Crossrail

Technical Report

Assessment of Noise and Vibration Impacts

Volume 1 of 8

Introduction, Scope and Methodology

Final Report

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1. INTRODUCTION

Introduction to Crossrail

1.1 Crossrail is a major new cross-London rail link project that has been developed to serve London and the southeast of England. Crossrail will support and maintain the status of London as a world city by providing a world class transport system. The project includes the construction of a twin-bore tunnel on an east-west alignment under central London and the upgrading of existing National Rail lines to the east and west of central London. The Crossrail route is shown in Figure 1.1.

FIGURE 1.1 - OVERVIEW OF CROSSRAIL ROUTE

1.2 The project will enable the introduction of a range of new and improved rail journeys into and through London. It includes the construction of seven central area stations, providing interchange with London Underground, National Rail and London bus services, and the upgrading or renewal of existing stations outside central London. Crossrail will provide fast, efficient and convenient rail access to the West End and the City by linking existing routes from Shenfield and Abbey Wood in the east with Maidenhead and Heathrow in the west.

1.3 Crossrail will be a significant addition to the transport infrastructure of London and the southeast of England. It will deliver improved services for rail users through the relief of crowding, faster journeys and the provision of a range of new direct journey opportunities. The project will also have wider social and economic benefits for London and the southeast of England.

Route Overview

1.4 Crossrail’s route has four distinct sections: a central section within central London and, outside central London, western, north eastern and south eastern sections. The boundaries of these route sections are shown in the schematic maps in Volumes 4 to 7.
1.5 In the west, Crossrail will use the Great Western Main Line between Maidenhead and Westbourne Park. The existing 25 kV overhead electrification between Paddington and Airport Junction will be extended to Maidenhead and bridge alterations will be undertaken as necessary. The main infrastructure changes are the construction of a flyover structure (the Stockley flyover) to allow Crossrail trains to access the existing tunnelled spur to Heathrow and the provision of a rail underpass (a dive-under) west of Acton Yard. A new line, within the existing railway corridor, will be provided between Langley and West Drayton. Enhancements will also be made to stations, with the most significant works being at Ealing Broadway, Southall, Hayes and Harlington, West Drayton, Slough and Maidenhead. New stabling sidings are also proposed at Old Oak Common, West Drayton and west of Maidenhead station.

1.6 The central route section will consist largely of a twin-bore tunnel beneath central London with portals at Royal Oak in the west, Pudding Mill Lane in the northeast and Victoria Dock Road in the southeast. The central route section extends from a point around 200m west of the A40 Westway to a point around 500m to the east of the portal at Pudding Mill Lane in the northeast and a point just to the east of Poplar Dock and the A1206 Prestons Road in the Isle of Dogs in the southeast. New stations and associated structures, such as ventilation shafts, will be provided along this part of the route.

1.7 On the northeast route section, Crossrail will use the existing Great Eastern Main Line between Pudding Mill Lane and Shenfield. The main infrastructure changes are a new train maintenance depot west of Romford station and the reinstatement of a track between Goodmayes and Chadwell Heath. Enhancements will also be made to stations, with the most significant works being proposed at Ilford and Romford. This route has existing 25kV overhead electrification. New stabling facilities will be provided at Gidea Park.

1.8 The southeast route section runs between a point to the east of the Isle of Dogs station and the eastern terminus at Abbey Wood, where Crossrail will serve a reconstructed station. Crossrail will operate in a twin-bore tunnel to Victoria Dock portal where it will serve a reconstructed station at Custom House. The route will then follow the existing alignment currently used by the North London Line through the Connaught Tunnel to Silvertown. At North Woolwich, a new twin-bore tunnel to Plumstead, referred to as the Thames Tunnel, will pass beneath the River Thames. Two new tracks will be provided between Plumstead and a point east of Abbey Wood station to accommodate Crossrail services on the North Kent Line corridor. This route will be provided with 25kV overhead electrification on the Crossrail lines.

1.9 This Technical Report (TR) provides the specialist noise and vibration assessment for the Crossrail scheme. The scope and methodology of the assessment is described together with full details of the results, including significant residual impacts and assumed mitigation. The route sections have been divided into route windows (RWs) and each RW contains a noise and vibration assessment covering both construction and operation, as applicable.

1.10 This report is divided into the following eight volumes:

- Volume 1 – Introduction, Scope and Methodology
- Volume 2 – Baseline Noise Monitoring Report, Part 1
• Volume 3 – Baseline Noise Monitoring Report, Part 2
• Volume 4 – Assessment of Noise and Vibration Impacts – Central Route Section
• Volume 5 - Assessment of Noise and Vibration Impacts – Western Route Section
• Volume 6 - Assessment of Noise and Vibration Impacts – North Eastern Route Section
• Volume 7 - Assessment of Noise and Vibration Impacts – South Eastern Route Section
• Volume 8 - Assessment of Noise and Vibration Impacts - Figures

1.11 This volume of the TR defines the scope of the assessment and the methodology and criteria adopted to assess impacts and optimise appropriate mitigation measures. A glossary of terms is provided in Appendix A.
2. NOISE AND VIBRATION UNITS

Noise Units

2.1 Noise is defined as unwanted sound. It is measured using the decibel scale which is a logarithmic scale which compresses the range of numbers required to describe the wide range of pressure intensities that occur. The logarithmic scale is also required as the human ear subjectively judges the relative loudness of two sounds by the ratio of their intensities, which is logarithmic behaviour. It is not an absolute scale; it is a ratio between a measured quantity and a reference level. The dB scale used to describe pressure is the SPL (Sound Pressure Level). If the pressure is multiplied by a factor of 10 then the overall dB level increases by 20 dB. In summary, the dB scale compresses a range of 10 million into 140 dB, as shown by the range in Table 2.1:

2.2 TABLE 2.1: dB SCALE

<table>
<thead>
<tr>
<th>Sound Pressure Level (dB)</th>
<th>Typical Source or Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Threshold of hearing</td>
</tr>
<tr>
<td>20</td>
<td>Leaves rustling</td>
</tr>
<tr>
<td>40</td>
<td>Computer fan</td>
</tr>
<tr>
<td>60</td>
<td>Normal conversation</td>
</tr>
<tr>
<td>80</td>
<td>Road traffic</td>
</tr>
<tr>
<td>100</td>
<td>Road drill/circular saw</td>
</tr>
<tr>
<td>120</td>
<td>Pneumatic chisel</td>
</tr>
<tr>
<td>140</td>
<td>Jet take-off at 20 m</td>
</tr>
<tr>
<td>160</td>
<td>1 m from jet aircraft</td>
</tr>
</tbody>
</table>

2.3 The range of audible sound is from 0 dB to 140 dB. The frequency response of the ear is usually taken to be about 18 Hz (number of oscillations per second) to 18000 Hz. The ear does not respond equally to different frequencies at the same level. It is more sensitive in the mid-frequency range than the lower and higher frequencies and because of this, when undertaking measurements, the low and high frequency components of a sound are reduced in importance by applying a weighting (filtering) circuit to the noise measuring instrument. The weighting which is most widely used and which correlates best with subjective response to noise is the A-weighting. This is an internationally accepted standard for noise measurements.
2.4 For variable noise sources such as traffic, a difference of 3 dB(A) is just distinguishable. In addition, a doubling of a noise source will increase the overall noise by 3 dB(A). For example, if one item of machinery results in noise levels of 30 dB(A) at 10m, then two identical items of machinery adjacent to one another will result in noise levels of 33 dB(A) at 10m. The "loudness" of a noise is a purely subjective parameter but it is generally accepted that an increase/decrease of 10 dB(A) corresponds to a doubling/halving in perceived loudness.

2.5 External noise levels are rarely steady but rise and fall according to activities within an area. In an attempt to produce a figure that relates this variable noise level to subjective response, a number of noise indices have been developed. These include:

$L_{A_{max}}$ **noise level**

2.6 This is the maximum noise level recorded over the measurement period.

$L_{A_{eq}}$ **noise level**

2.7 This is the "equivalent continuous A-weighted sound pressure level, in decibels" and is defined in British Standard BS 7445 [1] as the "value of the A-weighted sound pressure level of a continuous, steady sound that, within a specified time interval, T, has the same mean square sound pressure as a sound under consideration whose level varies with time".

2.8 It is a unit commonly used to describe community response, construction noise and noise from industrial premises and is the most suitable unit for the description of other forms of environmental noise. In more straightforward terms, it is a measure of energy within the varying noise. It is often termed the ambient noise as it includes all the noise occurring at the measurement location over the measurement time period.

$L_{A_{10}}$ **noise level**

2.9 This is the noise level that is exceeded for 10% of the measurement period and gives an indication of the noisier levels. It is a unit that has been used over many years for the measurement and assessment of road traffic noise.

$L_{A_{90}}$ **noise level**

2.10 This is the noise level that is exceeded for 90% of the measurement period and gives an indication of the noise level during quieter periods. It is often referred to as the background noise level and is used in the assessment of disturbance from industrial noise.
Vibration Units

2.11 Groundborne vibration from construction sources, such as piling, can be a source of concern for occupants of buildings in the vicinity. The concern can be that the building may suffer some form of cosmetic or structural damage or that groundborne vibration could give rise to ground settlement that could subsequently lead to damage. Research associated with British Standard (BS) 7385, Parts 1 and 2 [2, 3] concerned with vibration-induced building damage found that, although a large number of case histories were assembled, very few cases of vibration-induced damage were identified. However, structural vibration in buildings can be detected by the occupants and can affect them in many ways: their quality of life can be reduced, as also can their working efficiency, although, there is little evidence that whole-body vibration directly affects cognitive processes. It should be noted that there is a major difference between the sensitivity of people feeling vibration and the onset of levels of vibration that damage a structure, i.e. the threshold of perception is very low relative to vibration levels that will cause even cosmetic damage such as minor cracking.

Vibration Dose Value (VDV)

2.12 The effect of building vibration on people inside buildings is assessed by determining their vibration dose. Present knowledge indicates that this is best evaluated with the VDV, as promoted through BS 6472 [4]. VDV defines a relationship that yields a consistent assessment of intermittent, occasional and impulsive vibration, as well as continuous input, and correlates well with subjective response. The way in which people perceive building vibration depends upon various factors, including the vibration frequency and direction. The VDV is given by the fourth root of the integral of the fourth power of the acceleration after it has been frequency weighted.

Peak Particle Velocity (PPV)

2.13 Peak particle velocity is defined as “the maximum instantaneous velocity of a particle at a point during a given time interval”, and has been found to be the best single descriptor for correlating with case history data on the occurrence of vibration-induced damage to buildings. It is the unit recommended in BS 7385 for this purpose but is sometimes used instead of VDV to assess effects upon people, as it is easier to measure than VDV. However, it is contrary to guidance to use PPV in this context.

Groundborne Noise

2.14 The term groundborne noise refers to noise perceived by the sense of hearing that differs from noise in general only insofar as it arrives in the space where it is heard as a result of propagation as vibration (at acoustic frequencies) through the ground or through a structure. The vibrating room surfaces cause airborne sound to be radiated and the effect is sometimes referred to as re-radiated noise.
2.15 In many respects, the phenomenon merits using assessment methods applied to noise in general. However, there are special features that should be taken into account. The first is that whereas noise in a dwellings originating from outside tends primarily to affect one or two facades, with the result that the occupant can find lower noise levels in rooms the other side of the dwelling, groundborne noise tends to be the same in all rooms (albeit with a slight reduction with increasing floor level). The second feature is that, at night, groundborne noise may reach the ear without passing through air, through the bed and pillow, and cause a greater effect than would be expected from airborne noise at a similar level.

2.16 The practice adopted in the case of groundborne noise from underground railways has been to use $L_{A\text{max},S}$ noise parameter.
3. **PLANNING AND REGULATORY CONTEXT**

**Introduction**

3.1 This section describes the planning guidance and regulations which apply to the Crossrail scheme.

**Planning Guidance**

**Planning Policy Guidance PPG 24 – Planning and Noise**

3.2 Principles and specific guidelines on noise and planning issues are given in DoE Planning Policy Guidance: 24 - Planning and Noise [5]. This document, published by the Department of the Environment, supersedes DoE Circular 10/73 [6] but builds upon advice previously contained within it.

3.3 PPG 24 represents published government guidance on planning and noise, and contains the criteria most widely used in the UK for determining the suitability of sites for housing. PPG 24 sets out a range of “Noise Exposure Categories” (NECs), defined by ranges in noise level, each of which indicates advice to consider during the planning stage where noise sensitive developments (i.e. residential developments) are proposed close to existing noise sources, such as road traffic.

3.4 The table in Section 8 of Annex 1 contains a recommended range of noise levels for each NEC covering the day and night-time periods. However, it is acknowledged that, in some cases, it may be appropriate for local planning authorities to determine the range of noise levels which they wish to attribute to any or each of the NECs. For example, where there is a clear need for new residential development in an already noisy area, some or all NECs might be increased by up to 3 dB(A) above the recommended levels. In other cases, a reduction of up to 3 dB may be justified.

3.5 The four NEC categories defined for rail traffic noise are included in Table 3.1 below, with corresponding noise levels and advice on noise considerations.
TABLE 3.1: RECOMMENDED NOISE EXPOSURE CATEGORIES FOR NEW DWELLINGS IN ACCORDANCE WITH PPG 24

<table>
<thead>
<tr>
<th>Noise Exposure Category for Rail Traffic Noise</th>
<th>Free-field Noise Levels Corresponding to the Noise Exposure Categories for New Dwellings L_{Aeq,T} dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>07:00 – 23:00 hrs</td>
</tr>
<tr>
<td>A Noise need not be considered as a determining factor in granting planning permission, although the noise level at the high end of the category should not be regarded as a desirable level.</td>
<td>&lt;55</td>
</tr>
<tr>
<td>B Noise should be taken into account when determining planning applications and, where appropriate, conditions imposed to ensure an adequate level of protection against noise.</td>
<td>55 – 66</td>
</tr>
<tr>
<td>C Planning permission should not normally be granted. Where it is considered that permission should be given, for example because there are no alternative quieter sites available, conditions should be imposed to ensure a commensurate level of protection against noise.</td>
<td>66 – 74</td>
</tr>
<tr>
<td>D Planning permission should normally be refused.</td>
<td>&gt;74</td>
</tr>
</tbody>
</table>

3.6 The guidelines given in PPG 24, correspond to a noise level measured under free-field conditions (away from any reflecting facades) and at a height of 1.2 to 1.5 m above ground. The noise levels (L_{Aeq,T}) used when deciding the NEC of a site should be representative of typical conditions.

3.7 PPG 24 also recommends that the daytime period is from 07:00 to 23:00 hours and the night-time period is 23:00 to 07:00 hours; therefore, measurements should either be taken over the full day or night-time periods and the period L_{Aeq} determined, or if measurements of shorter duration are taken, then these need to be representative of the full day or night-time periods. PPG 24 further stipulates that sites where individual night-time noise events regularly exceed 82 dB L_{Amax} (Slow time weighting) several times in any hour, should be treated as being in NEC C, regardless of the L_{Aeq,8h}, except where the site already falls into NEC D.

