at up to 360kph (225mph)[66]. However, the alignment of the route has been designed to allow for train speeds of up to 400kph (248mph) in the future where there is a commercial justification for doing so. Operation at up to 400kph will require demonstration that improved train design enables services to

[66] Timetables are likely to use 330kph as a basis for most trains (assumed 90% of services), and 360kph for 10% of services.

operate at that higher speed without giving rise to additional significant environmental effects.

The operating speeds over each section of the route are anticipated to be as follows:

- up to 360kph on the between the interface with Phase 2a and Hoo Green Junction;
- decreasing from 360kph to 180kph from Hoo Green Junction to the West Coast Mainline (WCML) connection at Bamfurlong; and
- up to 230kph on the spur to Manchester Piccadilly Station.

In the absence of speed profiles for maintenance vehicles, an assumption is made that their operation could potentially be at 100kph along the whole length of route.

Rolling stock and track

At the environmental impact assessment stage for HS2 Phase One and Phase 2a, it was assumed that as HS2 was being designed under the Interoperability Directive, sound emissions from all rolling stock running on HS2 infrastructure will need to satisfy the limits specified in the rolling stock technical specification for interoperability (TSI) of the trans-European high-speed rail system[67]. Following the UK's exit from the European Union the same sound emission limits from rolling stock as specified in the TSI, have been transferred to a National Technical Specification Notice (NTSN) - Rolling Stock – Noise (NOI)[68].

It is assumed that the HS2 Phase 2b Proposed Scheme will be used by the following types of service:

- HS2 services operating on high speed infrastructure only will use standard European-sized high speed trains (referred to as 'captive' (CP) trains);
- HS2 services running on high speed and existing rail infrastructure will use specially designed high speed trains that are also capable of running on the existing UK rail network (referred to as 'conventional compatible' (CC) trains); and
- Northern Powerhouse Rail services.

It has been assumed that HS2 trains will be specified to be quieter than the relevant current European Union and NTSN requirements and this will include reduction of aerodynamic noise from the pantograph that will occur above 300kph (186mph) with current European pantograph designs, drawing on proven technology in use in East Asia. Overall, these measures will reduce noise emissions by approximately 3dB at 360kph compared to a current European high speed train.

[67] Commission Regulation (EU) No. 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock - noise'. Available online at: https://lovdata.no/static/SF/32014r1304e.pdf.

[68] Department for Transport (2021), *National Technical Specification Notice, Rolling Stock – Noise (NOI)*.

It is also assumed that HS2 will operate on slab track and that the track will be specified to reduce noise, as will the maintenance regime. Only field-proven 'noise mitigation at source' technologies were considered (e.g. by rail grinding as necessary). In deriving the source term magnitudes for HS2 trains, a number of assumptions were made. Rolling stock was assumed to consist of 200m long train sets, two of which could be combined to form a 400m long train. The train sets will be distributed power (EMU), and none of the vehicles will have cast iron tread brakes. Traditional bogie architecture was assumed (articulated bogie architectures could be considered as a form of noise mitigation).

The remaining rolling stock running on HS2 infrastructure will consist of Northern Powerhouse Rail services. Noise emissions from these trains are currently unknown. Therefore, on a reasonable worst-case basis it has been assumed that these trains will be just compliant with the relevant NTSN noise limits.

Further discussion of the specific source terms used in the assessment is provided in the following section. For slow moving sections of the route it is assumed that traditional crossovers will be utilised. Consequently, the correction factor of +2.5dB defined in CRN has been applied to affected track segments. Elsewhere, it is assumed that high speed swing nose crossovers will be employed and hence, based on data acquired for HS1, no correction to the source term is necessary.

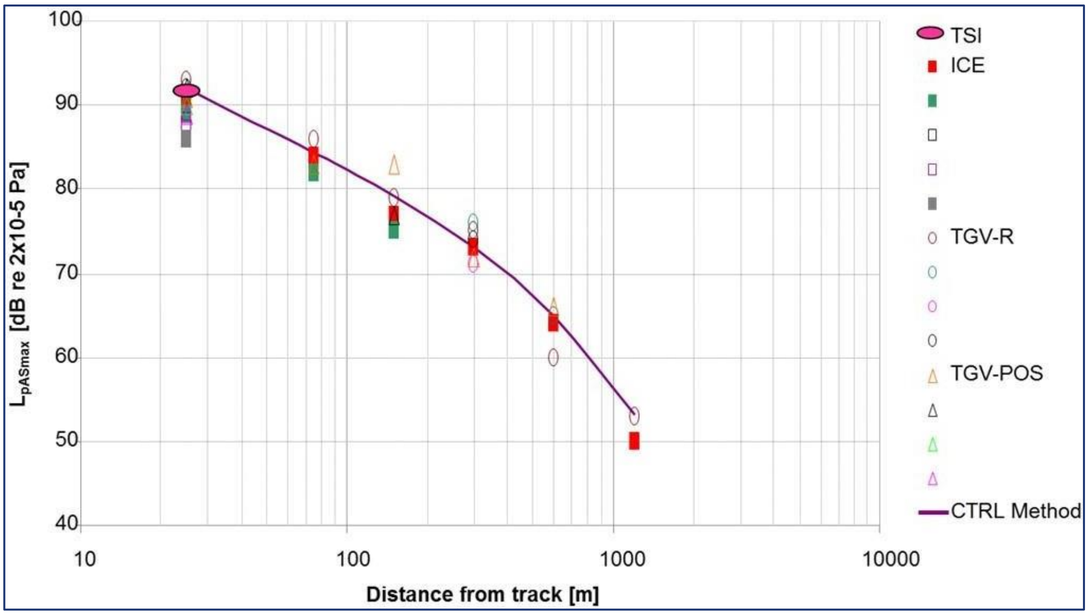
Avoidance and mitigation measures which have been incorporated into the Proposed Scheme are discussed in Volume 1, Section 9, and in each Volume 2 community area report.

4 Operational railway sound - prediction methodology

4.1 High Speed One (HS1) methodology

A calculation method[69] was developed to predict the noise impacts from the HS1. The model was validated in France and UK with an extensive series of noise measurements taken on the TGV. The method predates the Calculation of Railway Noise[46] (CRN) although much of the same data was used to develop CRN. The HS1 method is being used for the assessment of the Proposed Scheme because: it predicts maximum sound levels (L_{pAFmax}) as well as equivalent continuous ($L_{pAeq,T}$) levels; the method was used to successfully design and deliver HS1; measurements have shown that it provided an overestimate of actual in-service sound levels; and its forecasts for maximum levels fit well with measurements made on the LGV-Est railway line in France at distances out to 1km (refer to Figure D2 1).

Figure D2 1: Maximum noise levels for French TGV-POS and TGV-Reseau (TGV-R) and German ICE trains compared with the maximum level forecast using the HS1 calculation method and a TSI / NTSN source term (unobstructed propagation over soft ground)



4.2 Train sound sources

For conventional railways, the dominant sound sources are: rolling sound (the interaction between the wheels of the train and the rail), and power, traction and auxiliary systems. For trains running at high speeds (typically defined as >250kph), aerodynamic sound can

[69] Hood, R. A. et al. (1991), *Calculation of railway noise*, Proc. of the Institute of Acoustics 13 (8).

contribute to the overall pass-by sound level. Aerodynamic sound is caused by the flow of air over the train as it travels at high speed. The most important sources of aerodynamic sound on high speed trains vary from one train to another, but usually include[70]:

- the bogies, particularly the leading bogie; and
- the pantograph, its recess in the roof, and any other roof-mounted equipment such as insulators.

Other important sources can be the nose of the train, gaps between coaches, ventilation grills, projections (door handles, steps, etc.) and cavities (that can have resonant responses). Sources located towards the top of the train are particularly important when noise barriers are present.

The level of aerodynamic sound increases more rapidly with the train speed, V, than rolling sound. Rolling sound is typically assumed[71] to have a speed dependence of $30\log_{10}V$.

Aerodynamic sound is typically assumed,[71,72,73] to follow $60\log_{10}V$, although a speed dependence of $70\log_{10}V$ has also been suggested[71].

Given the importance of aerodynamic sound at high operational speeds, existing train pass-by sound prediction methods have been modified, and new methods developed to take aerodynamic sound into account. Examples are the German Schall 03[74], Dutch RMR[75] and Nordic 2000[76,77]. A common noise assessment method in Europe (CNOSSOS-EU)[72] which includes an aerodynamic sound prediction facility, has been proposed, but not yet implemented, by the European Commission for strategic noise mapping under the Environmental Noise Directive 2002/49/EC.

All these methods have a common concept – sound from a train pass-by is assumed to emanate from a set of discrete sources situated at different heights above rail head.

[70] Thompson, D. (2009), *Railway Noise and Vibration: Mechanisms, Modelling and Means of Control*, Elsevier.

[71] U.S. Department of Transportation (2012), *High-speed ground transportation - Noise and vibration impact assessment*, Federal Railroad Administration.

[72] European Commission (2012), *Common noise assessment methods in Europe* (CNOSSOS - EU), Joint Research Centre Reference Reports.

[73] Nagakura, K., Zenda, Y. (2003), *Prediction model of wayside noise level of Shinkansen,* Railway Technical Research Institute Japan.

[74] Moehler, U. et al. (2008), *The new German prediction model for railway noise 'Schall 03 2006' – Potentials of the new calculation method for noise mitigation of planned rail traffic,* Noise and Vibration Mitigation, NNFM 99, Springer-Verlag Berlin Heidelberg, pp. 186–192.

[75] Ministerie van Volkshuisvesting (2001), Ruimtelijke Ordening en Milieubeheer. Reken- en meetvoorschriften railverkeerslawaaai '96 [*Calculation and measurement requirements for railway traffic* '96].

[76] Zhang, X. (2010), *Prediction of high-speed train noise on Swedish tracks*, SP Technical Research Institute of Sweden, SP report 2010:75.

[77] Brekke, A. et al. (2013), *The Norwegian high speed rail study*, in Proceedings of the Joint Baltic-Nordic Acoustics Meeting.

The sound source powers are normally derived from national databases of pass-by measurements of operational rolling stock.

The source height is an important factor especially when considering noise barriers. Typically assumed source heights are 0.0m and 0.5m for rolling sound, 0.5 – 4.0m for traction and auxiliaries and 0.0 – 5.0m for aerodynamic sound.

The HS1 method assumes all sound originates from a source height of 0.5m above rail head. For trains running at very high speeds (>300kph) a multiple source version of the method is required.

4.3 HS2 source terms

The HS2 method builds upon the HS1 method by introducing a multi-source concept, similar to the other noise prediction methods mentioned.

Following a review of the different prediction methods, the following five sources have been included in the HS2 method:

- rolling sound, at a height of 0.0m above rail head, which includes sound emitted by the wheels and the track;
- body aerodynamic sound, at a height of 0.5m above rail head, which includes sound generated by flow in the lower regions of the train;
- starting sound, at a height of 2.0m above rail head, which includes sound generated by power, traction and auxiliary systems;
- pantograph recess aerodynamic sound, at a height of 4.0m above rail head; and
- raised pantograph aerodynamic sound, at a height of 5.0m above rail head.

The speed dependence for aerodynamic sound was assumed to follow $70\log_{10}V$ for L_{pAFmax} ($60\log_{10}V$ for sound exposure level (SEL)) to allow for a conservative extrapolation of maximum sound levels for speeds in excess of 320kph. The SEL relationships for all five sources are:

- $R_{SEL} + 20\log_{10}V$ for rolling sound;
- $B_{SEL} + 60\log_{10}V$ for body aerodynamic sound;
- $S_{SEL} - 10\log_{10}V$ for starting sound; and
- $P_{SEL} + 60\log_{10}V$ for pantograph and pantograph recess sound, where R_{SEL}, B_{SEL}, S_{SEL} and P_{SEL} are constants and V is the train speed.

The corresponding relationships for L_{pAFmax} are:

- $RL_{pAFmax} + 30\log_{10}V$ for rolling sound;
- $BL_{pAFmax} + 70\log_{10}V$ for body aerodynamic sound;
- SL_{pAFmax} for starting sound; and
- $PL_{pAFmax} + 70\log_{10}V$ for pantograph and pantograph recess sound.

$L_{pAeq,tp}$ exhibits the same speed dependencies as L_{pAFmax}.

Because HS2 trains have not yet been procured, the source terms for these five sources have been derived, based upon noise limits specified in the TSI / NTSN[68], and published literature. In doing so, it has been assumed that HS2 trains will be specified to be quieter than the relevant current UK and European Union requirements, by incorporating proven 'noise mitigation at source' technologies.

For rolling stock other than dedicated HS2 trains a reasonably foreseeable worst-case scenario (just NTSN-compliant trains) has been developed, where sound levels are the maximum permitted by statutory guidance.

4.4 Development of rolling and body aerodynamic source terms

The TSI/NTSN limit values for pass-by noise govern the total sound emitted by all five sources during the entire pass-by duration of the train. At speeds up to 300kph evidence shows that the contribution of the pantograph and pantograph recess to the SEL in the absence of any screening is negligible[72,78]. Furthermore, at speeds between 250kph to 320kph, the contribution of the starting and stationary sources can also be assumed to be negligible. Therefore, the pass-by SEL at 25m away from the track at the three speeds specified in the earlier TSI[79] (250, 300 and 320kph), which is consistent with NTSN, can be assumed to be due to the sum of the rolling and body aerodynamic components.

Assuming a relative contribution of <1dB(A) from body aerodynamic sound to the total level at 250kph[75, 80], an iterative procedure was carried out to obtain values for constants R_{SEL} and B_{SEL} such that the combined level was within ±0.5dB of the limits at 250, 300 and 320kph.

As already noted, the rolling sound component from a NTSN-compliant train running on in-service track can be higher than that measured on a NTSN reference track. This can be due to in-service growth of wheel and rail roughness, and a track system that radiates more sound than a NTSN reference track. However, it is assumed that wheel and rail roughness will be controlled via an appropriate maintenance regime, and a low-noise track will be specified, thereby ensuring that sound emissions from NTSN-compliant trains running on HS2 infrastructure will not exceed the NTSN noise limits.

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[78] Lölgen, T. (1999), *Wind tunnel noise measurements on full-scale pantograph models*, Journal of the Acoustical Society of America, 105(2):1136.

[79] European Commission (2008), 2008/232/CE, *Commission Decision of 21 February 2008 concerning a technical specification for interoperability relating to the 'rolling stock' subsystem of the trans-European high-speed rail system*, (notified under document C (2008) 648).

[80] Belingard, P. et al. (2012), *Experimental Study of Noise Barriers for High-Speed Trains*, Notes on Numerical Fluid Mechanics and Multidisciplinary Design, Vol. 118.

A linked but separate set of equations was developed by the same process described for L_{pAFmax} (and hence $L_{pAeq,Tp}$). These equations use $30\log_{10}V$ speed dependence for rolling sound and $70\log_{10}V$ speed dependence for aerodynamic sound.

4.5 Development of pantograph and pantograph recess source terms

There is limited published information[78,81, 82] on the absolute level of sound radiated by high speed train pantographs, including data from full scale models of two European high speed pantographs tested in the wind tunnel of the Rail Technical Research Institute (RTRI) in Japan. The two pantographs are an old crossed-arm type pantograph DSA350SEK, and a prototype actively controlled single arm pantograph (ASP) designed in part to reduce aerodynamic noise and tested with either one or two contact strips. Levels normalized to 320kph measured 25m from the line suggests maximum noise levels as the pantograph passes of around 90dB(A) for the DSA350SEK, and around 75 to 80dB(A) for the ASP with two pan heads and optimised insulators. A reduction of around 3dB was measured in changing from two contact strips to one.

Elsewhere[73], it is shown that the 700 series trains, with their low noise pantographs, exhibit pantograph aerodynamic noise emissions that are around 5dB(A) lower than the earliest bullet (Shinkansen) trains, and have a maximum noise level around 70 to 75dB(A) at a distance believed to be 25m from the line at 300kph. Results of wind tunnel tests[82] that show that pantographs designed for the E5 and 700N stock, in service since the end of 2011, are around 4dB quieter than the equipment on the 700 series trains.

Maximum pass-by sound levels of around 90dB(A) are estimated[83] at 25m for a TGV- A pantograph source at speeds between 300kph and 350kph. Simulated pass-by sound levels are also presented for a pantograph recess and raised pantograph on a TGV-Duplex using SNCF's train pass-by sound simulation software VAMPASS[84] yielding maximum pass-by levels of 87 and 85dB(A) respectively at 320kph.

The published data therefore shows that maximum aerodynamic noise levels from a pantograph pass-by are around 85dB(A) at 25m from the line for a traditional European high speed pantograph at 320kph and that this level can be reduced to around 75dB(A) or potentially less with more aerodynamic pantographs. This 10dB reduction in pantograph

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[81] Fodiman, P. and Gautier P.E. (2005), *Noise emission limits for railway Interoperability in Europe: Application to high-speed and conventional rail*, Forum Acusticum.

[82] Ikeda et al. (2012), *Aerodynamic noise reduction of a pantograph by shape-smoothing of panhead and its support and by the surface covering with porous material*, Notes on Numerical Fluid Mechanics and Multidisciplinary Design, Vol. 118.

[83] Gautier, P.E. et al. (2007), *High Speed Trains External Noise: A Review of Measurements and Source Models for the TGV Case up to 360kph*, SNCF, Innovation and Research Department, France.

[84] Bongini, E. et al. (2008), *Prediction and audio synthesis of vehicle pass-by noise*. Proc. of Acoustics 08 Paris.

noise at high speed is also cited by other work[85]. The selection for the most appropriate source level was further informed by additional analysis.

Measurements of train pass-by sound levels behind a noise barrier provide information on the relative contribution of pantograph aerodynamic noise, as the overall measured barrier insertion loss decreases as these unscreened sources increase in level. The validation of the HS1 prediction method[69] with its 0.5m source height showed that the in-situ barrier insertion loss recorded for a range of noise barriers (including bunds) up to 4m above rail was not affected by contribution from the pantograph aerodynamic noise at speeds up to 300kph. Trials[80] measuring the noise barrier insertion loss for trains running with high wheel/rail roughness levels at speeds up to 375kph showed that the barrier insertion loss provided by a 2.1m high reflective barrier for a TGV-POS was reduced by 1dB as train speed was increased from 320 to 375kph.

These outcomes were recreated in a series of multiple source barrier insertion loss calculations assuming the rolling and body aerodynamic source terms derived above together with each pantograph source level described in this section. These support a maximum pass-by aerodynamic sound source level of 83dB(A) for a current European HS train running at 320kph measured 25m from the track.

4.6 Development of power/traction/aux. sound source term

The NTSN limit for starting sound is defined at a distance of 7.5m from track centreline; this limit was converted to its equivalent at a distance of 25m from the track centreline to develop a complete set of source terms at this distance.

Power, traction and auxiliary sound sources behave somewhere between a point source and a line source. The sound attenuation due to geometric spreading from 7.5m to 25m can be calculated to be -10dB for a point source and -5dB for a line source.

The Community of European Railway and Infrastructure Companies (CER) commissioned a study[86] to determine a relationship between pass-by levels measured at 7.5m (1.2m above rail head) and 25m (3.5m above rail head) from track. The study found a relatively stable difference of 7dB(A) between the two measurement positions, based upon the analysis of more than 100 measured pass-bys of 15 types of high speed rolling stock on different tracks. CER propose the value of 7dB(A) should be used to derive pass-by noise limits for speeds above 190kph. This figure was assumed to be valid also for lower speeds for the purpose of deriving the HS2 source terms.

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[85] Asplan Viak AS (2011), *A methodology for environmental assessment - Norwegian high speed railway project Phase 2.*

[86] CER: Revision of TSI Noi (2012), *Towards an harmonized measurement distance for Pass-by noise of HS and CR trains*, Data collection and analysis v.1.

To determine the SEL source term from the L_{pAFmax}, a distributed power train with a configuration of [M–T–M–T–M–M–T–M–T–M] was assumed, where M denotes a motor vehicle with two starting sources (one at each bogie), and T denotes a trailer vehicle with no starting sources. A time domain sound model was used to determine the SEL of a distribution of starting sound sources, assuming the NTSN L_{pAFmax} limit of 83dB is met.

4.7 Development of source terms for L_{pAFmax}

The development of source terms for L_{pAFmax} is largely based on the SEL source terms, except for the pantograph and pantograph recess sources.

Predictions and measurements of the latest generation, disc-braked, distributed-power trains running on good quality track have shown that the L_{pAFmax} is typically 1dB(A) higher than the $L_{pAeq,tp}$. This relationship has been used to derive the L_{pAFmax} source terms for rolling, body aerodynamic and power/traction/aux. sources from the respective SEL.

The L_{pAFmax} for the pantograph and pantograph recess was assumed to be 83dB(A) at 320kph.

The total pass-by L_{pAFmax} is computed using the following equation:

L_{pAFmax} = MAX [(L_{pAFmax}, rolling + L_{pAFmax}, body aero + $L_{pAFmax,starting}$) , ($L_{pAFmax,\ rolling}$ + $L_{pAFmax\ pantograph}$ + $L_{pAFmax,\ starting}$)]

This equation is based on the assumption that the pantograph and pantograph recess are not on the leading and trailing coaches, and hence the $L_{pAFmax,\ body\ aero}$, which normally occurs at the front of the train (nose and leading bogie) does not occur at the same time as $L_{pAFmax,\ pantograph}$ which is robust for modern distributed power trains.

Table D2 1, below, shows the resulting values for the source terms for captive and conventional compatible trains, expressed in terms of the SEL and L_{pAmax}.

Table D2 1: Source values for NTSN-compliant trains expressed in terms of SEL and L_{pAmax}

Source term	Values for NTSN-compliant trains at 25m	
	SEL	L_{pAFmax}
R	45.1dB	16.6dB
B	-56. dB	-85.5dB
S	101.7dB	76.0dB
P (pantograph)	-69.3dB	-92.3dB

4.8 Development of source terms for HS2 trains

For the assessment undertaken as part of the ES, it has been assumed that HS2 trains will be specified to be quieter than the relevant current European Union requirements and this will include reduction of aerodynamic noise from the pantograph that will occur above 300kph

(186mph) with current pantograph designs, drawing on proven technology in use in East Asia. It is also assumed that HS2 will operate on slab track on the surface which will be specified to reduce noise, as will the maintenance regime.

Source terms for Captive (CP) and Conventional Compatible (CC) HS2 trains were developed by defining corrections to constants R, B, S and P to represent currently proven noise at source mitigation technologies. These corrections are presented in Table D2 2.

Table D2 2: Source corrections assumed for Captive (CP) and Conventional Compatible (CC) HS2 trains, with respect to NTSN-compliant trains

Source term	Correction (wrt NTSN-compliant trains) for CP trains	Correction (wrt NTSN-compliant trains) for CC trains	Available technologies and noise mitigation strategies
R_{SEL}	-3dB	-3dB	Control of rail and wheel roughness
B_{SEL}	-3dB	-1dB	Bogie shrouds (captive trains only), aerodynamic design of train body
S_{SEL}	-3dB	-3dB	Low noise fans
$P_{SEL\ (recess)}$	N/A	N/A	No recess assumed for HS2 train – pantograph mounted directly on roof (for a distributed-power train) with aerodynamic shrouds
$P_{SEL\ (pantograph)}$	-5dB	-5dB	Low noise pantograph design and no pantograph on leading/trailing car

Table D2 3: Source values for Captive (CP) and Conventional Compatible (CC) HS2 trains expressed in terms of SEL and L_{pAFmax}

Source term	Values HS2 trains at 25m			
	CP SEL	CP L_{pAFmax}	CC SEL	CC L_{pAFmax}
R	42.1dB	13.6dB	42.1dB	13.6dB
B	-59.9dB	-88.5dB	-57.9dB	-86.5dB
S	98.7dB	73.0dB	98.7dB	73.0dB
P (recess)	N/A	N/A	N/A	N/A
P (pantograph)	-74.3dB	-97.3dB	-74.3dB	-97.3dB

4.9 Source contributions at 360kph

The sound level contributions from the five sources at a speed of 360kph, for just NTSN-compliant trains, Captive (CP) HS2 trains and Conventional Compatible (CC), are shown in Table D2 4, Table D2 5 and Table D2 6 respectively.

