

High Speed Rail: HS2 Phase 2b Preferred Route

# **Sustainability Statement including Post Consultation Update**

**Appendix C5 – Noise and Vibration**

A report by Temple-RSK for HS2 Ltd



**TEMPLE**

LEADERS IN ENVIRONMENT,  
PLANNING & SUSTAINABILITY.

**RSK**

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## 1. INTRODUCTION

- 1.1.1. This report has been prepared to support the HS2 Phase 2b Sustainability Statement including Post Consultation Update report, which describes the extent to which the Government's preferred route for HS2 Phase 2b supports objectives for sustainable development. This document is a technical appendix which summarises the methodology for appraising noise and vibration, and the key findings and conclusions that inform the Sustainability Statement main report. The Sustainability Statement places emphasis on the known key impacts only at this stage in the design, prior to commencing the Environmental Impact Assessment (EIA).
- 1.1.2. The current strategic appraisal has primarily concentrated on operational airborne noise at residential areas. Airborne noise at other sensitive locations, construction noise, vibration and ground-borne noise have been appraised on either a qualitative basis or at commentary level. All of these matters will be considered in greater detail at the EIA stage of the project.

## 2. SCOPE AND METHOD

### 2.1. How railway noise is assessed

- 2.1.1. There are a number of indices that can be used to measure noise from the operation of a railway and it is therefore important to identify which most closely correlate with people's response when exposed to that noise. The consensus of many worldwide studies, reflected in legislation, standards and guidance, is that annoyance correlates best with the measure of equivalent continuous sound level  $L_{Aeq}$ . This is the sound level, which, if kept constant over the assessment period, would give the same noise energy as is received from the fluctuating noise of, for example, a new railway.
- 2.1.2. Its use is widespread; for example in the assessment of eligibility for sound insulation<sup>1</sup> and as the basis for noise mapping under "The Environmental Noise (England) Regulations 2006".
- 2.1.3. In order to predict  $L_{Aeq}$  from a railway service it is necessary to sum the received noise energy from each train event in the assessment period. Therefore, to determine the total noise energy from a railway, one needs to know the type of train, type of track, train length, train speed and the number of trains over the assessment period. Also, to predict railway noise at a particular location, one also needs to take account of the distance, any screening, surrounding topography and type of ground absorption (i.e. soft or hard ground), between the receiver and the railway.

### 2.2. Key drivers for noise standards and assessment

#### Noise Action Plans in England

- 2.2.1. The Government's (Defra) Noise Mapping in England for aircraft, road, rail and industrial noise sources was produced to help fulfil the requirements of The Environmental Noise (England) Regulations 2006 that themselves respond to the requirements of the EU Environmental Noise Directive.
- 2.2.2. From the results of the mapping it was a requirement that Action Plans be drawn up to determine locations which should be a focus for improved noise management.

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<sup>1</sup> The Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996

2.2.3. In England, Defra concluded that for railways, these “Important Areas” were those where 1% of the population are affected by the highest noise from major railways, with principal consideration given to those where the mapped noise level exceeded 73 dB L<sub>Aeq</sub> for the period 06.00 – 24.00 (L<sub>Aeq,18hr</sub>). Consistent with the mapping requirements, this was a free field noise level (no reflection effect from the building façade) for a receiver 4m above the ground.

### **Noise Policy Statement for England (NPSE) March 2010**

2.2.4. The NPSE sets out the following Noise Policy Aims :

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

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

2.2.5. These Policy Aims are consistent with the Appraisal of Sustainability (AoS) evaluation objectives which are to maintain, or where possible, enhance the local noise environment.

### **National Planning Policy Framework (NPPF) March 2012**

2.2.6. The NPPF sets out the Government’s planning policies for England and how these are expected to be applied. It is consistent with the NPSE Policy Aims, requiring that “*The planning system should contribute to and enhance the natural and local environment by ....preventing both new and existing development from contributing to ....noise pollution*”. It sets out a number of aims that seek to ensure noise impacts are minimised, which are also consistent with the AoS noise criteria.

### **Department of Transport TAG**

2.2.7. The Department for Transport (DfT) has produced a method for a common assessment of different transport proposals, Transport Analysis Guidance (TAG), which was developed for route options generation, development and the evaluation of impacts.

2.2.8. Since the publication of the consultation route in 2013, further route options have been appraised based on the TAG noise sub-objective updated in August 2012. The methodology adopted was identical to the methodology used previously for the consultation route announcement, as described in the technical appendix to the Sustainability Statement<sup>2</sup>. This appraisal identifies notional costs against proposals based on residents “perceived willingness to pay”, relative to impacts and estimates the change in population annoyed by railway noise due to the proposals.

2.2.9. TAG unit A3 which deals with Environmental Impact Appraisal and now includes guidance for the appraisal of noise impacts was updated in December 2015. Since December 2015, the updated guidance has been used for route option appraisal on the preferred route.

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<sup>2</sup> Temple/ERM (July 2013). [HS2 Phase Two sustainability statement appendix E6: noise and vibration](#)

- 2.2.10. The December 2015 updated guidance on noise impacts no longer focuses on annoyance, and is instead based on Defra guidance<sup>3</sup> of assessing the impacts of transport-related noise from different sources, covering road, rail and aviation noise, using an ‘impact pathway’ approach and covering a range of impacts on:
- annoyance,
  - sleep disturbance, and
  - health impacts, including heart disease (acute myocardial infarction, or AMI) stress and dementia.
- 2.2.11. Defra’s guidance uses dose response functions that describe how people are affected at different noise levels (such as whether ‘High’ or ‘Moderate’ sleep disturbance relationships should be used, and the uncertainties around the odds ratio for AMI impacts) to describe impacts in terms of Disability-Adjusted Life Years (DALYs) which is then used to derive the monetary valuation of those impacts.
- 2.2.12. The updated TAG approach provides an estimate of the affected population and a monetary valuation of noise impacts which are derived using the TAG Noise Workbook (updated March 2015).
- 2.2.13. The TAG Noise Workbook requires input of predicted numbers of households experiencing ‘without scheme’ and ‘with scheme’ noise levels. The prediction of with and without scheme noise levels has been completed using the same noise modelling approach as has been used previously prior to December 2015 which is detailed in **Section 4**.
- 2.2.14. TAG unit A3 states that “*for rail ... reliable transformations between day time and night time noise measures are not available.*” For this noise appraisal explicit modelling of night time noise and assessment of sleep disturbance impacts has not been considered proportionate, so has not been included in the scope of appraisal (further information in **Section 6**). As such, an estimate of costs related to sleep disturbance is not included in the monetary valuation of noise impacts reported.