3.8 It is considered that, provided a proposed development lies within NEC A or NEC B (lower end) then noise need not be a material consideration. If the properties were assessed as being within the higher end of NEC B, or the lower end of NEC C, then noise is considered to be a material issue but, provided that internal levels with windows closed meet the “good” criteria in BS 8233:1999 [7], then the development is generally considered to be acceptable.
3.9 Sections 10 to 11 of PPG 24 consider noisy development. Section 10 acknowledges that “Much of the development which is necessary for the creation of jobs and the construction and improvement of essential infrastructure will generate noise. The planning system should not place unjustifiable obstacles in the way of such development. Nevertheless, local planning authorities (LPAs) must ensure that development does not cause an unacceptable degree of disturbance. They should bear in mind that a subsequent intensification or change of use may result greater intrusion and they may wish to consider the use of appropriate conditions.

3.10 Section 11 guides the reader to Annex 3 for major noise sources such as railways, which is considered in Sections 2 to 5 (of Annex 3). Section 2 advises that railway noise emanates from various sources and indicates that the NEC categories should be used for assessing noise from operational railway lines affecting new residential development but that noise from stations activities, freight distribution depots and marshalling yards should be treated in the same way as industrial sources. This section also advises that LPAs are advised to ask the developer to provide the details of the present levels of noise, and to consult the railway operator to find out if there are proposals for significant operational changes.

3.11 Section 3 covers the requirement to consider the effects of using rail to transport goods or materials. Section 4 advises that the likelihood of significant ground-borne vibration will depend on the nature of the ground and the types of train; that the effects of trains in tunnels should not be overlooked; and that BS 6472: 1992 provides advice on acceptable levels of vibration. Section 5 mentions that in 1993 the DoT published draft noise insulation regulations, similar to those originally provided for roads; and that draft technical guidance for calculating noise from railways was also made available at the same time. The Noise Insulation (Railway and Other Guided Transport Systems) Regulations 1996 [8] for and Calculation of Railway Noise (CRN)1995 [9], as amended, are both now available.

Regulatory Context

The Control of Pollution Act/Environmental Protection Act

3.12 There are various standards and legislation applicable to construction activities associated with development of this type and these are outlined below:

3.13 Section 60, Part III of Chapter 40 of the CoPA [10] - Control of noise on construction sites. This provides legislation by which LAs can control noise from construction sites to prevent disturbance occurring.

3.14 Section 61, Part III of Chapter 40 of the CoPA - Prior consent for work on construction sites. This provides a method by which a contractor can seek consent to undertake construction works in advance of their commencement. If consent is given, and the stated method and hours of work complied with, then the LA cannot take action under Section 60.
3.15 Section 79, Part III of Chapter 43 of the EPA [11] - Statutory nuisances and inspections therefore. This defines statutory nuisance with regard to noise and other aspects and determines that LAs are under a duty to inspect their areas to detect such nuisances. This section also considers and defines the concept of "Best Practicable Means" (BPM) which originates from Section 72, Part III of Chapter 40 of CoPA where BPM is defined as "reasonably practical having regard, among other things, to local conditions and circumstances, to the current state of technical knowledge and to the financial implications".

3.16 Section 80, Part III of Chapter 43 of the EPA - Summary proceedings for statutory nuisances. This provides LAs with powers to serve an abatement notice requiring the abatement of a nuisance or requiring works to be executed to prevent their occurrence.

3.17 Some of the above are described in more detail below.

3.18 The CoPA gives LAs powers for controlling noise and vibration from construction sites and other similar works. These powers may be exercised either before works start or after they have started.

3.19 Section 60 of the CoPA enables a LA, in whose area work is going to be carried out, or is being carried out, to serve a notice of its requirements for the control of site noise on the person who appears to the LA to be carrying out the works and on such other persons appearing to the local authority to be responsible for, or to have control over, the carrying out of the works.

3.20 This notice can:

a) Specify the plant or machinery that is or is not to be used.

b) Specify the hours during which the construction work can be carried out.

c) Specify the level of noise and vibration that can be emitted from the premises in question or at any specified point on these premises or that can be emitted during specified hours.

d) Provide for any change of circumstances.

3.21 In serving such a notice, a LA must have regard to:

a) The relevant provisions of any Code of Practice issued and/or approved under Part III of the CoPA.

b) The need for ensuring that the best practicable means are employed to minimise noise.

c) Before specifying any particular methods or plant or machinery, the desirability, in the interests of the recipient of the notice in question of specifying other methods or plant or machinery that will be substantially as effective in minimising noise and vibration and that will be more acceptable to them.
d) The need to protect people in the locality of the site from the effects of noise and vibration.

3.22 A person served with such a notice can appeal to a Magistrates Court within 21 days from the date of the serving of the notice. Normally, the notice is not suspended pending an appeal unless it requires some expenditure on works and/or the noise or vibration in question arises or would arise in the course of the performance of a duty imposed by law on the appellant. The regulations governing appeals (The Control of Noise (Appeals) Regulations 1975 [12]) also give LAs discrections not to suspend a notice even when one or other of these conditions is met, if the noise is injurious to health, or is of such limited duration that a suspension would render the notice of no practical effect, or if the expenditure necessary on works is trivial compared to the public benefit expected.

3.23 Section 61 enables a contractor (or developer) to apply to the LA for a Consent and this represents an Application under this section of the CoPA.

3.24 Once a Consent has been granted, a LA cannot take action under Section 60 of the CoPA or Section 80 of the EPA, so long as the Consent remains in force and the contractor complies with its terms.

3.25 Compliance with a Consent does not, however, mean that nuisance action cannot be taken under Section 82 of the EPA or under common law. However, a Consent can be used as a defence in appeals against an Abatement Notice (Statutory Nuisance (Appeals) Regulations 1995 [13]) served by the LA under the EPA.

The Noise Insulation (Railway and Other Guided Transport Systems) Regulations 1996

3.26 The Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996 will apply to rail traffic using the new, additional or altered railway system associated with Crossrail.

3.27 The Regulations impose a duty upon the developer to offer noise insulation (or equivalent compensation) to properties subject to rail noise levels equal to, or in excess of 68 dB $L_{Aeq,18hr}$ (daytime) or 63 dB $L_{Aeq,6hr}$ (night-time). Similar to the NIR for roads, a contribution of at least 1.0 dB(A) from the initial, additional or altered railway and an increase of at least 1.0 dB(A) over the prevailing noise level are required for eligibility to arise.

3.28 Calculations to determine eligibility for noise insulation are required to be carried out in accordance with CRN.

EC Directives

Regulations Governing Noise from Plant and Equipment

3.30 Directive 2000/14/EC [14] on the approximation of the laws of the Member States relating to the noise emissions in the environment by equipment for use outdoors (Statutory Instrument 2001/1701) replaces the above existing directives which were repealed when this Directive came into force on the 1 January 2002.

Directive on Interoperability

3.31 EC Directive 2001/16/EC [15] on the interoperability of the trans-European conventional rail system came into effect in March 2001. This Directive replaces the existing Directive 95/19/EC and covers capacity allocation, charging and safety certification. Its main features are:

- it requires each member state to establish a regulatory body (which must be independent of infrastructure managers and train operators). These regulatory bodies should exchange views and experience;
- it applies to the main domestic networks (and will include the Channel Tunnel Rail Link);
- it sets out key principles for, and requires transparency in, allocating and charging for track access;
- it includes the principle of setting charges at the cost directly incurred as a result of operating the train service, but with the ability to add mark-ups and a rate of return;
• the infrastructure manager must produce a capacity enhancement plan and cost/benefit analysis where it cannot accommodate current or forecast bids for capacity;

• the infrastructure manager must publish a network statement covering the nature of the infrastructure, the charging principles, the capacity allocation and timetabling process, procedures and criteria for dealing with congested infrastructure and restrictions on the use of infrastructure; and

• access agreements may only be longer than ten years where they are linked to the delivery of long-term investment.

3.32 The Great Western Corridor is one of the nominated high speed lines and the relief lines for the Great Eastern and Great Western corridors form part of the Tens Network. To this extent, therefore, Crossrail will design or seek derogation as appropriate to the EC Directive in accordance with normal design principles. Crossrail has been in dialogue with both Network Rail and the SRA on this matter. With regard to noise, it is likely that Technical Standards Interoperability will be gradually introduced between 2004 and 2008 and will cover rolling stock and railway infrastructure. Noise emission limits are expected for new rolling stock.

Directive on Assessment and Management of Environmental Noise

3.33 EC Directive 2002/49/EC [16], relating to the assessment and management of environmental noise, came into force in July 2002. The aim of the directive is to minimise and reduce the harmful effects of environmental noise on a prioritised basis through:

• mapping of environmental noise in a consistent manner across the EC;

• ensuring that information on environmental noise and its effects is made available to the public; and

• member states adopting action plans, based on the mapping results, with a view to preventing/reducing environmental noise in larger conurbations and adjacent to major roads, railways and airports and preserving environmental noise quality where it is good.

3.34 This Directive was reviewed to determine implications upon either the assessment or the presentation of assessment details for Crossrail. The Directive currently has effect in relation to Noise Mapping, and defra is progressing with noise mapping for traffic noise (e.g. the London Noise Map). Other areas of the country are also being mapped. Defra is the "competent authority" responsible for noise mapping and the current requirement is for mapping of existing sources.

3.35 In due course (2008), the Directive's requirements for action plans will come into effect. Other EU countries are expecting action plans to include mitigation of existing railway noise and this may in due course have some consequences for Crossrail. The Directive also deals with assessment methodology, but as the UK has an established set of methodologies of its own, these continue to be used until eventually a new harmonised method is established. There is therefore no direct relevance of the Directive to Crossrail at the time that the assessment was completed.
Other Guidance

Draft Guidelines for Noise Impact Assessment

3.36 Draft guidelines for noise impact assessment [17] have been prepared by a Working Party jointly established by the Institutes of Acoustics and Environmental Management and Assessment. The current version is dated April 2002 and a final version was expected in 2004 but did not emerge. These guidelines have been reviewed to determine whether any of their recommendations or suggestions would influence the scope, methodology or approach to the various and diverse noise and vibration assessments necessary for Crossrail. It was concluded that, whilst the document was useful, its recommendations did not alter the intended approach to the baseline monitoring, the assessment process or the identification of appropriate mitigation measures.

The Mayor’s London Ambient Noise Strategy

3.37 The Greater London Authority (GLA) Act 1999 gave the Mayor a duty to prepare a “London Ambient Noise Strategy” [18]. The document was finalised and issued in March 2004.

3.38 Relevant key points of the draft strategy are as follows:

- The objectives are to stimulate improvements in the current and future track quality and maintenance of the rail network, to promote increased use of noise barriers and introduce quieter trains.

- An initial key priority includes seeking improved railway track quality and maintenance on national rail and Underground as far as organisation and funding allow.

- The objectives are supported by numerous policies, of which 17 are directly relevant to Crossrail, of which it is considered that the main issues are:
  - Policy 24, which urges Government to review and tighten up the Noise Insulation Regulations 1975 (amended 1988) (Railways and other guided transport systems).
  - Policy 36, which urges promoters of major rail, schemes to minimise any adverse impacts of noise and vibration, using the best available cost-effective technologies.

- It is considered that policies are strategic in nature and that they do not include fixed targets or criteria.

3.39 Specifically aimed at railway noise, Part 4B of the document highlights the need for an enhanced surface and underground railway service, if road traffic congestion and pollution problems are to be addressed. However, as many trains in London run close to noise-sensitive receptors, it is essential to ensure that the rail system is efficient, well-maintained and operated and does not generate needless noise or vibration. Investment in London’s railways provides the opportunity to minimise these issues.
3.40 Key issues involved in railway noise managements are identified as:

- track type and quality;
- quieter rolling stock and operation;
- railway structures and noise barriers;
- spatial planning and urban design; and
- building insulation.
4. NOISE AND VIBRATION STANDARDS AND GUIDANCE

BS 4142

4.1 Planning Policy Guidance 24 cites the use of BS 4142, Method for Rating industrial noise affecting mixed residential and industrial areas [19], to assess noise from industrial and commercial premises as it affects people residing in a building. Paragraph 19 of PPG 24 states the following:

"The likelihood of complaints about noise from industrial development can be assessed, where the Standard is appropriate, using guidance in BS 4142: 1990. Tonal or impulsive characteristics of the noise are taken into account by the “rating level” defined in BS 4142. This “rating level” should be used when stipulating the level of noise that can be permitted. The likelihood of complaints is indicated by the difference between the noise from the new development (expressed in terms of the rating level) and the existing background noise. The Standard states that: “A difference of around 10 dB or higher indicates that complaints are likely. A difference of around 5 dB is of marginal significance.” Since background noise levels vary throughout the a 24 hour period it has been necessary to assess the acceptability of noise levels for separate periods (e.g. day and night) chosen to suit the hours of operation of the project. Similar considerations apply to developments that will emit significant noise at the weekend as well as during the week. In addition, general guidance on acceptable noise levels within buildings can be found in BS 8233: 1987, and guidance on the control of noise from surface mineral workings can be found in MPG 11." (N.B. – It should be noted that PPG 24 refers to the 1990 version of BS 4142; the current version of the Standard is the 1997 version).

4.2 The method is based upon a comparison between the rating level of the noise from the specific source being considered and the background noise level (measured as an $L_{A90}$), in the absence of the specific source. The noise level from the specific source is increased by 5 dB(A), if the source has any distinctive characteristics (tones or impulses such as whines, hums or bangs), or if it is irregular enough to attract attention and becomes known as the rating level.

4.3 As stated above, the standard states that if the rating level of the noise exceeds the background noise by around 10 dB(A) or more, complaints are "likely". An increase of 5 dB(A) is deemed to be of "marginal significance" whilst a difference of minus 10 dB(A) or more indicates that "complaints are unlikely". These descriptions are summarised in Table 4.1 below:
<table>
<thead>
<tr>
<th>BS 4142 Assessment Level, dB(A) (Rating Level relative to Background Level)</th>
<th>BS 4142 Semantic (as described in the Standard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; -10</td>
<td>&quot;If the rating level is more than 10 dB below the measured background level then this is a positive indication that complaints are unlikely&quot;</td>
</tr>
<tr>
<td>-10 to +5</td>
<td>No BS description but the more negative the difference, the less the likelihood of complaints</td>
</tr>
<tr>
<td>+5</td>
<td>&quot;A difference of around +5 dB is of marginal significance&quot; - as BS description</td>
</tr>
<tr>
<td>+5 to +10</td>
<td>No BS description but the more positive the difference, the greater the likelihood of complaints</td>
</tr>
<tr>
<td>&gt; +10</td>
<td>&quot;A difference of around 10 dB or more indicates that complaints are likely&quot;</td>
</tr>
</tbody>
</table>

**4.4** In situations where the $L_{A90}$ background noise level at night is "low" (less than 30 dB(A)) and the Rating Level is low (less than 35 dB(A)), the standard states that the rating method of BS 4142 is not applicable. In these circumstances, it is standard practice to assess the noise effect by considering sleep disturbance criteria and other aspects such as noise change.

**BS 8233**

**4.5** BS 8233, Sound insulation and noise reduction in buildings, defines a range of ambient noise levels for a number of design criteria for good or reasonable conditions in certain habitable rooms. Table 4.2 provides a summary of the levels recommended in BS 8233 for rooms used for resting and sleeping.