Table D2 4: Sound emissions from a just NTSN-compliant train running at 360kph on assumed HS2 infrastructure, expressed in terms of the SEL, $L_{pAeq,tp}$ and L_{pAFmax} 25m from nearest track and 3.5m above ground

Source	Just NTSN-compliant train - Level, dB		
	L_{pAFmax}	$L_{pAeq,tp}$	SEL
Rolling	96	95	99
Body aerodynamic	93	92	96
Power/traction/auxiliaries	76	74	76
Pantograph recess	87	81	84
Raised pantograph	87	81	84
Total	96	96	100

Table D2 5: Sound emissions from Captive (CP) HS2 trains running at 360kph on assumed HS2 infrastructure, expressed in terms of the SEL, $L_{pAeq,tp}$ and L_{pAFmax} 25m from nearest track and 3.5m above ground

Source	Captive (CP) HS2 trains –Level, dB		
	L_{pAFmax}	$L_{pAeq,tp}$	SEL
Rolling	93	92	96
Body aerodynamic	90	89	93
Power/traction/auxiliaries	73	71	73
Pantograph recess	-	-	-
Raised pantograph	82	76	79
Total	93	93	97

Table D2 6: Sound emissions from Conventional Compatible (CC) HS2 trains running at 360kph on assumed HS2 infrastructure, expressed in terms of the SEL, $L_{pAeq,tp}$ and L_{pAFmax} 25m from nearest track and 3.5m above ground

Source	Conventional Compatible (CC) HS2 train- Level, dB		
	L_{pAFmax}	$L_{pAeq,tp}$	SEL
Rolling	93	92	96
Body aerodynamic	92	91	95
Power/traction/auxiliaries	73	71	73
Pantograph recess	-	-	-
Raised pantograph	82	76	79
Total	94	93	98

Evaluation of HS2 source terms

Figure D2 2 and Figure D2 3, below, show the predicted pass-by sound level, in $L_{pAeq,tp}$ and L_{pAFmax} terms respectively, for a noise NTSN-compliant train running on HS2 infrastructure, as a function of train speed. Figure D2 2 also shows the current NTSN limits, and data measured for the Deufrako and NOEMIE[71] projects. The highest sound levels correspond to older first-generation European HS trains. On these trains, the leading and rear power cars have high power cooling fans and cast-iron tread-brakes, which are known to generate higher levels of noise in service. Furthermore, the train bodies do not include the aerodynamic improvements that feature in the latest generation trains. The curve for NTSN-compliant trains models the average trend well both in terms of $L_{pAeq,tp}$ and L_{pAFmax}.

Figure D2 4 and Figure D2 5 show the equivalent comparisons for HS2 trains, which represents what can reasonably be achieved using already proven mitigation intervention in use around the world. Levels are 2-3dB lower for $L_{pAeq,tp}$, and 4-5dB lower for L_{pAFmax} compared to the first-generation European HS train data measured between 300 – 360kph. The predictions in Figure D2 4 and Figure D2 5 assume that HS2 trains are operating on ballast track which has been specified to reduce noise.

HS2 plans to operate trains on slab track. The airborne noise emission characteristics of slab track are different to ballast. Typically, 'soft' rail fastenings are used on slab track. This can lead to higher noise levels than for the case of ballast track because 'soft' rail pads decrease the rail decay rate of the track[87]. To account for this, 3dB has been added to the rolling noise source in the model. Figure D2 6 and Figure D2 7 show the predicted pass-by sound level when the HS2 train is operating on slab track.

[87] The rail decay rate is a measure of the rate at which vibration, and hence rail noise, decays with distance along the track from the wheel rail interface. All other parameters remaining equal, rolling noise will increase with decreasing decay rate.

Figure D2 2: $L_{pAeq,tp}$ vs speed for total and source component pass-by sound at 25m from the track predicted using source terms for NTSN-compliant trains. The red square markers show the current TSI / NTSN limits (including the +1dB allowance). The black markers show measured sound levels for TGV–A, TGV–Duplex and Thalys

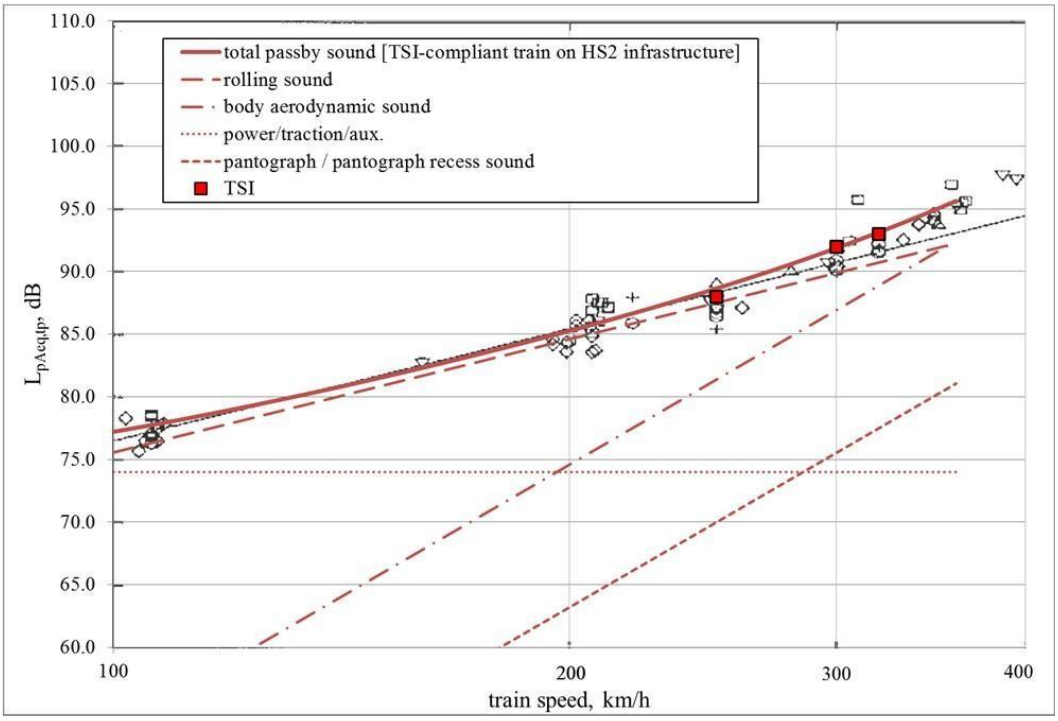


Figure D2 3: L_{pAFmax} vs speed for total and source component pass-by sound at 25m from the track predicted using source terms for NTSN-compliant trains. The black markers show measured sound levels for a TGV–A as presented in [1]: leading power cars, rear power cars, trailer vehicles

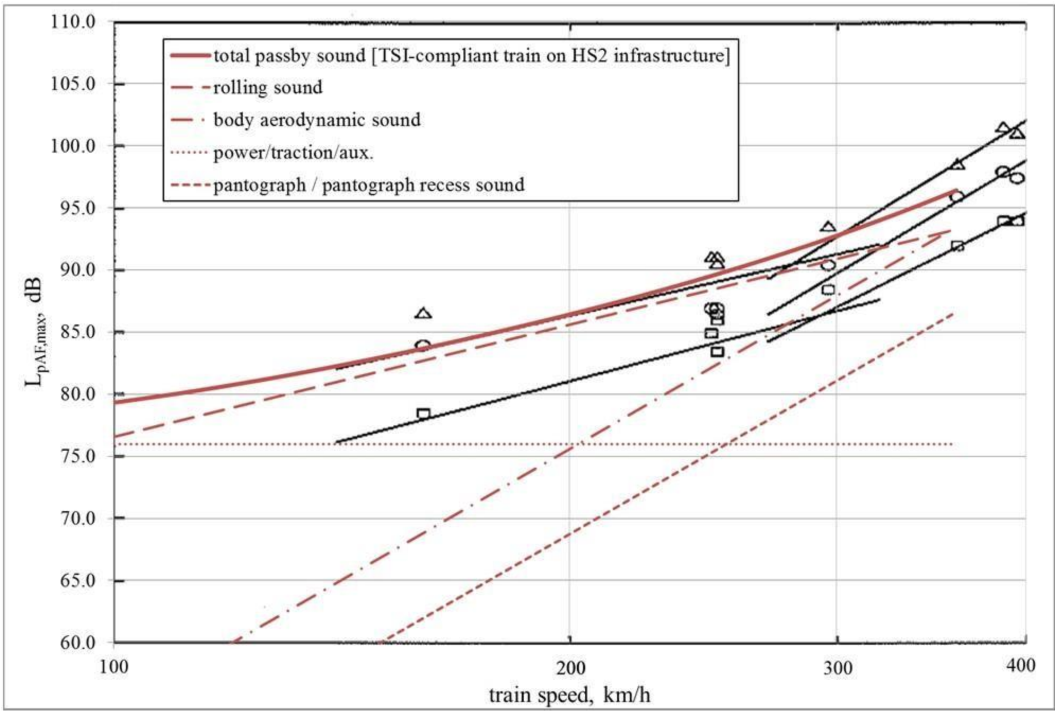


Figure D2 4: $L_{pAeq,tp}$ vs speed for total and source component pass-by sound at 25m from the track predicted using the HS2 trains source terms

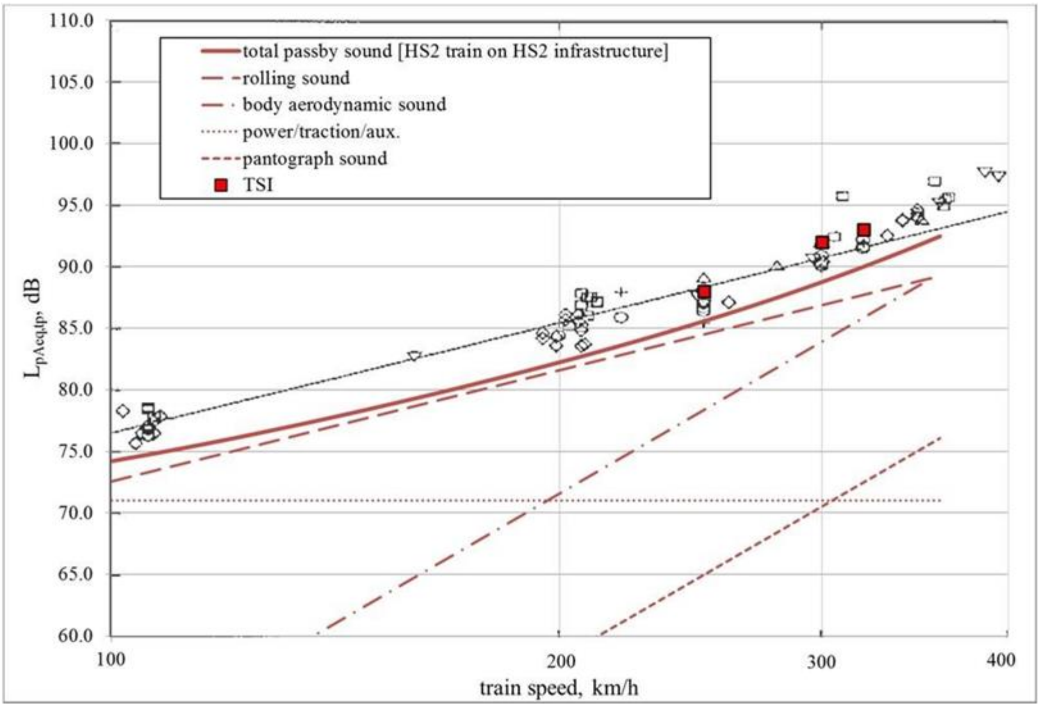


Figure D2 5: L_{pAFmax} vs speed for total and source component pass-by sound at 25m from the track predicted using the HS2 trains source terms

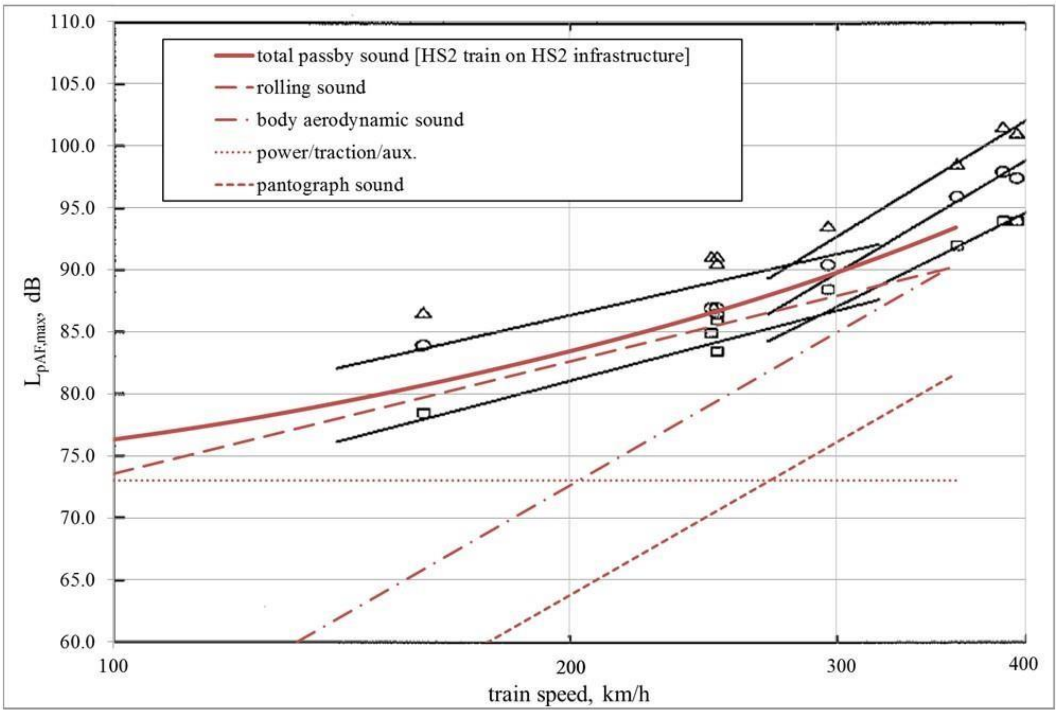


Figure D2 6: $L_{pAeq,tp}$ vs speed for total and source component pass-by sound at 25m from the track predicted using the HS2 trains source terms and assuming the train is operating on slab track

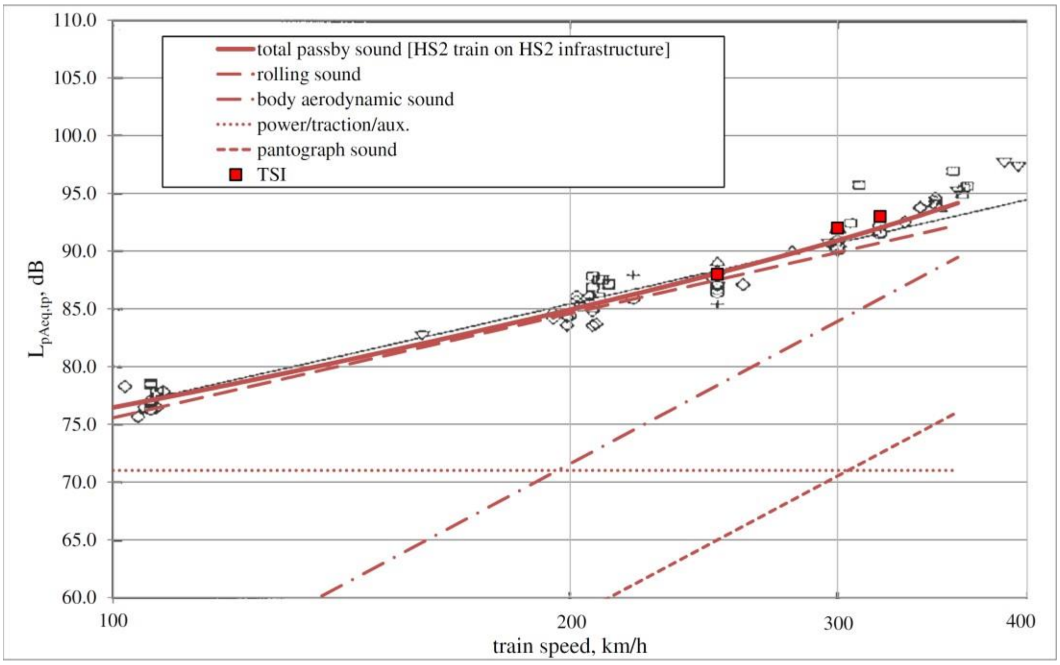
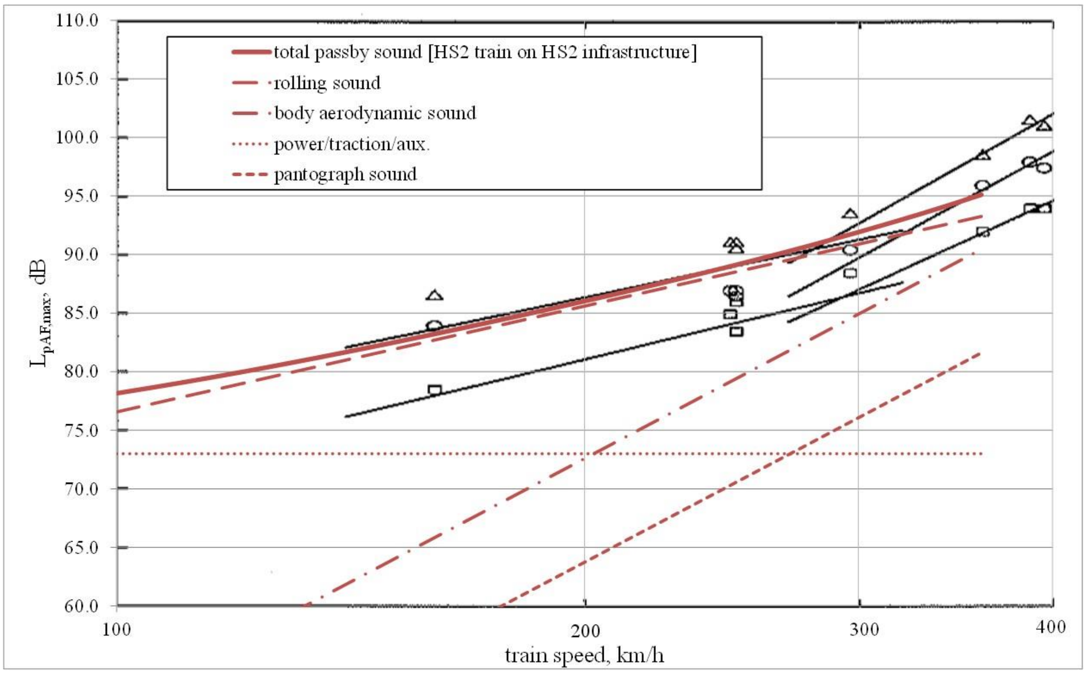


Figure D2 7: L_{pAFmax} vs speed for total and source component pass-by sound at 25m from the track predicted using the HS2 trains source terms and assuming the train is operating on slab track



4.10 Modelling of ground-borne vibration: Rayleigh waves

The occurrence of high levels of vibration from Rayleigh waves is a relatively rare situation which can occur where trains are travelling at a speed, known as the critical speed, over a railway situated on very soft ground. The critical speed is dependent on the ground conditions below and is not confined to high speed railways. This is understood[88] and is mitigated by appropriate design and construction techniques (e.g. HS1 across Wennington Marshes). Where this could occur, measures such as soil strengthening or bridging over soft ground to ensure Rayleigh waves do not adversely affect train operations or damage the infrastructure will be incorporated. These measures also ensure that there is no impact caused by this phenomenon on people and wildlife in the wayside of the line.

4.11 Modelling of airborne noise: tunnel portals

Noise can be generated at exist portals due to pressure waves created inside a tunnel as a train enters the tunnel. This is a well understood phenomenon and is mitigated by appropriate design and construction techniques. The design of the tunnel portals, tunnels and vent shafts (where required) will control and reduce in-tunnel pressure waves to assure passenger comfort. Tunnel portals, tunnels and vent shafts (where required) will be designed to avoid any significant airborne noise effects caused by the trains entering the tunnel.

Airborne noise and ground-borne vibration: maintenance

At night, there will be regular line inspections and planned maintenance work at some location along the route. At any one location on the route maintenance is likely to be very occasional. Given the irregularity of the activity and short duration at any one location, maintenance work is considered unlikely to give rise to significant noise or vibration effects.

A small number of diesel-powered specialist engineering trains will travel on most nights from the Ashley Infrastructure Maintenance Base - Rail (IMB-R) to either inspect the line or to a location of planned maintenance. Planned maintenance movements are likely to leave the IMB-R as soon as possible after passenger services finish at 24:00 and return to the IMB-R shortly before passenger services start again at 05:00. It is assumed that the engineering trains will be specified and operated so that any adverse noise or vibration effects are no greater than those for the night-time passenger services operating on the HS2 mainlines.

[88] Thompson, D. J. (2009), *Railway noise and vibration: mechanisms, modelling and means of control*, Elsevier, pp. 399–435, Oxford, UK.

Noise from regular maintenance trains on the HS2 mainlines is therefore considered unlikely to give rise to significant noise or vibration effects.

4.12 Modelling of road traffic sound

Direct impacts

The direct impacts of road traffic i.e. those arising from the passage of vehicles on highways which have either been newly introduced or altered to facilitate the Proposed Scheme, have been calculated using the 3-dimensional acoustic (NoiseMap) model of the study area implementing the methodology detailed in the Calculation of Road Traffic Noise (CRTN)[55].

For each new or altered road link in the model, data on traffic flow, speed, proportion of heavy goods vehicles (HGV) have been determined as far as possible from data provided in the Transport Assessment (see Volume 5, Appendices TR-001, TR-002, TR-003 and TR-005). The 18-hour Annual Average Weekday Traffic (AAWT) road traffic data have been used to evaluate the road traffic sound level in accordance with CRTN, $L_{pA10,18hr}$, with NoiseMap then implementing corrections[89] in order to predict the resultant free-field sound level due to the Proposed Scheme for parameters considered within the assessment i.e. $L_{pAeq,16hr}$, $L_{pAeq,8hr}$, at each of the identified assessment locations in the vicinity of the highway. These data have then been incorporated into the 'Proposed Scheme Only' and 'Do Something (Opening Year +15)' fields of the impact and effect tables in each community area Volume 5 appendix (Appendices SV-003).

Indirect impacts

Indirect effects of airborne noise could be caused by changes to road traffic patterns on existing networks due to the Proposed Scheme (e.g. example due to a permanent road closure) and/or its operation (e.g. to traffic generated by a new station). In order to illustrate changes in sound level in 2038 with the scheme in place, compared with the without scheme situation, road traffic sound source levels for both the with and without scheme situations have been predicted as 'Basic Noise Levels' (BNLs) from the CRTN. These predictions have been based upon predicted road traffic flows, speeds and percentage HGV identified in the Transport Assessment (see Volume 5, Appendices TR-001, TR-002, TR-003 and TR-005).