## 3. TYPES OF TRAIN NOISE

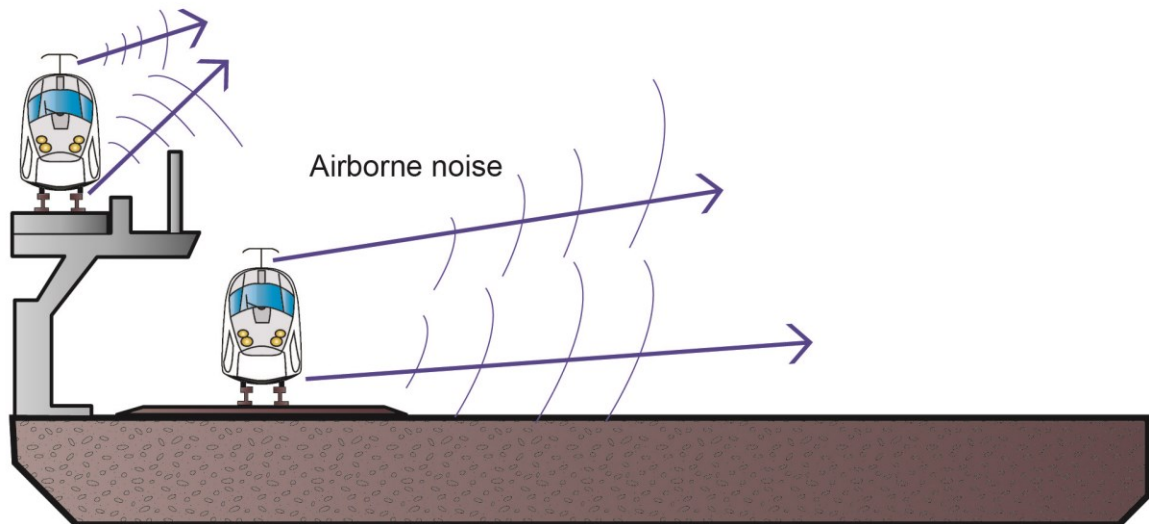
### 3.1. Direct airborne noise

- 3.1.1. Direct airborne noise includes the following:
- mechanical noise from motors, fans and ancillary equipment on the train; which tends to be the dominant source at low speeds;
  - ‘rolling’ noise from wheels passing along the rails, which is predominant at higher speeds; and
  - aerodynamic noise from general air flow around the train body and the air flow around the pantograph and wheel areas, which starts to become prevalent at the highest speeds, over 300kph
- 3.1.2. **Figure 3-1** illustrates typical propagation paths of airborne noise associated with railway operation as described above.

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<sup>3</sup> Gov.uk (December 2014). [Noise pollution: economic analysis](#)

**Figure 3-1 – Environmental airborne noise from railways**



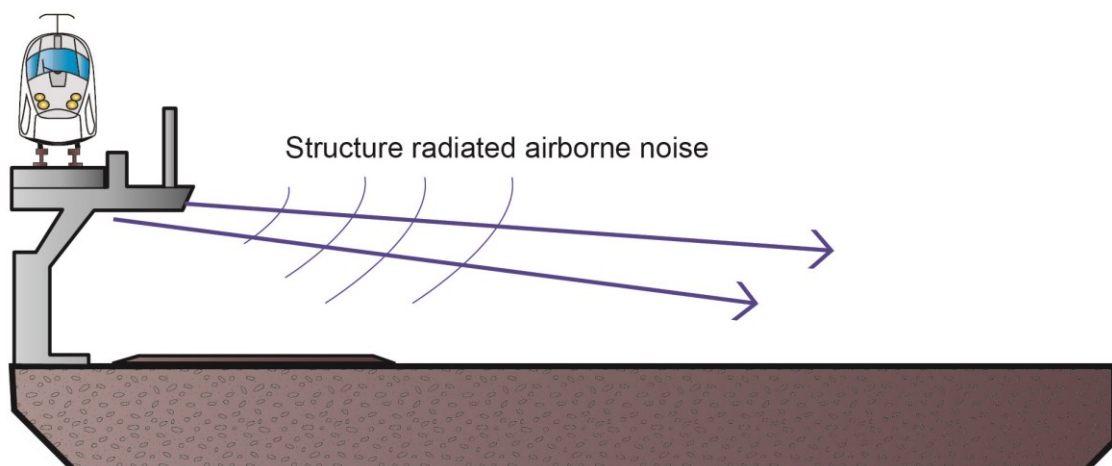
3.1.3. Airborne noise from railways can be mitigated in the following ways:

- at the source, through advanced rolling stock and track design,
- at the propagation pathway, by using barriers and earth bunds; and
- at the receptor by using noise insulation.

### 3.2. Structure-radiated airborne noise

3.2.1. Airborne noise also includes structure radiated noise, for example from viaducts. **Figure 3-2** illustrates typical propagation paths of structure radiated noise associated with railway operation as described above.

**Figure 3-2 - Structure radiated noise from railways**



3.2.2. Structure radiated noise from railways can be mitigated by damping the track structure, using resilient fixings or track supports.

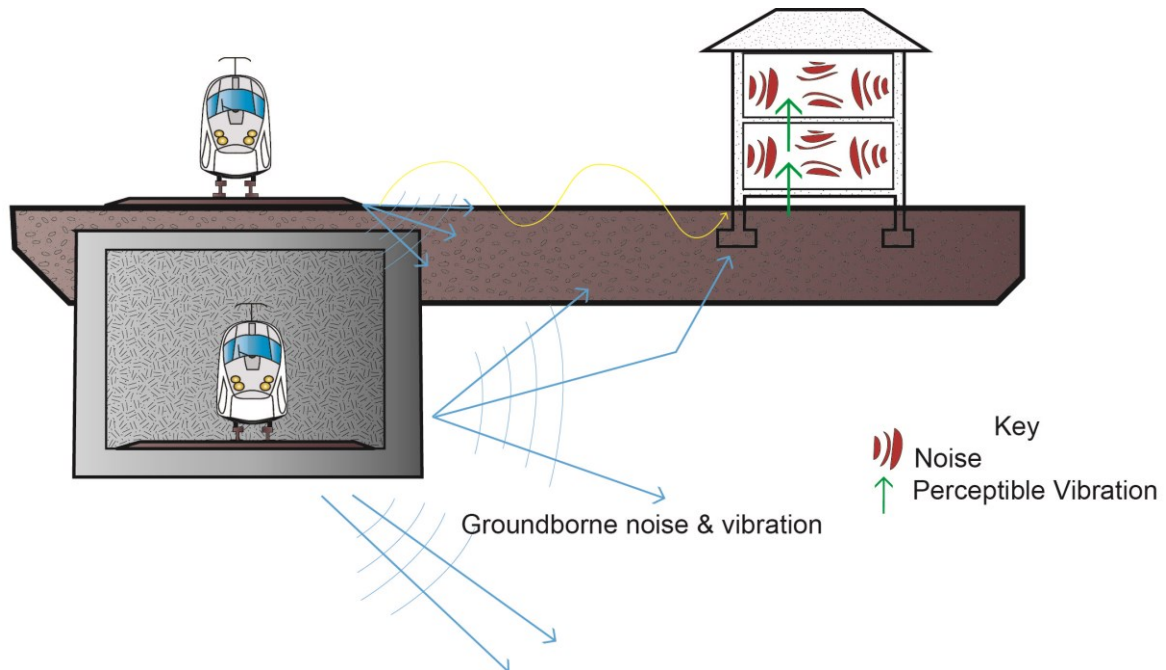
### 3.3. Ground-borne noise and vibration

3.3.1. Ground-borne noise and vibration consists of:

- Ground-borne vibration (tactile vibration); and
- Ground-borne noise (audible low frequency ‘rumbling’ sound generated inside rooms by low amplitude vibration on walls, floors and ceilings).

3.3.2. **Figure 3-3** illustrates typical propagation paths of ground-borne noise and vibration associated with railway operation as described above.

**Figure 3-3- Ground-borne noise and vibration from railways**



3.3.3. Ground-borne noise and vibration from railways can be mitigated by incorporating vibration isolating track forms, for example booted sleepers.