**TABLE 4.2: INDOOR AMBIENT NOISE LEVELS AS RECOMMENDED IN BS 8233**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Typical Situation</th>
<th>Designed Range, $L_{Aeq,T}$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasonable resting/sleeping conditions</td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Living Rooms</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Bedrooms</td>
<td></td>
<td>30</td>
</tr>
</tbody>
</table>

**BS 5228**

**4.6** BS 5228, Noise and vibration control on construction and open sites: Parts 1, 2 and 4 [20, 21,22] provide guidance on the assessment, prediction and control of noise from construction and open sites. Part 4 of the standard deals specifically with noise and vibration generated by piling operations. This Standard, in its various parts, has been adopted under s. 71 of CoPA (Codes of Practice for minimising noise).
4.7 Part 1, Code of practice for basic information and procedures for noise and vibration control, gives recommendations for basic methods of noise and vibration control relating to construction and open sites where work activities/operations generate significant noise and/or vibration levels. It includes sections on: legislative background; community relations; training; occupational noise effects; neighbourhood nuisance; project supervision; and control of noise and vibration. Annexes include: a list of EC and UK legislation; noise sources, remedies and their effectiveness (mitigation options); guide to sound level data on site equipment and site activities (source terms that are used for modelling); estimating noise from sites (calculation procedures which form the basis of the modelling packages); and noise monitoring.

4.8 Part 2, Guide to noise and vibration control legislation for construction and demolition including road construction and maintenance, provides further detail on the legislation applicable to construction and related aspects.

4.9 Part 4, Code of practice for noise and vibration control applicable to piling operations, provides specific advice and information on legislation, source terms, prediction, monitoring etc of noise and vibration from piling operations. Also included is guidance on human response to vibration and the response of structures.

**BS 7385**

4.10 BS 7385, Evaluation and measurement for vibration in buildings: Parts 1 and 2 provide guidance on the measurement, assessment and damage levels for vibration effecting buildings. Part 1, Guide for measurement of vibrations and evaluation of their effects on buildings, provides advice on measurement, measurement instrumentation, location and fixing of transducers and data evaluation. Annexes also provide advice on classifying buildings with regard to their likely sensitivity; estimating peak stress from peak particle velocity; random data; a bibliography is also provided. For BS 7385, vibration is measured as PPV.

4.11 Part 2, Guide to damage levels from groundborne vibration, provides guidance on the levels of vibration above which building structures could be damaged. It identifies the factors which influence the vibration response of buildings, and describes the basic procedure for carrying out measurements. It also states that there is a major difference between the sensitivity of people feeling vibration and the onset of levels of vibration which damage structures; and that levels of vibration at which adverse comment from people is likely are below levels of vibration which damage buildings, except at lower frequencies.

**BS 6472**

4.12 BS 6472, Guide to Evaluation of human exposure to vibration in buildings, provides guidance on human response to vibration experienced in buildings. The standard includes weighting curves related to human response. However, it should be noted that the Standard is currently being revised and a Draft for Public Comment is expected in mid 2005. One of the main proposed amendments is a change to the weighting curve in the vertical axis from the current $W_g$ to $W_b$. This is likely to lower the level at which adverse comment is expected to arise.
World Health Organisation

4.13 A report was submitted to the WHO in 1995 [23] for consideration as a revision to the 1980 [24] document and revised community guidelines [25] were issued in 2000. In the 2000 guidelines, it is considered that the sleep disturbance criteria should be taken as internal noise levels of 30 dB $L_{Aeq}$ and 45 dB $L_{Amax}$ (assumed to be with windows open or closed) or external levels of 45 dB $L_{Aeq}$ and 60 dB $L_{Amax}$, with windows open.

4.14 For daytime levels, the 2000 WHO document states that “To protect the majority of people from being seriously annoyed during the daytime, the outdoor sound level from steady, continuous noise should not exceed 55 dB $L_{Aeq}$ on balconies, terraces, and outdoor living areas. To protect the majority of people from being moderately annoyed during the daytime, the outdoor sound level should not exceed 50 dB $L_{Aeq}$. Where it is practical and feasible, the lower outdoor sound level should be considered the maximum desirable sound level for new development.”

4.15 However, the National Noise Incidence Study 2000 [26] found the following:

4.16 “The National Noise Incidence Study 2000 has found that 55±3% of the population of England and Wales live in dwellings exposed to day-time noise levels above the WHO level of 55 dB $L_{Aeq,day}$. In 1990 we now estimate that 60±3% of the population were exposed above the level of 55 dB $L_{Aeq,day}$. This change represents a statistically significant decrease in the proportion of the population exposed above this level in 2000 when compared to the results of the 1990 study.

4.17 The National Noise Incidence Study 2000 has found that 68±3% of the population of England and Wales live in dwellings exposed to night-time noise levels above the WHO level of 45 dB $L_{Aeq,night}$. In 1990 we now estimate that 66±3% of the population were exposed above the level of 45 dB $L_{Aeq,night}$. This change represents a statistically non-significant increase in the proportion of the population exposed above this level in 2000 when compared to the results of the 1990 study. It should be noted that this is the only (one) of the established guideline values where we have detected an increase in population exposure in 2000 when compared to the 1990 study.”

4.18 Furthermore, in a review of health effects based noise assessment methods undertaken for the DETR [27] just before the issue of the 2000 WHO guidelines, it is noted that:

“Perhaps the main weakness of both WHO-inspired documents is that they fail to consider the practicality of actually being able to achieve any of the stated guideline values.”
The report goes on to say:

“The percentages exposed above the WHO guideline values could not be significantly reduced without drastic action to virtually eliminate road traffic noise and other forms of transportation noise (including public transport) from the vicinity of houses. The social and economic consequences of such action would be likely to be far greater than any environmental advantages of reducing the proportion of the population annoyed by noise. In addition, there is no evidence that anything other than a small minority of the population exposed at such noise levels find them to be particularly onerous in the context of their daily lives.”
5. **SCOPE, METHODOLOGY AND APPROACH TO PREDICTION AND ASSESSMENT OF IMPACTS**

**Introduction**

5.1 This section of the report describes the scope, methods and approach to the prediction and assessment of impacts arising from the construction and operation of Crossrail. This includes the establishment of the baseline noise and vibration levels, prediction methods and modelling, assessment criteria and mitigation measures.

**Sources of Potential Impact**

5.2 Impacts will arise through either noise and/or vibration changes or through exceedence of noise levels/limits. Different impacts may arise at the different resources and receptors, the impacts have therefore been considered on an individual basis.

5.3 Potential impacts during construction may arise from:

- noise and vibration from activities carried out on the surface including station works, trackworks, associated utilities works, handling of construction and excavated materials, works around tunnel portals and works at vent and grout shaft sites;

- groundborne noise and vibration from underground works including tunnel boring, construction trains and excavated materials conveyors; and

- noise associated with off-site heavy goods vehicle movements and any additional rail traffic movements.

5.4 Potential impacts during operation may arise from:

- noise and vibration from new or altered sections of line (initial, additional or altered works) including power supply facilities;

- increases in noise and vibration levels along existing rail corridors where rail services have increased (intensification) or the mix of services has changed;

- noise from plant in ventilation shafts;

- noise from Public Address (PA) systems in stations and depots;

- noise from maintenance depots;

- groundborne noise and vibration from trains running in new tunnelled sections of line;

- noise from underground train passbys emitted to surface through vent shafts; and

- noise from changes in road traffic.

5.5 From the lists in paragraphs 5.3 and 5.4, the following are considered unlikely to result in significant effects:
Vibration from trains running on sections of line that have not been realigned or have been realigned but only where receptors (occupants of dwellings) occur in excess of 25 m from the line. This is on the basis that, according to the Crossrail assessment criteria, there are two ways in which a significant impact due to surface vibration can arise. The first is in cases where the existing vibration dose value (VDV) is less than 0.22 ms\(^{-1.75}\) day or 0.13 ms\(^{-1.75}\) night, when the operation of Crossrail would cause VDVs of at least 0.31 ms\(^{-1.75}\) day or 0.18 ms\(^{-1.75}\) night. The second is in cases where the existing vibration dose value (VDV) is more than 0.22 ms\(^{-1.75}\) day or 0.13 ms\(^{-1.75}\) night, when the operation of Crossrail causes an increase in VDV of at least 40%.

Given that Crossrail rolling stock will intrinsically not cause more vibration than existing EMU stock, the principal ways of causing a 40% increase in VDV are track realignment (including the installation of points and crossings) and increase in train numbers. VDV is sensitive to the fourth root of train numbers, so to cause a 40% increase, train numbers would have to increase by a factor of 3.8. This will not occur based on likely service patterns, leaving only realignment. Vibration can be said to vary as the square root of the distance, in the worst case, so that a halving of the distance from the track to the receptor would normally be required to cause a 40% increase. Modern points and crossings should not cause an increase of vibration of that magnitude.

Having eliminated the 40% increase cases except in special cases of realignment, where no property becomes exposed to more than 0.31 ms\(^{-1.75}\) (day) or 0.18 ms\(^{-1.75}\) (night), it is possible to scope out surface vibration. The methodology does not state precisely where the vibration is to be assessed but the inference is that it is at the point of perception by the receiving person. Breaking this down into VDV per train, assuming the greatest projected total train service, the worst case is that individual train VDV at the point of perception by the receiving person should not exceed 0.044 ms\(^{-1.75}\). Based upon the above, receptors generally only need to be considered where they are within 10 m of the nearest track.

Vibration from the operational railway affecting structures and buildings. This is on the basis that vibration levels arising from modern railways with continuous welded rail (CWR) are generally low and whilst they may be perceptible, as indicated above, levels are most unlikely to cause even cosmetic damage to structures unless other factors such as differential settlement are affecting the structure.

Noise from the construction and operation of OLE, signalling and communications. This is on the basis that most significant works (level and duration) will not be required at night, and daytime work would be no different from typical occasional daytime roadside or construction work carried out by utilities lasting only a short time.

Noise from the construction and operation of electrification feeder stations and other similar works. This is on the basis that significant construction activity will not be required and their operation is unlikely to result in significant impact.
• Noise from PA systems at Stations and Depots – This is on the basis that where existing PA systems are present, the proposed change will not cause increased noise impact, and modern PA systems (including, for example, background sensitive level control) can have less impact. This can offset moving the PA system or speakers nearer to residents because of platform extensions. Furthermore, where there is to be a new PA installation, where there was none previously, technology is available to avoid a significant impact or disturbance arising. This is also necessary as local authorities use nuisance control powers to limit noise from PA systems.

• Noise and/or vibration arising from works remote or distant from noise sensitive receptors. This is on the basis that at distance from construction activities or operational sources, the noise or vibration attenuation will be sufficient to prevent any impact arising.

5.6 Accordingly, the above aspects are not considered further and are scoped out of the assessment process. This allows focus on the remaining aspects where significant impacts will potentially arise.

Spatial Scope

5.7 The spatial scope of the noise and vibration assessment includes the following geographic coverage:

• areas within approximately 100 m of construction worksites for the central route section and within approximately 250 m of the outer route sections, including grout shafts, excavated material and general materials handling facilities and utilities worksites, where significant activities may affect sensitive receptors. These distances were not strictly applied but used as a guide to limit the geographic distribution of receptors. The initial modelling included all receptors likely to be subject to a significant impact but receptor distribution was extended, if modelling indicated that further receptors could be subject to significant impacts;

• a corridor along and above the tunnel alignment where sensitive receptors may be subject to impacts from tunnel construction plant and activities, including materials delivery and excavated material removal. No specific modelling was carried out and hence it was not necessary to identify spatial extent of receptors requiring consideration;

• construction traffic routes and routes subject to changes in traffic flow associated with diversions, road closures etc, which will experience changes in flows where sensitive receptors may be affected. Noise changes along the roads/routes were calculated as affecting receptors along the road/route;

• rail routes which will experience direct or indirect changes in service patterns where sensitive receptors may be affected. The assessments have generally been carried out for receptors within 100 m of rail routes but this does vary slightly with ambient levels;
• a corridor along and above the tunnel alignment where sensitive receptors may be subject to impacts from the operational underground railway. However, a fixed corridor was not defined but the contours provided in Volume 8 of this TR indicate their extent. For individual buildings, the distance within which consideration was required depends on the sensitivity, and this was determined iteratively by considering the results of individual calculations and deciding whether extend the distance from the tunnel for possible cases of significance. For general cases of piled or deep foundations without special sensitivity, the 25 dB(A) contour is effectively the envelope on the principle that the effect of foundations is unlikely to be more than 15 dB(A);

• areas around vent shafts subject to noise from ventilation fans and underground train passbys. The assessments have generally included receptors within 100 m of these sources of noise; and

• road routes which will experience changes in flows as a result of Crossrail, causing migration from road to rail or increasing traffic to stations, where sensitive receptors will be affected (e.g. a possible reduction in road traffic along some routes but possible increase in traffic to/from stations). Noise changes along the roads/routes were calculated as affecting receptors along the road/route.

Temporal Scope

5.8 The noise and vibration assessment has included both construction and operation. For construction, the main activities are likely to occur between 2007 and 2013 but the duration of works at specific sites will vary and will normally be less than the total period. The temporal scope has also taken into account the time of day during which the works will be undertaken and this has included the following periods: 07:00 to 19:00 hours (day); 19:00 to 23:00 hours (evening); and 23:00 to 07:00 hours (night).

5.9 For the temporal scope during operation, baseline flows, without Crossrail, were taken for the period 2003/2004. For the with Crossrail scenario, the baseline services were altered to accommodate the additional services and consequential changes to the network, i.e. there is no specific design year but the scenarios are just baseline and with Crossrail. Conventionally, for assessments of this type, it is typical to take the maximum flow within 15 years of scheme opening. However, for this assessment, the future flows with Crossrail were considered to accommodate future service changes or increases. Further details on this are provided below.

Noise Sensitive Receptors

5.10 The following list identifies receptors which were considered to be noise and/or vibration sensitive. However, not all of these receptors were found to be present in the areas affected by the construction or operation of the scheme and hence impacts at all receptor types have not necessarily been identified:

• residential property and other buildings in residential use;

• theatres;

• auditoria and concert halls;

• studios;
- churches and buildings of similar religious sensitivity;
- courts;
- lecture theatres;
- schools;
- colleges;
- hospitals;
- laboratories and other critical work areas;
- libraries;
- cemeteries;
- public open space including recreational areas and sports grounds;
- where appropriate, and feasible, sites of nature conservation importance and other designations; and
- above and below ground utilities and any other noise/vibration sensitive infrastructure.

5.11 For the operational assessment, noise from the surface railway has only been assessed at dwellings but groundborne noise and vibration from the underground railway has been assessed at dwellings and other commercial or other buildings with especially noise sensitive uses such as auditoria, concert halls and studios.

Establishment of Baseline

5.12 The following baseline information has been obtained, as appropriate to the proposals within each RW:

- existing background and ambient noise levels;
- vibration levels to allow assessment of the likely effects from the operational railway with Crossrail services; and

- existing rail services and road traffic data for route sections and roads, which will be subject to change as a result of the new Crossrail services.

5.13 With regard to the first bullet point, the noise and vibration assessments for both construction and operation require baseline data, which have been used to assess the extent of impact by considering the change in noise and vibration levels at receptors along the route. Most of the monitoring was carried out on private property and hence the public was approached to gain consent to access the monitoring locations. This section describes in further detail why the monitoring was required, what was involved, where the monitoring was carried out, how the public was approached and consultation with LPAs.
The Need for Monitoring

5.14 A fundamental part of the assessment process is the comparison of baseline noise levels with future levels including the proposed infrastructure; this provides a noise change from which the impact is derived. For construction, the ambient $L_{Aeq}$ was required for the day, evening and night periods. Once this has been derived, it was then used to determine the threshold values above which significant impact is deemed to occur. Ambient noise levels have also been used in the determination of eligibility for noise insulation and temporary re-housing when construction noise levels exceed certain limits.