The focus of the predicted BNL change assessment has been on those roads with an 18-hour AAWT flow of 1000 vehicles or more; 1,000 vehicles being the lower limit of the CRTN prediction method. However, the assessment of change in BNL for those roads either increasing to a flow above 1,000 vehicles or reducing to a flow below 1,000 vehicles with the scheme in place, has also been included to provide an indication of the change. To allow BNL

[89] Abbot, P.G. and Stephenson, S.J. (2006), *Method for converting the UK road traffic noise index,* L TRL Casella Stanger for Defra.

prediction to be undertaken within the limits of the prediction method and to provide a worst-case estimate, traffic speeds of less than 20kph have also been rounded up to 20kph.

The change in the BNL has been assumed to be equivalent to the change in daytime $L_{pAeq,16hr}$ and night-time $L_{pAeq,8hr}$ sound levels at properties to the side of each road considered.

The assessment of predicted adverse and beneficial effects due to changes in BNLs has also focused on changes of $3dBL_{Aeq,16hr}$ or greater, unless the predicted BNL in 2038 without the scheme is already considered high (taken as $65dBL_{Aeq,16hr}$ free-field), in which case the focus has also included a change of 1dB or greater.

It should be noted, however, that the predicted change in BNL from any given road provides only an indication of traffic sound level change at a position 10m from the kerb of that road, or at receptors nearby. This is particularly the case for those roads with a relatively low flow compared to surrounding roads and/or those locations affected by other ambient (traffic and non-traffic) sound sources. In such situations, the full magnitude of the predicted BNL changes is unlikely to occur once the contribution from other ambient sound sources are taken into account.

4.13 Stationary systems

Stationary systems cover the following installations (where applicable):

- tunnel ventilation;
- mechanical ventilation at shafts and at tunnel portals;
- tunnel draught (pressure) relief shafts;
- trackside equipment (particularly electrical equipment such as autotransformers);
- static equipment located at stations including mechanical ventilation plant, chillers etc.; and
- static sources located within depots such as mechanical plant, pumps, carriage wash plant, wheel lathes, and stationary trains etc.

Public address/voice alarm systems or other audible warning systems installed at stations or depots are considered separately because of the particular characteristics and operational requirements associated with such systems.

Measures have been developed which will be employed in the future design and installation of stationary systems in order to avoid significant adverse noise effects. Further details of these measures are presented in Annex E.

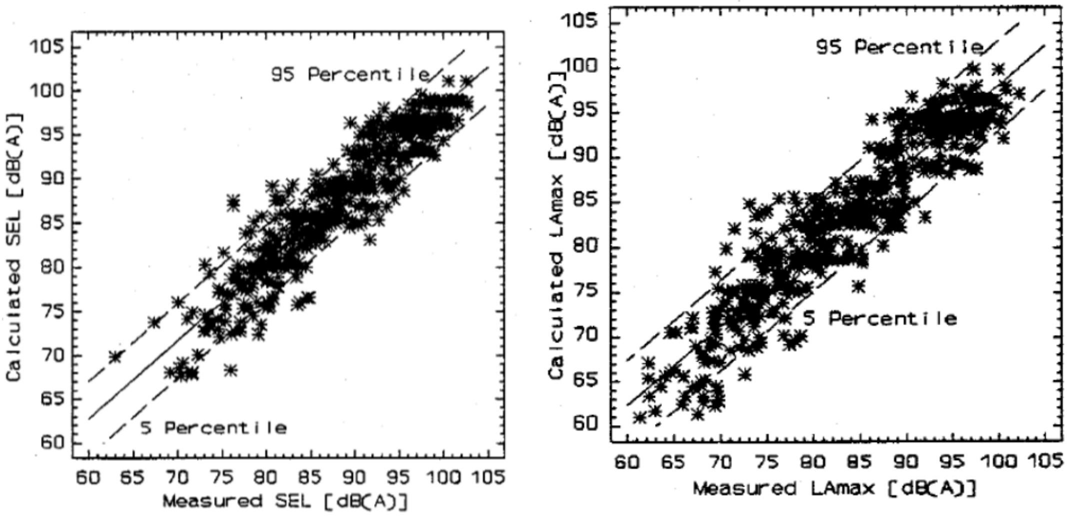
5 Limitations: Sensitivity tests

5.1 Validation of HS1 method

The HS1 airborne sound prediction method was originally validated against a large number of high speed train noise measurements covering a broad range of scenarios, including propagation over flat ground up to distances of 800m from the railway, effects of screening (including reflective and absorptive barriers) and varying angles of view. The overall regression analyses gave a standard error, for the goodness of fit between predicated and measured levels of approximately 3dB(A) for SEL and L_{pAFmax}. This means that the difference between predicted and measured sound levels is typically within ±3dB(A) - see Figure D2 8 below. As discussed later in this section this for 'downwind' conditions only (i.e. with the wind blowing noise from the railway to the observation position).

Measurements undertaken along HS1 since it came into operation have shown that the prediction method tends to over-estimate in-service noise levels.

Figure D2 8: Validation of HS1 method: left SEL; right L_{pAFmax}

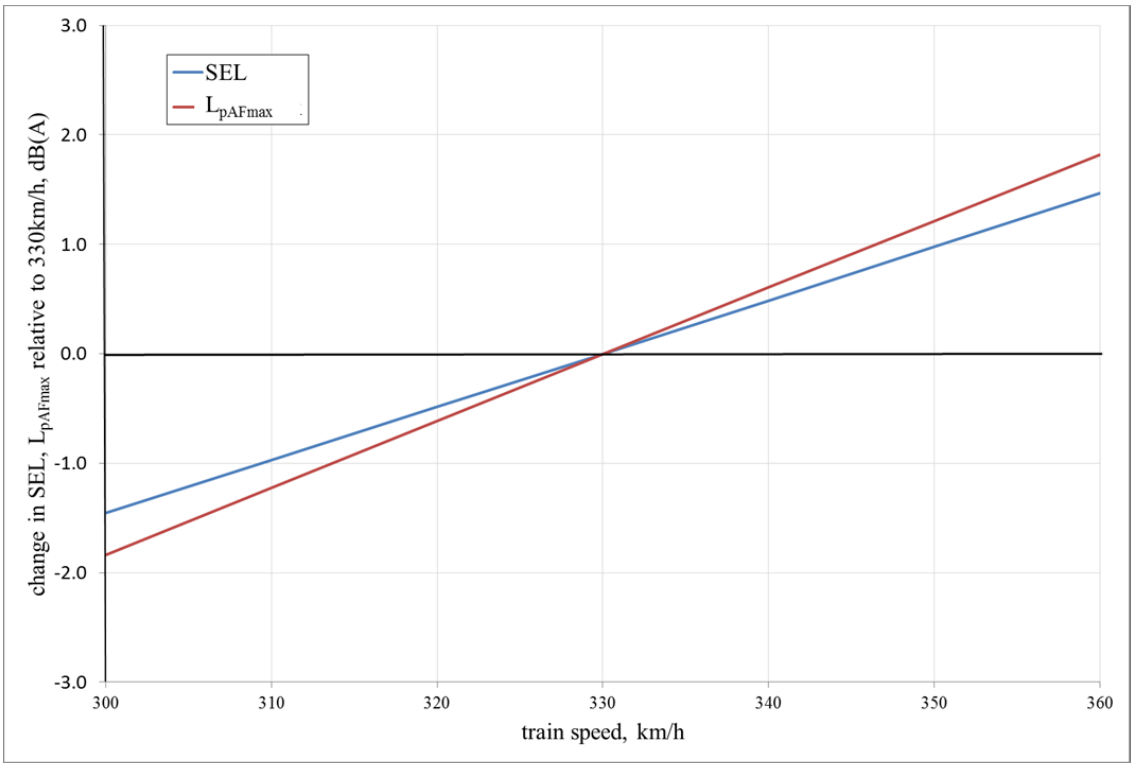


Changes in the model input parameters (such as speed, train specification, etc.) will result in changes in sound level. Sensitivity tests were carried out to identify which parameters have a greater impact on overall forecast sound levels (with a greater sensitivity attributed to those inputs where any reasonably foreseeable change in the parameter value used for the assessment could lead to a change in predicted sound level of ≥3dB(A)). This information was used to refine the relevant input parameter values assumed for the assessment to provide a reasonable worst-case forecast of sound levels.

5.2 Sensitivity to change in speed

Changes of 10% in train speed with respect to a reference of 330kph result in changes of less than 2dB(A) in the overall pass-by SEL and L_{pAFmax}. Please refer to Figure D2 9. In the assessment, to calculate the equivalent continuous daytime and night-time sound levels, trains have been assumed to operate at timetabled speed of 330kph on the fastest sections of the route with 10% of services assumed to be travelling on these sections a 360kph as needed to assure journey times. Maximum sound levels have been calculated assuming that trains run at their fastest speeds for each section of the route (i.e. at 360kph where the design allows).

Figure D2 9: Change in sound level, SEL and L_{pAFmax}, relative to train speed



5.3 Sensitivity to train specification

The HS2 'captive' and 'conventional compatible' trains will be specified to be quieter than the relevant current European Union requirements. Furthermore, a relatively small number of 'Just NTSN-complaint' trains may operate on HS2 infrastructure. These would be NPR trains operating on the HS2 WCML connection and the HS2 spur to Manchester.

The train specification is an important parameter in the sound modelling. Nevertheless, given that most of trains running on HS2 infrastructure will be HS2 trains, small changes in the number of captive and conventional compatible trains running on the network do not give rise in significant changes in the predicted levels (Figure D2 11).

Figure D2 10 shows that at 330kph, sound levels for HS2 captive trains are around 1dB lower than for HS2 conventional compatible trains.

Figure D2 10: Change in sound level, SEL, relative to train speed

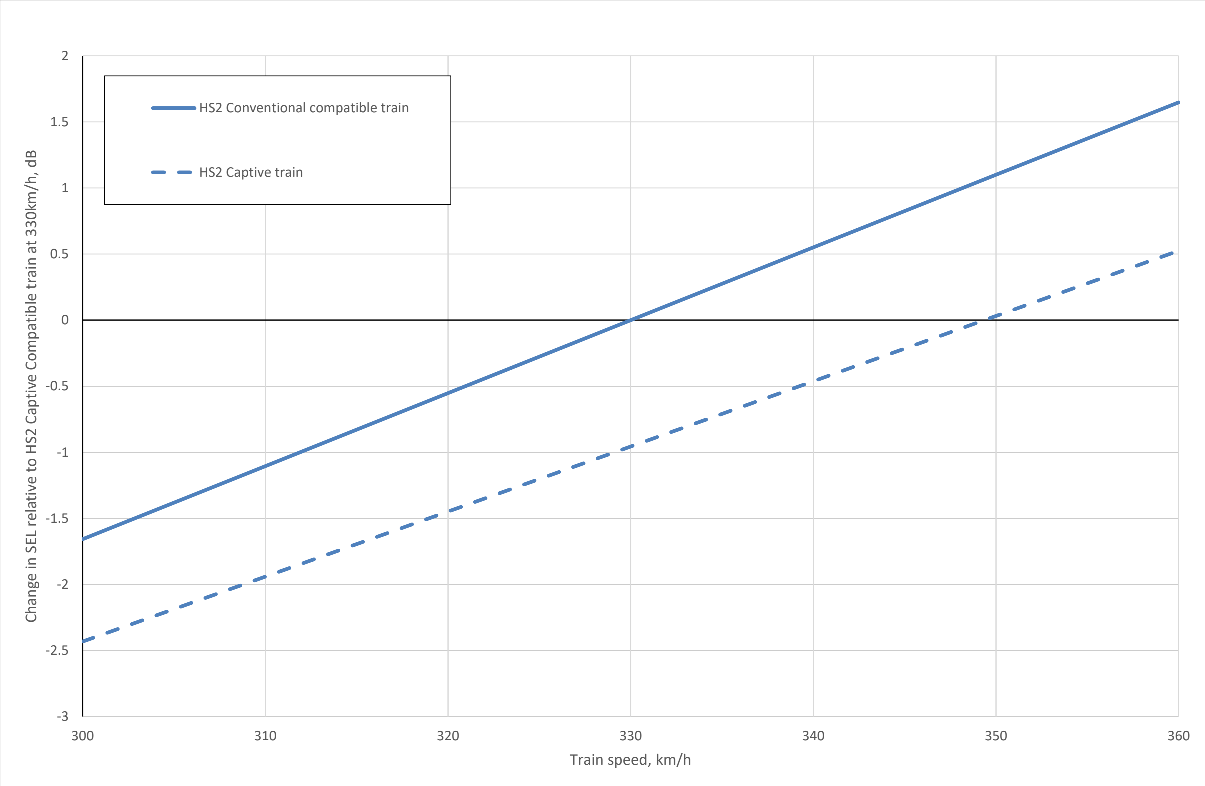


Figure D2 11: Change in daytime equivalent continuous sound level, $L_{pAeq,1hr}$, relative to proportion of HS2 train types

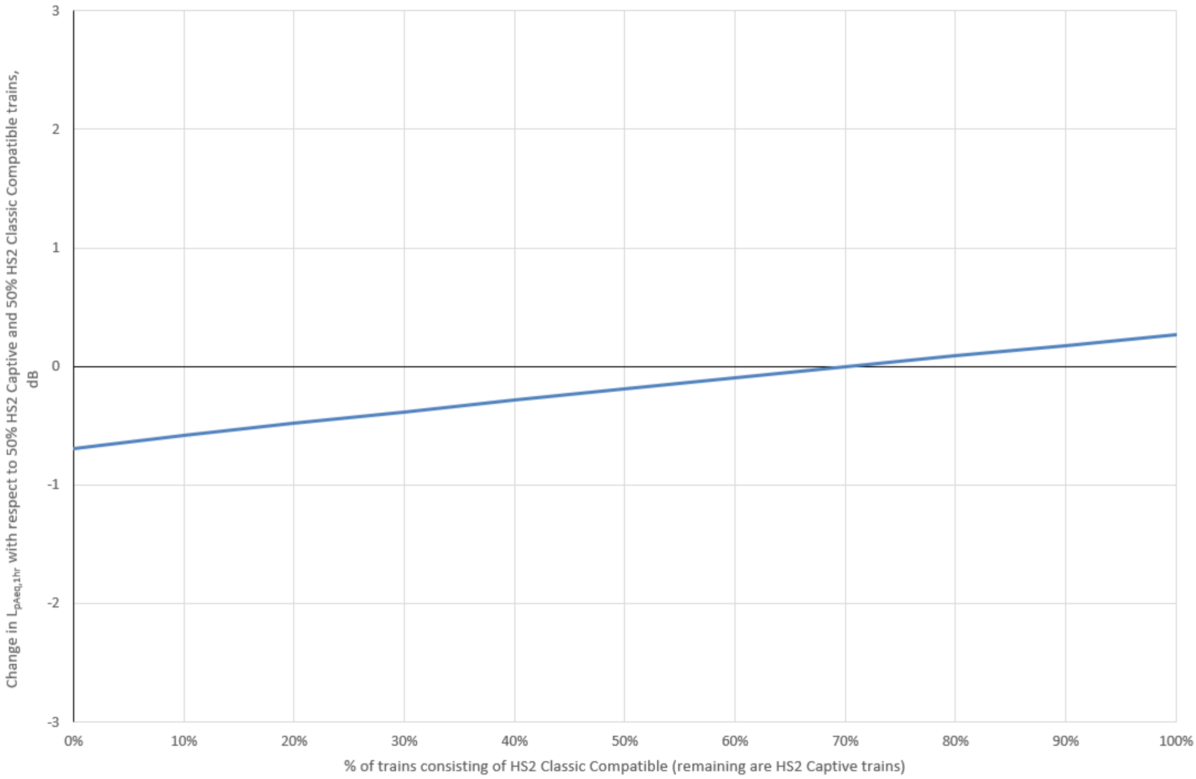
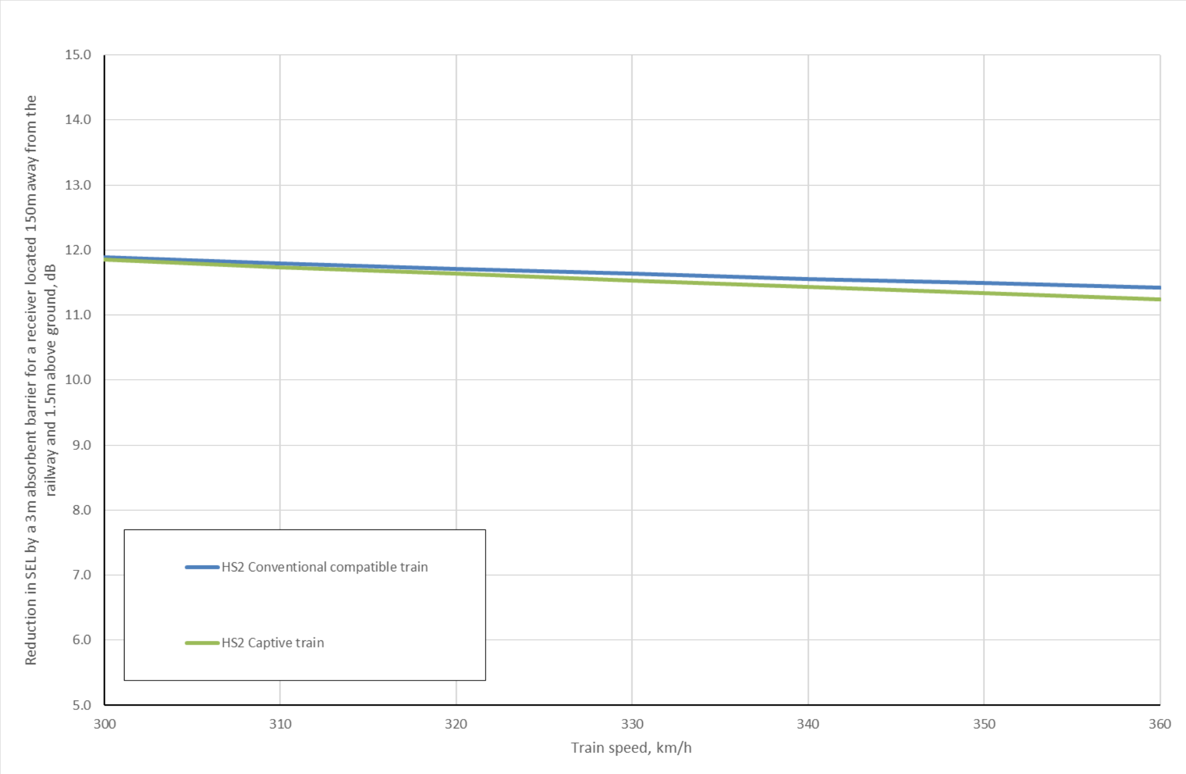


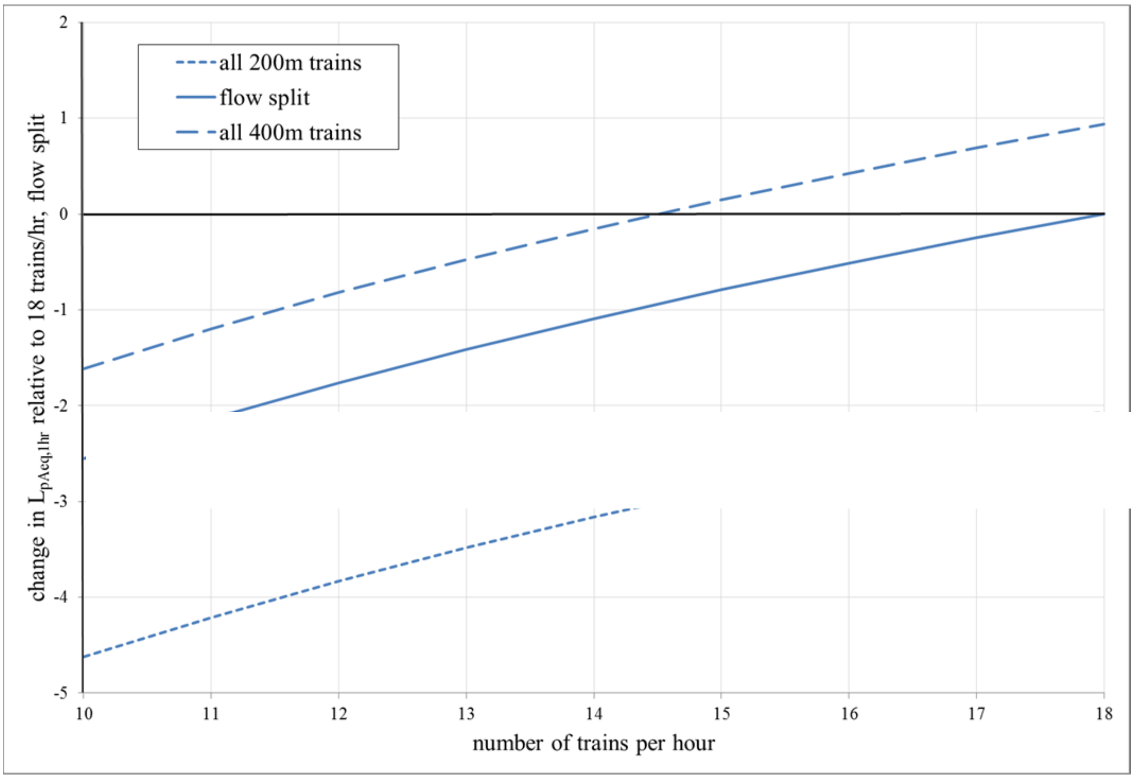
Figure D2 12: Change in barrier performance relative to train speed



5.4 Sensitivity to changes in train flow

Small changes in train flows, or in the split between 200m long and 400m long trains, only give rise to small changes in sound levels (Figure D2 13).

Figure D2 13: Change in sound level, $L_{pAeq,1hr}$, relative to proportion train flow ('flow split' is that assumed in the assessment)



5.5 Outdoor sound propagation

Sound attenuation due to geometric spreading, air and ground absorption can be significant, particularly at large distances from the railway (Figure D2 14). For example, at 300m from the railway, changes in level of ±3dB(A) correspond to changes in distance of ±100m (Figure D2 15).

The HS2 airborne sound prediction method uses empirically derived formulae to predict the SEL and maximum sound pressure level (L_{pAFmax}) at a distance 'd' from the railway tracks, based upon a set of source terms defined at 25m from the track. The source terms are specific to a particular train running on a specific type of track.

In the absence of any screening, the SEL and L_{pAFmax} at a distance d from the track can be determined by:

- $SEL_d = SEL_{25} - 10log_{10}\left(\frac{d}{25m}\right) - \frac{d}{120} - \frac{d}{130 \times mph}$; and
- $L_{pAFmax,d} = L_{pAFmax,25} - 14.5\ log_{10}\left(\frac{d}{25m}\right) - \frac{d}{120} - \frac{d}{130 \times mph}$

The first term represents the source term, the last three terms represent geometrical spreading, air absorption and ground attenuation, respectively.

Screening effects are calculated separately. If screening is present (for example earth bunds or noise barriers), the last term is omitted.

Ground absorption is not included in the calculation when wayside noise barriers are present.

The HS2 airborne sound prediction method models moderate downwind conditions (wind blowing from railway to receiver) or, equivalently, moderate ground-based temperature inversions occurring on still nights. During upwind conditions, sound levels will be significantly lower than predicted, particularly at larger distances from the railway. This is considered further in the following subsection.