## 4. NOISE APPRAISAL AND THE AOS

### 4.1. Background

- 4.1.1. The approach to noise appraisal for Phase 2b followed the approach used on Phase One and Phase 2a. This method was developed and endorsed by the HS2 noise and vibration working group, which included specialists from outside the AoS team. The working group was established to provide scrutiny, advice and direction on the application and relevance of emerging noise and vibration legislation and guidance, as well as on new research findings.
- 4.1.2. The noise appraisal method that was used for option development and selection was based on DfT's guidance provided in TAG noise sub-objective Unit 3.3.2 August 2012. This was updated in December 2015, so further noise appraisal and a TAG appraisal carried out for the preferred scheme, is based on the updated guidance which is presented in **Section 5-2**.
- 4.1.3. As the preferred scheme emerged, the appraisal criteria described in **Section 4-9** were used to help inform the design process and identify the potential noise impacts at a community level. The effect of indicative additional mitigation was also appraised and this is discussed in **Section 5**.

## 4.2. Assumptions and limitations

- 4.2.1. Operational noise at non-residential noise sensitive receivers has not been appraised to a similar level of detail at this stage.
- 4.2.2. Construction noise and vibration has not been appraised as it is not appropriate at this stage of the project. However, such matters would be addressed as part of the HS2 Code of Construction Practice (CoCP).
- 4.2.3. Ground-borne noise and vibration have been appraised at a strategically high level to determine the potential impacts to sensitive properties (residential and non-residential) and indicative mitigation measures have been considered.
- 4.2.4. All potential noise and vibration impacts including construction noise and vibration, operational noise at non-residential receivers and ground-borne noise and vibration at residential and non-residential receptors will be fully assessed at EIA stage.
- 4.2.5. A more detailed set of assumptions and limitations is provided in **Section 8**.

## 4.3. Computer Noise Model

- 4.3.1. The approach developed to perform the airborne noise appraisal of the preferred scheme includes predicting noise levels at receivers and undertaking statistical calculations of the results such as calculating the numbers of dwellings which meet the appraisal criteria.
- 4.3.2. The HS2 Noise Model has been developed using the CadnaA<sup>4</sup> noise prediction software which involves modelling a three dimensional approximation of the study area and implements the railway noise calculation methodology (Calculation of Railway Noise 1995). ArcView GIS (geographic information system) software<sup>5</sup> has been used to perform the statistical calculations on the resulting receiver noise levels.

## 4.4. Study areas

- 4.4.1. A study area 3km either side of the preferred scheme has been used as it is considered sufficient to encompass all areas subject to potential HS2 residential airborne noise impacts.

## 4.5. Modelled scenarios

- 4.5.1. Noise levels were predicted for both with-scheme and without-scheme scenarios.
- 4.5.2. The predictions of 'with scheme' noise impacts for the opening year and 15 years after opening were carried out by calculating noise levels at receiver points representative of residential dwellings using the HS2 Noise Model. Noise sources 'with scheme' consisted of the proposed railway as well as existing railways. Further details of assumptions regarding the opening year and 15 years after opening are presented in **Section 8**.
- 4.5.3. The prediction of 'without scheme' noise impacts was carried out calculating noise levels at receiver points representative of residential dwellings using the HS2 Noise Model. Noise sources 'without scheme' consisted of the existing railways only.

## 4.6. Existing noise

- 4.6.1. The perception and potential effect of mixed noise (noise which contains contributions from more than one type of noise source, e.g. rail and road noise) is not easily predicted and genuine uncertainties remain on how best to assess mixed noise. This is due to the changes in the perception and potential effect of different noise sources related not only to

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<sup>4</sup> CadnaA (Computer Aided Noise Abatement) software version 4.3.143 (64bit) - DataKustik GmbH.

<sup>5</sup> Esri ArcMap 10.1 Build 3035



the noise level (or 'volume') of the source, but also its characteristics (tonality, intermittency, etc.)

- 4.6.2. No baseline noise surveys have been undertaken for the AoS. Baseline noise monitoring will be undertaken as part of the EIA. However, in the absence of measured ambient noise data and due to the uncertainty described above with assessing mixed noise, predicted potential impacts have been identified based on a comparison of HS2 and other existing rail noise only, subject to a minimum value of 45dB  $L_{Aeq,18hr}$ <sup>6</sup>. As a result the calculation of HS2 noise impacts at this stage is likely to be an over-estimate.
- 4.6.3. The existing rail noise levels at dwellings have been calculated within the HS2 Noise Model. Existing railway source noise levels have been based on published Defra railway noise contour maps<sup>7</sup>. The Defra railway noise maps are strategic in nature, and therefore do not give accurate noise levels at specific locations. However, this was considered sufficient for the strategic level appraisal.
- 4.6.4. The location of existing railways within the vicinity of the study area was input to the model. The source noise level attributed to these railways was calibrated so that the noise levels they produced were reasonably consistent with those provided in the Defra railway noise contour maps.
- 4.6.5. Where predicted rail noise levels are low, a minimum value of 45dB  $L_{Aeq,18hr}$  has been chosen and this has also been taken as the assumed level in areas where railway noise is not present.

## 4.7. Factors affecting train noise

### Overview

- 4.7.1. The HS2 source noise level used in the Noise Model relies upon:
- assumed noise levels of HS2 trains are based on the noise levels of currently operating high speed trains<sup>8</sup> together with noise level requirements for new trains from European specifications<sup>9</sup> (Technical Specification for Interoperability [TSI]);
  - operating speeds for different sections of the route, as supplied by HS2 Ltd;
  - the number and length of the trains;
  - details on the preferred scheme alignment, including proposed embankments, cuttings, tunnels and viaducts, within the context of the surrounding landscape; and
  - a defined time period.

### Source noise level

- 4.7.2. HS2 source levels were derived using both 2008 measurement data of TGV trains at 350 km/h and high speed TSI requirements. **Figure 4-1** below shows the  $L_{Aeq,18hr}$ <sup>10</sup> HS2 source

<sup>6</sup> This level is used as the cut-off for valuation calculations in TAG

<sup>7</sup> Department for Environment, Food and Rural Affairs: London. Noise Mapping England. [Online] Accessed on 29 June 2009 <http://www.Defra.gov.uk/environment/quality/noise/mapping/index.htm>