5.15 For operation, the assessment approach was that impacts arise when noise changes are equal to or exceed + 3 dB(A) (negative or adverse impact) or –3 dB(A) (positive or beneficial impact). The baseline $L_{Aeq}$ was required for the day (07:00 to 23:00 hours) and night-time (23:00 to 07:00 hours) periods. The future noise impacts, with Crossrail, have been determined from the difference between the ambient and the ambient plus the noise level from the development. This is then related to a semantic scale, which describes the severity of the impact.

5.16 There was, therefore, a fundamental requirement for noise monitoring, and to a lesser extent, vibration monitoring, to establish baseline levels along all sections of the route where service and/or infrastructure changes associated with Crossrail would cause changes in noise and/or vibration levels.

Description of Monitoring Activities

Noise

5.17 Baseline noise surveys have been carried out at representative locations along the route. These were mostly carried out in the gardens of private properties, in public open spaces and at some other sensitive buildings or land use areas. In order to provide representative data and to robustly provide appropriate levels for both the day, evening and night-time periods, the following measurement types were adopted:

- 7-day unattended external measurements at key representative locations along the route;
- 24 hour unattended external measurements at representative locations along the route;
- 3 hour/short term attended external daytime measurements at representative locations along the route;

5.18 The measurements were taken with sound level meters of various types either running off internal batteries or external sealed lead acid batteries. Some of the surveys were carried out at elevated positions using poles to mount the microphones or from balconies or other rooftop locations. For all but the 3 hour/short term survey types, the surveys were set up by one or two individuals and then left to be picked up at the end of the monitoring period designated for the site.

Vibration

5.19 Vibration monitoring was only carried out at one location on 11 October 2004, at a site very close to the track, 0.5km west of Brentwood Station. Full details of the measurements and the results are provided in Appendix B.
Approach to the Public

5.20 The majority of noise and vibration measurements were carried out in the gardens, on the balconies or outside windows of private properties. Some measurements were also carried out external to commercial, community or other premises which were considered noise sensitive.

5.21 The normal approach was to knock on the doors of the chosen properties to seek consent to establish the survey equipment in the appropriate locations. ID cards were carried together with a letter providing brief details of the Project and explaining why the measurements were necessary and how they will be used. The consultants generally answered any further questions that arose. This is the only practicable approach to this type of monitoring for a project of this type. Most people were generally happy to give consent although many properties were unoccupied during the day. Normally the preferred property was approached but others to the sides were then tried if either the occupants were out or they wouldn't give consent. For commercial properties, a similar approach was adopted.

Consultation with LPAs

5.22 One of the key aspects of the assessment process is consultation with the statutory consultees of which the local authorities are the most important for noise and vibration issues. The consultation process with the LPAs affected by Crossrail is ongoing but included identification of the proposed survey locations and durations. Plans were submitted at A3, 1:2,500 scale, which identified the proposed locations and durations of the monitoring. These were accompanied by a letter to each LPA briefly describing the project, the proposed approach to the assessment and the noise monitoring that was to be carried out together with a request that the LPA considers and comments on the proposals. Following submission of this information, the LPAs were contacted to discuss the proposals and a log was maintained of all contacts and their outcome.

5.23 The full results of the baseline monitoring and detailed approach are provided in Volumes 2 and 3.

Prediction Methods

5.24 Noise and vibration impacts have been assessed using a variety of prediction methodologies. These are summarised in Table 5.1 but further details of each model are provided in subsequent sections of this chapter.
TABLE 5.1: NOISE AND VIBRATION PREDICTION METHODS

<table>
<thead>
<tr>
<th>Impact</th>
<th>Prediction Methods</th>
<th>Key Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction noise</td>
<td>WS Atkins “SiteNoise” model and spreadsheet</td>
<td>“SiteNoise” implements the calculation methodology in BS 5228, Part 1. This model allows for spatial and temporal variations within the construction programme to be taken into account. Computerised modelling carried out for all main worksites. Utilities worksites assessed using spreadsheet method.</td>
</tr>
<tr>
<td>Construction Vibration</td>
<td>Methodology contained in BS 5228, Part 4 and Transport Research Laboratory Report 429</td>
<td>Distance from source to receptor critical, significantly more critical than for noise.</td>
</tr>
<tr>
<td>Construction road traffic noise</td>
<td>Methodology contained in “Calculation of Road Traffic Noise”</td>
<td>Changes in noise levels calculated from differences in light and heavy vehicles without and with Crossrail construction traffic.</td>
</tr>
<tr>
<td>Operational railway noise</td>
<td>WS Atkins “RailNoise” model</td>
<td>Computerised modelling used where detailed assessments required.</td>
</tr>
<tr>
<td></td>
<td>Methodology contained in “Calculation of Railway Noise”</td>
<td>Consideration of noise change only. No detailed modelling for areas subject to intensification.</td>
</tr>
<tr>
<td>Operational railway vibration</td>
<td>“FINDWAVE®” model</td>
<td>Computerised modelling used to identify areas potentially subject to significant vibration levels and to specify appropriate mitigation measures.</td>
</tr>
<tr>
<td>Operational ground-borne noise and vibration (tunnelled sections)</td>
<td>“FINDWAVE®” model</td>
<td>This model, developed by Rupert Taylor, was adopted for the detailed prediction of ground-borne noise and vibration from the JLE and other national and international rail schemes.</td>
</tr>
<tr>
<td>Operational road traffic noise</td>
<td>Methodology contained in “Calculation of Road Traffic Noise”</td>
<td>Changes in noise levels calculated from differences in light and heavy vehicles without and with Crossrail operational traffic.</td>
</tr>
<tr>
<td>Noise from vent shafts and depots (fixed plant)</td>
<td>“SoundPLAN” model</td>
<td>Computerised model used to predict noise from fixed plant.</td>
</tr>
</tbody>
</table>
Evaluation of Impacts

Introduction
5.25 The evaluation of noise and vibration impacts is based upon assessment methodologies and criteria, including eligibility for noise insulation (NI) and temporary rehousing (TRH), that have been developed following a review of criteria and policies adopted by other, recent major rail projects together with current best practice. The criteria that have been adopted are set out in the paragraphs below and are also contained in the Scope and Methodology Report, which has been circulated to stakeholders to facilitate consultation on the scheme.

Summaries of Reviews, Comparisons and Position Papers

Review of Previous Noise and Vibration Standards
5.26 In order to establish current best practice on noise and vibration assessments for major rail projects, Rupert Taylor Ltd [29] carried out a review of standards and assessment criteria adopted for construction and operation by other projects. This mostly focused on UK projects and included previous CrossRail, Railtrack (Network Rail) projects (Euston Area Remodelling (part of the West Coast Main Line Route Modernisation), and the West Coast Main Line Route Modernisation itself and Thameslink 2000), London Underground projects (Jubilee Line Extension and East London Line Extension) and the Channel Tunnel Rail Link. Consideration was also given to: current guidance on noise provided by the National Physical Laboratory [28] reflecting upon World Health Authority guidance on health effects; and Guidance on the Methodology for Multi-Modal Studies (GOMMMS) [29].

5.27 This review provided guidance on the criteria for the determination of noise and vibration impact and eligibility for NI and TRH adopted by other projects, which formed the basis for proposing criteria for Crossrail. In addition to the above, the criteria for the assessment of noise and vibration during construction and operation and the various commitments and undertakings made for various projects have been summarised for comparative purposes and these summaries are provided in Appendix C.

Work Undertaken for Previous Crossrail Schemes
5.28 In order to identify and assimilate work undertaken for previous CrossRail schemes, Rupert Taylor Ltd [30] carried out a review of work previously completed. When CrossRail was promoted in Parliament in 1995, a largely complete design existed together with supporting noise and vibration assessments. This referenced report reviews the work that was carried out in the period prior to the deposit of the CrossRail Bill.

5.29 The noise and vibration studies were of three kinds. Operational noise effects in the outer areas were studied by Colin Stanworth, then of BR Research, British Rail being joint promoters of CrossRail. Construction noise system-wide, and operational noise in the central section, were studied by Rupert Taylor FIOA, and Rupert Taylor Ltd was technical contractor to the project (Contract K680 Noise and Vibration Assessment and Mitigation).
5.30 A summary of the work undertaken was published in the Proceedings of the Institution of Civil Engineers Transport/Volume TR147/Issue 02 CrossRail: Noise and vibration control CG Stanworth and RM Taylor. Given the changes to the outer areas since 1995, the work on outer areas operational noise is not relevant to the present scheme, and was not reviewed. The construction and central section operational noise work, to varying degrees, is still relevant and is briefly described below.

5.31 Rupert Taylor Ltd has been consultant in two recent development schemes involving Crossrail. The first was Moorhouse, a redevelopment at Moorgate, which is currently under construction; and the second was Paddington Central, which is a proposed development over the western tunnelling site and works sidings.

5.32 The work reviewed was carried out by Rupert Taylor, since, apart from Colin Stanworth, no other acoustic consultants were employed by the CrossRail project. Acoustic work commissioned by others included a construction noise report for an alternative scheme at Paddington promoted by Trafalgar House, and work on station acoustics, carried out for the individual station architects by practices including Tim Smith Acoustics. The Trafalgar House work is no longer relevant. The architects’ work will continue to be relevant according to the degree to which station designs remain unchanged. The station acoustics work has not been reviewed.

Vibration Limits

5.33 A review of vibration limits was carried out by Rupert Taylor Ltd [31] to consider whether to assess/specify vibration limits for human exposure in terms of PPV or VDV and what are the equivalences, if any, between them. Following a review of BS 6472, the relevant standard to address human exposure, the clear conclusion is that VDV is the preferred unit to use and this has been adopted for assessment purposes.

Construction Noise, Triggers for Significance, Noise Insulation and Temporary Rehousing

5.34 Following previous work undertaken on criteria for the identification of significant noise impact and eligibility for NI and TRH, further work was carried out following identification of anomalies arising from the use of method originally adopted. This followed the method promoted by Arup Acoustics for the Channel Tunnel Rail Link. However, it was found that the range of existing ambient levels covered did not satisfactorily reflect ambient levels found at all sites affected by Crossrail. Due to this problem, this work was undertaken to identify a more appropriate method to determine impact and this is described below. The paper is attached at Appendix D.
Noise and Vibration from Construction

Introduction

5.35 Construction of the railway, and associated infrastructure, is anticipated to occur from 2007 to 2013. Activities at the surface worksites within the central area are likely to take four to five years, and most work will be carried out during the daytime. However, 24 hour working will be required for activities associated with tunnelling and temporary groundborne noise and vibration impacts are anticipated to arise from the tunnel boring machines, as they pass under sensitive property, and subsequently from the use of the underground construction railway. There will also be some 24 hour above ground working associated with the handling of excavated material and logistical backup to the to the underground work including fitting out of the tunnels and stations.

5.36 For the surface routes in the west, northeast and southeast, lines will run mainly along existing railway corridors and work is likely to be carried out during possessions, i.e. requiring night-time and weekend working, although such works will generally be over short periods at any one location. However, significant works are also required at some stations and at other various locations such as Stockley Flyover, where a new viaduct structure is required to facilitate the connection with the rail route to Heathrow, and at the Thames tunnel.

Noise from Surface Sources

Prediction Methods

5.37 SiteNoise 98 is a program for calculating noise levels produced by any type of open-air activity using mechanical plant. This could range from a single item of plant through to a major construction site active over a number of years. SiteNoise 98 uses a calculation procedure that implements the approach set out in BS 5228: Part 1: 1997 “Code of Practice for assessing Noise and Vibration on Construction and Open Sites”.

5.38 SiteNoise 98 provides an accurate method of performing the BS 5228 calculation procedure, together with a number of optional alternative methods of assessing: soft ground attenuation; barrier attenuation; angle of view correction; and source-receiver distance.

5.39 For Crossrail, SiteNoise 98 has been used to calculate noise levels from construction activities arising from construction sites and for construction works on the existing railway. Modelling of all significant works within the construction programmes for every site was carried out and the model output was in terms of noise levels that vary through the programme at every receptor appropriate to the works. Due to the size of the model output, RPS developed an assessment spreadsheet that applied the impact, NI and TRH (level and time dependent) criteria to the noise levels, although some manual interrogation and confirmation was required for the latter two elements.

5.40 The only exception to the above was where assessments were undertaken for works associated with utilities diversions or changes required as a consequence of Crossrail, where a spreadsheet approach was adopted, as the works were generally simpler and of shorter duration than for the main sites.
5.41 The predicted levels from either modelling technique were then compared with the assessment criteria and on-site mitigation measures incorporated to minimise the noise impacts and properties that may be eligible for NI or TRH (cf. Chapter 6 which includes a table showing the core time periods applicable to the determination of NI and TRH), in accordance with the Crossrail (or nominated undertaker’s) scheme for the provision of NI and TRH during construction. Where properties may be eligible for NI or TRH, they were deemed to be not subject to a noise impact. For the period of works, the worst impact and duration is reported.

**Determination of Impact**

5.42 For noise from surface construction activity, levels predicted to occur at sensitive receptors (residential and community) have been considered significant if the total noise (pre-existing ambient plus airborne construction noise) exceeds the pre-existing ambient noise by 5 dB or more, assessed in accordance with the core time and averaging periods adopted for the NI and TRH scheme. The above is subject to lower cut-off values of 65, 55 and 45 dB $L_{Aeq,\text{Period}}$ from construction noise alone, for the daytime, evening and night-time periods, respectively. Further information and justification of this approach is provided in Appendix D.

5.43 Significant impact has been identified where properties were deemed to be eligible for NI or TRH. However, assuming NI or TRH will then be provided as part of the mitigation process, these properties were deemed to be not significantly affected by noise. The effects and implications of the provision of NI and TRH are discussed further in Section 6.

**Groundborne Noise and Vibration from Underground Sources**

**Prediction Methods**

5.44 Predictions of groundborne noise from the underground construction railway have been carried out using Findwave® which is a finite difference time-domain (FDTD) numerical model for computing the propagation of waves in a visco-elastic media, proprietary to Rupert Taylor Ltd. While it can be used to solve any acoustical or other 3-dimensional wave propagation problem, its principal use is for the modelling of railway noise and vibration.

**Determination of Impact**

5.45 The significance of groundborne noise levels arising from underground construction activity has been determined from the criteria defined in Table 5.2. Impact has been considered significant if groundborne noise levels exceed 40 dB $L_{Amax,S}$. 
TABLE 5.2: GROUNDBORNE NOISE FROM UNDERGROUND SOURCES - THRESHOLD OF SIGNIFICANT IMPACTS ON BUILDING OCCUPANTS

<table>
<thead>
<tr>
<th>Impact Classification</th>
<th>Groundborne Noise Level dB ($L_{A_{max},S}$) (measured near the centre of any dwelling room on the ground floor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>35-39</td>
</tr>
<tr>
<td>Medium</td>
<td>40-44</td>
</tr>
<tr>
<td>High</td>
<td>45-49</td>
</tr>
<tr>
<td>Very High</td>
<td>&gt;49</td>
</tr>
</tbody>
</table>

Significant Impact

Note 1: Excluding TBM passage which is short term and transitory and has been qualitatively described and addressed

5.46 In the case of buildings lawfully used as reference libraries, lecture theatres, auditoria, theatres, hospitals, churches and schools and similar buildings, the use of which is particularly sensitive to noise or vibration, significant impact have been deemed to occur if the levels in the Table 5.3 below are exceeded during periods of their use.