Figure D2 14: Effect of ground and air absorption on sound level (25m)

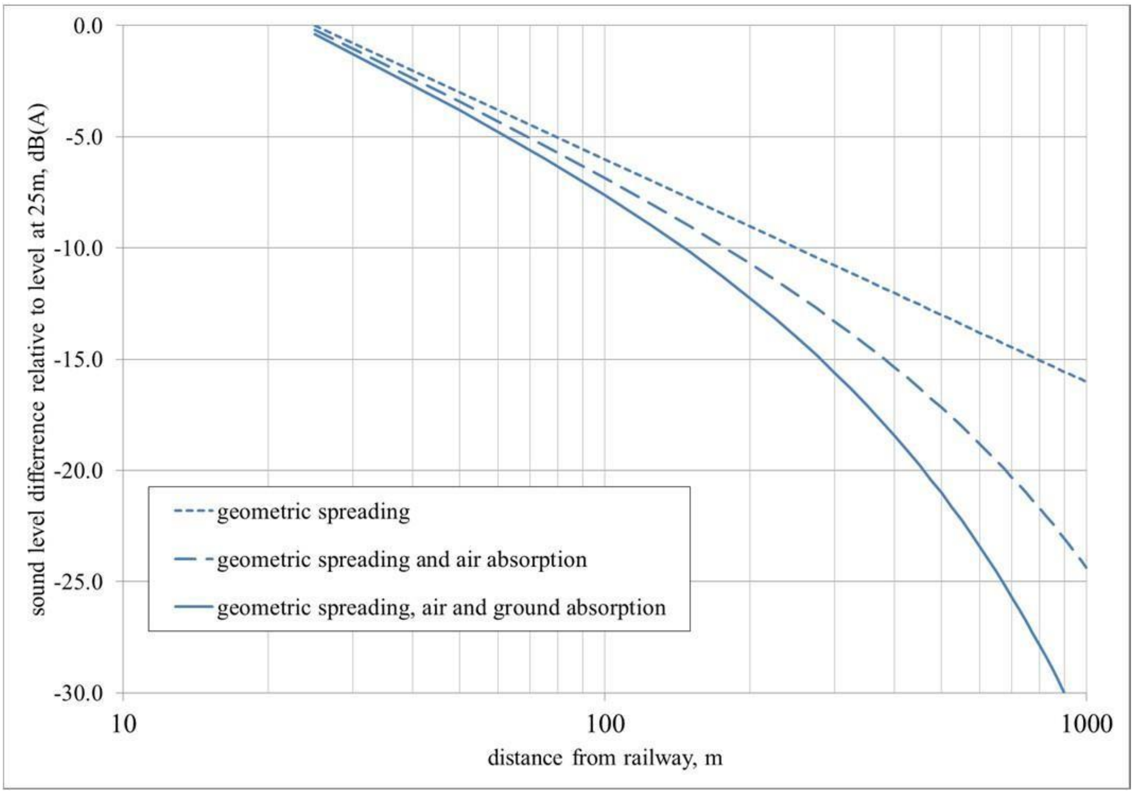
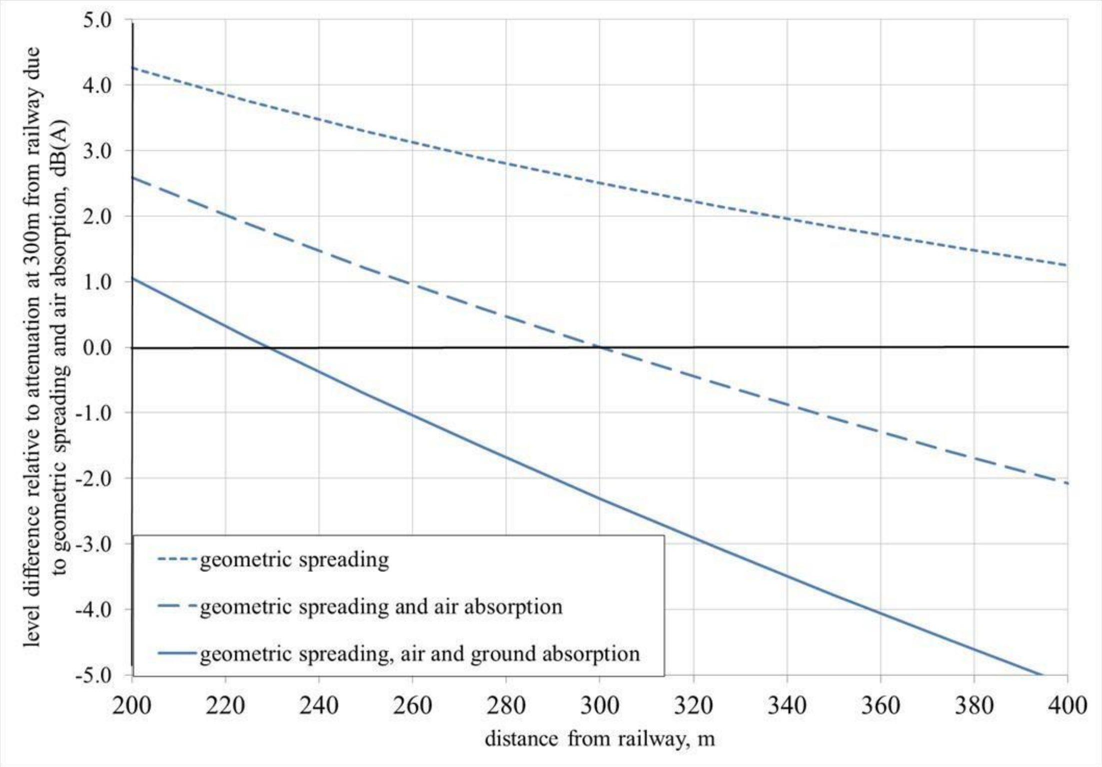


Figure D2 15: Effect of ground and air absorption on sound level (300m)



5.6 Outdoor sound propagation and meteorological effects

Outdoor sound is attenuated by distance, by topography (screening effects), by interaction with ground and by atmospheric effects including refraction and absorption.

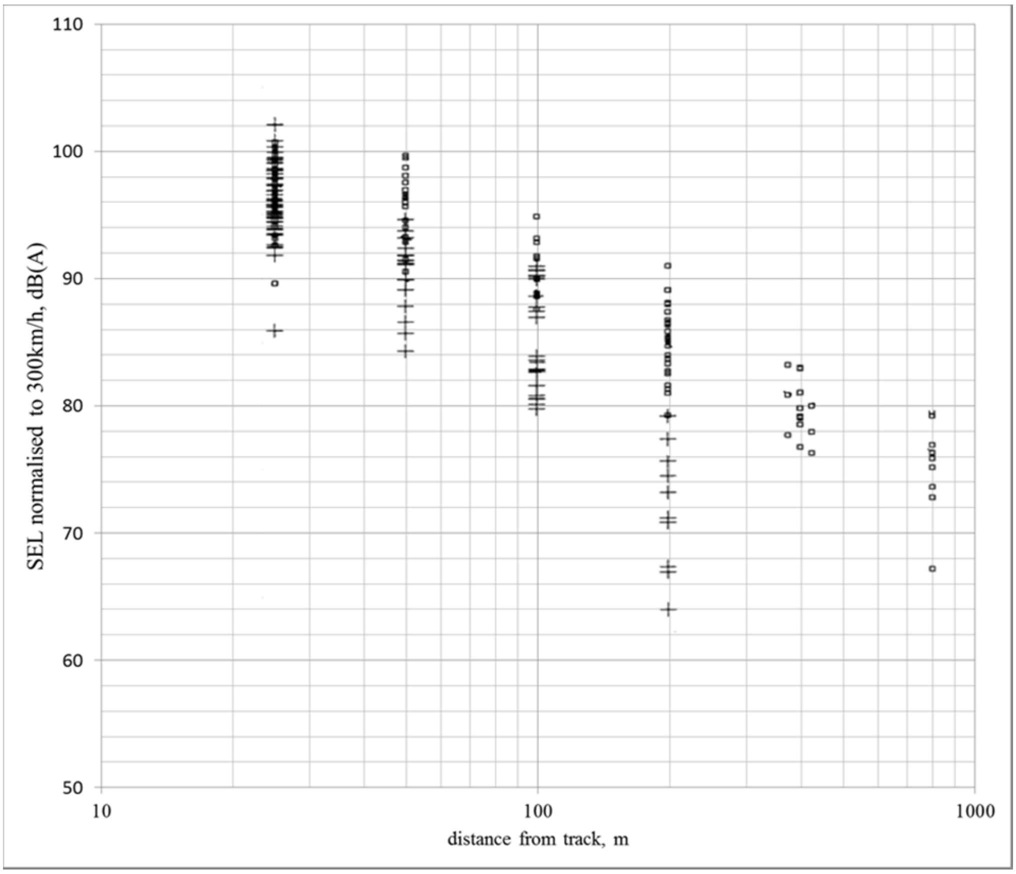
Atmospheric effect, such as wind speed and direction, and temperature gradients also affect sound propagation. For example, when wind is blowing from the source to the receiver (termed 'downwind' or 'positive wind' conditions), sound levels increase compared to still conditions. Sound levels will similarly be increased at distance from a source when there is a positive temperature gradient (for example night-time with clear sky or foggy days).

The HS2 airborne sound propagation method is an empirical method, based upon a large number of measurements of high speed train pass-bys. These measurements include the effect of meteorological effects, such as upwind or downwind conditions. For the purpose of developing the prediction methods, to lean generally towards a worst-case, only sound level data for which the receiver was downwind of the source was used. This means that the method is representative of downwind conditions (i.e. forecasting high noise levels at distance from the route).

Figure D2 16 and Figure D2 17 show measured SEL and L_{pAFmax} levels from a measurement campaign carried out in 1989 – 1990 on the TGV Atlantique route in France. TGV-A high speed trains were running at nominal speeds of 300kph. Both the sound exposure level (SEL) and the maximum pass-by sound level (L_{pAFmax}) were quantified in these surveys. The data shown corresponds to 'flatground sites', i.e. sites where the surrounding land was at grade, and the track was positioned solely on ballast up to a maximum height of 0.8m above ground. Data is clearly marked depending whether the receiver was situated downwind or upwind of the railway.

At a given distance from the track, the measured data is characterized by a large spread. At short distances, the spread is mostly due to variations in the source term[90] and small changes in the local topography resulting in some screening. At larger distances, the data for upwind and downwind conditions starts to segregate. The spread observed under downwind conditions was smaller than that for upwind conditions, consistent with ISO 9613-2[91].

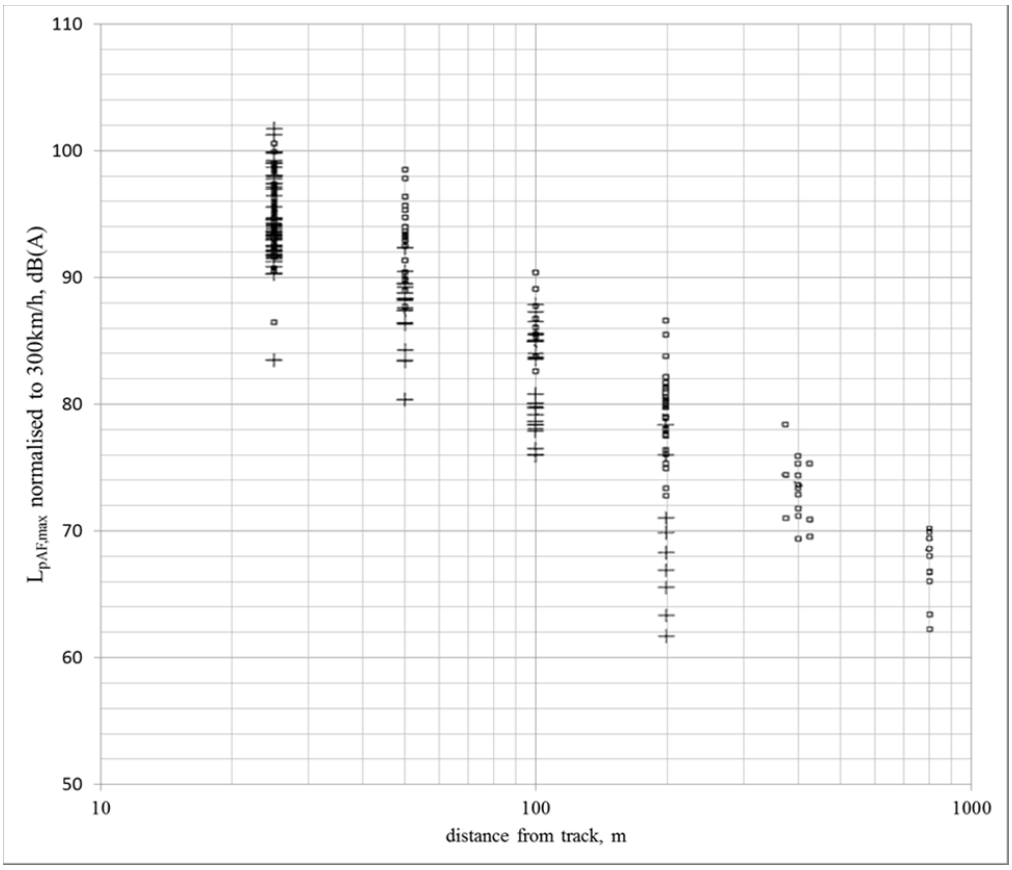
Figure D2 16: Normalised sound exposure levels of high speed train pass-bys in upwind (+) and downwind (-) measurement conditions



[90] Each data point corresponds to a specific train pass-by at a particular location. Variations in wheel and rail roughness across trains and locations give rise in variations in the source term.

[91] International Standards Organisation (1996), *Acoustics – Attenuation of sound during propagation outdoors – Part 2: General Method of Calculation*, International Standard ISO 9613-2: 1996 (E).

Figure D2 17: Normalised maximum sound pressure levels of high speed train pass-bys in upwind (+) and downwind (-) measurement conditions



The measured mean difference in the TGV data for SEL due to wind direction at a distance of 200m from track is over 10dB. Differences of 15dB have also been observed in other research at receivers 1km away from a source due to such effects[92].

Figure D2 18 and Figure D2 19 show the HS2 prediction method compared to the measured data for SEL and L_{pAFmax}, respectively. The solid line represents all three attenuation mechanisms (geometric spreading, air absorption and ground effects). The dotted line only includes geometric spreading and air attenuation, and therefore is representative of long distance propagation effects when screening is present close to the railway.

The curves clearly demonstrate that the HS2 prediction method is representative of downwind conditions, which is consistent with standardized outdoor sound propagation methods such as ISO 9613-2. As discussed previously, the spread around the predictions can be partly attributed to variations in the sound emission levels across trains and measurement sites.

As discussed in the introduction to this subsection, noise levels to the side of the railway can also be due to positive temperature gradients (where noise propagating up into the sky is

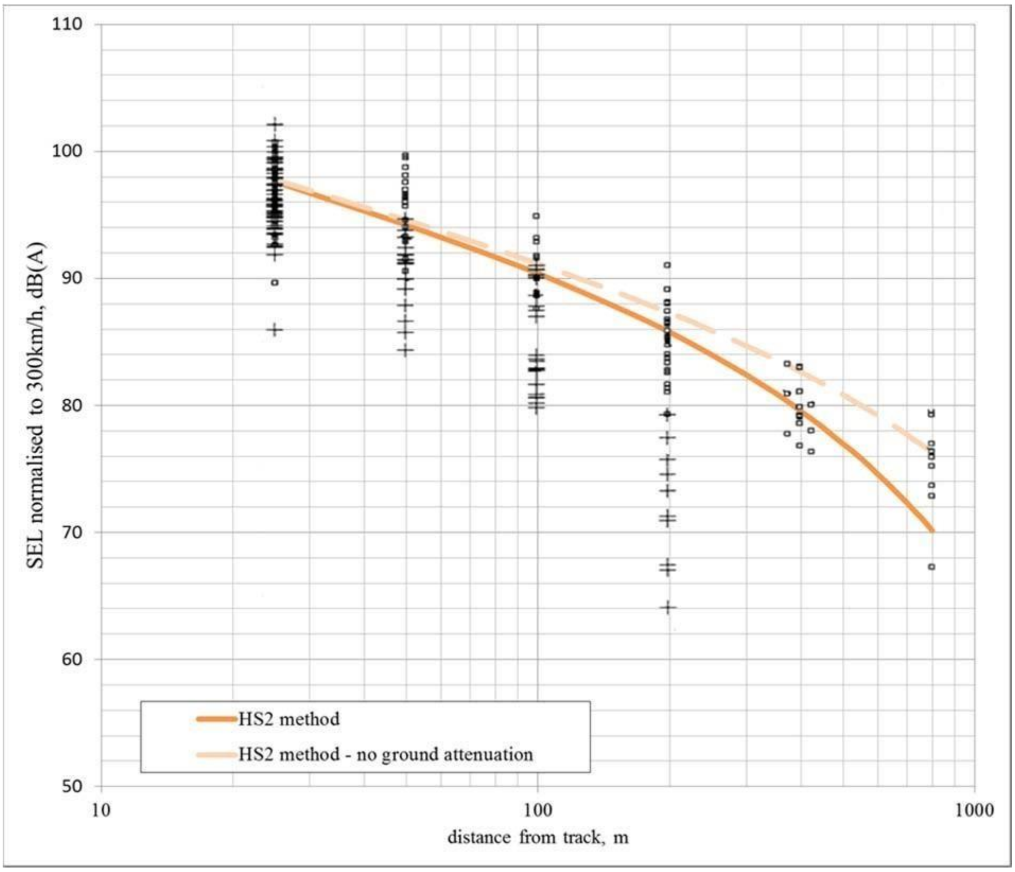
[92] Attenborough, K., Ming, Li and Horoshenkov, K. (2007), *Predicting outdoor sound*, Taylor & Francis.

'bent' down to the ground). These conditions typically occur on still nights with clear skies. According to ISO 9613-2 and the CONCAWE[93] prediction method, well-developed moderate positive temperature gradients (also called ground-based temperature inversions) only occur on still days and result in similar levels of sound increase at distance from the route as downwind conditions.

Therefore, the HS2 prediction method also holds for average propagation during clear calm nights.

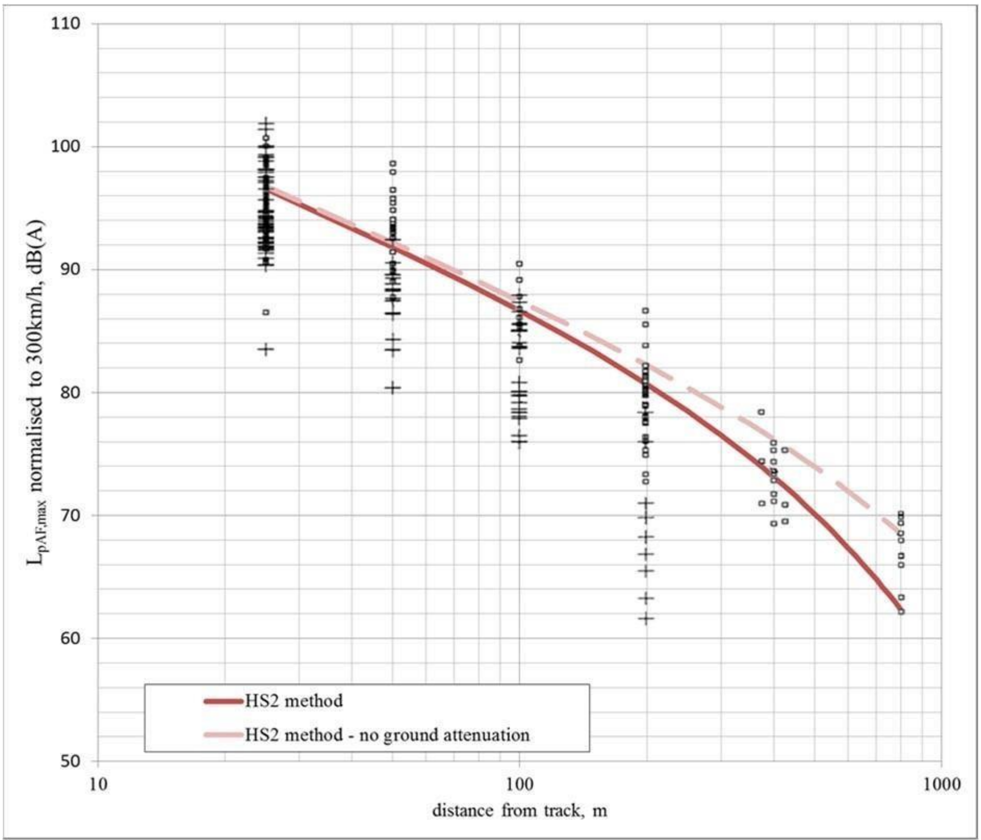
Wind speed and temperature gradients are not independent. For example, very large temperature and wind speed gradients cannot coexist. Therefore, the HS2 method predicts reasonable worst-case sound levels at receptors situated at large distances from the railway.

Figure D2 18: Comparison of HS2 prediction method against measured data, SEL



[93] Manning, C.J. (1981), *The propagation of noise from petroleum and petrochemical complexes to neighbouring communities*, CONCAWE, ATL Report No 4/81.

Figure D2 19: Comparison of HS2 prediction method against measured data, L_{pAFmax}



5.7 Train flows

The assessment of operational sound, noise and vibration from rail sources associated with the Proposed Scheme are based upon the train flows presented in Volume 1, Section 8. In addition to the HS2 train services, these flows include Northern Powerhouse Rail services which are anticipated to operate on the Proposed Scheme.

In the event that the Northern Powerhouse Rail services do not use the Proposed Scheme, it is envisaged that HS2 only services would include train flows as described in the Volume 1, Section 4.3. This scenario includes the fewer trains operating on some parts of the Scheme. An assessment has been undertaken to determine the potential changes in likely significant effects and mitigation as a result of these reductions. Outcomes of this assessment indicate no material change in likely significant operational sound, noise or vibration effects or required noise and vibration mitigation.

Annex E: Operation of stationary systems

1 Purpose

This annex covers the measures that will be put in place to control the noise produced by stationary systems. For the majority of these installations, the level of design detail available at the time of ES preparation was limited, as would be the case at this stage for any infrastructure project of this nature.

The main purpose of this annex is therefore to describe the steps that will be taken to:

- reduce any adverse effects from noise emitted by stationary systems, as far as reasonably practicable; and
- avoid any likely significant adverse effects from noise emitted by stationary systems, by specifying noise limits, set at noise sensitive receptors, which the noise levels cannot exceed.

2 Scope

Stationary systems cover the following installations (where applicable):

- tunnel ventilation including:
  - mechanical ventilation at intervention shafts and tunnel portals; and
  - tunnel draught (pressure) relief shafts;
- trackside equipment (particularly electrical equipment such as auto-transformer feeder stations);
- static equipment located at stations such as mechanical ventilation plant, chillers etc.; and
- static sources located within depots such as mechanical plant, pumps, carriage wash plant, wheel lathes, and stationary trains etc.

Public address/voice alarm (PA/VA) systems or other audible warning systems installed at stations or depots are considered separately because of the particular characteristics and operational requirements associated with such systems.

The level and nature of sound produced by all of these systems and the ability to practicably control the sound emissions will vary significantly. Therefore, this methodology is designed to ensure an appropriate level of consistency in the approach to be applied to the different sources of fixed plant installations, whilst ensuring a suitable level of flexibility to address different situations and circumstances.

3 Approach to mitigation

The assessment methodology used for the sound and vibration assessment is provided in the Section 18 of the SMR (see Volume 5: Appendix CT-001-00001). This explains that 'permanent static equipment will be designed so that it will avoid significant effects and will minimise adverse noise effects as far as sustainable. This was achieved on HS2 Phase One via the assurances provided in Information Paper E22[94]. The effects are therefore considered unlikely to be significant.'