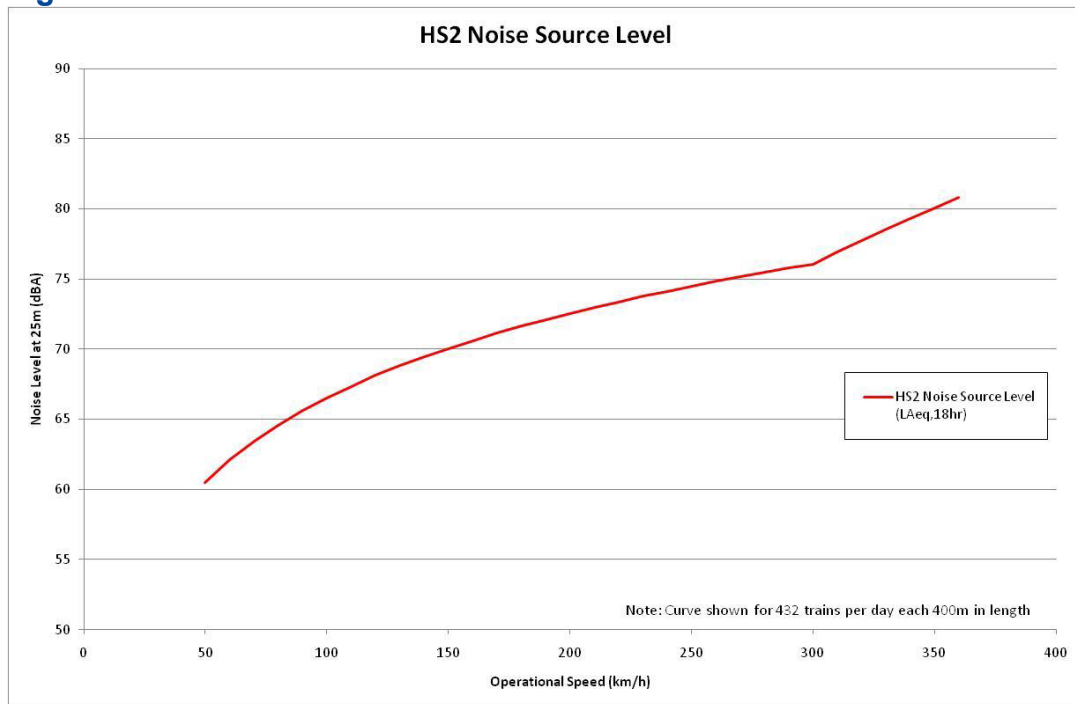
<sup>8</sup> Gautier, P.-E., Létourneaux, F., & Poisson, F. (2007). High Speed Trains External Noise: A Review of Measurements and Source Models for the TGV Case up to 360km/h. SNCF, Innovation and Research Department, France.

<sup>9</sup> COMMISSION DECISION of 21 February 2008 concerning a technical specification for interoperability relating to the „rolling stock“ sub-system of the trans-European high-speed rail system (notified under document number C(2008) 648) (2008/232/CE).

<sup>10</sup> The  $L_{Aeq}$  is the A-weighted sound level, which, if kept constant over the assessment period (06:00-24:00), would give the same noise energy as is received from the fluctuating noise (in this case noise from the new railway)

noise level at 25m for various operational speeds; for a specific number of trains (432 per day) with no mitigation and hard flat ground.

**Figure 4-1 - HS2 noise source level**



### Operational speeds

- 4.7.3. Operational speed data within the HS2 Noise Model is the design speed provided by HS2 Ltd in the HS2 geospatial data (shapefiles); where design speeds are over 360km/h, a maximum of 360 km/h is used as listed in the HS2 Project Specification.

### Operational service patterns

- 4.7.4. Operational characteristics have been provided by HS2 Ltd including the number of trains and length of trains on each route segment, and track speeds. These train frequencies represent the future worst-case scenario – the maximum number of trains the route is designed to carry. These are provided in **Table 4-1**.

**Table 4-1 – HS2 Phase 2b indicative train movements**

Phase 2b Western Leg		Operational Year 15 (trains per period)		
Section number	Route description	Total trains per direction per hour	Total for both directions per hour	Total for both directions per 18 hours
1	Crewe Junction to South Mancunian Junction	9	18	324
2	South Mancunian Junction to Manchester Station	6	12	216
3	South Mancunian Junction to Golborne North Junction	3	6	108

Phase 2b Western Leg		Operational Year 15 (trains per period)		
Section number	Route description	Total trains per direction per hour	Total for both directions per hour	Total for both directions per 18 hours
1	Hams Hall Junction to East Midlands Interchange	10	20	360
2	East Midlands Interchange to Clay Cross Junction	10	20	360
3	Clay Cross Junction to Sheffield Midland	4	8	144
4	Clay Cross Junction to West Riding Junction	10 <sup>11</sup>	20	360
5	West Riding Junction to East Coast Main Line (ECML) connection	4	8	144
6	West Riding Junction to Leeds	6	12	216

### Route alignment

4.7.5. The HS2 Phase 2b preferred scheme alignment was provided as a three dimensional shapefile, the height of which is the rail head height. Only a single rail line was modelled, which was considered reasonable for the strategic level appraisal.

### Noise source height of High Speed trains

- 4.7.6. HS2 noise predictions have used the UK modelling methodology Calculation of Railway Noise 1995 (CRN). This is the official model for assessing eligibility for sound insulation under England and Wales Noise Insulation Regulations for Railways and the model previously used for the HS2 Phase One and Phase 2a AoS. The AoS method involves some modification to the base CRN calculation to account for aerodynamic noise from high speed trains which falls outside of the scope of CRN.
- 4.7.7. In its general form, this model assumes there are three possible noise source heights:
1. At the head of the nearest rail (of the relevant track); to model rolling noise and
  2. At 2m or 4m above rail head:
    - To model diesel locomotive power noise, the source is located 4m above the head of the nearest rail (of the relevant track); or
    - For fan noise from Eurostar high speed train locomotives the source is located 2m above the head of the nearest rail (of the relevant track).
- 4.7.8. For very high speed rail, i.e. above 300km/h, CRN needs to be adapted to have sources at two or more heights above rail: for example rolling noise and others for aerodynamic noise. This is the approach adopted for the HS2 Phase 1 Environmental Statement. The AoS methodology maintains consistency with the method previously used for the HS2 Phase One and Phase 2a AoS.

<sup>11</sup> Train services 400m in length will split into two 200m services at Clay Cross Junction.

- 4.7.9. The AoS method modifications to the base CRN calculation to account for aerodynamic noise involve retaining a single noise source but altering the source height.
- 4.7.10. A source located 1m above the head of the rail is used as a series of comparative calculations indicated that this gave the most consistent results when compared with SNCF<sup>12</sup> data for speeds in excess of 300km/h. For train speeds less than 300km/h the rolling noise source location of CRN was used (rail head height).
- 4.7.11. Following a review of 3m high barriers, the acoustic barrier effect, for these or higher barriers, expected from high speed rail at above 300km/h was simulated for modelling purposes by reducing the actual barrier height by 1m for calculation purposes only and retaining a source 1m above the head of the rail.

### Time period of assessment

- 4.7.12. The noise from the operation of HS2 has been appraised, for the purpose of the AoS, in terms of the equivalent continuous sound level  $L_{Aeq,18hr}$  (the 18hr time period is 06:00 to 24:00). This approach is considered appropriate due to the predominantly daytime operation of HS2<sup>13</sup>. Night-time noise has been qualitatively appraised in **Section 6-2**.
- 4.7.13. The recently updated TAG uses the noise metric  $L_{Aeq,16h}$  (the 16 hour time period is defined as 07:00 to 23:00 hours) instead of  $L_{Aeq,18h}$ , which has been used in previous TAG guidance, as it does not overlap with the  $L_{night}$  period (23:00 to 07:00) used in the appraisal of sleep disturbance impacts.
- 4.7.14. Using CRN, railway noise levels are calculated in  $L_{Aeq,18h}$ , and Defra recommends<sup>14</sup> that equivalence can be assumed between 'daytime' indicators for rail, so for TAG calculations no conversion is required and the  $L_{Aeq,18h}$  has been used.

## 4.8. Modelling the receiving environment

- 4.8.1. The following inputs were included in the HS2 CadnaA Noise Model to provide an adequate level of precision in the calculated noise levels.