TABLE 5.3: GROUNDBORNE NOISE FROM UNDERGROUND SOURCES - THRESHOLD OF SIGNIFICANT IMPACTS ON NON-RESIDENTIAL BUILDINGS

<table>
<thead>
<tr>
<th>Building</th>
<th>Level/Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theatres</td>
<td>25 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Large Auditoria/Concert Halls</td>
<td>25 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Studios</td>
<td>30 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Churches</td>
<td>35 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Courts, lecture theatres</td>
<td>35 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Small Auditoria/halls</td>
<td>35 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Schools Colleges</td>
<td>40 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Hospitals, laboratories</td>
<td>40 dB $L_{A_{max},S}$</td>
</tr>
<tr>
<td>Libraries</td>
<td>40 dB $L_{A_{max},S}$</td>
</tr>
</tbody>
</table>

Note 1: Excluding TBM passage which is short term and transitory and has been qualitatively described and addressed
Vibration from Construction

Introduction

5.47 Vibration from construction can cause disturbance to humans, including concern over building damage, and actual building damage ranging from cosmetic (minor cracking) to full structural effects (major cracking and movement) although the latter is very rare and generally requires the occurrence of other aspects, such as differential settlement, for significant damage to occur. The effects of vibration from construction have been assessed for effects on both people and buildings.

Prediction Methods

5.48 Prediction of vibration from construction sources has been carried out following the procedure identified in Transport Research Laboratory Report 429 on Groundborne vibration caused by mechanised construction works [32]. The algorithms have been applied by spreadsheet.

Determination of Impacts

5.49 The significance of vibration levels affecting building occupants arising from construction activity has been determined from the criteria defined in Table 5.4. Impact has been considered significant if the predicted levels were at or above those defined as adverse comment possible.

<table>
<thead>
<tr>
<th>Place</th>
<th>Low Probability of Adverse Comment - VDV ms$^{-1.75}$</th>
<th>Adverse Comment Possible - VDV ms$^{-1.75}$</th>
<th>Adverse Comment Probable - VDV ms$^{-1.75}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16h day</td>
<td>0.2-0.4</td>
<td>0.4-0.8</td>
<td>0.8-1.6</td>
</tr>
<tr>
<td>Residential Buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8h night</td>
<td>0.13</td>
<td>0.26</td>
<td>0.51</td>
</tr>
</tbody>
</table>

5.50 The potential for significant impact upon structures has been deemed to occur if the limits defined in Table 5.5 were predicted to be exceeded. Where they were predicted to be exceeded, individual receptors have been screened and assessed for sensitivity, both to their structure and content, to determine whether impact was likely.

<table>
<thead>
<tr>
<th>Category of Building</th>
<th>Threshold of Potential Cosmetic Damage (Peak Particle Velocity at Building Foundation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard buildings</td>
<td>5 mm/s</td>
</tr>
<tr>
<td>Listed or potentially vulnerable buildings</td>
<td>3 mm/s</td>
</tr>
</tbody>
</table>
Construction Road Traffic Noise

5.51 The construction of Crossrail will require considerable numbers of lorry movements to deliver materials and remove excavated material. The changes in road traffic noise on the road links affected have been determined using the method described below.

Prediction of Noise From Road Traffic

5.52 The method to predict noise at a reception point from a road scheme is described in Calculation of Road Traffic Noise (CRTN) [33], a formal procedure originally issued in accordance with the requirements of the Noise Insulation Regulations 1975, consists of five main parts:

i) Divide the road scheme into one or more segments such that the variation of noise within the segment is small.

ii) Calculate the basic noise level at a reference distance of 10 m away from the nearside carriageway edge for each segment.

iii) Assess for each segment the noise level at the reception point taking into account distance attenuation and screening of the source line.

iv) Correct the noise level at the reception point to take into account site layout feature including reflections from buildings and facades, and the size of the source segment.

v) Combine the contributions from all segments to give the predicted noise level at the reception point for the whole road scheme.

5.53 For Crossrail, the CRTN methodology has been used in a simplified form to predict changes in road traffic noise levels along route sections, i.e. calculations have not been carried out at individual receptors but for sections of road subject to the same changes in traffic flow. On this basis, all receptors along a route section will be subject to the same change in noise level. CLRLL’s transport specialists have provided traffic flows, for appropriate years, without and with Crossrail construction traffic and these flows have formed the basis of the assessment.

Determination of Impact

5.54 The assessment then considers the change in the noise level without and with Crossrail construction traffic, with a change in excess of +/-3 dB(A) (increase or decrease) being considered significant. The semantic scale adopted for this assessment is the same as that provided below for the surface operational railway.

Noise and Vibration during Operation

Groundborne Noise from the Underground Railway
Introduction

5.55 Groundborne noise arising from the operational railway running in tunnels is a key aspect and is of considerable concern to consultees and stakeholders. The assessment has been carried out by Rupert Taylor Ltd and is based upon the modelling and mitigation developed for other major rail schemes throughout the world.

Input Assumptions

5.56 The following input assumptions have been adopted for the groundborne noise modelling and prediction work:

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rolling Stock</td>
<td></td>
</tr>
<tr>
<td>1.1. Train Formation -10 Cars</td>
<td></td>
</tr>
<tr>
<td>1.2. Body Mass – 45640 kg</td>
<td></td>
</tr>
<tr>
<td>1.3. Car Length – 20 m</td>
<td></td>
</tr>
<tr>
<td>1.4 Distance Between Bogie Centres - 15.75 m</td>
<td></td>
</tr>
<tr>
<td>Bogies And Suspension (Per Bogie)</td>
<td></td>
</tr>
<tr>
<td>1.5. Bogie Wheelbase - 2.6m</td>
<td></td>
</tr>
<tr>
<td>1.6. Wheel Type - Monobloc</td>
<td></td>
</tr>
<tr>
<td>1.7. Unsprung Mass – 835 kg</td>
<td></td>
</tr>
<tr>
<td>1.8. Sprung Mass – 815 kg</td>
<td></td>
</tr>
<tr>
<td>1.9. Primary Suspension Vertical Dynamic Stiffness - 1.3 MN/n</td>
<td></td>
</tr>
<tr>
<td>1.10. Primary Suspension Vertical Damping - 0.01 MNs/m</td>
<td></td>
</tr>
<tr>
<td>1.11. Secondary Suspension Dynamic Stiffness - 0.1175 MN/m</td>
<td></td>
</tr>
<tr>
<td>1.12. Secondary Suspension Damping 0.011651 MNs/m</td>
<td></td>
</tr>
<tr>
<td>2. Train Performance</td>
<td></td>
</tr>
<tr>
<td>2.1 Speed/Distance Profile</td>
<td>See Speed Profiles In Appendix E</td>
</tr>
<tr>
<td>3. Rails</td>
<td></td>
</tr>
<tr>
<td>3.1. Rail Mass - 60.34 kg/M</td>
<td></td>
</tr>
<tr>
<td>3.2. Rail Section - UIC60</td>
<td></td>
</tr>
<tr>
<td>3.3. Second Moment of Area of Rail Section - 3.055 x 10⁻⁵ m⁴</td>
<td></td>
</tr>
</tbody>
</table>
4. Rail Fastenings
4.1. Spacing - 650 mm
4.2. Fastener Dynamic Stiffness, Vertical - 9.1mn/M
4.5. Fastener Damping, Vertical 0.1 (Dimensionless Loss Factor)

5. Track
5.1. Alignment, Horizontal - Alignment K
5.2. Alignment, Vertical - Alignment K

6. Track Support
6.1 Track Design (Ballasted, Non-Ballasted etc) - Non-Ballasted

7. Tunnels
7.1. Diameter - 6m
7.2. Lining Specification - Concrete
7.3. Concrete: Density – 2400 kgm⁻³
7.4. Concrete: Young’s Modulus – 50 GNm⁻²
7.5. Concrete: Poisson's Ratio - 0.01 (Dimensionless Loss Factor)

8. Soil Assumed For Contours (Worst Case)
8.1 Compression Modulus - 4.41gn/M²
8.2 Shear Modulus - 0.735gmn/M²
8.3 Loss Factor - 0.05 (Dimensionless)
8.4 Reflective Layer Assumed 7m Below Tunnel

Prediction Method

Groundborne noise from the underground railway has been predicted using FINDWAVE® which is a finite difference time-domain (FDTD) numerical model for computing the propagation of waves in a visco-elastic media, proprietary to Rupert Taylor Ltd. While it can be used to solve any acoustical or other 3-dimensional wave propagation problem, its principal use is for the modelling of railway noise and vibration.
5.58 The current version of FINDWAVE® was validated for Crossrail by undertaking measurements above one of the tunnels of the Lewisham Extension of the Docklands Light Railway where it runs in circular bored tunnel between Cutty Sark Station and the River Thames. The location was selected because of the presence of a wide range of soil layers, in order to validate in particular the modelling of the transmission of vibration through layered ground. This work, carried out by Rupert Taylor Ltd, was undertaken with the assistance of CGL Rail plc and Docklands Light Railway Ltd. The full report is provided as Appendix F.

5.59 FINDWAVE® is also capable of modelling the vibration of railways at grade or in underground tunnels, including the transmission of groundborne noise and vibration from the tunnels to the ground surface and into buildings.

5.60 The railway implementation of FINDWAVE® contains two principal (mutually interacting) modules, the train module, and the track/structure/environment module. The train module represents the train as a stack of damped masses and springs representing the rail vehicle. The excitation is provided from an input file containing either a measured or assumed vertical railhead profile, together with the gravitational effect of the rolling train. The train moves in the model and the location of the contact patch for each wheel is constantly advancing (re-entering the model at the front when it goes beyond the end).

5.61 The track/structure/environment module models the dynamic behaviour of the track and structure supporting the train, and the medium surrounding it, e.g. soil or air, together with structures below or above ground level. The structures concerned are represented as cells in a 3-dimensional orthogonal grid, each cell being assigned density, Lamé constants and loss factor.

5.62 For Crossrail, FINDWAVE® has primarily been used to predict groundborne noise levels in terms of $L_{A_{max, s}}$ arising from the operational railway in buildings above the Crossrail tunnels. These include residential property and other buildings with special uses such as theatres etc, which are also deemed to be noise sensitive. Predictions have been made for the location within the building concerned, where the greatest noise or vibration is likely to be experienced, usually the basement if that has a noise/vibration-sensitive use. The predicted levels are compared with the assessment criteria and, where impacts are predicted, mitigation to the rail support system has been included in the assumptions and optimised to minimise subsequent impacts.

5.63 Three levels of assessment have been necessary. Firstly, portal-to-portal contours of groundborne noise were generated, making standard assumptions about building designs (no deep or piled foundations) and simplified soil assumptions. Secondly, individual calculations for buildings with deep or piled foundations have been made. Thirdly, when the detailed design phase is reached, full numerical models of major buildings with particular noise or vibration sensitivity are created; this level has already been applied to two buildings.

**Determination of Impact**

5.64 Potential impacts arising from groundborne noise have been identified using the criteria set out in Tables 5.6 and 5.7.
TABLE 5.6: GROUNDBORNE NOISE FROM THE OPERATIONAL RAILWAY
APPLICABLE TO DWELLINGS

<table>
<thead>
<tr>
<th>Impact Classification</th>
<th>Groundborne Noise Level dB ($L_{A\text{max},S}$) (measured near the centre of any dwelling room on the ground floor)</th>
</tr>
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<tbody>
<tr>
<td>Low</td>
<td>35-39</td>
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<td>Medium</td>
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<td>High</td>
<td>45-49</td>
</tr>
<tr>
<td>Very High</td>
<td>&gt;49</td>
</tr>
</tbody>
</table>

Significant Impact

TABLE 5.7: GROUNDBORNE NOISE FROM THE OPERATIONAL RAILWAY
APPLICABLE TO NON-RESIDENTIAL RECEPTORS

<table>
<thead>
<tr>
<th>Building</th>
<th>LEVEL/MEASURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theatres</td>
<td>25 dB $L_{A\text{max},S}$</td>
</tr>
<tr>
<td>Large Auditoria/Concert Halls</td>
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</tr>
<tr>
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<td>30 dB $L_{A\text{max},S}$</td>
</tr>
<tr>
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<td>35 dB $L_{A\text{max},S}$</td>
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<td>40 dB $L_{A\text{max},S}$</td>
</tr>
<tr>
<td>Hospitals, laboratories</td>
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</tr>
<tr>
<td>Libraries</td>
<td>40 dB $L_{A\text{max},S}$</td>
</tr>
</tbody>
</table>

Noise from the Surface Railway

Introduction

5.65 The provision of Crossrail's new train services will require some new or altered sections of line but some services will run on the existing network which will not be altered. Therefore, the assessments have varied from calculations of noise changes on the existing network to detailed modelling of complex junctions and other areas. A preliminary assessment of noise insulation eligibility under the Noise Insulation (Railways and other Guided Transport Systems) Regulations 1996 has also been carried out.
5.66 When the work started on the operational noise modelling, the franchises on the routes over which Crossrail would operate had to go through at least one potential change of Operator/Owner before 2016; Route Utilisation Strategies were and are still under development by the SRA, which again could influence train times and type. Finally some of the rolling stock is likely to be replaced by 2016 (e.g. High Speed Trains on Great Western), new rolling stock acquired for CTRL domestic services. As a consequence, the without Crossrail service after 2013 (the year operations are to start) was based on the Winter 2003/4 timetables. The modelling with Crossrail operating was based on the same timetables but adjusted, either by addition or substitution, to take account of Crossrail operating. The only areas where known service enhancements were included in the modelling of Crossrail were where they were affected by future development of the Docklands Light Railway (DLR).

**Prediction Method**

5.67 Three levels of assessment were adopted for the modelling and assessment work as follows:

- Level 1 – assessment based purely on the intensification of railway traffic on unaltered existing surface railway lines as a result of the introduction of Crossrail.
- Level 2 – assessment based upon changes in railway traffic on existing lines and on other infrastructure alterations (track realignments, new tracks along an existing railway corridor).
- Level 3 – assessment based upon detailed modelling using RailNoise and taking into account the detailed mix of railway traffic and speeds, surrounding topography, the presence of noise barriers and obstructions and numerous receptor locations around the site of interest.

5.68 The level of assessment required at each site was determined following a detailed review of route sections and services, both without and with Crossrail. Initially, the service changes were subject to Level 1 assessment to determine where service changes could result in noise increases or decreases of 3 dB(A). Consideration was then given as to whether there were also any infrastructure changes or other aspects that could influence the noise changes. Where it was considered possible that significant noise changes could occur, either a Level 2 or Level 3 assessment was carried out.

**Assumptions**

5.69 Train noise source terms for both Level 2 and 3 assessments were obtained from four sources:

- AEA TR Report produced for Defra;
- AEA TR Report produced for RPS;
- Calculation of Railway Noise 1995 (CRN) tables; and
- Surrogate source terms to be used in absence of specific data.
5.70 Rail traffic patterns were supplied by CLRLL. Two sets of information were provided; the first is described as year 2003/4 and represents the current traffic pattern which has been assumed to represent the traffic pattern in the baseline year (2013). The second set of data provides traffic patterns for the Crossrail scheme along with any other service pattern change as a result of Crossrail.