Section 18 of the SMR also identifies that the equivalent Information Paper (E11[95]) will be published alongside the ES. The methodology defined in the Information Paper (E11) is based on the principles set out in BS4142:2014[96]. This methodology requires an assessment of the sound produced by the stationary system under assessment against the background level.

The background sound level, $L_{A90,T}$, is defined in BS4142:2014 as the A-weighted sound pressure level that is exceeded by the residual sound at the assessment location for 90% of a given time interval, T, measured using time weighting F and quoted to the nearest whole number of decibels. The specific sound level, $L_{Aeq,Tr}$, is the equivalent continuous 'A' weighted sound pressure level produced by specific sound source at the assessment location over a given time interval, T. The rating level, $L_{Ar,Tr}$, is the specific level plus any adjustment made for the characteristic features of the sound.

The background sound level used in the assessment at each residential receptor potentially affected by noise from fixed plant will be representative of those occurring during the day and night depending on the sources and their hours of operation.

If the sound is likely to have distinguishing characteristics at the residential receptor, for example, in the case of some fans which may be tonal, a further 5dB correction is then added and the specific level $L_{Aeq,Tr}$ becomes the rating level $L_{Ar,Tr}$.

3.1 Avoiding and reducing significant adverse effects of noise

The aim will be to design, construct, operate and maintain the installations so that the rating level $L_{Aeq,Tr}$ of the fixed installations in normal operation at the worst affected residential

[94] High Speed Two Ltd (2017), *Phase One Information Paper E22: Control of noise from the operation of stationary systems v1.4*.

[95] High Speed Two Ltd (2022), *Phase 2b Information Paper E11: Control of noise from the operation of stationary systems*.

[96] British Standards Institute (2014), *BS4142, Method for rating industrial noise affecting mixed residential and industrial areas*.

receptor, minus the background level ($L_{A90,T}$), is not more than - 5dB, determined in accordance with BS4142:2014.

It is anticipated that it will be reasonably practicable to achieve a rating level minus the background level of not more than -5dB for the majority of the fixed plant that will be required to operate the proposed scheme. The exceptions to this are the tunnel ventilation systems where, in some locations, it may not be reasonably practicable to achieve the lower design aim. Robust procedures will be developed and adopted to ensure that sound from all stationary systems is reduced as far as is reasonably practicable. In this context, reasonably practicable will include consideration of:

- engineering feasibility;
- cost; and
- other design considerations such as the visual appearance of any plant and equipment and any structures which house such plant and equipment.

Where it is not reasonably practicable to achieve a rating level $L_{Ar,Tr}$ minus the background level ($L_{A90,T}$) of not more than -5dB as described above, installations will be designed, constructed, installed and maintained so that, with additional allowances made for calculation uncertainty, under all reasonably foreseeable circumstances the rating level $L_{Ar,Tr}$ of the fixed installations in normal operation at the worst affected residential receptor, minus the existing background level ($L_{A90,T}$) , is not more than +5dB, determined in accordance with BS4142:2014.

The proposed control regime contains two distinct principles. Installations will be designed, constructed, installed and maintained so that:

- the rating level minus the background level is not more than -5dB, as far as reasonably practicable; and
- limiting the rating level not to exceed +5dB above the background level.

The above steps will help to achieve the Government's noise policy (as set out in the Noise Policy Statement for England), in so far as:

- the steps to be taken to control and reduce adverse effects of noise from stationary systems as far as is reasonably practicable is consistent with HS2 Ltd Sustainability Policy and supports the second aim of Government's noise policy, which is to minimise adverse effects on health and quality of life as far as is sustainable; and
- specifying noise limits so as to not exceed a rating level of +5 above the background level will ensure that the likely significant effects will be avoided. This will achieve the first aim of the Government's noise policy which requires, as a primary aim, to avoid significant adverse effects on health and quality of life.

3.2 Low background levels

Special consideration will be given to the assessment of sound from stationary systems when the background level is low, namely where the background levels are less than 30 $L_{A90,T}$. The assessment will have regard to, amongst other things, the absolute level and character of the sound from the stationary system and the absolute level and character of the existing sound environment.

3.3 Non-residential receptors

For non-residential receptors, the methodology set out in BS4142:2014 is not relevant and does not apply to such sources. To reconcile this, sound from stationary systems at noise sensitive non-residential receptors will be controlled to avoid likely significant effects on that receptor. Likely significant effects will be assessed having regard to:

- the type of effect being considered;
- the use and sensitivity of the receptor;
- the building design of the receptor affected;
- guidance on reasonable noise criteria obtained from standards and guidance which are relevant to the particular type of receptor[36,97];
- the existing sound environment at the receptor; and
- the magnitude of the forecast impact including consideration of any acoustic features associated with the sound.

3.4 Background level

The guidance regarding background levels within BS4142:2014 states that to:

- 'Ensure that the measurement time interval is sufficient to obtain a representative value of the background sound level for the period of interest';
- 'The monitoring duration should reflect the range of background sound levels for the period being assessed. In practice, there is no 'single' background sound level as this is a fluctuating parameter. However, the background sound level used for the assessment should be representative of the period being assessed'; and
- 'Measure the background sound level at times when the specific sound source(s) is intended to be operated'.

[97] Department for Education/Education Funding Agency (2014), *Acoustic design of schools: Performance standards*, Building Bulletin 93.

Consequently, any measurement of the background level shall be of sufficient time period to be representative those typically quiet periods occurring at the receptor day and night depending on hours of operation.

Since the ES will be published several years in advance of the design and installation of many stationary systems, the surveys used to define the background levels will need to be carried out at the time of the detailed design. This will ensure that the background level will be established using up-to-date and robust information.

3.5 Steps to be taken to achieve the acoustic requirements

The design aims in this annex will apply to the totality of all stationary systems that affect any noise sensitive receptor. The following steps will be taken to control noise from the stationary systems:

- specifying noise limits and incorporating acoustic requirements into contract documents such that they will apply to the design of all the stationary systems that are to be installed and operated as part of the Proposed Scheme;
- determining the relevant $L_{A90,T}$ levels, to be jointly established with the relevant local authorities;
- procuring, installing and commissioning plant, equipment and machinery, including sound attenuation equipment that meets the specific requirements;
- where it is not possible to achieve the lower design criterion (noise rating to be -5 below background level), details will be provided to the relevant local authority (whose comments will be taken into account) of the steps to be taken to ensure that, under all reasonably foreseeable circumstances, the design process and procurement process for fixed installations is adequate to achieve compliance with the design criteria; and
- before operating the fixed installation, a standard suite of acceptance tests will be completed to demonstrate that the operational sound levels achieve the design criteria.

3.6 Public address and voice alarm systems

Acoustic safeguards in the form of acoustic specifications and other control measures for Public Address (PA) and Voice Alarm (VA) systems will be included as part of the detailed design process to avoid significant noise effects. Correspondingly, an operational sound level assessment will be carried out as part of the detailed design. The noise assessment will include, amongst other things:

- the use and sensitivity of the receptor;
- the building design of the receptor;
- the existing sound environment at the receptor, including pre-existing levels of PA/VA noise;

- the magnitude of the forecast impact including consideration of the background sound;
- the absolute level of sound in relation to any relevant British Standards or other design guides; and
- any acoustic features associated with the sound.

In addition to the measures to be taken to avoid significant effects, all reasonable steps will be taken to design, install, operate and maintain PA and VA systems to minimise potential adverse effects from environmental sound whilst also seeking to ensure that public safety and information requirements are met.

At noise sensitive sites for all non-essential PA, there should be a general presumption against the use of such systems between 23:00 and 07:00. For PA systems used as voice alarms, the intelligibility of the announcement is paramount; during emergencies these provide safety information/alarms to manage the safe evacuation of customers and staff. During emergencies, it may not be possible to meet the acoustic requirements described in this document.

Annex F: Effects of noise on animals

1 Introduction

The assessment of the likely impacts, effects and significant effects of airborne noise on animals are reported as necessary in:

- Agriculture, forestry and soils (Volume 5, Appendices AG-001); and
- Ecology (Volume 2, Community Area reports).

This annex provides a discussion of the available information regarding the effects of noise, and more specifically noise arising from high speed railways, on fauna. The manner in which this information has been applied to the identification of potentially significant effects associated with the Proposed Scheme is also discussed.

2 Review of the effects of anthropogenic sound on UK fauna

Studies on the effects of sound from transportation infrastructure on fauna are predominantly for highways rather than rail infrastructure, whilst much research from the United States (US) is based upon studies considering overflights of military aircraft. Of the published research, studies are dominated by birds and on behavioural impacts rather than on physiological effects or assessment of physical fitness or community level effects (such as conservation status). Conclusions are often limited because:

- there are confounding disturbance factors – the visual effect of low-flying aircraft in the wild may outweigh the auditory effect;
- noise levels seldom are quantified – most studies adequately described the source of noise and the animal response, but the actual noise levels on the ground were unknown or roughly estimated; and
- observers are not trained in acoustics – levels, frequency content, duration often not reported.

A study by the Department for Environment, Food and Rural Affairs (Defra)[98] concluded that a strong evidence base does not exist regarding the potential impact of anthropogenic noise on (non-marine) UK Priority Species and Species of Principal Importance. The report states that:

'Definite conclusions could be made only about the reed bunting (*Emberiza schoeniclus*), which exhibits shifts in song frequency in response to road traffic noise. It is also likely that foraging in brown long-eared bats (*Plecotus auritus*), singing in European robins (*Erithacus rubecula*), house sparrows (*Passer domesticus*), starlings (*Sturnus vulgaris*) and bullfinches (*Pyrrhula pyrrhula*), and the behaviour of common toads (*Bufo bufo*) are affected by road traffic noise to some degree'.

Most studies on birds have addressed the impact of road traffic, with song frequency shifts a common finding at high traffic volumes and sound levels, song frequency shift serving as a potential proxy for fitness. Even so, it is not known that this affects long term population viability. There is much less information on terrestrial mammals, which are underrepresented in published literature. For UK Priority Species and Species of Principal Importance, there are direct studies on badger (*Meles meles*), a water vole (*Arvicola sp.*)[99] and Daubenton's bat (*Myotis daubentonii*)[100]. In relation to bats, the Defra report goes on to state:

[98] Radford, A.N., Morley, E.L. and Jones, G. (2012), *The effects of noise on biodiversity*, Defra Report NO0235.

[99] Iglesias, C., Mata, C. and Malo, J. E. (2011), *The influence of traffic noise on vertebrate road crossing through underpasses*, AMBIO 41, 193–201.

[100] Shirley, M.D.F. et al. (2001), *Assessing the impact of a music festival on the emergence behaviour of a breeding colony of Daubenton's bats (Myotis daubentonii)*, Journal of Zoology, London, 254, 367-373.

'Assessments of the impact of road traffic noise on a species of gleaning bat (the greater mouse-eared bat (*Myotis myotis*)) represent some of the best work on the influence of anthropogenic noise in mammals[101,102]. Rather than using echolocation for the detection and localisation of prey (echolocation is still used for orientation), this species listens for prey-generated sounds and gleans food items from the ground or other substrate. These bats avoid foraging when exposed to playback of road traffic noise, but when noise is unavoidable they show reduced foraging efficiency. Greater mouse-eared bats use the same foraging strategy as the brown long-eared bat[103,104]. It can be inferred therefore that foraging efficiency in this species is likely to be influenced by the presence of road traffic noise. In contrast to gleaning bats, echolocating bats appear to be at relatively low risk of direct impacts of anthropogenic noise[105]. Audiograms indicate that the best frequencies of these bats are high above the dominant frequencies of the main sources of anthropogenic noise (road traffic, aircraft).'

Published studies for reptiles, amphibians, fish and invertebrates are very limited. For reptiles, studies on the sand lizard indicate no behavioural responses observed above 8kHz; the low frequency susceptibility of reptiles may mean this group is vulnerable to road traffic and other similar sources for which low frequencies are dominant. Studies on amphibians show variable responses with some species showing plastic responses in calling behaviours and others which either do not do so, or are unable to do so. For the common toad, best frequencies are below 2kHz, within the dominant range of most studied anthropogenic noise sources; in response to white noise, the common toad has been shown to demonstrate increased locomotion and escape behaviours[106].

There is very little knowledge on the impact of anthropogenic sound on terrestrial invertebrates, and the Defra 2012 report[98] identified no direct studies within the UK and only one paper found worldwide. The hearing sensitivity and capability of the vast majority of invertebrate species remain unknown. Crickets and grasshoppers (*Orthoptera*) are considered potentially sensitive to anthropogenic sound though their best frequencies (4 – 20kHz) may be above that of the dominant frequencies for transportation noise.

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[101] Schaub, A., Ostwald, J. and Siemers, B. M. (2008), *Foraging bats avoid noise*, Journal of Experimental Biology, 211, 3174-3180.

[102] Siemers, B. and Schaub, A. (2011), *Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators*, Proceedings of the Royal Society, B. 278, 1646-1652.

[103] Swift, S.M. and Racey, P.A. (2002), *Gleaning as a foraging strategy in Natterer's bat Myotis nattereri*, Behavioural Ecology and Sociobiology, 52, 408–416.

[104] Siemers, B M. and Swift, S.M. (2006), *Differences in sensory ecology contribute to resource partitioning in the bats Myotis bechsteinii and Myotis nattereri (Chiroptera: Vespertilionidae)*, Behavioural Ecology and Sociobiology, 59, 373-380.

[105] Tressler, J. and Smotherman, M.S. (2009), *Context-dependent effects of noise on echolocation pulse characteristics in free-tailed bats*, Journal of Comparative Physiology, A 195, 923–934.

[106] Llusia, D., Márquez, R. and Beltrán, J.F. (2010), *Non-selective and time-dependent behavioural responses of common toads (Bufo bufo) to predator acoustic cues*, Ethology, 116, 1146-1154.

A review of existing research[107] by Hanson identifies reported effects of noise upon different animals, including interference with communication, masking predation, startle and fright, along with other physiological effects. Hearing acuity differs significantly between species and consequently no uniform frequency weighting has been established to best evaluate response. In this absence, the A-weighted sound pressure continues to be used and a number of studies are cited using various noise sources which suggest that levels of around 100 are associated with an observable effect for disturbance in domestic and wild birds (effects such as accelerated hatching, nest abandonment and panic responses), domestic animals (reduction in cattle milk production, changes hormonal composition in swine) and startle/panic effects in terrestrial mammals.

Studies specifically investigating the effects of sound from high speed rail and other rail transport are few but it is important to note that high speed train pass-by have a different signature to sound from heavily used highways where the sound levels are more continuous and more likely to result in masking and communication interference effects than startle or panic effects. There are however some similarities between the characteristics of noise arising from high speed rail and sub-sonic low flying aircraft, including rapid onset rates, high maximum sound pressure levels and spectra dominated by low frequencies. It is however acknowledged that high speed train pass-by are more regular, fixed in terms of route and more consistent in terms of signature, so that habituation may be more likely to occur than for irregular and less predictable over-flights by aircraft.

Hanson suggests that the Sound Exposure Level (SEL), which accounts for both sound pressure level and duration of the event, is the most useful predictor of responses in both wildlife and domestic animals. SEL can be described as the sum of the sound energy over the duration of a noise event normalised to a one second reference period.

Some of the research studies indicate that some animals habituate to noise after several repetitions of exposure. Previous exposure to noise levels below 100 served to eliminate panic among turkeys, and swine showed initial alarm followed by indifference to aircraft noise greater than 100(A).

With regard to the effects of noise on horses, the International League for Protection of Horses issued advice in relation to the Airdrie-Bathgate Railway Improvements Bill[108] which indicated that horses usually became habituated to repeated noise including that from passing trains, although it was acknowledged by the Promoter of the scheme that there may be a short period of adjustment.

Based on the preliminary indications identified in these studies regarding the most appropriate descriptor, threshold levels for disturbance and habituation characteristics of a

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[107] Hanson, C.E. (2007), *High speed train noise effects on wildlife and domestic livestock*, Proc IWRN 9.

[108] Committee Report reporting the findings of the Scottish Parliament Committee hearings into Airdrie-Bathgate Railway Improvements Bill, and the Environmental Statement submitted with the Chiltern Railways (Bicester to Oxford) Improvements Order application (December 2009). Available online at: http://www.parliament.scot/parliamentarybusiness/PreviousCommittees/15387.aspx.

small number of species, the US Department of Transportation, Federal Railroad Administration (FRA) has identified interim criteria for identifying the potential impact of high speed rail noise on animals in wilderness and farming areas.

The FRA interim criteria[71] have been defined as follows:

- noise metric – A-weighted sound pressure level (dB(A));
- noise descriptor – SEL;
- threshold for impact – 100(A); and
- habituation – no general criterion (insufficient information on species specific responses).

It should be noted that these criteria are based on responses observed in birds and mammals only. Criteria are not yet fully developed to the point where dose-response relationships can be fully described for different animal species.

3 Review of the effects of sound on livestock

In their second Special Report of Session 2015-16, the House of Commons Select Committee on the High Speed Rail (London – West Midlands) Bill requested that HS2 Ltd undertake a study to understand how livestock might be affected by the operation of HS2 Phase One. HS2 Ltd agreed to undertake the requested study and the findings are presented in report Noise effects on Livestock[109]. The report identifies an additional screening criteria for HS2 train sound levels at an animal's ear:

- daytime 70dB $L_{pAeq,\ 16hour}$;
- night-time 60dB $L_{pAeq,\ 8hour}$; and
- during a train pass-by 90dB L_{pAFmax}[110].

[109] High Speed Two Ltd (2017), *Phase One Noise effects on Livestock*, Issue 2. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/590162/Noise_Effects_on_Livestock.pdf.

[110] Where the animal is habituated to the source then this screening criterion is not applicable.

4 Potential effects arising from the Proposed Scheme

4.1 Ecological receptors

Having considered the foregoing literature, the approach to assessment of noise effects on fauna arising from operation of the Proposed Scheme has been developed on the basis of the FRA interim criterion[111]. A screening distance equivalent to SEL 100(A) has therefore been used to identify relevant ecological species along the route which may potentially be subject to significant adverse effects.

For a 400m high speed train (source sound level as defined in Annex D of this appendix) travelling at a speed of 360kph and in the absence of natural or man-made wayside barriers, the SEL 100(A) contour lies at a distance of approximately 25m from the track. For lower speed sections of the route, or where wayside features reduce the level of sound, this distance is reduced. Consideration of the FRA guidance suggests that adverse effects on relevant wildlife species are less likely to occur beyond this distance.

Relevant ecology receptors along the route were identified within the screening distance from the Proposed Scheme. Consideration was then given to the line speed and the presence of wayside barriers at that location in order to confirm whether the SEL 100dB(A) criterion will be exceeded.

The assessment of effects is detailed within the relevant Volume 2 CA report, or Volume 5 Appendix, taking into consideration relevant factors for each specific receptor, such as sensitivity and value of species.

No specific, separate approach has been defined for the assessment of construction sound. Effects arising from construction noise are likely to be temporary and reversible and more detailed assessment is likely to be necessary only for particularly sensitive receptors such as sites of special scientific interest (SSSI) designated for waterbirds where large numbers of sensitive species could be affected during the construction period.

4.2 Livestock

In conjunction with the Agriculture and land use assessment, livestock receptors have been identified and predicted operational airborne noise levels presented for these locations and assessment.

Relevant agricultural livestock receptors along the route were identified in conjunction with the agriculture and land use assessors and predicted operational airborne noise levels are

[111] U.S. Department of Transportation. (2012), *High-speed ground transportation - Noise and Vibration Impact Assessment*, Federal Railroad Administration.

provided in the relevant Volume 5 appendices (Appendices SV-003) and where the additional screening criteria is exceeded then an assessment is provided in the Agriculture and land use section of the relevant Volume 2 Community Area reports.

No specific, separate approach has been defined for the assessment of construction sound. Effects arising from construction noise are likely to be temporary and habituation is shown to occur reasonably quickly.

Annex G: Assessment of effects (route-wide)

1 Introduction

In this annex, assessment consideration has been given to a number of potential noise and vibration effects which apply on a route-wide basis to either construction or operation of the Proposed Scheme (or both). The assessment of all other noise and vibration effects is presented in the relevant Volume 2 Community Area report with further information provided in the relevant Volume 5 appendices (Appendices SV-002 and SV-003).

2 Route-wide source specific effects

2.1 Ground-borne noise and vibration: tunnel boring machines (TBM)

To excavate the tunnels TBM will be used, which can generate ground-borne noise and vibration as the rotating head of the TBM 'cuts' through the ground. TBM can therefore give rise to ground-borne noise and vibration impacts, albeit only for short periods of time (generally a matter of days) at any individual receptor.

The material cut away by the TBM (excavated material) is generally carried to the surface by conveyors, which in themselves generate no significant ground-borne noise or vibration outside of the tunnel.

The ground-borne noise and vibration generated by a number of TBM drives has previously been measured and reported in TRL Report 429[51]. Since then, further experience has been gained from tunnel drives in projects such as the Channel Tunnel Rail Link (now HS1[10]), London Cable tunnels, Thames Water's River Lee tunnel Southern Water's new wastewater tunnels and most recently Crossrail[112].

The empirical data and experience described above includes TBM of a similar size to those proposed for the Proposed Scheme driving through similar ground conditions.

For each pair of HS2 tunnels, where two TBM are required it has been assumed that the two drives will be staggered in time, so it is likely that there will be no cumulative effect in terms of ground-borne noise and vibration. However, the passage of two machines will increase the duration of any impact predicted. This is considered in more detail below.

Ground-borne vibration - building damage: Where the tunnels are shallowest, the predicted vibration generated by TBM operation is approximately 2mm/s at overlying locations. This magnitude of vibration is substantially lower than the (conservative) criterion specified in Table A 3 in Annex A of this document, below which there is no risk of cosmetic damage to buildings.

Ground-borne noise and vibration - using the prediction methodologies of TRL 429 it has been estimated that disturbance (annoyance) of occupants and users of buildings: sound and vibration inside properties will be perceptible for a few days either side of when the TBM passes closest to overlying properties. The effects of ground-borne noise and vibration from TBM on building occupants will be short-term and hence they are not considered to be significant. This is further supported by the recent evidence from the Crossrail project[113].

[112] Cobbing, C. (2013), *Groundborne noise and vibration from tunnel boring*, Presentation to Institute of Acoustics Midlands Branch.

[113] Crossrail project website. Available online at: https://www.crossrail.co.uk/#.

The adverse effects arising from TBM ground-borne noise and vibration are not considered to be significant for residential properties, office buildings, hotels, schools, colleges, libraries and the residential and office parts of hospitals and laboratories.

2.2 Ground-borne noise and vibration: temporary construction railway

Materials (including tunnel lining segments) and equipment are likely to be transported from the surface to the TBM using a temporary railway which travels at relatively low speeds. It should be noted that other methods of moving material and equipment are available, but the temporary railway is the most likely and is also the method which represents a reasonably foreseeable worst-case in terms of ground-borne noise or vibration impacts. Supply trains can also be used to transport spoil from the TBM to the surface, but it is more likely to be undertaken by conveyor. The temporary railway can generate ground-borne noise and vibration in the same way as the permanent railway.

The trains and track used for these temporary operations are generally different from permanent rail systems. It is not reasonably practicable for the temporary track laid for construction to provide the same level of ground-borne noise and vibration control as the permanent track laid for operation. Firstly, the temporary track needs to be installed quickly and in short rail lengths as the TBM advances. Secondly, the temporary track is at a different level and line than the permanent track as the concrete tunnel invert is not in place and cannot be put in place as the tunnel is bored. Thirdly, the temporary track doesn't have to be designed to the same standards as the permanent track, for example the permanent track has to remain safe for public operation and have low maintenance requirements over a long design period, e.g. 60 years.