### Digital terrain model

- 4.8.2. The existing digital terrain model is based on 5m interval contour lines extracted from ordnance survey data provided by HS2 Ltd.
- 4.8.3. To model the terrain changes due to the alignment of the HS2 preferred scheme, the three dimensional shapefile lines provided by HS2 Ltd (i.e. embankments, cuttings and viaducts for example) were converted to contour lines to define the ground terrain.

### Built up areas

- 4.8.4. The effect of acoustic shielding from buildings has been approximated by calculating the noise attenuation at dwellings located in areas of densely populated buildings. The attenuation of built-up areas is based on the guidance within the ISO 9613-2 standard<sup>15</sup> for noise propagation with a relative height of 8m above ground level assigned to all built up areas. Other detailed built-up areas have not been incorporated into the HS2 Noise Model.

### Ground absorption

- 4.8.5. The calculations have been carried out with a default ground absorption assuming hard ground in built up areas and soft ground elsewhere.

<sup>12</sup> P. Belingard, F. Poisson, S. Bellaj (2010). Experimental study of noise barriers for high-speed trains;; IWRN10; SNCF

<sup>13</sup> HS2 likely operating hours are 05:00 to 24:00

<sup>14</sup> Gov.uk (2014). [Noise pollution: economic analysis](#)

<sup>15</sup> ISO 9613-2: (1996) Attenuation of sound during propagation outdoors – Part 2 General method of calculation

## Receivers

- 4.8.6. Calculations of noise exposure have been completed at receiver locations which represent either individual dwelling address points close to the route or clusters of dwellings further from the route. All receivers are represented in the HS2 Noise Model as points located 4m above the existing ground height.
- 4.8.7. Within 300m of the route centreline (i.e. 600m corridor), individual address points from the postal address points data<sup>16</sup> provided by HS2 Ltd (this can represent more than one dwelling) were used. This was done to provide a higher level of detail to receivers near the line of route which are more noise sensitive to the precise geometry of the source-to-receiver sound propagation path.
- 4.8.8. To represent dwellings further than 300m from the route centreline, point receivers have been used, each representing a group of all the dwellings located in the postal address point data in a 50m square surrounding the point.
- 4.8.9. All airborne noise levels calculated and reported are free field (see glossary for further explanation) with the exception of those used to represent noise insulation criteria. In this case, a facade correction of 3 dB has been used to convert free field noise levels to facade noise levels.
- 4.8.10. Calculations have been carried out using the noise exposure results at receiver points calculated in the HS2 Noise Model, using GIS software.

## Barriers

- 4.8.11. Barriers are included in the HS2 Noise Model as part of the calculation of the predicted noise levels due to the HS2 preferred scheme with indicative additional mitigation. Barriers have been included where an area has been identified as a Preliminary Candidate Area for Mitigation (PCAM - based on the 'without additional mitigation' Noise Model results) although barriers may not necessarily be employed in the final form of mitigation in any given location. Further information regarding the selection of PCAM's and barrier height is discussed below in **Section 7**.

## 4.9. Appraisal criteria

### High noise levels

- 4.9.1. To indicate potential noise impacts associated with the preferred scheme, the number of dwellings that could potentially experience high HS2 noise levels have been reported. The proposed criterion for a high noise level exposure is defined as a free field noise level greater than or equal to 73 dB  $L_{Aeq,18hr}$ <sup>17</sup>.

### Noise insulation

- 4.9.2. The Noise Insulation (Railway) Regulations (NIRR 1996) are England and Wales legislation that applies to works on new, altered or additional railway systems such as HS2. The regulations set the daytime criterion for noise insulation of residential buildings at:
- greater than or equal to 68 dB  $L_{Aeq,18hr}$  at the building façade (i.e. a facade noise level);
  - the new altered or additional railway must make a contribution of at least 1 dB  $L_{Aeq,18hr}$  to the total railway noise;

<sup>16</sup> Dwellings extracted from February 2014 Ordnance Survey Master Map Address Layer 2 provided by HS2 Ltd. Dwellings likely to be demolished have been removed from all results. However, the data does not consider any future dwelling developments.

<sup>17</sup> This criterion for railway noise exposure has been used in the past by Defra, to identify First Priority Locations for Noise Action Planning as part of The Environmental Noise (England) Regulations 2006.

- at least 1dB  $L_{Aeq,18hr}$  increase in total railway noise level; and
- within 300m of the new, altered or additional railway.

### Noticeable noise increase

- 4.9.3. The noise level criteria above, i.e. High HS2 Noise Levels and Noise Insulation levels, have been identified at National level. However, neither represents an acceptable design level and should be viewed as an upper limit when no further reduction of noise is possible having regard to all reasonably practicable mitigation measures.
- 4.9.4. It follows that other design criteria need to be developed to inform the appraisal process and design of the railway in order to minimise the noise impacts on the local community. There is no universally accepted approach but there is general acceptance that it is appropriate to evaluate rail noise impact in terms of noise change, as evidenced by noise impact assessments on recent railway schemes e.g. HS2 Phase One, HS1 Channel Tunnel Rail Link (CTRL), West Coast Main Line (WCML) and Crossrail. This is also the approach for roads as set out in the Design Manual for Roads and Bridges. Additional criteria (referred to as “assessment criteria”) will be developed at the EIA stage should the scheme be progressed, to provide further guidance on the community impacts and to inform the design process.
- 4.9.5. In terms of a railway noise change, 3 dB  $L_{Aeq}$  or more is generally considered a noticeable change. For the AoS, this has been taken as the difference in railway noise, with and without the presence of HS2 Phase 2b; this approach is consistent with the approach taken for HS2 Phase One, HS1 (CTRL), Crossrail and WCML.
- 4.9.6. The World Health Organisation, in its 1999 Noise Guidelines<sup>18</sup> report in 2000 states “to protect the majority of people from being moderately annoyed during the daytime, the outdoor sound level should not exceed 50 dB  $L_{Aeq}$ ”.
- 4.9.7. This has been taken as an indicator of the onset of annoyance and, therefore, a Noticeable Noise Increase for HS2 AoS purposes is defined as having a total rail noise level of greater than or equal to 50 dB  $L_{Aeq}$  06:00 – 24:00 with an increase in rail noise of at least 3 dB  $L_{Aeq}$  06:00 – 24:00. At receiver locations where predicted existing rail noise levels are low or there is no rail traffic (assumed at 45 dB  $L_{Aeq,18hr}$ ), a predicted HS2 noise level of 50 dB  $L_{Aeq,18hr}$  or above would result in a Noticeable Noise Increase as per this definition.