5.71 All freight traffic operating on the north east and south east legs was assumed to comprise one Cl66 diesel loco hauling 20 freightliner vehicles and, for the purposes of calculation at any point along the tracks, these trains were assumed to be spending 50% of the time coasting and 50% with locos on full power. For the western leg, the freight trains comprise Cl57 diesel loco hauling 15 freightliner wagons. Only moving trains were considered. Noise from stationary idling trains was not considered. Only rolling noise was considered from Diesel Multiple Units as implied in CRN.

5.72 All “at grade” track was assumed to be ballasted for both existing rail systems and proposed new or altered lines. Elevated sections of the DLR, where applicable, were assumed to be slab track (+2 dB correction), and to have a structure radiated noise correction of +1 dB applied in accordance with CRN.

5.73 The preliminary assessment of noise insulation eligibility under the Noise Insulation (Railways and other Guided Transport Systems) Regulations 1996 was based purely upon exceedences of the absolute levels (68 dB(A) day/63 dB(A) night), and the total increase in railway noise of at least 1 dB(A). Where dwellings were identified as being eligible under the above, then further investigation into whether at least 1 dB(A) of the increase was attributable to the “additional” or “altered” works was undertaken.

5.74 Train speeds on sidings were assumed to be 30 km/h unless specified otherwise. DLR trains were assumed to accelerate at 1.8 ms⁻², brake at 0.8 ms⁻² and to operate at a maximum permissible line speed of 80 km/h. Alignment Rev K was used to develop the Crossrail, RailNoise models for the north east and south east route sections, with design drawings being used to define the alignment for the west.

Level 3 Assessments

5.75 For Level 3 assessments, jointed track was assumed for sidings and for turnout/crossover sections. All other track is assumed to be CWR. All track was assumed to be in “good condition”. For Level 3, only track that was assumed to be essential to the noise assessment, i.e. in current operational use, was modelled, with disused rail, irrelevant crossover sections and track devoid of services being disregarded.

5.76 For non-stopping services, the trains were assumed to be travelling at the maximum permitted line speed or the maximum possible speed for the train type whichever was lower along the specific section of track. Acceleration and deceleration profiles were only used where trains were calling or stopping (at nearby stations or sidings) and only at 50 m segment resolution. The speed at the head of the train was used to represent the train speed over each 50 m segment. Local ground was modelled at 0.8 m below the height of the rails to take account of the track form and ballast depth.
For all new tunnel portals on the north eastern and south eastern legs, a track slab form was assumed to continue from the actual tunnel portal to a point 100 m before the end of the cutting from where ballasted track will continue. For the Connaught Tunnel, it was assumed that track slab continues for 100 m beyond each tunnel portal. A 1.5 m high solid wall was assumed around the top of all retained cuttings at tunnel portal sites. Platforms were modelled, where appropriate, for Level 3 assessments and at a height of 1.0 m above rail height. Trains moving into or out of sidings were assumed to be distributed equally amongst the total number of sidings at any site for Level 3 assessments.

Where significant impacts were identified as a result of railway noise changes, then further consideration was given to the non-railway attributable noise contributions by analysis of any available monitoring data in the vicinity of the receptors affected.

Baseline noise measurements were used to derive estimated baseline levels at all receptor locations where railway noise was not considered to be dominant. Levels were estimated using conservative extrapolation techniques. Where investigation into the baseline monitoring results was required to provide an estimate of the non-railway related noise, the residual non-railway related noise was calculated by subtracting the predicted railway noise from the measured levels logarithmically.

Height data obtained by Crossrail and spot height information presented on the OS base mapping was used to generate the ground profiles in the models for the existing situation. CLRLL sourced extranet information was also used to estimate changes in the engineering detail that is expected around the new infrastructure with Crossrail in place. Where insufficient information was available to understand any quantitative changes to the engineering detail, then the ground profiles were assumed to remain unchanged as a result of Crossrail.

Property counts were only undertaken for receptors where impacts (after mitigation has been applied) were identified. Only the first floors of public houses were assumed to be residential and hotels were assumed to be non-residential.

Only large areas of open grassland were included for consideration for Level 3 assessments. Rear gardens and grass verges were ignored for the purposes of this study.

Calculations undertaken at Level 2 did not consider soft ground or air absorption and assumed an infinite length line source with no angle of view correction applied. Hardcopy consultation drawings (and, where available, electronic alignment drawings) were used to measure distances from receptors to infrastructure alignments.

All rail track was assumed to be CWR except for sidings or crossover/turnout sections, where jointed rail track was assumed. All track was assumed to be in “good condition”. All track was assumed to be ballasted for both existing rail systems and proposed additional or altered lines.
5.85 All Train speeds were modelled in kph, with a speed of 20 kph being applied to trains stopping at station platforms. For non-stopping trains, the trains were assumed to be travelling at the maximum permitted line speed or the maximum possible speed for the train type whichever is lower. Acceleration and deceleration profiles were only used where trains are calling or stopping (at nearby stations or sidings), with speeds for these services being derived with regards to each receptor’s distance from stopping location. Train speeds on sidings were assumed to be 30 kph. DLR trains were assumed to accelerate at 1.8 ms\(^{-2}\), brake at 0.8 ms\(^{-2}\) and to operate at a maximum permissible line speed of 80 kph. For 166/165 train set combinations, speed profiles for the 165 train set were used.

5.86 For all Level 2 assessments, the topography of the site was assumed to be flat ground, with the ground type being assumed as hard for the entire site.

5.87 All receivers were modelled in at a ground height of 1.5 m, as per the defined ground floor level outlined in the “default receptor and building height” assumptions document. Selected receptors were positioned to best provide a comprehensive spread across the section of line of interest, concentrating on sensitive locations that were judged to be at most risk of changes in noise levels as a result of intensification or track relocation. Screening effects, where appropriate, were assumed.

5.88 Train flows for the baseline year 03/04 and future years with the Crossrail operational were derived for the 16hr/8hr and 18hr/6hr time periods. Basic train route descriptions in hand-annotated form were provided with the train flow data provided by CLRLL.

**Modelling**

5.89 RailNoise 98 calculates the amount of noise generated by an operational railway. The noise arises mainly from the wheel/rail interface, but it can also arise from cooling fans, other mechanical equipment on rail vehicles, and diesel locomotive exhaust. The noise spreads out from the source until it reaches a receiver (or observation) position. As the noise spreads out, it affects a wider area, but its intensity reduces. This is an effect called geometrical spreading or distance attenuation.

5.90 If the sound crosses “soft” ground, then further reductions can occur, depending on the mean propagation height. This is called ground attenuation or soft ground excess.

5.91 The sound may also have to cross an obstruction to reach the receiver position, which may cause some screening of the noise, or barrier attenuation. Reflections between a trackside barrier and the side of a railway train can reduce the effectiveness of barriers.

5.92 If there are any reflecting surfaces within view of the reception point, this can increase the noise level at the receiver position. Reflecting surfaces must be fairly large to have any significant effect.

5.93 The sound level is affected by the wind direction. RailNoise 98 assumes that the receiver is downwind of the noise source, to ensure a robust assessment.
5.94 RailNoise 98 uses the calculation procedure set out in Calculation of Railway Noise (1995 edition). This is a procedure published by the UK Department of Transport for use in assessment of entitlement to statutory insulation against railway noise under the UK Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1995.

**Determination of Impact**

5.95 Operational noise impacts have been identified by comparing the noise levels at residential and community facilities before and after the railway becomes operational, as described above. The scale of impact has been identified using the semantic scale presented in Table 5.8.

**TABLE 5.8: OPERATIONAL AIRBORNE NOISE**

<table>
<thead>
<tr>
<th>Predicted Noise Change</th>
<th>Scale Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_{Aeq} (07:00 – 23:00) Day or L_{Aeq} (23:00 – 07:00) Night</td>
<td></td>
</tr>
<tr>
<td>Decrease of more than 3 dB</td>
<td>Significant decrease</td>
</tr>
<tr>
<td>Less than 3 dB</td>
<td>No Significant change</td>
</tr>
<tr>
<td>Increase of 3-5 dB</td>
<td>Slight increase</td>
</tr>
<tr>
<td>Increase of 6-10 dB</td>
<td>Moderate increase</td>
</tr>
<tr>
<td>Increase of more than 10 dB</td>
<td>Substantial increase</td>
</tr>
</tbody>
</table>

In addition, a significant impact will occur if the maximum night-time level due to Crossrail trains exceeds 85 dB L_{Amax,F} and where pre-existing noise levels due to trains are below 85 dB L_{Amax,F}.

**Vibration from the Surface Railway**

*Introduction*

5.96 Vibration arising from the future railway with Crossrail was considered with regard to absolute levels and changes in level. However, with the new services and with CWR assumed to be incorporated as a base case, the railway has to be very close to receptors for impacts to be significant (cf. Section 5.5). In order to assess the likely effects of Crossrail, vibration measurements were carried out adjacent to the railway at a site to the west of Brentwood to establish likely levels from existing trains running on existing track, as described in Appendix B.

**Prediction Method**

5.98 Findwave® has been used to calculate vibration levels and changes from the operational railway based upon the results from the Brentwood vibration survey.

**Determination of Impact**
5.100 Potential impacts on occupants of dwellings arising from surface vibration are identified using the criteria set out in Table 5.9.

**TABLE 5.9: VIBRATION FROM THE OPERATIONAL RAILWAY AFFECTING THE OCCUPANTS OF DWELLINGS**

<table>
<thead>
<tr>
<th>Impact Classification</th>
<th>In the Absence of Appreciable Existing Levels of Vibration</th>
<th>Appreciable Existing Levels of Vibration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VDV ms(^{-1.75})</td>
<td>VDV ms(^{-1.75})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Daytime (07:00-23:00)</td>
<td>Night-time (23:00-07:00)</td>
<td></td>
</tr>
<tr>
<td>Slight</td>
<td>&gt; 0.22 – 0.31</td>
<td>&gt; 0.13 – 0.18</td>
<td>25 – 40%</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt; 0.31 – 0.44</td>
<td>&gt; 0.18 – 0.26</td>
<td>&gt; 40 – 100%</td>
</tr>
<tr>
<td>Substantial</td>
<td>&gt; 0.44 – 0.62</td>
<td>&gt; 0.26 – 0.37</td>
<td>&gt; 100 – 185%</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt; 0.62</td>
<td>&gt; 0.37</td>
<td>&gt; 185%</td>
</tr>
</tbody>
</table>

(1) Highest impact category used, daytime or night-time.

(2) Where there is an appreciable existing level of vibration and daytime and night-time vibration dose values (VDVs) exceed 0.22 ms\(^{-1.75}\) and 0.13 ms\(^{-1.75}\).

Operational Road Traffic Noise

*Introduction*

5.101 The operation of Crossrail will result in some changes in road traffic levels on the road network which have been assessed.

*Prediction of Noise From Road Traffic*

5.102 The same method was applied to operation as is described above for construction. CLRLL’s transport specialists have provided traffic flows, for appropriate years, without and with traffic effects associated with Crossrail and these flows have formed the basis of the assessment.

*Determination of Impact*

5.103 The assessment is based upon the change in noise level, without and with Crossrail, with a change in excess of +/-3 dB(A) (increase or decrease) being considered significant. The semantic scale adopted for this assessment is the same as that provided above for the surface operational railway.

Noise from Fixed Plant – Ventilation Shafts and Depots
Introduction

5.104 The operation of Crossrail will require some fixed plant to provide ventilation to the tunnels and to maintain the trains in the depot and stabling sidings. These aspects have been assessed separately from the other operational aspects of the railway.

Prediction of Noise From Fixed Plant

5.105 Modelling using a computer program known as SoundPLAN has been carried out for these fixed plant noise sources. This program can calculate noise emitted from various sources including roads, railways, airports, industry including point, line and area sources inside and outside buildings. The program uses various internationally recognised noise calculation procedures. All sources have their own definition file for coordinates and other descriptions. For road, railways and aircraft noise, SoundPLAN contains a source model calculating the sound power or a derived value from the traffic data. Industry noise requires use of measured data. The emission data is written in specialized control lines and defines the next section of geometric data.

5.106 The propagation model within SoundPLAN chosen for predicting noise for Crossrail was CONCAWE (N.B. SoundPLAN contains various propagation models to predict noise levels at distance; CONCAWE was considered the most applicable for this application). The model has been used to predict noise from fans ventilating the operational tunnels and from the operation of the depot. The output is provided as noise levels at receptors and/or as noise contours.

5.107 Noise from tunnel ventilation fans will require mitigation in the form of noise attenuators included in the shafts, sized to achieve the required noise reduction to meet specified noise targets. Thus any change in location assumed for the plant would have the effect of changing the specification of the required attenuators rather than to make a significant change in the predicted noise levels.

Determination of Impact

5.108 Chapter 4 includes a review of BS 4142 which was used to assess noise from tunnel ventilation plant and the depot. SoundPLAN was used to calculate noise levels at receptors and then the BS 4142 assessment methodology was applied to these levels.

5.109 Mechanical and electrical services including ventilation and draught relief shafts forming part of the railway works will be designed and constructed to ensure that, at locations relevant to neighbouring residential or other noise sensitive development, the difference between the Rating Level of the plant in normal operation and the existing L_{A_{90}} background noise level is not more than +5 dB, assessed in accordance with BS 4142. However, notwithstanding this, detailed assessments of noise from the ventilation fans and depot have been completed and additional mitigation, or changes to the design, have been included in the final noise predictions and assessment of impact.
6. **APPLICATION OF MITIGATION INCLUDING NOISE INSULATION AND TEMPORARY RE-HOUSING**

**Introduction**

6.1 There are two discrete parts to the project, construction and operation, and the approach adopted for the incorporation and design of the mitigation is described below.

**Construction**

6.2 The project has adopted a suite of noise and vibration mitigation measures for construction, which are presented below. In addition to this, a scheme for the provision of noise insulation and temporary re-housing during construction has also been developed, which is also described below.

6.3 As described in Chapter 5, the assessment criteria have been developed from a review of criteria and policies promoted by other similar, recent rail projects. These criteria have also been developed following due consideration of the provisions of Section 8 (Insulation of buildings against construction noise) of the Building and Buildings, The Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996, which allow for the discretionary provision of noise insulation, or the making of grants for noise insulation, to eligible buildings subject to noise levels which may affect the enjoyment of an eligible building.

6.4 The noise and vibration impacts associated with the construction of Crossrail have been assessed assuming that particular mitigation measures and controls are applied to all plant and activities at each worksite individually. For this reason the mitigation measures and controls applied differ from worksite to worksite. The mitigation measures and controls, which have been assumed for the assessment and which will be adopted on the various work sites, have been drawn from the range of controls described below.

6.5 In order to comply with the Project’s desire to minimise the noise and vibration impacts of the scheme, the following approach to developing mitigation in line with the findings of the noise and vibration assessment has been adopted.

**Surface Construction Activity**

**Noise**

*Selection and Use of Equipment*

6.6 The nominated undertaker or any contractor will require that each item of plant used on the project complies with the noise limits quoted in the relevant European Commission Directive 2000/14/EC and United Kingdom Statutory Instrument (SI) 2001/1701, The Noise Emission in the Environment by Equipment for use Outdoors Regulations 2001.

6.7 The nominated undertaker or any contractor will adopt the recommendations set out in Annex B of Part 1 of BS 5228 and Sections 7.3 and 9.2 of Part 4 of BS 5228 with regard to noise and vibration mitigation options.
6.8 Plant and equipment liable to create noise and/or vibration whilst in operation will, as far as reasonably practicable, be located away from sensitive receptors. The use of barriers to absorb and/or deflect noise away from noise sensitive areas will be employed where required and reasonably practicable.