Temporary track is therefore fundamentally different from permanent track and has to be installed and removed. The economics and sustainability of this process need to be considered and this often results in track components being recycled between tunnelling projects. Additionally, the rolling stock for the construction and permanent stages is very different, with the permanent railway incorporating more ground-borne noise and vibration control.

The Crossrail Environmental Statement[114] showed that adoption of the measures listed below will be likely to result in the criteria for the performance specification for residential buildings, offices, hotels, schools, colleges, hospitals, laboratories and libraries not being breached at any location by the movement of TBM supply trains during construction:

[114] Department for Transport (2005), *Crossrail Environmental Statement.* Available online at: https://www.crossrail.co.uk/about-us/crossrail-bill-supporting-documents/environmental-statement?folder=/l0/111.

- the use of smooth track (new rail without corrugations or discrete irregularities) will be installed at the start of the works with joints achieving variation in rail height of not more than 2mm;
- where appropriate the use of adequate elasticity in the track support system in order to reduce the transmission of vibration and ground-borne noise from the passage of rail vehicles, for example the use of resilient rail pads in the fastening system between the rails and the sleepers;
- a speed limit on construction trains of 15kph;
- all diesel locomotives used will be fitted with efficient exhaust silencers; and
- a maintenance programme that ensures the condition of the track does not deteriorate over time thereby causing noise in breach of the agreed threshold.

Crossrail's detailed design and delivery has shown that further 'tuning' of the above measures on a location–by–location basis can ensure that the ground-borne noise from the movement of TBM supply trains that is experienced by sensitive receptors (such as residential dwellings, theatre, large auditorium/concert hall, recording studio, etc.) does not either exceed the levels from existing railway and road transport operations, or the levels impact criteria defined in this ES, whichever is the higher noise level.

On this basis that HS2 will employ similar measures to those used by Crossrail, which are specified in the Code of Construction Practice (CoCP), and therefore significant effects from supply train ground-borne noise and vibration are considered unlikely. Hence no quantitative assessment is considered necessary. Where required, significant effects will be avoided through the specification of requirements.

3 Route-wide receptor specific effects

3.1 Public rights of way

Public rights of way (PRoW) are by their nature transitory in their use, with users not staying in any one location for any length of time. Levels of noise from the construction and operation of the proposed scheme will vary as the right of way moves closer to and further from the Proposed Scheme. Noise effects will generally be reduced by the control measures defined in the CoCP during construction. During operation, noise levels on PRoW will be reduced by engineering cuttings, landscape earthworks provided to reduce the visual impact of the scheme and noise mitigation provided to protect adjacent residential and non-residential receptors.

Train sound from the Proposed Scheme is intermittent. Significant noise effects are therefore considered unlikely on PRoW during either construction or operation.

3.2 Moorings

Temporary and static moorings have, by their nature, transitory use with users staying only for short periods of time (e.g. a few hours at a time). People generally use such moorings when starting on journeys to other locations along the waterways network or whilst en-route between locations. Increases in noise due to construction and operation of the Proposed Scheme may adversely affect the acoustic character of the area around such facilities. However, as users will not be exposed to any increased noise for long periods any adverse noise effects on users are not considered significant.

Facilities that permit occasional overnight stays such as static moorings, camp sites or caravan parks but do not permit long term residential use are not considered to be significantly affected by noise due to construction or operation of the Proposed Scheme due to the short and irregular exposure to noise from the Proposed Scheme.

Permanent moorings are treated as residential, but allowing for the lower sound insulation provided by the 'shell' of a boat compared to a house.

3.3 Public open spaces and outdoor community facilities

Public open spaces[115] and outdoor sports/recreation community facilities (e.g. football pitches, golf courses) are, by their nature, transitory in their use. Outdoor sport activities are

[115] Except where the open spaces are those that the National Planning Practice Guidance identifies may partially offset a noise effect experienced by residents at their dwellings due to the Proposed Scheme as

not significantly affected by noise at the levels associated with construction or operation of the Scheme, even very close to the route or the construction sites. Increases in noise due to construction and operation of the Proposed Scheme may adversely affect the acoustic character of the area around such facilities. However, as users will not be exposed to any increased noise for long periods the adverse noise effects on users are not considered significant. Quantitative assessments have been undertaken for any outdoor community facility formally identified or designated as a quiet area under Government regulations[116] or policy[9] but none have been located in the study area for this assessment.

Some commercial receptors (e.g. equestrian facilities) include outdoor areas used by animals. The International League for Protection of Horses has issued advice which suggests that horses usually became accustomed to repeated noise including that from passing trains. Additionally, with the mitigation measures proposed for the construction and operation of the Proposed Scheme, the noise levels identified (see Annex F) as resulting in risk of startle will not be exceeded in the wayside of the route. It is therefore considered that any adverse effects of noise on outdoor riding, equestrian centres and horse racing courses, will not be significant. The effect of noise is also rarely significant on other animal species as set out in Annex F.

reported in Volume 2 community area reports or where the area falls within a Landscape Character Area identified as currently enjoying high tranquillity as reported and assessed in Volume 2 community area reports.

[116] *The Environmental Noise (England) Regulations 2006*. HMSO.

Annex H: Health evidence base

1 Overview of noise effects

Sound is produced by mechanical disturbance propagated as a wave motion in air or other media. Noise is unwanted sound. According to the WHO, 'in some situations, but not always, noise may adversely affect the health and well-being of individuals or populations'[117]. More recently, the WHO has stated that ‘environmental noise is a threat to public health, having negative impacts on human health and well-being’[118].

Hearing loss does not occur from typical exposure to environmental noise, it is more commonly associated with occupational exposure to much higher noise levels. In the everyday environment, the response of an individual to both sound and noise can be behavioural; psychological or physiological, collectively referred to as non-auditory effects. There are a wide range of non-auditory health effects that may be associated with exposure to environmental noise, although the pathways, strength of association, and possible causal mechanisms for these are not fully understood. Examples of non-auditory health effects which have been linked to environmental noise include annoyance, sleep disturbance, cardiovascular and metabolic effects, mental health effects, reduced performance, communication and learning effects.

Previous reviews of the links between everyday noise exposure and longer-term health outcomes have proposed various conceptual ‘models’ to try to simplify and describe the complexities of the subject and to help to design and improve future research. One such model that encompasses many of the known and suggested health outcomes is that proposed by Babisch in 2002[119] and updated in 2013[120], reproduced here as Figure H 1.

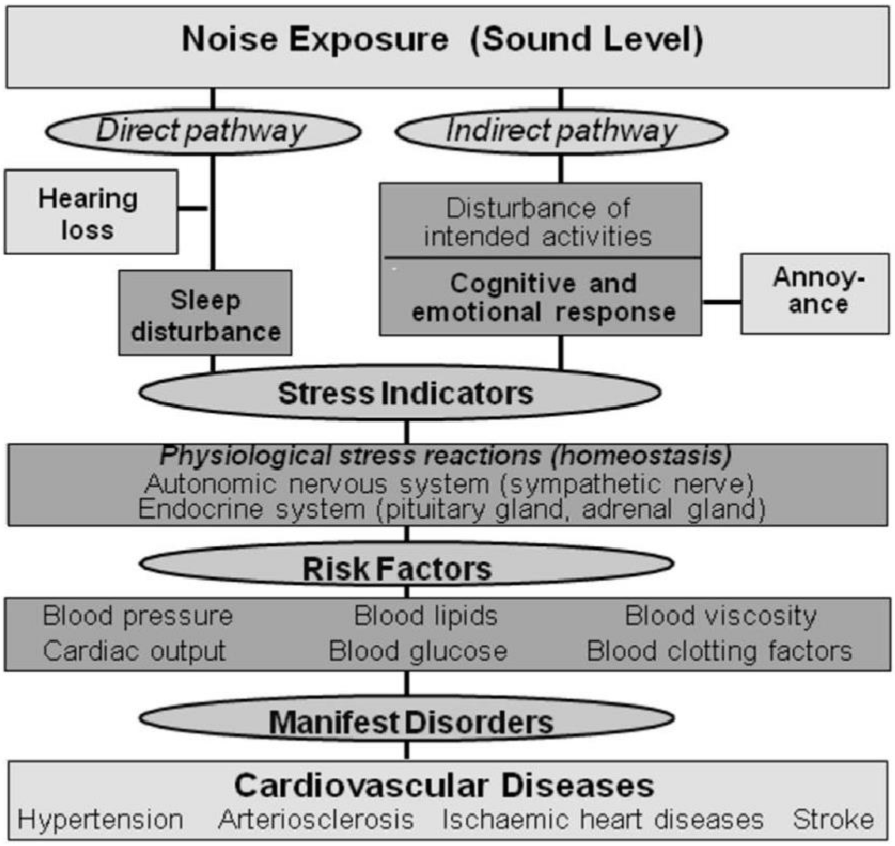
[117] World Health Organization (1995), *Community Noise*, Edited by B. Berglund & T. Lindvall.

[118] World Health Organization (2009), *Night Noise guidelines for Europe*.

[119] Babisch, W. (2002), *The noise/stress concept, risk assessment and research needs*, Noise Health 4(16):1-11.

[120] Babisch, W. (2013), *Exposure-response curves of the association between transportation noise and cardiovascular diseases - an overview*, First International Congress on Hygiene and Preventative Medicine, Belgrade, Serbia.

Figure H 1: Noise effects model (after Babisch et al., 2002)



The Babisch model seeks to describe the cause-effect chain (i.e. noise- annoyance- physiological arousal- biological risk factors- disease). This theoretical model initially differentiates between the direct (non-conscious) and indirect (conscious and subjective) effect pathways, but both are depicted acting through an intermediate stress reaction stage which then, depending on individual risk factors, may ultimately lead to disease outcomes. To quote Babisch[121] 'Causality in epidemiology can never be proven. It is a gradual term of which evidence is increasing with increasing number of facts. However, the magnitude of effect, presence of dose-response relationship, consistency with other studies in different populations and with different methodology, and coherence (biological plausibility) are commonly accepted arguments for a causal relationship'.

The Government's Noise Policy Statement for England[8] (NPSE) acknowledges that noise can affect people's quality of life and that there is evidence linking noise with direct health effects. The NPSE clearly states the long term vision of Government noise policy which is 'to promote good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development'.

[121] Babisch, W. (2006), *Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased*, Noise Health, 8(30):1-29.

Environmental noise, and in particular road traffic noise, remains a major environmental problem affecting the health and wellbeing of millions of people in Europe[122]. There is significantly more literature available on the health and wellbeing effects of road traffic noise and air transport noise than of conventional rail noise, and relatively little research on the effects of high speed rail noise.

Establishing exposure-response relationships for environmental noise can be subject to significant uncertainty. The effects of exposure vary between different types of noise source and are compounded by other environmental factors, as well as personal factors such as sensitivity, attitude and pre-existing health conditions. There is a great deal of variation between individual responses to noise, and variation between studies. Typically, there is no threshold of effect, but the effect increases slowly with increasing noise exposure.

Notwithstanding the variability between individual studies recent years have seen an increasing number of 'meta- analyses' where the results of individual studies are combined to estimate the exposure-response relationships and to quantify the strength of the association across studies, for example, the percentage of the population highly annoyed at a certain noise exposure level. This approach has been used in the influential work of Miedema[123] which subsequently formed the basis of the European Union Position Paper on exposure-response relationships between transport noise and annoyance[124] as well as underpinning other key WHO[125] and European Environment Agency[126] documents in this field, as well as the recent WHO Environmental Noise Guidelines for the European Region[127].

[122] European Environment Agency (2020), *Environmental Noise in Europe*. Available online at: https://www.eea.europa.eu/publications/environmental-noise-in-europe.

[123] Miedema, H.M. and Vos, H. (1998), *Exposure-response relationships for transportation noise*, Journal of the Acoustical Society of America,104(6), 3432-3445. Available online at: https://doi.org/10.1121/1.423927.

[124] European Commission (2002), *Position paper on dose response relationships between transportation noise and annoyance*. Retrieved from Luxembourg Office for Official Publications of the European Communities, ISBN 92-894-3894-0. Available online at: http://www.noiseineu.eu/en/2928-a/homeindex/file?objectid=2705&objecttypeid=0.

[125] World Health Organization (2011), *Burden of disease from environmental noise - Quantification of healthy life years lost in Europe*. Available online at: https://www.who.int/publications/i/item/burden-of-disease-from-environmental-noise-quantification-of-healthy-life-years-lost-in-europe.

[126] European Environment Agency (2010), *Good practice guide on noise exposure and potential health effects*, EEA Technical Report 11/2010.

[127] World Health Organization (2018), *Environmental Noise Exposure for the European Region*, Copenhagen: Denmark: World Health Organization Europe.

2 Annoyance

Annoyance is the most frequently reported problem caused by exposure to transport noise and is often the primary outcome used to evaluate the effect of noise on communities. There is some evidence that attitudes and opinions about some sources of transport noise may have been changing over the past twenty or thirty years. A widely cited example is a study on people's attitude to aircraft noise by Jansen et al.[128], who observed an increase in annoyance at a given level of aircraft noise exposure. There is, however, no equivalent study for conventional or high speed railway noise. but the recent WHO Environmental Noise Guidelines for the European Region which includes studies published between 2000-2014 found a stronger exposure-response relationship between conventional railway noise and annoyance than had previously been estimated by the Miedema curves in 2002 (Figure H 1)[129].

On the other hand, there is some evidence from Grimwood et al.[130,131] and Notley et al.[132] which suggests that people's attitude towards railway noise in the UK has not significantly changed since 1990. Notley reports the results from the UK National Noise Attitude Survey undertaken during 2012 which indicate that around 30% of those who hear road traffic noise report being moderately, very or extremely bothered, annoyed or disturbed whereas about 2% of those who hear noise from trains or railway stations (albeit a much smaller sample in the study) report this same level of moderate, very or extreme disturbance.

Acoustic factors, such as the source of the noise and sound level, account for only some of the annoyance response observed: other factors such as interference with activities, ability to cope, noise sensitivity, expectations, anger, attitudes to the source, and beliefs about whether noise could be reduced by those responsible influence annoyance responses[129,133].

The WHO systematic review identified only one study of high speed trains and annoyance, which showed a lower threshold for annoyance, as well as a much steeper relationship than found for studies of conventional railway noise (Figure H 2[129]). Studies have found significant

[128] Janssen, S., Vos, H., Eisses, A. and Pedersen, E. (2011), *Trends in aircraft noise annoyance*, Journal of the Acoustical Society of America 129 (4), pp 3746-3753.

[129] Guski, R., Schreckenberg, D. and Schuemer, R. (2017), *WHO Environmental Noise Guidelines for the European Region: A systematic review on environmental noise and annoyance*, International Journal of Environmental Research and Public Health, 14(12), 1539.

[130] Grimwood, C., Skinner, C. and Raw, G. (2005), *The UK Noise Climate 1990-2001: Population Exposure and Attitudes to Environmental Noise*, Applied Acoustics Vol 66 (2) pp231-243.

[131] Grimwood, C., Skinner, C. and Raw, G. (2002), *The UK national noise attitude survey 1999/2000*, Noise Forum Conference. Available online at: http://www.bre.co.uk/pdf/NAS.pdf.

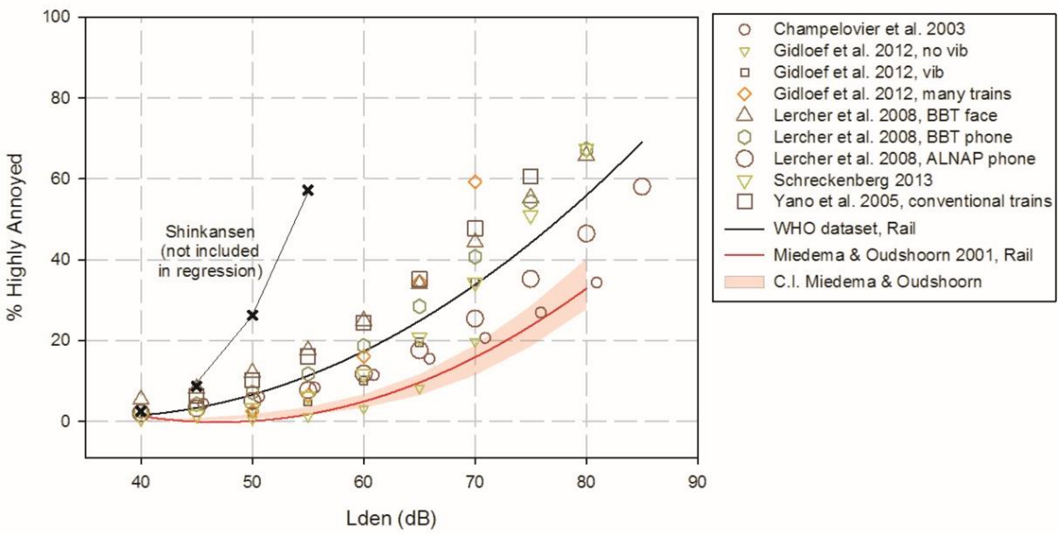
[132] Notley, C. et al. (2013), *The UK national noise attitude survey 2012 - the sample, analysis and some results*, Proc. Internoise.

[133] World Health Organization (2000), *Transport, environment and health*, World Health Organization Regional Publications, European Series No.89, p9.

variability between studies of high speed trains and annoyance[134]. A recent review found that the prevalence of being highly annoyed varied greatly across six social surveys of four Shinkansen lines in Japan over the past 20 years, for both L_{dn} and L_{max} exposure for those living in detached wooden framed houses (Figure H 3)[135]. Higher annoyance was reported for those who also experienced vibration (vertical measurements at ground). Both noise and vibration contributed to annoyance. Unfortunately, this study did not meta-analyse the results of the six studies to derive a combined exposure response relationship.

An earlier review by Fenech et al.[134] found no evidence that the different spectral content of high speed train sound might affect annoyance and no difference in noise annoyance between traditional and high speed rail for the same timetable frequency[136]. A study from Japan found that annoyance from Shinkansen schemes with appropriate noise and vibration mitigation measures was comparable to that represented by the Miedema curve[137].

Figure H 2: Exposure-response relationship for railway noise (L_{den}) and being highly annoyed from the WHO 2017 (Guski et al., 2017)



On-going research into noise annoyance from high speed rail suggests a number of modifying factors may be influencing response. These factors include distance from railway, onset rate, combined effects of noise and vibration, and number of train pass-bys (especially for people living very close to the railway). For new railway schemes there is also evidence that uncertainty about the future may increase annoyance whilst subsequent habituation

[134] Fenech, B., Cobbing, C., Greer, R. and Marshall, T. (2013), *Health effects from high-speed railway noise - a literature review*, Proc. Internoise.

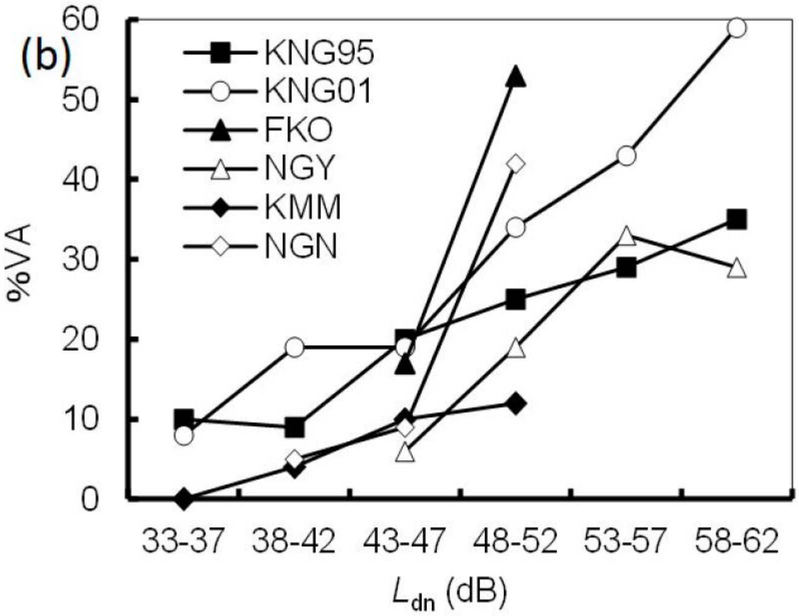
[135] Yokoshima, S., Morihara, T., Sato, T. and Yano, T. (2017), *Combined Effects of High-Speed Railway Noise and Ground Vibrations on Annoyance*, International Journal of Environmental Research and Public Health, 14(8). Available online at: https://doi.org/10.3390/ijerph14080845.

[136] Botteldooren, D., De Coensel, B. and De Muer, T. (2005), *Experimental investigation of noise annoyance caused by high speed trains*, Proc. 12th International Congress on Sound & Vibration.

[137] Oka, S., Murakami, Y., Tetsuya, H. and Yano, T. (2013), *Community response to a step change in railway noise and vibration exposures by the opening of a new Shinkansen Line*, Proc. Internoise.

with the changed situation may reduce annoyance. In one study in France 75% of the sample living close to TGV-Atlantique became accustomed to the noise within one year[134].

Figure H 3: Exposure-response function for being highly annoyed by high speed railway noise (L_{dn}) from six Japanese studies (Yokoshima et al., 2017)



A study by Oka et al.[137] reports a case study (in Kumamoto, Japan) of changes in community response to railway noise exposure caused by a shift from conventional express trains to 'super-express' high speed trains on the Kyushu Shinkansen Line. The authors report that the noise and vibration exposures were almost the same before and after the shift, but that community annoyance decreased after the opening. The authors suggest this may have been due to the inclusion (and related communication) of effective noise and vibration countermeasures in the scheme.

Overall, in recent years evidence for a higher annoyance response in relation to high speed railways in comparison to traditional railways has increased but there remains a need for further evidence from more contexts and for meta-analyses to overcome uncertainty in the evidence.

3 Sleep disturbance

A WHO Report[138] cites numerous studies that detail the effects of transport noise on sleep, as does the systematic review carried out for the revised WHO Noise Guidelines for the European Region[139]. Studies have shown that noise can affect sleep in terms of immediate effects (e.g. arousal responses, sleep state changes, awakenings, body movements, total wake time, autonomic responses), after-effects (e.g. sleepiness, daytime performance, cognitive function) and long-term effects (e.g. self-reported chronic sleep disturbance). Sleep disturbances can be quantified either by subjective means or by monitoring physiological or behavioural awakenings. However, it is important to recognise that people are not conscious of their own bodies when asleep and studies[161,140] have reported inconsistencies between the physiological effects of noise exposure (objective measures) and the subjects' perceived disturbance. At least one study[141] found no statistically significant relation between the subjective assessment of perceived sleep quality and noise data (whole night averages and single event levels). In fact, self-reported sleep disturbance is often considered to be a poor indicator of actual sleep disturbance and associated health effects. Nonetheless, self-reported sleep disturbance is an important indicator of community perception of night noise effects.

An updated exposure-response function for railway noise and self-reported sleep disturbance, was published to inform the WHO Guidelines for the European Region, based on meta-analyses of studies published between 2000 and 2015[142]. A 10dB L_{night} increase in railway noise exposure was associated with a three-fold increase in the odds of reporting sleep disturbance. Figure H 4 shows the exposure-response functions (ERFs) derived for different noise sources, which was stronger for railway noise than predicted in the previous Miedema exposure-response relationship used by the European Union (EU) (red line)[143]. Whilst the WHO ERFs are the most current available for self-reported sleep disturbance, they do not include any studies of high speed railway noise.

[138] World Health Organization (2009), *Night Noise Guidelines for Europe*, Copenhagen: Denmark: World Health Organization Europe.