## 4.10. Mitigation

### Preliminary mitigation

- 4.10.1. The development of the preferred route has resulted in a number of changes to the alignment to reduce environmental and community impacts. These have already been described in Appendix B (AoS Methodology and Alternatives), and they include new or deeper cuttings, as well as re-alignments away from certain settlements informed by consultation feedback.
- 4.10.2. In addition, other locations were identified as candidate areas for additional mitigation (PCAM). The general approach taken has been to locate the PCAM where they would have the greatest benefit to reducing overall numbers of noise impacts and involved the following:

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<sup>18</sup> World Health Organisation (1999). Guidelines for Community Noise

- 4.10.3. PCAM were typically located adjacent to ‘clusters’ of dwellings shown to be potentially impacted by the unmitigated noise modelling results. A cluster would normally be five or more dwellings potentially qualifying for noise insulation within 250m of the route. This is consistent with the approach taken in the Phase One AoS and for earlier schemes such as HS1.
- 4.10.4. A rigid rule for selecting clusters could miss out or include situations where mitigation could respectively be beneficial or not required. Roundtable meetings were therefore held between HS2 Ltd, Temple RSK and the engineers to review the PCAM locations in terms of feasibility and acoustic performance. The following was further considered when reviewing the PCAM:
- Additional locations may have been selected as a PCAM if there were more than five Noticeable Noise Increase (NNI) properties identified within 500m.
  - An area may also have been identified as a PCAM if in the opinion of the acoustic and engineering teams, the intervening topography may not offer particularly effective noise attenuation. For example where there is little screening from built up areas, or over a valley or gravel works where there may be little ground attenuation.
  - It is assumed that barriers can be installed to PCAM; i.e. that there is sufficient space alongside the route.
- 4.10.5. These locations have been highlighted on the Residential Airborne Noise Appraisal Maps (see Volume 2: maps for the Appraisal of Sustainability). Due to the strategic nature of this study, these locations should be considered as preliminary at this stage and subject to change as the design develops in detail.

### Further mitigation options

- 4.10.6. The consideration of mitigation at this stage of the scheme’s development is necessarily strategic. The airborne noise mitigation hierarchy consists of mitigation at the source, including the rolling stock and track, before mitigation of the propagation pathway, including barriers and earth bunds. Mitigation at the receiver, including noise insulation, should only be considered for residual effects, and as a last resort.
- 4.10.7. To mitigate potential impacts in areas of high operating speeds, there is a need to control aerodynamic noise through advanced rolling stock design. Without first mitigating the source of aerodynamic noise, wayside noise barriers are not likely to be as effective or feasible, due to the required increase in barrier height, to provide shielding to the entire train.
- 4.10.8. The assumptions used in the additional indicative mitigation scenario drew on the knowledge and experience of the engineers and acoustic specialists.
- 4.10.9. The principal assumptions used to model this scenario are set out below.
- At operation, there would be a 3 dB reduction in noise emissions at source based on the anticipated noise control improvements in the next generation of high speed rolling stock.
  - Noise reduction would be equivalent to that achieved by use of 3m high<sup>19</sup> noise barriers (or bund) at all the preliminary candidate areas for mitigation or, at viaducts, by 2m high barriers; noise-absorbent materials would be used throughout. For the western and eastern leg respectively, approximately 23km and 93km of noise barriers have been applied broadly in the Noise Model at preliminary candidate areas for mitigation. The

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<sup>19</sup> Barrier height quoted is the height above ground level; suitable barrier locations within the preliminary candidate areas for mitigation were chosen to give the greatest screening effect; based on the location.

actual mitigation technique employed at each location may not be a barrier; and may take the form of earth bund, building structure, or some other technical innovation and local conditions would be considered at a later stage in deciding which technology would be most appropriate.

- 4.10.10. The way in which noise would eventually be mitigated would depend on various considerations, such as engineering feasibility and effectiveness, and may use any of the techniques set out, either independently or in combination, and these will be developed further as part of the EIA.

## 5. AIRBORNE NOISE APPRAISAL FINDINGS

### 5.1. HS2 preferred scheme airborne noise appraisal

- 5.1.1. **Table 5-1** shows the estimated number of dwellings potentially impacted by operational noise from the preferred scheme according to the HS2 appraisal criteria with and without additional indicative mitigation. This table should be read in conjunction with the residential airborne noise appraisal maps (Volume 2: maps for the Appraisal of Sustainability). These results are based on indicative operational service patterns for Phase 2b.

**Table 5-1 – HS2 Phase 2b preferred scheme airborne noise appraisal findings**

HS2 Phase 2b preferred scheme: Number of dwellings affected by airborne noise						
	High noise levels <sup>1</sup>		Noise Insulation Regulations <sup>2</sup>		Noticeable Noise Increase <sup>3</sup>	
	Including Additional Indicative Mitigation	Without Additional Mitigation	Including Additional Indicative Mitigation	Without Additional Mitigation	Including Additional Indicative Mitigation	Without Additional Mitigation
Western Leg	<5	<15	<50	150	1,100	4,400
Eastern Leg	<5	<30	<30	200	4,500	26,800
<b>Total*</b>	<b>&lt;5</b>	<b>&lt;40</b>	<b>&lt;80</b>	350	<b>5,600</b>	31,300
<sup>1</sup> Dwellings potentially exposed to high HS2 noise levels, greater than 73dBLAeq18hr <sup>2</sup> Dwellings potentially qualifying for noise insulation under the Noise Insulation Regulations <sup>3</sup> Dwellings potentially exposed to a Noticeable Noise Increase * Numbers may not add up due to rounding Estimated numbers exclude dwellings likely to be demolished.						

### 5.2. TAG Appraisal

- 5.2.1. TAG appraisal results for the preferred scheme with the additional indicative mitigation applied are reported in the AoS framework tables and summarised in **Table 5-2** below.

- 5.2.2. Given the strategic nature of the study, reported numbers have been rounded<sup>20</sup>.

<sup>20</sup> See Section 11 for details of rounding methodology



**Table 5-2 - HS2 Phase 2b Airborne Noise Impacts from TAG Appraisal**

TAG appraisal outputs of HS2 Phase 2b preferred scheme							
Criteria	Description of Criteria	HS2 Phase 2b preferred scheme					
		Western Leg		Eastern Leg		Total*	
		Including Additional Indicative Mitigation	Without Additional Mitigation	Including Additional Indicative Mitigation	Without Additional Mitigation	Including Additional Indicative Mitigation	Without Additional Mitigation
<b>TAG Net present value of change in noise</b>	Including impact on Amenity, AML, Stroke and Dementia	<b>-£2.5m</b>	-£11m	<b>-£8.5m</b>	-£48m	<b>-£11.5m</b>	-£58.5m
<b>Non – Residential noise sensitive properties</b>	Number of non-residential noise sensitive properties within 300m either side of the line of route (No. schools in brackets)	<b>N/A</b>	11 (2)	<b>N/A</b>	84 (10)	<b>N/A</b>	95 (12)

\*Numbers may not add up due to rounding  
Estimated numbers exclude dwellings likely to be demolished.

- 5.2.3. The monetary valuation of changes in noise, is based on estimation of the number of Disability-Adjusted Life Years (DALYs) lost (or gained) under each impact pathway (amenity and health), and monetisation with a value of £60,000 per DALY. These are increased in line with forecasts of GDP per capita and discounted over the appraisal period to give a present value of changes in noise. A negative value represents a cost whereas a positive value would represent a benefit.
- 5.2.4. The number of potentially impacted non-residential noise sensitive receivers has been identified by counting the number of educational, health, community and recreational properties located within 300 metres of the route centreline, which are considered to be those potentially at risk of airborne operational noise impacts. These results are also presented in **Table 5-2**.
- 5.2.5. Locations identified by the operational airborne noise appraisal with a higher risk of HS2 operational noise impacts include<sup>21</sup>:
- **Western leg:** North of Crewe near the tunnel portal, Lostock Green and Lostock Gram; and
  - **Eastern leg:** Kingsbury, Measham, Hucknall, Pinxton, Hilcote, Bolsover, Aston, Brampton-en-le-Morthen, Thurcroft, Mexborough, Crofton, New Crofton and Sharlston.
- 5.2.6. With ambient noise from existing roads (motorways and A roads) also taken into account, noise impacts from HS2 would be expected to be moderately less in terms of overall change in noise level and/or the overall number of people affected.