6.9 All plant, equipment and noise control measures applied to plant and equipment shall be maintained in good and efficient working order and operated such that noise emissions are minimised as far as reasonably practicable. Any plant, equipment or items fitted with noise control equipment found to be defective will not be operated until repaired.

6.10 Where reasonably practicable, fixed items of construction plant should be electrically powered in preference to diesel or petrol driven.

6.11 Machines in intermittent use should be shut down or throttled down to a minimum during periods between work. Static noise emitting equipment operating continuously will be housed within suitable acoustic enclosure, where appropriate.

**Approach to the Selection of Mitigation**

6.12 The modelling and assessment of construction noise has been based upon the provision of three tiers of on-site mitigation. These have been designed to apply increasing levels of control to each worksite resulting in reductions in the numbers of properties subject to significant impact and eligible for NI or TRH. The tiers are as follows:

- Tier 1 – The provision of conventional on-site mitigation consisting of: 2.4 m high hoardings; use of low noise, well maintained plant, plant to be in compliance with the latest EC Directive and amendments; and the use of local noise screens, barriers and enclosures, including the sheeting of buildings during the demolition phase, as practicable.

- Tier 2 – The provision of all the above plus the raising of hoarding heights to 3.6 m, or in some cases 5.0 m, and the enclosure of major, noisy items of plant (grout pumps, ventilation fans, concrete lorry unloading areas, etc).

- Tier 3 – The provision of all the above plus total enclosure of all or parts of sites for all or part of the construction programme, as practicable.

6.13 The transition through the above tiers was dependent upon the predicted severity of impact, including the duration, associated with works at each site. Where significant impacts were predicted and/or significant numbers of buildings were likely to be eligible for NI or TRH, then the next tier of mitigation was adopted. The provisions regarding NI and TRH are described further below.
The Provision of NI and TRH during Construction

6.14 The provision of NI and TRH during construction occurs when noise levels are considered likely, in the opinion of the responsible authority, to seriously affect for a substantial period of time, the enjoyment of the eligible building. The incorporation of NI, which may include the provision of alternative ventilation arrangements, will only protect the internal habitable rooms of a property by reducing the level of noise that is transmitted through the glazing. However, windows need to be kept closed for the benefit to apply and no protection is provided to external recreational or play areas. On this basis, this form of mitigation is not as beneficial as on-site mitigation, which reduces noise at source.

6.15 When predicted levels are 10 dB in excess of the levels at which eligibility for NI occurs, the occupants of the affected buildings become eligible for TRH. This is obviously inconvenient and disruptive but allows works to continue when unacceptable disturbance and interference with sleep and other activities would otherwise occur.

6.16 This assessment has sought primarily to identify reasonably practicable ways in which noise can be minimised at source (on and within the worksites) and then identify which properties would qualify for NI and TRH under the Crossrail scheme. NI does adversely affect the occupants of the buildings concerned, and it cannot, therefore, be assumed that its provision is equivalent to having lower noise levels, i.e. if an internal noise level of 40 dB(A) could be achieved by on-site mitigation, or alternatively, the same internal level could be achieved through the use of NI, the former option would be preferred.

6.17 Where properties are considered likely to be eligible for noise insulation or temporary re-housing, they are considered to be not significantly affected by noise as a consequence of this mitigation. However, it is recognized that some of the properties at which noise insulation is installed will, despite the insulation, experience internal noise levels that are above the equivalent external level at which significance is defined. Although it is considered that this will only apply to a minority of the properties identified as being likely to be eligible for insulation, it is not practical to quantify the numbers of properties at this stage. Further information on the above aspects are provided in Appendix D on triggers for significance, NI and TRH.

6.18 It is also acknowledged that noise insulation will not necessarily be taken up by all the affected parties and may not even be technically feasible at some affected properties. It is not possible to predict or estimate the level of take up and it is assumed for the purposes of the assessment that where properties have been identified as eligible for noise insulation that it will be taken up by the affected party.

6.19 Furthermore, where noise insulation is installed, while it will mitigate the predicted noise impacts, there will be some inconvenience to the occupants during the fitting of noise insulation, and the property will not benefit from the insulation if windows are opened. In addition, any garden and other outside space will not be protected from noise impact.

6.20 Where TRH is necessary, whilst this removes any significant noise impact, the affected residents will be subject to a significant disruption impact.
6.21 The arrangements for the provision of NI and TRH and the determination of eligibility are described below.

6.22 Where, in spite of the measures set out above and any Section 61 consents, noise levels at some properties are expected to exceed the trigger levels for the periods defined below, a scheme for the installation of NI or the reasonable costs thereof, or a scheme to facilitate TRH of occupants, as appropriate, will be implemented. The scheme will include provision for the notification of affected parties.

6.23 Noise insulation or the reasonable costs thereof will be offered to owners, where applied for by owners or occupiers, subject to meeting the other requirements of the proposed scheme, if either of the following apply to a property lawfully occupied as a permanent dwelling:

- the Predicted Noise Level exceeds the Noise Insulation Trigger Level, as presented in Table 6.1; or

- where the total noise (pre-existing ambient plus airborne construction noise) is 5 dB above the existing airborne noise level for the corresponding times of day, whichever is the higher; and

- for a period of 10 or more days of working in any 15 consecutive days or for a total of days exceeding 40 in any six-month period.

**TABLE 6.1 AIRBORNE NOISE TRIGGER LEVELS FOR NI**

<table>
<thead>
<tr>
<th>Time</th>
<th>Relevant Time Period</th>
<th>Averaging Time T</th>
<th>Noise Insulation Trigger Level dB $L_{Aeq,T}$ (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday to Friday</td>
<td>07:00 – 08:00</td>
<td>1 hr</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>08:00 – 18:00</td>
<td>10 hr</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>18:00 – 19:00</td>
<td>1 hr</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>19:00 – 22:00</td>
<td>3 hr</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>22:00 – 07:00</td>
<td>1 hr</td>
<td>55</td>
</tr>
<tr>
<td>Saturday</td>
<td>07:00 – 08:00</td>
<td>1 hr</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>08:00 – 13:00</td>
<td>5 hr</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>13:00 – 14:00</td>
<td>1 hr</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>14:00 – 22:00</td>
<td>3 hr</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>22:00 – 07:00</td>
<td>1 hr</td>
<td>55</td>
</tr>
<tr>
<td>Sunday and Public</td>
<td>07:00 – 21:00</td>
<td>1 hr</td>
<td>65</td>
</tr>
<tr>
<td>Holidays</td>
<td>21:00 – 07:00</td>
<td>1 hr</td>
<td>55</td>
</tr>
</tbody>
</table>

Note 1: All noise levels are predicted or measured at a point one metre in front of the most exposed of any windows and doors in any facade of an eligible dwelling.

6.24 TRH, or the reasonable costs thereof, will be provided, where applied for by legal occupiers, subject to meeting the other requirements of the proposed scheme, where the construction of the railway causes, or is expected to cause, construction noise levels to exceed whichever is the higher of either:

- 10 dB above any of the noise levels in Table 6.1; or
• 10 dB above the existing airborne noise level for the corresponding time of day, whichever is the higher; and

• for a period of 10 or more days of working in any 15 consecutive days or for a total of days exceeding 40 in any six-month period.

6.25 Buildings which may be particularly sensitive to noise (these include commercial and educational establishments, hospitals and clinics) will be subject to individual consideration by the nominated undertaker, upon application by the affected party.

Vibration

6.26 Where impact was considered likely, mitigation measures were optimised to reduce levels as far as was reasonably practicable. Condition surveys will be undertaken at buildings deemed sensitive and vibration monitoring at these buildings will be carried out during periods when the levels in Table 5.5 may be exceeded. If exceptional sensitive receptors are identified (e.g. certain medical, scientific or commercial operations) during pre-construction inspections, appropriate limits will be defined and protective measures identified.

6.27 Where there are buildings that are attached or contiguous to buildings that are proposed for demolition, the attached or contiguous buildings will be unattached, as far as possible, using non-vibratory techniques, such as diamond sawing. These techniques will be undertaken before demolition commences and as it progresses.

6.28 Prior to the commencement of works, appropriate plant and working methods will be identified based on predicted vibration levels. An appropriate continuous vibration-monitoring regime will be adopted during the works to allow monitoring of levels and cessation of activity if levels potentially exceed the limits.

Underground Construction Activity

6.29 For underground activities, measures to be considered for limiting noise will include one or more of the following, where reasonably practicable and appropriate:

Conveyor

• The mounting for conveyors used to remove excavated material from the tunnel face will be designed and installed so as to mitigate the transmission of groundborne noise and vibration to buildings above the tunnel;

• A maintenance programme will be implemented to ensure that the noise generation of the conveyor does not deteriorate over time; and

• The surface conveyor systems will be of a similar standard to underground conveyors and will be acoustically enclosed where it they run through or adjacent to noise sensitive areas. They too will be the subject of a maintenance programme.
Temporary Construction Railway

- New rail (smooth track without corrugations or discrete irregularities) will be installed at the start of the works with joints achieving variations in rail height of not more than 2mm. The rail will be relocated as the location of temporary railway is altered during the construction of the works. The rail will be fastened to sleepers using resilient rail pads, or adequate elasticity to the support of the track system, between the rail foot and the sleeper, or tunnel invert, in order to reduce the transmission of vibration and groundborne noise from the passage of rail vehicles, where appropriate.

- A speed limit on construction trains of 15 km per hour will be imposed.

- All diesel locomotives used will be fitted with efficient exhaust silencers.

- A maintenance programme will be operated to ensure that the condition of the track does not deteriorate over time thereby causing noise. The maintenance programme will also help to reduce the occurrence of wheel squeal or flattening of wheels that might otherwise develop over time.

Temporary Tunnel Ventilation

6.30 All tunnel ventilation plant with connections to the atmosphere in any noise-sensitive location will be subject to mitigation measures appropriate to its local environment.

General

6.31 In addition to the above, it has been assumed that the appointed contractors will obtain from the local authority, in whose district or borough the site lies, “Prior consent for work on construction sites” under s. 61 of the CoPA. This should prevent any local authority applying a “Stop Notice” to the works, as is provided for under s. 60 of CoPA, providing that the works are expedited in the manner described in the s. 61 application, or within conditions attached to the consent. The other important element contained within CoPA derives from s. 72, “Best Practicable Means”. This requires that as much mitigation is incorporated within the works as is technically and financially practicable. This element will need to be proven in any s. 61 application.

Operation

Noise from the Surface Railway

6.32 For the operation of Crossrail, there are two main elements that require consideration, relative to the statutory regulations that apply. For noise from the surface railway, the NI Regulations [8] clearly define the provisions, duties and powers that apply to the initial, additional or altered works. Therefore, where these provisions apply, the Project will carry out, or make a grant in respect of, the provision of noise insulation.

6.33 However, the second element is groundborne noise from the underground railway and any statutory duty associated with the provision of mitigation, specifically NI, which wouldn’t be appropriate in any case as the noise will arise from beneath the property and be transferred into the property via the building structure, is obviated by s. 3 of the Regulations, which state that the Regulations do not apply in respect noise resulting from groundborne vibration.
• Notwithstanding the above, for noise from the surface railway, where this assessment has identified that significant impacts are likely or where buildings may be eligible for NI, lineside barriers incorporated in the design will be sufficient in almost all cases to mitigate these impacts. This is on the basis that the barriers will reduce noise levels to both the inside of the buildings and to external recreational space. Where lineside barriers are not practicable, or where heights and/or lengths have been optimised but buildings are still likely to be eligible for NI, then this, or the making of grants in respect of NI, will occur.

The Provision of NI during Operation
6.34 As described above, the design of the railway will include mitigation (track, lineside and rail design) to reduce noise levels at source. Where this assessment has identified that despite this, noise levels would be significant, it has identified where this can be reduced practicably by the incorporation of lineside barriers. This will reduce the impacts; however, some buildings may still be eligible for NI, or grants in respect of NI, and this will be provided as required by the NI Regulations.

Vibration from the Surface Railway
6.35 With regard to vibration, Crossrail trains running on certain limited sections of surface railway, where re-alignment has occurred, have been identified as potentially causing significant vibration impacts and, for these areas, this assessment has identified that ballast mats will be sufficient to mitigate this impact.

Groundborne Noise from the Underground Railway
6.36 The trackform within the tunnels has been designed with the aim that noise levels in overlying buildings will be below the significance criteria of 40 dB $L_{A_{max,s}}$. Continuously welded rail, supported on resilient base plates, will be used throughout the tunnels.

6.37 Where it is not possible to achieve required standards within particularly sensitive non-residential facilities, alternative track forms have been considered with the aim of reducing groundborne noise levels to an acceptable standard. Where this is likely, the potential impacts will be identified, although the mitigation will be addressed as part of the detailed design.
REFERENCES


APPENDIX A

GLOSSARY OF NOISE AND VIBRATION AND RAILWAY ABBREVIATIONS AND TERMS
GLOSSARY OF NOISE AND VIBRATION AND RAILWAY ABBREVIATIONS AND TERMS

Noise and Vibration Abbreviations and Terms
CRTN  The Calculation of Road Traffic Noise
CRN   Calculation of Railway Noise
dB    Decibel
Hz    Hertz
NEC   Noise Exposure Category
NSR   Noise Sensitive Receptors
PPV   Peak Particle Velocity
VDV   Vibration Dose Value

A-weighting - weighting of the audible frequencies designed to reflect the response of the human ear to noise. The ear is more sensitive to noise at frequencies in the middle of the audible range than it is to either very high or very low frequencies. Noise measurements are often A-weighted (using a dedicated filter) to compensate for the sensitivity of the ear.

Airborne Noise – noise radiated directly from a source, such as a loud speaker or machine, into the surrounding air.

Ambient Noise – The all encompassing noise in a particular situation measured as an Equivalent Continuous Sound Level, the \( L_{Aeq} \), which is usually measured over a particular time period.

Broadband - a noise containing a wide range of frequencies.

C-weighting - weighting of the audible frequencies often used for the measurement of peak sound pressure level. C-weighting has an almost flat (or linear) response across the audible frequency range.

Decibel - units of sound measurement and noise exposure measurement.

\( \text{dB}(A) \) - decibels A-weighted.

\( \text{dB}(A) \) - decibels C-weighted.

Directivity - the uniform/non-uniform directional characteristics of a noise source (as noise may be emitted from the source in different directions with varying intensities and frequencies).
Equivalent continuous sound pressure level ($L_{AeqT}$) - a measure of the average sound pressure level during a period of time, in dB (A weighted).

**Frequency (Hz)** - the pitch of the sound, measured in Hertz.

**Fundamental frequency** - the lowest natural frequency of a vibrating system.

**Groundborne Noise** - noise perceived by the sense of hearing that differs from noise in general only insofar as it arrives in the space where it is heard as a result of propagation as vibration (at acoustic frequencies) through the ground or through a structure.

**Harmonic** - a signal having a repetitive pattern.

**Hz** - hertz, the unit of frequency.

**Impulsive noise** - any type of single or repeated noise of short duration, e.g. the noise from an explosion or the noise of a power press.

$L_{Amax}$ - maximum value of the A-weighted sound pressure level, measured using the fast (F) time weighting (in dBA).

$L_{Amax, S}$ - As above but measured using the Slow time-weighting, as adopted for the measurement of groundborne noise.