[139] Basner, M. and McGuire, S. (2018), *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep*, Int J Environ Res Public Health, 15(3):519.

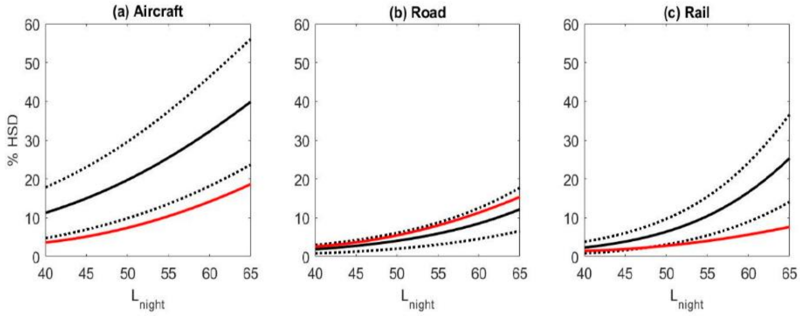
[140] Elmenhorst, E.M., Griefahn, B., Rolny, V. and Basner, M. (2019), *Comparing the Effects of Road, Railway and Aircraft Noise on Sleep: Exposure (-) Response Relationships from Pooled Data of Three Laboratory Studies*, Int J Environ Res Public Health, 16(6).

[141] Griefahn, B., Schuemer-Kohrs, A., Schuemer, R., Moehler, U., and Mehnert, P. (2000), *Physiological, subjective, and behavioural responses during sleep to noise from road and rail traffic*, Noise Health 2000;3:59-71.

[142] Basner, M. and McGuire, S. (2018), *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep*, Int J Environ Res Public Health, 15(3):519.

[143] Miedema, H.M. and Vos, H. (2007), *Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies*, Behavioural Sleep Medicine, 5(1), 1-20.

Figure H 4: Exposure Response Function for aircraft noise, road traffic noise and railway noise for self-reported sleep disturbance from the WHO 2017 (black line): red line = (Miedema & Vos 2007) (Basner & McGuire, 2018)



Research has been carried out into noise- induced sleep disturbance using objective techniques such as EEG and polysomnography. In 1982 Rice and Morgan[144] published a synthesis of studies on noise-induced sleep disturbance, in which they concluded that: 'Source specific noise disturbance of sleep may be expected to become significant once the outdoor night- time (22:00-07:00 hour) L_{Aeq} exceeds 55dB providing the peak levels do not exceed about 75-80. Higher L_{Aeq} values up to 60dB may be allowed providing the peak levels do not exceed 85(A), and the number of such events is less than about 20 per night. In this latter context, special account also needs to be taken of the 2200-2400 hour going-to-sleep period, when particularly noisy events should be avoided.' This conclusion was based on the best available studies at that time, and included data from social surveys, and laboratory and field studies using objective measures of awakenings (electroencephalograms (EEG)).

According to the European Environment Agency[126], the best quantitative insight into awakenings observed using polysomnography comes from research undertaken by the German Aerospace Centre (DLR) on aircraft noise. Two similar and related subsequent studies, have been published that investigate railway noise, as well as aircraft noise and road traffic noise using the same methodology as the DLR study[145,146]. Elmenhorst et al. 2012[145] found that railway noise did not lead to prolonged sleep latencies or to impaired sleep efficiency compared to normal population values. Important modifying factors include the number and duration of train pass-bys; pass-by sound rise time (onset rate); distance to railway; and incidence of perceptible vibration.

[144] Rice, C.G. and Morgan, P.A. (1982), *A synthesis of studies on noise-induced sleep disturbance*, ISVR Memorandum No. 623.

[145] Elmenhorst, E.M. et al. (2012), *Examining nocturnal railway noise and aircraft noise in the field: sleep, psychomotor performance, and annoyance*, Science of the Total Environment, 424, 48-56. Available online at: https://pubmed.ncbi.nlm.nih.gov/22444069/.

[146] Elmenhorst, E.M., Griefahn, B., Rolny, V. and Basner, M. (2019), *Comparing the Effects of Road, Railway, and Aircraft Noise on Sleep: Exposure(-)Response Relationships from Pooled Data of Three Laboratory Studies*, International Journal of Environmental Research and Public Health,16(6). Available online at: https://www.mdpi.com/1660-4601/16/6/1073.

A recent analysis of all three studies found that the probability of awakening from equal max A-weighted sound pressure level events differed between noise sources, and increased in the order of aircraft noise<road<railway noise[146] (Figure H 5), confirming earlier findings railway noise has a higher awakening probability[147]. This might be explained by the high frequency components for railway noise events which are more likely to induce event-related arousals and increase heart rate[146,148] vibrations from passing trains, as well as fluctuations and sharpness associated with freight trains. Whether this relationship would hold for high speed railway noise or exposure that does not include freight trains remains unknown.

The earlier DLR and Elmenhorst study were pooled in the meta-analyses undertaken for the WHO to derive exposure response relationships for railway noise, road noise and aircraft noise and objective awakenings (Figure H 6)[149]. For all transportation modes there was a significant association between L_{ASmax} indoor of single events and the probability of an additional awakening. The threshold for the probability of an additional awakening was between 33-38dBA for all transportation modes. The estimates for railway noise, road traffic noise and aircraft noise were similar, indicating a 31-34% increase in odds for awakening for a 10dB increase in noise. However, these findings are inconsistent with other evidence discussed earlier, which suggests that railway noise and road traffic noise result in a greater probability of awakening than aircraft noise events at the same level[150,151].

All the evidence available for objective sleep disturbance are based on studies of healthy samples and the relationships may underestimate the effects of noise on objective sleep in the general population[152]. The possibility of underestimation is supported by a study which found considerable individual differences in susceptibility to noise-induced sleep

[147] Basner, M., Brink, M. and Elmenhorst, E.M. (2012), *Critical appraisal of methods for the assessment of noise effects on sleep*, Noise Health 2012;14:321-9.

[148] Smith, M., Amann, R., Cavadino, A., Raphael, D., Kearns, R., Mackett, R., Mackay, L., Carroll, P., Forsyth E., Mavoa, S., Zhao, J., Ikeda, E. and Witten, K. (2019), *Children's Transport Built Environments: A Mixed Methods Study of Associations between Perceived and Objective Measures and Relationships with Parent Licence for Independent Mobility in Auckland, New Zealand*, International Journal of Environmental Research and Public Health, 16(8):1361. Available online at: https://doi.org/10.3390/ijerph16081361.

[149] Additional awakenings are calculated by subtracting 'spontaneous' awakenings not attributed to a noise event from the total number of awakenings.

[150] Basner, M., Müller, U. and Elmenhorst, E.M. (2011), *Single and combined effects of air, road and rail traffic noise on sleep and recuperation*, SLEEP(1):11-23.

[151] Elmenhorst, E.M., Griefahn, B., Rolny, V., and Basner, M. (2019), *Comparing the Effects of Road, Railway, and Aircraft Noise on Sleep: Exposure–Response Relationships from Pooled Data of Three Laboratory Studies*, International Journal of Environmental Research and Public Health, 16: 1073. Available online at: https://doi.org/10.3390/ijerph16061073.

[152] Basner, M. and McGuire, S. (2018), *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep,* International Journal of Environmental Research and Public Health, 15(3):519.

disturbance even in a healthy study population[153]. No studies of high speed railway noise and objective awakenings have been identified.

Figure H 5: Probability of EEG awakenings due to noise from railway noise, road traffic noise and aircraft noise (after Elmenhorst et al., 2019)

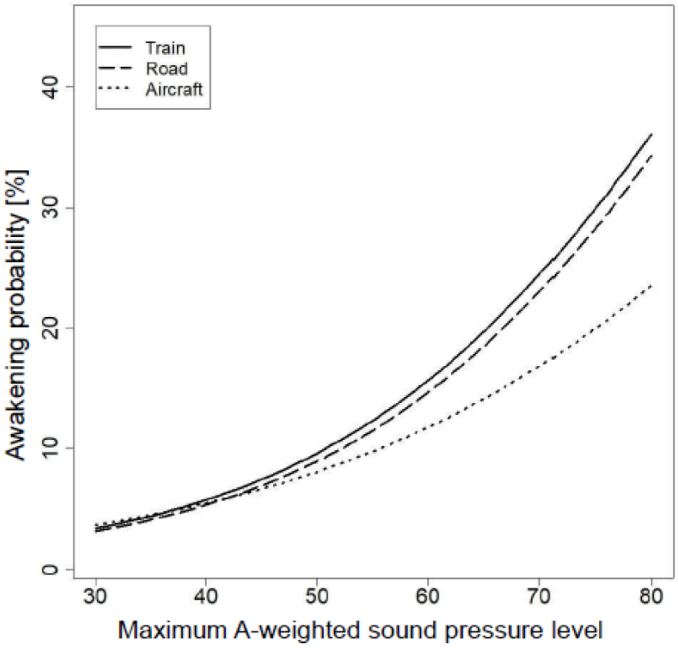
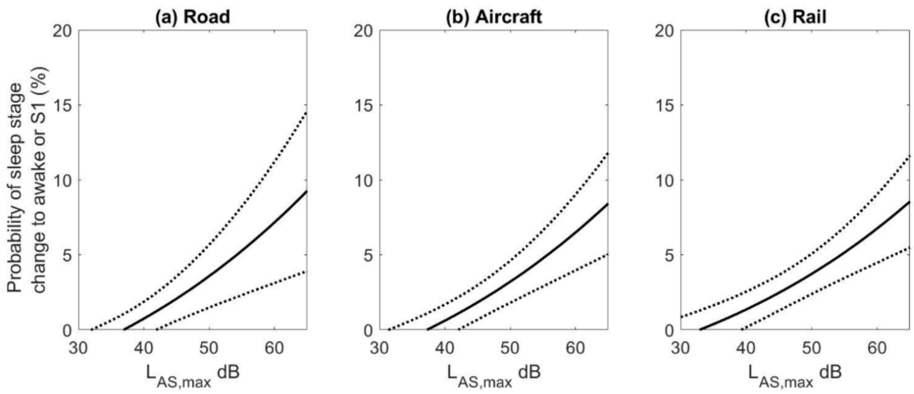


Figure H 6: Exposure response function for aircraft noise, road traffic noise and railway noise for additional awakenings from the WHO 2017



The long-term health consequences of noise induced EEG awakenings are not fully understood. There are some suggestions that humans may be able to adapt to a certain level of noise induced awakening without negative health consequences. In this context, it is necessary to consider the level of impact on sleep resulting from noise induced EEG

[153] McGuire, S., Müller, U., Elmenhorst, E.M. and Basner, M. (2016), *Inter-individual Differences in the Effects of Aircraft Noise on Sleep Fragmentation*, Sleep, 39(5), 1107–1110. Available online at: https://doi.org/10.5665/sleep.5764.

awakenings in comparison to those that will naturally occur in the absence of noise. For example, one additional awakening per night is a value that has been suggested by Basner et al.[154], and is currently used by the Leipzig/Halle airport in Germany, to manage the risk of sleep disturbances associated with aircraft noise[155].

In particular, Basner et al. recommended that:

- on average there should be less than one additional EEG awakening induced by aircraft per night;
- awakenings recalled the following morning should be prevented as much as possible; and
- there should be no relevant impairment to the process of falling asleep again.

In order to prevent recalled awakenings Basner et al. proposed that the maximum noise level[156] inside the bedroom should not exceed 65dB. The impairment to the process of falling asleep again is suggested to be dependent upon the number of events and the time interval between events. Assuming a sound level difference between indoors and outdoors of 15dB (representative of a bedroom façade with a partially open window), the most recent findings by Basner and Elmenhorst are generally consistent with the findings by Rice and Morgan in the 1980s and the aircraft study in the 1990s.

Recent research has examined the DLR concept in the context of railway noise[157,158,159]. Re-analysing the NORAH and DEUFRAKO studies, on behalf of the Hessian Ministry of the Environment in Germany it was found that the L_{Aeq} on its own was not enough to explain the percentage with high sleep disturbance and that L_{Amax} should also be taken into account[158]. The study suggests that that L_{Amax} on its own or in combination with the number of trains may better characterise high sleep disturbance[158]. To protect sleep, it was proposed within the context of the German night-time limit for noise of 49dB(A) that for railway noise the difference between the L_{Amax} and L_{Aeq} should be limited to 15dB(A) and the maximum number of awakenings should not exceed three[158].

[154] Basner, M., Samel, A. and Isermann, U. (2006), *Aircraft noise effect on sleep: application of the results of a large polysomnographic field study*, The Journal of the Acoustical Society of America, 119(5), 2772-2784.

[155] Leipzig/Halle Airport (2010), *Current Noise Pollution Protection Programme*. Available online at: https://www.leipzig-halle-airport.de/en/company/community/environmental-protection/current- noise-pollution-protection-programme-863.html.

[156] Quoted values for the maximum noise refer to the L_{pmax} sound pressure level.

[157] Mohler, E. et al. (2018), *Maximum sound pressure level as an additional criterion for the assessment of railway noise at night: Acoustic criteria for the maximum-level in regulations*, Euronoise Crete.

[158] Schreckenberg, D., Belke, C. and Spilski J. (2018), *The Development of a Multiple-Item Annoyance Scale (MIAS) for Transportation Noise Annoyance*, International Journal of Environmental Research and Public Health, 15(5):971. Available online at: https://doi.org/10.3390/ijerph15050971.

[159] Muller, U., Schreckenberg, D., Mohler, U. and Liepert, M. (2018), *Maximum-level as an additional criterion for the assessment of railway noise at night: Derivation of a wake-up protection criterion for standards and regulations*, Euronoise Crete.

4 Cardiovascular disease

Whilst the association of environmental noise with a range of cardiovascular disease outcomes, including coronary heart disease, Ischaemic Heart Disease (IHD), Myocardial Infarction and high blood pressure, have been studied it remains the case that there are few studies that examine the cardiovascular effects of exposure to rail traffic noise[160,161]. No studies assessing high speed railway noise in relation to cardiovascular disease have been identified.

A recent meta-analysis for the WHO Environmental Noise Guidelines for the European Region estimated ERF between railway noise and hypertension, IHD and stroke[161]. A further meta-analysis updated the WHO estimates for IHD adding three additional studies[162]. The findings from both these meta-analyses (Table H 1) suggest there is no statistically significant association between railway noise and the cardiovascular outcomes. For example, the results for IHD suggest there is no significant association for a 10dB increase (L_{den}) in railway noise, with the effect across studies ranging from 1% - 18% increase in risk. However, given the small number of studies examined, the WHO concluded that further research is very likely to have an impact on the estimate of the effect. A recent review undertaken for Defra[163], identified further relevant papers and suggested that an update of the meta-analyses on hypertension and ischaemic heart disease is warranted to clarify whether and how the results of the newly found studies affect the conclusions of the WHO review. However, the paper did not undertake a meta-analysis.

Uncertainty in estimate of effects for cardiovascular outcomes is also evident in individual study evidence. Recent studies support a lack of association between railway noise and hypertension [164,165], thereby agreeing with the WHO review but other studies have found an

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[160] World Health Organization (2011*), Burden of Disease from Environmental Noise*.

[161] Van Kempen, E., Casas, M., Pershagen, G. and Foraster, M. (2018), *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary*, International Journal of Environmental Research and Public Health, 15(2), 379. Available online at: https://doi.org/10.3390/ijerph15020379.

[162] Vienneau, D., Eze, I., Probst-Hensch, N. and Roosli, M. (2019), *Association between transportation noise and cardio-metabolic diseases: an update of the WHO meta-analysis*, Proceedings on the 23rd International Congress on Acoustics, Acchen, Germany.

[163] Van Kamp, I., Simon, S., Notley, H., Baliatsas, C. and Van Kempen, E. (2020), *Evidence Relating to Environmental Noise Exposure and Annoyance, Sleep Disturbance, Cardio-Vascular and Metabolic Health Outcomes in the Context of IGCB (N): A Scoping Review of New Evidence*, International Journal for Environmental Research and Public Health, 17, 3016.

[164] Zeeb, H., Hegewald, J., Schubert, M., Wagne,r M., Dröge, P., Swart, E. and Seidler, A. (2017), *Traffic noise and hypertension-results from a large case-control study*, Environmental Research, 157, 110–117.

[165] Pyko, A. et al. (2018), *Transportation noise and incidence of hypertension*, International Journal of Hygiene and Environmental Health, 221(8), 1133–1141. Available online at: https://doi.org/10.1016/j.ijheh.2018.06.005.

increased risk of cardiovascular mortality[166,167] and risk of stroke[168], thereby disagreeing with the WHO review conclusions.

Table H 1: The combined effect size and study types included from Van Kempen et al., 2018 and Vienneau et al., 2019 meta-analysis, assessing the association between rail traffic noise and cardiovascular health outcomes

Cardiovascular outcome	Combined effect size (RR) per 10dB (L_{den}) Short term impact classification	Studies included (2000 – 2015)
Van Kempen et al., 2018		
Prevalence of Hypertension	1.05 (95% CI 0.88 – 1.26)	5
Incidence of Hypertension	0.96 (95% CI 0.88 – 1.04)	1
Prevalence of Ischaemic Heart Disease	1.18 (95% CI 0.82 – 1.68)	4
Prevalence of Stroke	1.07 (95% CI 0.92 – 1.25)	1
Vienneau et al., 2019		
Prevalence of Ischaemic Heart Disease	1.01 (95% CI 0.99 – 1.03)	3

A recent Defra systematic review found no studies that examined the relationship between railway noise exposure and dementia and concluded that there was no effect of road traffic noise on the incidence of vascular dementia[169]. The review included evidence from a large-scale UK study which found that the association between road noise and an incidence diagnosis of dementia became non-significant after adjustment for air pollution[170]. This evidence is more recent than that which informed the WebTAG guidance which quantified

[166] Héritier H. et al. (2017), *Transportation noise exposure and cardiovascular mortality: a nationwide cohort study from Switzerland*, European Journal of Epidemiology.

[167] Héritier H. et al. (2019), *A systematic analysis of mutual effects of transportation noise and air pollution exposure on myocardial infarction mortality: a nationwide cohort study in Switzerland*, European Heart Journal, Volume 40, Issue 7, 14: 598–603. Available online at: https://doi.org/10.1093/eurheartj/ehy650.

[168] Seidler, A.L., Hegewald, J., Schubert, M., Weihofen, V.M., Wagner, M., Dröge, P., Swart, E., Zeeb, H. and Seidler, A. (2018), *The effect of aircraft, road, and railway traffic noise on stroke – results of a case-control study based on secondary data*, Noise & Health, 20(95), 152–161.

[169] Clark, C., Crumpler, C. and Notley, A.H. (2020), *Evidence for Environmental Noise Effects on Health for the United Kingdom Policy Context: A Systematic Review of the Effects of Environmental Noise on Mental Health, Wellbeing, Quality of Life, Cancer, Dementia, Birth, Reproductive Outcomes, and Cognition*, International Journal Environmental Research and Public Health, 17(2),393. Available online at: https://doi.org/10.3390/ijerph17020393.

[170] Carey, I.M., Anderson, H.R., Atkinson, R.W. et al. (2018), *Are noise and air pollution related to the incidence of dementia?* A cohort study in London, England.

effects on dementia, via the pathway from hypertension to vascular dementia as opposed to evaluating the direct association between noise and dementia[171].

There are no reported studies that specifically investigate possible associations between cardiovascular disease and noise from high speed rail. It should also be borne in mind that hypertension is one of many risk factors for cardiovascular disease, other risk factors include genetic predisposition, age, sex, socio-economic status, lifestyle and risk-taking behaviour. Exposure to air pollutions may also be a relevant factor.

In 2016 an analysis of the NORAH (Noise-Related Annoyance, cognition and Health) case-control study, which was based on secondary data, investigated the risks of myocardial infarction related to traffic noise, using a data set of 1,026,658 over-40-year-olds insured with three health insurers in the Rhine-Main region of Germany. The association between a diagnosis of myocardial infarction for road, rail and aircraft noise. The relationship between myocardial infarction and 24-hour continuous noise level tended to be stronger for road and rail traffic noise than for aircraft noise. For railway noise, the odds of incidence of myocardial infarction was found to be similar that estimated by the Babisch relationship which is the Defra recommended method for estimated the change in the risk of incidences of AMI due to railway noise[172].

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[171] Harding, A.H. et al. (2011), *Quantifying the links between environmental noise related hypertension and health effects*, Health and Safety Laboratory.

[172] Department for Environment Food & Rural Affairs (2014), *Environmental Noise – Valuing impacts on sleep disturbance, annoyance, hypertension, productivity and quiet*. Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/380852/environmental-noise-valuing-imapcts-PB14227.pdf.

5 Mental health, wellbeing and quality of life

The terms mental health, wellbeing and quality of life are separate but related constructs, but the terms are often presented interchangeably. Mental Health and wellbeing are defined by the WHO as a 'state of well-being in which every individual realises his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community'[173]. Mental health typically refers to the presence of psychological or psychiatric illness, whereas wellbeing refers to positive psychological health such as sense of fulfilment and life satisfaction.

Quality of life is related to both mental health and wellbeing. The World Health Organization define quality of life as 'as an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person's physical health, psychological state, personal beliefs, social relationships and their relationship to salient features of their environment'[174].

Noise exposure is hypothesised to influence mental health through stress responses activating the endocrine system and autonomic nervous system[119] which can lead to increased levels of catecholamines (adrenaline/noradrenaline) and cortisol[119,175,176]. Noise exposure over prolonged periods of time can cause continuous activation of these biological responses, which can lead to the decline of mental health, wellbeing and quality of life. Annoyance, as a result of noise exposure, could also directly activate stress hormones. Exposure to night-time noise may also lead to low mood and fatigue due to interference with sleep[177].

Recent systematic reviews undertaken for the WHO[178] and Defra[169] concluded that for adults there was evidence for a harmful association of railway noise on a range of outcomes including self-reported health and quality of life; on medication intake for treatment of anxiety and depression; and on interview measures of anxiety and psychological symptoms. No evidence was identified for railway noise effects on self-reported depression, anxiety and psychological symptoms. Both reviews acknowledge the small number of studies available

[173] World Health Organization (2004), *Promoting Mental Health; Concepts emerging evidence and practice*, Summary report, Geneva.

[174] World Health Organization (2012), *The World Health Organization Quality of Life*. Available online at: https://www.who.int/tools/whoqol.

[175] Stansfeld, S. and Clark, C. (2011), *Mental Health Effects of Noise*, In J. O. Nriagu (Ed.), Encyclopedia of Environmental Health, pp. 683-689, Burlington: Elsevier.

[176] Stansfeld, S. and Clark, C. (2015), *Health effects of noise exposure in children*, Current Environmental Health Reports, 2(2), 171-178.

[177] Health Council of the Netherlands (1994), *Noise and Health*, The Hague, The Netherlands.

[178] Clark, C. and Paunovic, K. (2018), *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Quality of Life*, Wellbeing and Mental Health International Journal of Environmental Research and Public Health, 15(11).

for railway noise and identified no studies of high-speed railway noise on these outcomes. However, these reviews did not produce exposure-response functions for the associations. A recent meta-analysis[179] of three studies of railway noise found no association with depression risk per 10dB increase in railway noise (L_{den}) (OR 1.02 95%CI 0.95 - 1.08). Similarly, a meta-analysis of three studies assessing railway noise and anxiety[180] found no association between railway noise and anxiety (OR 1.01 95%CI 0.97 – 1.05).

The available results from the systematic reviews and meta-analysis present some evidence to suggest that railway noise is associated with adverse mental health, wellbeing and quality of life in adults. Further longitudinal research will provide clarity on inconsistencies in evidence observed to date and clarify the strength of the relationship.