<sup>21</sup> Further locations of residual noise impact may be identified on the noise maps; however these are predicted to receive a relatively higher change in annoyance by the TAG appraisal.

## 6. OTHER POTENTIAL NOISE IMPACTS

### 6.1. Introduction

6.1.1. Due to the strategic nature of this appraisal, not all potential noise issues have been addressed quantitatively. This section identifies these further issues at commentary level. These issues will be assessed in more detail at the EIA stage.

### 6.2. Night-time noise

6.2.1. The noise appraisal has identified preliminary candidate areas for mitigation. The application of this mitigation would also benefit those who may experience night noise effects since:

- It is likely that all the properties which would be identified as eligible for noise insulation under the night time noise insulation criteria within the Noise Insulation Regulations have already been identified in the AoS as being eligible under the daytime noise insulation criteria; and
- It is unlikely that any further candidate areas for mitigation would arise as a result of a night time noise assessment using a high maximum noise level (e.g. 85 dB  $L_{Amax}$ ).

### 6.3. Stations and depots

6.3.1. The following sources of noise from HS2 stations and depots have the potential to cause impacts at sensitive locations in proximity to the proposed stations and depots:

- Passenger and maintenance trains accessing stations or depots;
- Potential wheel squeal issues at curved track;
- Fixed plant installations at stations or depots e.g. wheel lathes, CET (Controlled Emissions Tanking) units, wash plant etc;
- Mobile plant and maintenance activities not considered a constant noise source e.g. forklift trucks, hand tools etc;
- Local road traffic accessing stations and depots, and changes to local road infrastructure; and
- Public Address (PA) systems.

6.3.2. However, past experience has shown that the majority of these impacts can be avoided or minimised to a large degree through the use of effective planning/design and other noise mitigation measures.

6.3.3. During construction there could be potential for construction noise impacts depending on proximity to residential receptors as some of the work may need to be carried out during night-time and weekend possessions.

### 6.4. Tunnel ventilation shafts

6.4.1. Tunnel ventilation shafts (TVS) are required to provide:

- natural ventilation, which also acts as pressure relief;
- forced, mechanical ventilation, to operate during maintenance or emergency situations; and
- Access and egress for emergency services.

6.4.2. The forced ventilation system would not operate continuously but only in the event of

severely disrupted operation, an emergency or testing. When the ventilation system is not operating, the main noise source from the tunnel would be associated with the passage of trains, that is pressure relief and train pass-by noise.

- 6.4.3. HS1 and the Jubilee Line Extension experience indicates that impacts can be avoided if vent shafts are built with appropriate mitigation. Crossrail will also feature noise-controlled vent shafts including noise attenuators installed on each side of the tunnel ventilation fans as necessary. The approach to HS2 TVS noise would adopt best practice for noise control. Past experience has shown that the majority of potential noise impacts can be avoided through the use of effective planning/design and other noise mitigation measures.

## 6.5. Tranquillity and Quiet Areas

- 6.5.1. The TAG noise sub-objective states that tranquillity is to be taken into account in the assessment of Landscape impacts. Thus, in order to avoid double counting, the noise impacts of schemes in quiet or tranquil areas have not been assessed under the noise sub-objective.

## 6.6. Tunnel Portal Noise

- 6.6.1. For tunnelled route sections, pressure waves created as a high speed train enters a tunnel portal can result in micropressure waves that cause a boom or bursting noise at the exit of long tunnels comprising a slab track rail formation. If unmitigated, the boom noise associated with high speed rail in tunnels can create a significant environmental impact at the exit of the tunnel.
- 6.6.2. The Environmental Statement for HS2 Phase One states *“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.”*

## 6.7. Modal shift

- 6.7.1. There may be the potential for some modal shift from road to rail on both HS2 and the existing rail network and the resultant shift could produce a small reduction in traffic numbers. However, it is unlikely that this effect would result in any perceived benefit in terms of reduced overall noise levels.

## 6.8. Secondary benefits

- 6.8.1. In some instances noise barriers or earth bunds may be implemented as part of a noise mitigation strategy. These also have the potential to provide acoustic screening of noise from existing roads and/or railways as has been the case with other schemes.
- 6.8.2. In these areas, some properties may experience a noticeable reduction in overall noise level (existing sources and HS2 combined), due to the attenuation effect of such noise barriers or bunds. The specific locations where this benefit may arise will be explored further as part of the EIA.
- 6.8.3. The implementation of noise insulation under the Noise Insulation Regulations at some properties may also benefit some residents who live near an existing transport corridor and are already exposed to high existing noise levels, and the implementation of such noise insulation could reduce internal noise levels from existing noise sources.

## 7. VIBRATION AND GROUND-BORNE NOISE

### 7.1. Introduction

- 7.1.1. Vibration and ground-borne noise is dependent upon numerous factors at the source, during ground propagation and at receivers. The design at this early stage of a development provides insufficient detail to undertake a quantitative assessment. However, substantial experience from other projects, particularly HS1, enables a robust qualitative assessment to be made.
- 7.1.2. Experience from HS1 and international guidance<sup>22</sup> suggests that, *without* any mitigation, ground-borne noise and vibration impacts from HS2 could occur up to 100m from the Manchester tunnel and up to 200m from all other tunnels, the difference reflecting the greater speed of these tunnels compared to the Manchester tunnel. However, HS1 and other international high speed rail experience suggest that potential vibration and ground-borne noise impacts could be avoided.

### 7.2. Approach

- 7.2.1. Whilst later, more detailed assessments would need to consider potential ground-borne noise and vibration impacts arising from all sections of the line, this strategic appraisal has been based on the overarching conclusion of HS1 and the majority of high-speed lines in Europe: that airborne noise is the dominant issue for surface sections of line; and ground-borne noise is the key issue for tunnelled sections.
- 7.2.2. Receivers considered for the vibration and ground-borne noise appraisal consisted of geo-referenced postal address point data. Both residential dwellings and a small number of non-residential noise sensitive receivers are included within this address point data.
- 7.2.3. Two buffer distances were used to screen potential ground-borne noise and vibration impacts. For the Manchester tunnel a buffer distance of 100m was used to assess properties potentially at risk. For all other tunnels, a buffer distance of 200m was used. The smaller buffer distance used to assess the Manchester tunnel was selected because train speeds are relatively slow in this tunnel (230km/h) compared to train speeds in most other tunnels (which run at 300km/h and above).

### 7.3. Vibration and ground-borne noise findings

- 7.3.1. The number of properties potentially at risk of vibration and re-radiated noise around the eastern leg tunnels is around 6,800 dwellings and 70 non-residential properties sensitive to noise or vibration (including six schools). The number of sensitive properties potentially at risk of vibration and reradiated noise around the western leg tunnels is around 920 dwellings and seven non-residential properties sensitive to noise or vibration (including three schools).
- 7.3.2. Where properties may experience adverse effects based on the above, mitigation would first be assessed by further optimisation of the track design e.g. HS1 substantially extended the level of ground-borne noise and vibration mitigation possible for underground high speed train operations. Such mitigation could avoid potential adverse effects over the tunnels. HS2 Ltd is committed to ensuring that no significant effects arise.