The WHO systematic review identified that there was evidence for a harmful association of railway noise on emotional and conduct disorders in children but not for an effect on hyperactivity[178]. Similarly, a recent meta-analysis found an association between railway noise (L_{den}) and some outcomes (peer-relationship problems/total difficulty scores) but not for other behavioural outcomes such as hyperactivity/inattention, conduct problems, or emotional symptoms[181].

The results from systematic review and meta-analysis present limited evidence to suggest that railway noise has adverse effects on mental health in children although inconsistencies are observed across outcomes and the number of studies is limited. More research is needed to draw firm conclusions on railway noise associations with adverse mental health wellbeing and quality of life in children.

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[179] Hegewald, J. et al. (2020), *Traffic Noise and Mental Health: A Systematic Review and Meta-Analysis*, International Journal of Environmental Research and Public Health, 17(17), 6175. Available online at: https://www.mdpi.com/1660-4601/17/17/6175/htm.

[180] Lan, Y., Roberts, H., Kwan, M.P. and Helbich, M. (2020), *Transportation noise exposure and anxiety: A systematic review and meta-analysis*, Environmental Research, 191, 110118. Available online at: https://doi.org/10.1016/j.envres.2020.110118.

[181] Hjortebjerg, D. et al. (2016), *Exposure to road traffic noise and behavioral problems in 7-year-old children: a cohort study*, Environmental Health Perspectives, 124(2), 228–234. Available online at: http://dx.doi.org/10.1289/ehp.1409430.

6 Cognitive impairment in schoolchildren

A WHO document on Burden of Disease[182] references three European studies on cognitive impairment in schoolchildren from transport noise. Of the three studies, only one included railway noise within scope, and this was in a specific narrow Alpine valley setting where it was difficult to separate road and rail noise. There is evidence from the other two studies (Munich and RANCH)[183,184] of an association between aircraft noise exposure and cognitive performance in schoolchildren (reading comprehension and recognition memory), but the same association was not seen for road traffic noise. Neither aircraft noise nor road traffic noise affected sustained attention, self-reported health, or mental health[184].

The Burden of Disease document and a separate document by the European Environment Agency (EEA)[126] present a hypothetical exposure-response for cognitive impairment based upon these studies. The relationship assumes 100% of children are cognitively impaired at a very high noise level (95 L_{dn}) and that none are affected at a safe low level (50 L_{dn}). Within this range cognitive impairment is assumed to follow a sigmoidal function, as shown in Figure H 7.

Systematic reviews carried out for the WHO[185] and Defra[169] in 2018 and 2020 did not identify any recent studies that assessed the effects of railway noise on cognition or that established updated exposure-effect relationships.

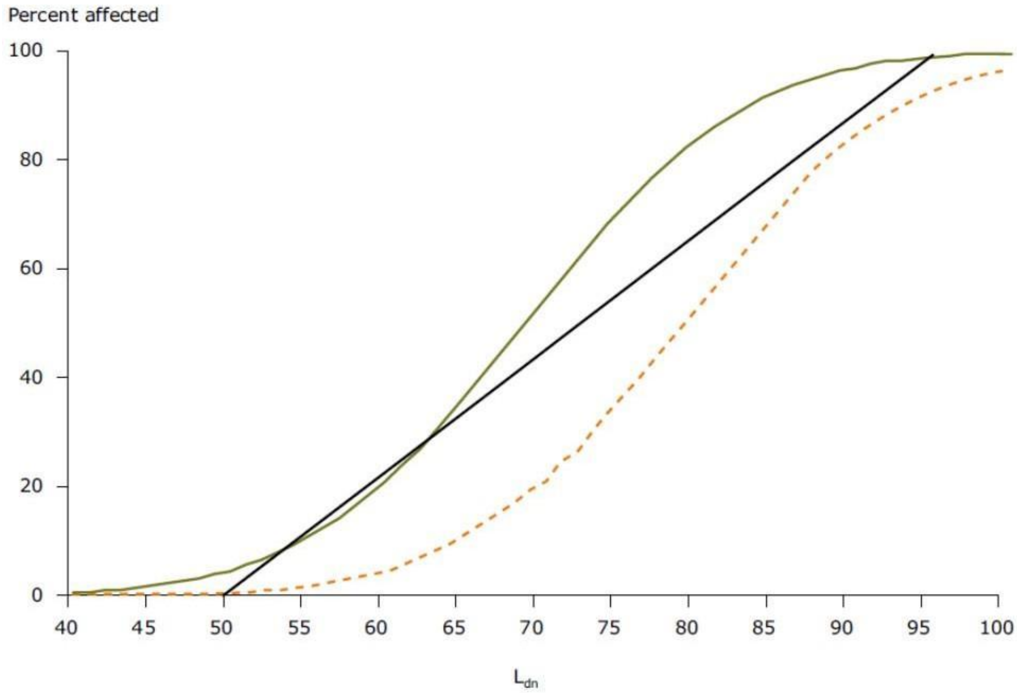
[182] World Health Organization (2011), *Burden of Disease from Environmental Noise*, World Health Organization, Europe.

[183] Hygge, S., Evans, G.W. and Bullinger, M. (2002), *A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren*, Psychological Science, 13(5), 469-74.

[184] Stansfeld, S.A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Ohrström, E., Haines, M.M., Head, J., Hygge, S., Van Kamp, I. and Berry, B.F., RANCH study team (2005), *Aircraft and road traffic noise and children's cognition and health: a cross-national study*, Lancet. 10;365(9475):1942-9.

[185] Clark, C. and Paunović, K. (2018a), *WHO Environmental Noise Guidelines for the European Region: A systematic review on environmental noise and cognition*, International Journal of Environmental Research and Public Health, 15, 285.

Figure H 7: Hypothetical association between aircraft noise level and cognitive impairment in children, assuming all children are cognitively impaired at 95 L_{dn} and that none are affected at 50 L_{dn}. A straight line connecting the two points will be an underestimation of the real effect, which is assumed to follow a sigmoidal distribution (dashed yellow curve). The assumed association (solid green curve) shows that the percentage of children affected is 20% at 55-65 L_{dn}, 45-50% at 65-75 L_{dn} and 70-85% above 75 L_{dn} (after European Environmental Agency, 2020)



Data from the Munich and RANCH studies was reanalysed by Stansfeld et al.[186], who concluded that night aircraft noise exposure did not appear to add any cognitive performance impairment to the cognitive impairment induced by daytime aircraft noise alone. Based on the data from the two studies, the authors suggested that the school should be the main focus of attention for protection of children against the effects of aircraft noise on school performance.

It has been suggested that the intensity, location of source, variability and unpredictability of aircraft noise is likely to result in a greater effect on children's reading than road traffic noise, which was of a more constant level in the studies. Whilst railway sound occurs as events and may therefore be considered more similar to aircraft exposure than road traffic noise exposure, there are important differences between railway and aircraft noise events. For an equivalent distance, high speed train sound levels are lower than aircraft. Trains operate on fixed tracks and therefore train sound events are more repeatable than aircraft where flight paths will vary due to a range of factors, particularly meteorological conditions. For modern passenger railways the character of the train sound is consistent and regular as the train approaches the listener and after it passes. For aircraft the character not only

[186] Stansfeld, S.A., Hygge, S., Clark, C. and Alfred T. (2010), *Night time aircraft noise exposure and children's cognitive performance*, Noise and Health 12(49), 255-62.

changes as it passes as a function of the type of plane but also for each type of plane the sound character will vary as the pilot/aircraft responds to meteorological conditions (e.g. change in engine speed due to varying wind conditions during approach to an airport). The duration of an audible aircraft sound event is longer than for a train due to differences in the directivity of the two sources and also because topography, building and noise barriers screen train sound.

The weakness in the evidence relative to railway noise means that it will not be possible to quantify this effect. However, the absence of evidence does not mean that there is an absence of effect or that there is not a potential risk. Consequently, a high level risk assessment based upon noise exposure levels above 50dB day (07:00 – 23:00)[187] outside schools from the Proposed Scheme, where noise levels from the Proposed Scheme will be equal to, or higher than existing noise levels, will be appropriate.

[187] Based on the assumed train movements during the day and night, the $L_{pAeq,0700\text{-}2300}$ is approximately equal to L_{dn}.

7 Vulnerable groups

Few studies specifically examine vulnerabilities for the effects of railway noise on health. The European Environment Agency recently reviewed the evidence, which is summarised in Table H 2 alongside additional evidence, drawing on studies of aircraft noise and road traffic noise.

Table H 2: Table showing the summary of evidence for groups vulnerable to the effects of environmental noise on health

Group	Vulnerability	References
Children	May be more vulnerable to noise effects on sleep and are additionally exposed to noise whilst sleep during the evening period. May be more susceptible to noise effects on mental health and cognition as they may lack coping strategies and have less control over the environment than adults and are in a sensitive developmental period.	(M. Basner and McGuire, 2018)[188] (WHO, 2009)[189] (WHO, 2018)[190] (Van Kamp and Davies, 2013)[191] (Clark and Paunović, 2018)[185]
Elderly	May be more vulnerable to noise effects on sleep as sleep becomes more fragmented. May be more vulnerable to noise effects on cardiovascular health. May be more prone to suffering cardiovascular effects of noise than younger adults as risks for cardiovascular conditions increase with age. They may also spend more time at home or have lived in a property exposed to noise for many years.	(Van Kamp and Davies, 2013)[191] (European Environment Agency, 2020)[192]
Noise sensitive	Noise sensitive individuals might be more susceptible to psychological effects due to noise.	(Marks and Griefahn, 2007)[193] (S. A. Stansfeld, 1992)[194] (S. Stansfeld and Clark, 2019)[195]

[188] Basner, M. and McGuire, S. (2018), *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep.* Int J Environ Res Public Health.15(3):519.

[189] WHO (2009), *Night Noise Guidelines for Europe*, Cophenhagen, Denmark: World Health Organization Europe.

[190] World Health Organization (2018), *The World Health Organization Guidelines for Environmental Noise Exposure for the European Region*. Copenhagen: Denmark: World Health Organization Europe. Available online at: http://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf.

[191] Van Kamp, I. and Davies, H. (2013), *Noise and health in vulnerable groups: a review*. Noise and Health, 15(64), 153-159.

[192] European Environment Agency (2020), *Environmental Noise in Europe 2020*, Luxembourg: Publications of the European Union.

[193] Marks, A. and Griefahn, B. (2007), *Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise*, Noise Health. 9(34), 1-7.

[194] Stansfeld, S.A. (1992), *Noise, noise sensitivity and psychiatric disorder: epidemiological and psychophysiological studies*, Psychological Medicine, Suppl 22, 1-44.

[195] Stansfeld, S.A. and Clark, C. (2019), *Mental Health Effects of Noise*. In J.O. Nriagu (Ed.), Encyclopedia of Environmental Health 2nd Edition (4). Burlington: Elsevier.

Group	Vulnerability	References
Existing poorer health	Those with existing chronic conditions may have a higher risk of heart disease as a result of traffic noise than those without existing poor health. Those with a history or who currently experience poor mental health may be more vulnerable to the effects of environmental noise on mental health, wellbeing or quality of life.	(Babisch, 2006)[196] (European Environment Agency, 2020)[197]
Ethnicity	South Asian individuals are particularly vulnerable to cardiovascular ill-health. In the UK, individuals of black ethnicity are more likely to live in the 50dB contour of railway noise.	(Tonne et al., 2018)[198]
Social deprivation	Groups with lower socioeconomic position are exposed to higher levels of railway noise. In the UK the odds of living in the 50dB contour of railway noise is higher for respondents with high levels of deprivation. Those with lower socioeconomic position may also have poorer housing, pre-existing housing conditions or fewer opportunities for coping with noise or access to quiet areas. Noise effects on children's cognition may be stronger for children who are not.	(Tonne et al., 2018)[198] (Dreger, Schüle, Hilz, & Bolte, 2019)[192] (Klatte et al., 2016; Seabi, Cockcroft, Goldschagg, & Greyling, 2015)[199,200]

[196] Babisch, W. (2006), *Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased*, Noise and Health. 8(30):1-29.

[197] European Environment Agency (2020), *Environmental Noise in Europe 2020*, Luxembourg: Publications of the European Union.

[198] Tonne, C. et al. (2018), *Socioeconomic and ethnic inequalities in exposure to air and noise pollution in London*, Environment International, 115, 170 - 179. Available online at: https://pubmed.ncbi.nlm.nih.gov/29574337/.

[199] Klatte, M., Spilski, J., Mayerl, J.U.M.T.L and Bergström, K. (2016), *Effects of aircraft noise on reading and quality of life in primary school children in Germany: results from the NORAH study*, Environment and Behavior. 49, 390-424.

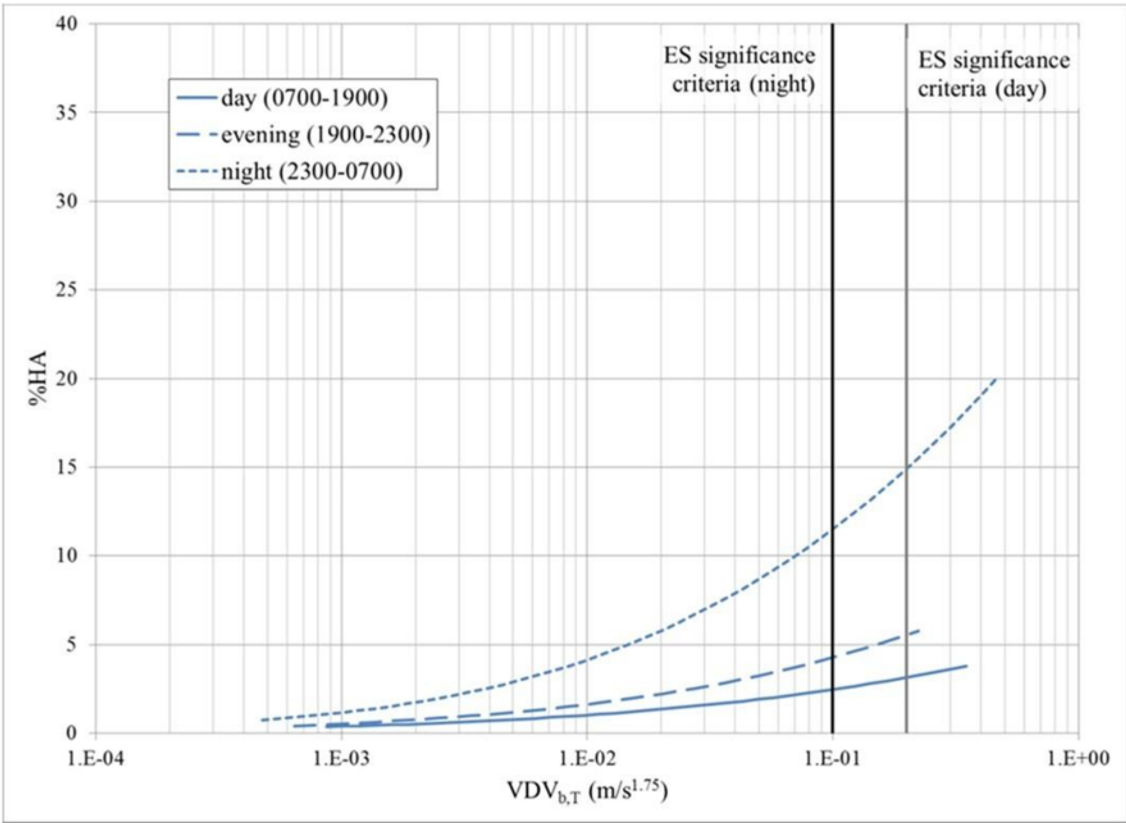
[200] Seabi, J., Cockcroft, K., Goldschagg, P. and Greyling, M. (2015), *A prospective follow-up study of the effects of chronic aircraft noise exposure on learners' reading comprehension in South Africa*, Journal of Exposure Science & Environmental Epidemiology, 25(1), 84-88.

8 Vibration

The reaction of the human body to vibration can range from annoyance, sleep disturbance, discomfort, interference with activities and it may affect quality of life. Occupants of buildings where there is perceptible vibration may have additional concerns of building damage, safety or a reduction in property value. Levels of vibration at which adverse comment is likely are well below the levels of vibration that may result in even cosmetic damage to buildings.

A recent study in the UK was undertaken for Defra and carried out by a team from Salford University, reporting in 2011[201]. This was a major study, involving almost one thousand face to face interviews and over 500 measurements of vibration inside buildings. The study was carried out in the North-West of England and the Midlands area during 2009 and 2010. Exposure-response relationships were developed for human response to railway vibration. (Figure H 8).

Figure H 8: Percentage highly annoyed by vibration during the day, evening and night



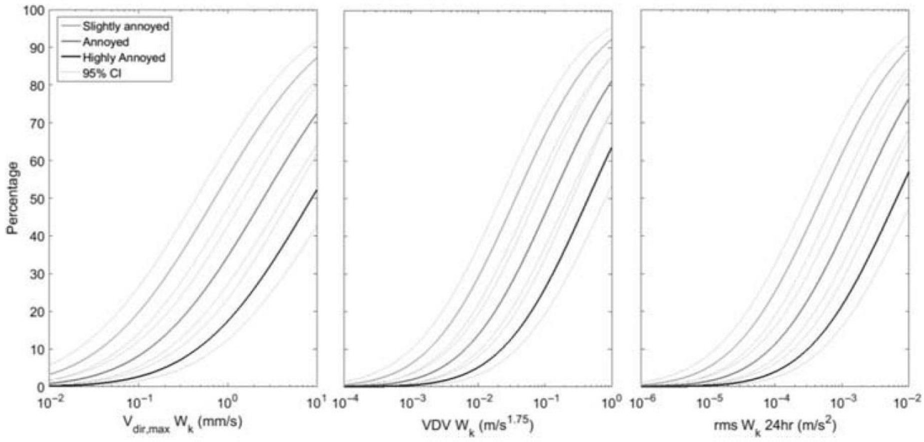
The percentage of respondents expressing a given level of annoyance is higher for night than it is for evening and higher for evening than it is for day. For a vibration level of

[201] University of Salford for Department for Environment, Food and Rural Affairs (2011), *Human response to vibration in residential environments*, Report 1–6.

$0.1ms^{-1.75}$[202], the proportion of respondents expressing high annoyance is around 2% during the day, 4% in the evening, and 12% during the night.

Further exposure-response relationships for railway vibration and being highly annoyed have been estimated[203] by combining data from the recent EU CargoVibes laboratory and field studies, along with previous study estimates. The combined data reflects the associations for use of freight and passenger rail, underground and light rail sources. This study chose to not include Shinkansen and high speed train studies[203]. Potential reasons for this are discussed further in Section 8.1. Figure H 9 shows the relationships for $V_{dir,max}$, VDV (vibration dose value) and rms (root mean squared acceleration) for being slightly annoyed, annoyed and highly annoyed.

Figure H 9: Exposure-response functions derived from meta-analysis of the available studies showing the associations between railway noise vibration and annoyance (n=4129) for $V_{dir,max}$, VDV and rmw



A recent Swedish study (EpiVib) found that the type of train was an important modifier of the association between distance to the railway and vibration annoyance. Lighter, faster trains such as passenger and fast trains were associated with lower vibration annoyance than heavier, slower freight trains, diesel trains and track maintenance trains[204].

As observed for noise annoyance, vibration annoyance is influenced by other factors. Vibration annoyance is higher at night-time and in the evening compared to the same exposure during the day-time; higher for those living in rural areas; for those who can see the noise source; for those who are middle-aged, noise sensitive or who have negative

[202] Quoted vibration levels in 1ms-1.75 refer to the frequency weighted Vibration Dose Value for the respective day and night periods.

[203] Waddington, D., Woodcock, J., Smith, M.G., Janssen, S. and Persson Waye, K. (2015), *CargoVibes: human response to vibration due to freight rail traffic*, International Journal of Rail Transportation, 3:4, 233-248.

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attitudes about the source and for those with concerns about property damage, or who expect exposure to get worse[204,205,206].

There is very little evidence in the existing literature to suggest direct long-term physical health effects on people inside buildings are relevant in relation to vibration at the typical levels encountered in the everyday environment[207].

8.1 Combined effects of noise and vibration

Numerous laboratory and field studies[208,209,210] have consistently found an interaction between vibration and noise with respect to annoyance to both stimuli. Vibrations may facilitate the perception of noise and make it difficult to ignore and habituate to, which may lead to an increased risk of perceiving the railway noise as more annoying than in situations with no simultaneous vibrations. This synergistic effect is believed to be one of the main factors why studies in Asia report higher level of annoyance than that predicted using the Miedema curve[137,211]. In countries such as Japan and Korea properties tend to be situated very close to the railway, and ground-borne vibrations tend to be exacerbated by the lightweight residential constructions.

There is also evidence that vibration annoyance is greater when vibration-induced audible rattle is also present[212]. Co-exposure to airborne noise is thought to increase vibration annoyance response and vice versa[213], however not all studies find these associations.

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[210] Lee, P. and Griffin, M. (2013), *Combined effect of noise and vibration produced by high-speed trains on annoyance in buildings*. J. Acous. Soc. Am. 133(4):2126-2135.

[211] Yokoshima, S., Matsumoto, Y., Shiraishi, H., Ota, A. and Tamura, A. (2013), *Effects of house vibrations on community response to ground transportation noise*, Proc. Internoise 2013.

[212] Woodcock, J., Sica, G., Peris, E., Sharp, C., Moorhouse, A.T. and Waddington, D.C. (2016), *Quantification of the effects of audible rattle and source type on the human response to environmental vibration*, Journal of the Acoustical Society of America, 139(3), 1225-1234.

[213] Trollé, A., Marquis-Favre, C. and Parizet, É. (2015), *Perception and Annoyance Due to Vibrations in Dwellings Generated from Ground Transportation: A Review*, Journal of Low Frequency Noise, Vibration and Active Control, 34(4):413-457.

A recent laboratory study of freight train and passenger train noise and vibration found no effect of vibration level on noise annoyance (vibration from 72 to 116dB Lv_{eq}[214] corresponding to VDV_b values ranging from 0.004 to 0.316 $m.s.^{-1.75}$)[214]. Vibration annoyance was only slightly influenced by noise level when the vibration level was at least equal to 116dB.

[214] Maigrot, P., Parizet, E. and Marquis-Favre C. (2020), *Annoyance due to combined railway noise and vibration: Comparison and testing of results from the literature*, Applied Acoustics, 165(107324).

9 Construction noise and vibration

Much of the evidence underpinning the discussion of noise and vibration related health effects comes from studies where there has been long term exposure, during the day, evening and night to the various sources of transport noise. The current models which suggest an association between noise exposure and adverse health effects operate through longer term stress reaction mechanisms.

Potentially high levels of construction noise over a sustained period could impact upon children at school if there was prolonged exposure during the school day. Noise could have an adverse effect on children's learning indoors and on various outdoor learning or rest activities.

However, experience on other projects such as HS1 and Crossrail has shown that such impacts can be successfully managed. Therefore, it is reasonable to assume that such effects can be avoided if proper levels of protection will be put in place for schools as part of the CoCP.

It is important to note that the potential for sleep disturbance will normally only arise in those locations where it is necessary to work at night for engineering, safety or other operational reasons. The amount of surface work at night is likely to represent a small proportion of the overall works. It is recognised that there may be an impact on shift workers or others who have to sleep during the day.

The recent Defra-commissioned study[215] on human response to vibration in residential environments derived exposure-response relationships for annoyance from construction noise and vibration.

There is a reasonable level of consensus from other major projects about tolerable levels of construction noise which clearly depend on the duration of works as well as the level of noise (or vibration) in any particular locality. This issue will be addressed in the CoCP.

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