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<sup>22</sup> Harris Miller Miller & Hanson Inc. (October 2005). U.S. Department of Transportation Federal Railroad Administration HMMH Report No. 293630-4:High-Speed Ground Transportation Noise and Vibration Impact Assessment

## 8. ASSUMPTIONS AND LIMITATIONS

- 8.1.1. **Tables 8-1 – 8-4** set out key assumptions and limitations for the airborne noise appraisal, and should be read in conjunction with those already discussed in this chapter.

**Table 8-1 - Assumptions - TAG airborne noise appraisal**

The limited strategic level data available on ‘with scheme’ and ‘without scheme’ scenarios is sufficient to provide a plan level TAG appraisal of route.
Monetary valuation provided in TAG can be used to assess noise from high speed railways.
Daytime 18hr (06:00-24:00 hrs) operational noise levels ( $L_{Aeq,18hr}$ ) between 45 dB $L_{Aeq,18hr}$ and 81 dB $L_{Aeq,18hr}$ are appropriate for the TAG appraisal and equivalence is assumed between $L_{Aeq,16hr}$ and $L_{Aeq,18hr}$ for rail.
The effect of night time noise and potential sleep disturbance impacts has not been included in the TAG appraisal or the monetary valuation of the change in noise.
TAG noise appraisal has been based on the ‘with scheme’ and ‘without scheme’ noise levels during operational year 15.
The difference between the ‘with scheme’ and ‘without scheme’ noise levels is considered to be constant throughout the life of the 60 year appraisal period.
Dwellings located in areas with noise levels over 81 dB $L_{Aeq,18hr}$ have been considered to be relocated to an area experiencing the same noise level as the predicted existing noise level.
Monetary values have been based on 2010 data with no adjustment for income levels, property values, deprivation or demographic.
Monetary values based on operational year 15 noise levels with GDP growth and discounting applied as per TAG guidance.
Habituation to noise has not been considered in monetary value calculations.
Assumed average household size is 2.3 people per dwelling.
Reported numbers of dwellings have been rounded. Generally, those in the hundreds have all been rounded to the nearest fifty, in the thousands to the nearest hundred and less than 100 have been reported as “less than”. Reported monetary costs have all been rounded to the nearest half a million.

**Table 8-2 - Assumptions - airborne noise source level**

Existing aircraft noise has not been considered in calculations.
Existing road traffic noise has not been considered in calculations.
Noise levels ‘without scheme’ are considered to be existing railway noise levels only, subject to a minimum 45 dB(A).
Existing railway source levels have been calculated using the HS2 CadnaA Noise Model. Published Defra railway noise contour maps have been used to calibrate existing railway source noise levels for use in the model.
Noise levels ‘with scheme’ are considered to be existing railway noise levels combined logarithmically with future HS2 noise levels.
HS2 source levels have been based on TGV measured data up to 360 km/h and further extrapolated to higher speeds.

Aerodynamic noise contribution starts to influence overall levels at 300 km/h.
Maximum operational speed for HS2 is 360 km/h.
Operational characteristics such as service patterns, train length and design speed were provided by HS2 Ltd.
Speed used to calculate HS2 sources noise level is 360 km/h where design speed is above 360 km/h and design speed where design speed is below 360 km/h.
3dB reduction in HS2 source noise level for the mitigated scenario irrespective of speed or numbers of trains.*

\*this assumption is only valid for the preferred scheme with additional indicative mitigation

**Table 8-3 - Assumptions - Airborne Noise Model**

HS2 and existing rail receiver noise levels have been calculated using CRN prediction methods combined with ISO 9613-2 prediction methods for shielding from buildings.
Shielding from residential and commercial buildings has been approximated by built up areas (8m relative height at edges) using ISO 9613-2 prediction methods with an attenuation of 15dB per 100m.
Receiver heights have been set at 4m relative to ground.
Dwellings within 300m of route centreline have been spatially located from postal address point data.
All dwellings outside of 300m from route centreline have been spatially located from postal address point data and grouped to 50m x 50m grid squares.
Estimated numbers exclude dwellings likely to be demolished.
3D route alignment shapefile provided has been modelled as 3D
3D earthworks shapefile (cuttings and embankments) provided has been modelled as 3D.
Existing Digital terrain model is based on 5m ground contours.
Built up areas assumed to be hard ground; elsewhere assumed to be soft ground.
Barrier locations within the model based on preliminary candidate areas for mitigation. These have been derived according to the method described in the report. *
Indicative barriers applied as 2m barriers at the top of cuttings and embankments where speed is over 300km/h; 3m barriers where speed is below 300km/h and 2m on all viaducts. *
Source height has been assumed as 1m above rail head for speeds over 300km/ and Rail head height for speeds below 300km/h.
Attenuation from barriers has been calculated using CRN method, except, where speeds are above 300kph, and barrier height is 3m, barrier height has been reduced by 1m. *

\*this assumption is only valid for the preferred scheme with additional indicative mitigation

**Table 8-4 - Limitations - airborne noise**

Noise model accurate as a community level appraisal.
'With scheme' and 'without scheme' noise levels do not consider released capacity or future changes to traffic volumes of road or rail.
Noise levels do not consider stationary environmental noise sources (eg, industrial, commercial sources).
The influence of detailed variations in ground attenuation and meteorological conditions

are not considered in sound propagation.

The feasibility of additional indicative mitigation options has only been examined at a strategic level.

Limited research available on dose response relationship of high speed rail noise. The appraisal, therefore has assumed a traditional railway dose response.

No site surveys or baseline surveys have been carried out at the time of the noise appraisal.

## Glossary

Aerodynamic Noise	Acoustic noise caused by turbulent airflow over the surface of the train body, pantograph and bogie areas..
Defra Noise Maps	Noise maps produced by Defra to meet the requirements of the Environmental Noise (England) Regulations 2006, and are intended to inform the production of noise action plans for large urban areas, major transport sources, and significant industrial sites in England.
dB	Decibel. The unit used to describe the magnitude of sound. The decibel scale is logarithmic and it ascribes equal values to proportional changes in sound pressure.
dBA	The unit of sound pressure level, weighted according to the A scale, which takes into account the increased sensitivity of the human ear at some frequencies.
Free Field	An environment in which there are no sound reflections other than from the ground. A façade correction of -3 dB is commonly used to convert free field noise levels to façade noise levels.
HGV	Heavy Goods Vehicle (a lorry/ truck weighing more than 3.5 tonnes)
$L_{Aeq,18h}$	The A-weighted equivalent continuous sounds pressure level over the 18 hour daytime period (06:00 to 24:00).
$L_{Aeq,Tp}$	The A-weighted equivalent continuous sounds pressure level of a train passbynormalised to the passby duration (buffer to buffer).
$L_{den}$	The day, evening, night level, $L_{den}$ is a logarithmic composite of the $L_{day}$ , $L_{evening}$ , and $L_{night}$ levels but with 5 dBA being added to the $L_{evening}$ value and 10 dBA being added to the $L_{night}$ value
PCAM	Preliminary Candidate Area for Mitigation. Areas where additional mitigation, such as noise barriers or earth bunds, would potentially have the greatest benefit to reducing the overall number of noise impacts. For the purposes of modelling the scheme 'including additional indicative mitigation' it has been assumed that mitigation at these locations would achieve a noise reduction equivalent to that achieved by use of 3m high noise barriers (or bund) or, at viaducts, by 2m high barriers with noise-absorbent materials used throughout.





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