$L_{AE}$ - see under sound exposure level (SEL).

$L_{eq}$ - see “Equivalent continuous sound pressure level”.

$L_{A10}$ - This is the noise level that is exceeded for 10% of the measurement period and gives an indication of the noisier levels. It is a unit that has been used over many years for the measurement and assessment of road traffic noise.

$L_{A90}$ - This is the noise level that is exceeded for 90% of the measurement period and gives an indication of the noise level during quieter periods. It is often referred to as the background noise level and is used in the assessment of disturbance from industrial noise.

**Loudness** - the measure of the subjective impression of the magnitude or strength of a sound.

**Mixed source** - a noise environment where no specific source of noise is dominant.

**Noise** - unwanted sound or unwanted signal (usually electrical) in a measurement or instrumentation system

**Noise spectrum** - a noise represented by its frequency components.
Octave – the range between two frequencies whose ration is 2:1

Peak Particle Velocity – A unit of vibration magnitude measurement. Peak particle velocity is defined as “the maximum instantaneous velocity of a particle at a point during a given time interval”, and has been found to be the best single descriptor for correlating with case history data on the occurrence of vibration-induced damage.

Sound Exposure Level (L_{AE}) - the total sound energy of a noise event compressed into a unit time period, i.e. one second.

Sound pressure level (SPL) - the basic measure of noise expressed in decibels, usually measured with an appropriate frequency weighting (e.g. the A-weighted SPL in dBA).

Tonal - noise sources sometimes contain pure tone components that can be identified as hums, whistles etc. The presence of these tonal components is sometimes considered to add an extra, annoying, quality to the noise.

Vibration – a to-and fro motion; a motion which oscillates about a fixed equilibrium position.

Vibration Dose Value (VDV) – A unit of vibration measurement for evaluating the effects of vibration on humans in buildings. The VDV is given by the fourth root of the integral of the fourth power of the acceleration after it has been frequency weighted.

Railway Abbreviations and Terms

CWR – Continuously Welded Rail – Track which is laid and the joints welded to form a smooth running surface hence reducing noise and vibration emissions to air and ground.

EMU – Electric Multiple Unit

TOC – Train Operating Company
APPENDIX B

SURFACE VIBRATION MEASUREMENTS AT BRENTWOOD
CROSSRAIL

Surface vibration measurements at Brentwood

Prepared by Rupert Taylor

11 February 2005

Measurements were made on 11 October 2004 at a site very close to the track 0.5km west of Brentwood Station (Plate 1 and Plan 1). At this location there is plain track only, with no points or crossings.

The measurements were made using a B&K type 4378 piezoelectric accelerometer, mounted on a 40mm steel cube, and a B&K 2631 charge amplifier. Measurements of vertical velocity were recorded. The conditioned signal was recorded using a Sony DAT recorder, subsequently downloaded to a computer and post processed using Rupert Taylor software. The weather was wet, and for this reason it was necessary to position the survey vehicle near to the transducer to keep the electronic equipment under cover. However, the presence of the vehicle would only have affected the results if there had been significant vibration at vehicle suspension frequencies, which was not the case.

The rolling stock consisted of Class 315 EMUs and the more modern Class 321 and Class 360, together with some loco-hauled Mk2 trains. Class 321 has similarities to the assumptions being made for Crossrail vehicles.

The results are shown in Figure 1. Ignoring the very close results (4.7m), the rmq average z-axis VDV was $0.024 \text{ ms}^{-1.75}$, with greater inter-train variability than distance or speed dependence.

During set-up of the survey, a container freight train passed and caused perceptible vibration. Though it was not measured, it can safely be assumed that the VDV for this event was well over $0.03 \text{ ms}^{-1.75}$.

Frequency analysis of the Brentwood measurements shows that the bulk of the vibration is in the range 10-40Hz (see figure 2).

A FINDWAVE® model of the site was created, consisting of sleeper and ballast track on a clay half-space with a surface representative of the car park surface. A train speed of 160km/h was assumed, consisting of Class 321 stock. The results are shown in Figure 3 in terms of vertical VDV as a function of distance.
Plate 1 Position of measurement transducer (near white line below vehicle)

Plan 1 Measurement location
Figure 1 Results in terms of z-axis VDV

Figure 2 Spectra of train vibration events
Figure 3 Comparison of Findwave results with measurements.
APPENDIX C

COMPARISON OF CONSTRUCTION NOISE AND VIBRATION CRITERIA APPLIED IN ENVIRONMENTAL STATEMENTS; COMPARISON OF OPERATIONAL NOISE AND VIBRATION CRITERIA APPLIED IN ENVIRONMENTAL STATEMENTS; AND COMPARISON OF FORMAL NOISE AND VIBRATION COMMITMENTS AND UNDERTAKINGS FOR VARIOUS PROJECTS
### COMPARISON OF CONSTRUCTION NOISE AND VIBRATION CRITERIA APPLIED IN ENVIRONMENTAL STATEMENTS

#### Crossrail 2002

#### Noise

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Impact</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Thresholds:**
- Night: D 70 75  E 65  N 65
- Day: D 90 100  E 85  N 85

#### Vibration – people

- Residential sensitive: 0.56 mm/s ppv
- Office, retail, recreational: 1.12 mm/s ppv
- Industrial/Commercial: 2.24 mm/s ppv

#### Vibration – buildings

- Standard buildings: 5 mm/s ppv
- Listed and potentially vulnerable buildings: 10 mm/s ppv

#### THAMESLINK 2000

#### Noise

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
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<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Thresholds:**
- Night: D 70 75  E 65  N 65
- Day: D 90 100  E 85  N 85

#### Vibration – people

- Residential sensitive: 0.28 mm/s ppv
- Office, retail, recreational: 0.56 mm/s ppv
- Industrial/Commercial: 1.12 mm/s ppv

#### Vibration – buildings

- Standard buildings: 5 mm/s ppv
- Listed and potentially vulnerable buildings: 10 mm/s ppv

#### WEST COAST MAIN LINE

#### Noise

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Impact</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Thresholds:**
- Night: D 70 75  E 65  N 65
- Day: D 90 100  E 85  N 85

#### JUBILEE LINE EXTENSION

#### Noise

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Impact</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Thresholds:**
- Night: D 70 75  E 65  N 65
- Day: D 90 100  E 85  N 85

#### Vibration – people

- Residential sensitive: 0.1 mm/s rms
- Office, retail, recreational: 0.2 mm/s rms
- Industrial/Commercial: 0.4 mm/s rms

#### Vibration – buildings

- Standard buildings: 5 mm/s ppv
- Listed and potentially vulnerable buildings: 10 mm/s ppv

---

*Note that there is a statutory undertaking that operation and construction will be Not Environmentally Worse Than (NEWT) the effects identified in the ES.*

---

**Impact severity significant if thresholds exceeded for one day, evening or night per week or more.**

**To maintain speech communication:**
- D 75 16h
- E 65 16h

**To avoid sleep disturbance:**
- N 55 8h

**Annoyance threshold:**
- D 16h 10mm/s ppv
- N 8h 1.75mm/s ppv

---

**L_{A,eq} determined over:**

- D 0700-1900
- E 1900-2300
- N 2300-0700

---

**Significant effects if total ambient noise levels (construction and future baseline) exceed the baseline by 10 dB or more or the construction noise level is greater than the following thresholds and the total ambient is at least 3 dB greater than future baseline:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Mon-Fri</th>
<th>Sat</th>
<th>Sun/pub hols</th>
</tr>
</thead>
<tbody>
<tr>
<td>D 0700-1900</td>
<td>75 L_{A,eq} 12h</td>
<td>70 L_{A,eq} 6h</td>
<td>65 L_{A,eq} 1h</td>
</tr>
<tr>
<td>E 1900-2300</td>
<td>65 L_{A,eq} 4h</td>
<td>65 L_{A,eq} 16h</td>
<td>65 L_{A,eq} 10h</td>
</tr>
<tr>
<td>N 2300-0700</td>
<td>55 L_{A,eq} 1h</td>
<td>55 L_{A,eq} 1h</td>
<td>55 L_{A,eq} 1h</td>
</tr>
</tbody>
</table>

---

**Limit of perception:**
- Residential sensitive: 0.1 mm/s rms
- Office, retail, recreational: 0.2 mm/s rms
- Industrial/Commercial: 0.4 mm/s rms

---

**Annoyance threshold:**
- D 16h VDV 0.9 mm/s
- N 8h VDV 0.13 mm/s
### Operational Noise and Vibration Criteria

#### Crossrail 2002

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Residential</th>
<th>Non-residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential complaint threshold:</td>
<td>40 dB $L_{A1max}$, single train</td>
<td>40 dB $L_{A1max}$, single train</td>
</tr>
<tr>
<td>Limit of perception:</td>
<td>D: 0.22 m/s</td>
<td>D: 0.22 m/s</td>
</tr>
<tr>
<td>VD: 0.31</td>
<td>Slight</td>
<td>0.13</td>
</tr>
<tr>
<td>Monitoring level:</td>
<td>D: &gt;0.22 m/s</td>
<td>D: &gt;0.22 m/s</td>
</tr>
<tr>
<td>VD: &gt;0.31</td>
<td>Slight</td>
<td>&gt;0.13</td>
</tr>
</tbody>
</table>

#### Crossrail 1995

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Residential</th>
<th>Non-residential</th>
</tr>
</thead>
<tbody>
<tr>
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<td>D: 0.22 m/s</td>
</tr>
<tr>
<td>VD: 0.31</td>
<td>Slight</td>
<td>0.13</td>
</tr>
<tr>
<td>Monitoring level:</td>
<td>D: &gt;0.22 m/s</td>
<td>D: &gt;0.22 m/s</td>
</tr>
<tr>
<td>VD: &gt;0.31</td>
<td>Slight</td>
<td>&gt;0.13</td>
</tr>
</tbody>
</table>

#### Thameslink 2000

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Residential</th>
<th>Non-residential</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Slight</td>
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</tr>
<tr>
<td>Monitoring level:</td>
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<td>D: &gt;0.22 m/s</td>
</tr>
<tr>
<td>VD: &gt;0.31</td>
<td>Slight</td>
<td>&gt;0.13</td>
</tr>
</tbody>
</table>

#### West Coast Main Line

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Residential</th>
<th>Non-residential</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>Slight</td>
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<td>Monitoring level:</td>
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<td>D: &gt;0.22 m/s</td>
</tr>
<tr>
<td>VD: &gt;0.31</td>
<td>Slight</td>
<td>&gt;0.13</td>
</tr>
</tbody>
</table>

#### Jubilee Line Extension

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Residential</th>
<th>Non-residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential complaint threshold:</td>
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<tr>
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<td>Slight</td>
<td>0.13</td>
</tr>
<tr>
<td>Monitoring level:</td>
<td>D: &gt;0.22 m/s</td>
<td>D: &gt;0.22 m/s</td>
</tr>
<tr>
<td>VD: &gt;0.31</td>
<td>Slight</td>
<td>&gt;0.13</td>
</tr>
</tbody>
</table>

#### CTRL

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Residential</th>
<th>Non-residential</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
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<td>D: 0.22 m/s</td>
</tr>
<tr>
<td>VD: 0.31</td>
<td>Slight</td>
<td>0.13</td>
</tr>
<tr>
<td>Monitoring level:</td>
<td>D: &gt;0.22 m/s</td>
<td>D: &gt;0.22 m/s</td>
</tr>
<tr>
<td>VD: &gt;0.31</td>
<td>Slight</td>
<td>&gt;0.13</td>
</tr>
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</table>

#### ELL

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Residential</th>
<th>Non-residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential complaint threshold:</td>
<td>40 dB $L_{A1max}$, single train</td>
<td>40 dB $L_{A1max}$, single train</td>
</tr>
<tr>
<td>Limit of perception:</td>
<td>D: 0.22 m/s</td>
<td>D: 0.22 m/s</td>
</tr>
<tr>
<td>VD: 0.31</td>
<td>Slight</td>
<td>0.13</td>
</tr>
<tr>
<td>Monitoring level:</td>
<td>D: &gt;0.22 m/s</td>
<td>D: &gt;0.22 m/s</td>
</tr>
<tr>
<td>VD: &gt;0.31</td>
<td>Slight</td>
<td>&gt;0.13</td>
</tr>
</tbody>
</table>

### Notes
- $L_{Aeq 24h}$: Equivalent continuous A-weighted sound level.
- $L_{Amax}$: Maximum A-weighted sound level.
- $L_{D 16h}$: Dynamic vibration level.
- $L_{N 8h}$: Noise level.
- $L_{10th}$: 10th percentile noise level.
- $L_{50th}$: 50th percentile noise level.
- $L_{90th}$: 90th percentile noise level.

### Thresholds for Operational Noise and Vibration

1. **Residential: Daytime Noise**
   - $L_{Aeq 24h} ≤ 68$ dB
   - $L_{Aeq 18h} ≤ 70$ dB
   - $L_{Amax,night} ≤ 80$ dB

2. **Residential: Nighttime Noise**
   - $L_{Aeq 24h} ≤ 63$ dB
   - $L_{Aeq 18h} ≤ 65$ dB
   - $L_{Amax,night} ≤ 70$ dB

3. **Residential: Airborne Noise**
   - $L_{Aeq} ≤ 60$ dB (7:00-23:00)
   - $L_{Amax} ≤ 70$ dB (7:00-23:00)

4. **Residential: Groundborne Noise**
   - $L_{D 16h} ≤ 0.22$ m/s
   - $L_{N 8h} ≤ 0.14$ m/s

5. **Non-residential: Residential**
   - $L_{Aeq} ≤ 40$ dB
   - $L_{Amax} ≤ 50$ dB

6. **Non-residential: Non-residential**
   - $L_{Aeq} ≤ 40$ dB
   - $L_{Amax} ≤ 50$ dB

### Additional Notes
- **Operational As Crossrail 2002**
  - No appreciable existing vibration
  - Low probability of adverse comment

- **Possible complaint threshold**
  - 40 dB $L_{A1max}$ (stated as “peak”) but inferred to mean $L_{Aeq 18h}$

### Limits of Adverse Comment
- **Limit of perception:**
  - 0.1 mm/s rms
  - 0.2 mm/s rms

### Environmental Statements
- **Operational Noise and Vibration**
  - Compliance with statutory undertakings
  - Operation and construction will be Not Environmentally Worse Than (NEWT) the effects identified in the ES

### Additional Information
- **Crossrail 2002**
  - No appreciable existing vibration
  - Low probability of adverse comment

- **Crossrail 1995**
  - No appreciable existing vibration
  - Low probability of adverse comment

- **Thameslink 2000**
  - No appreciable existing vibration
  - Low probability of adverse comment

- **West Coast Main Line**
  - No appreciable existing vibration
  - Low probability of adverse comment

- **Jubilee Line Extension**
  - No appreciable existing vibration
  - Low probability of adverse comment

- **CTRL**
  - No appreciable existing vibration
  - Low probability of adverse comment

- **ELL**
  - No appreciable existing vibration
  - Low probability of adverse comment
### COMPARISON OF FORMAL NOISE AND VIBRATION COMMITMENTS AND UNDERTAKINGS FOR VARIOUS PROJECTS

<table>
<thead>
<tr>
<th>Date</th>
<th>Proposed for Crossrail 2002</th>
<th>Crossrail 1995</th>
<th>Thameslink 2002</th>
<th>West Coast Main Line</th>
<th>Jubilee Line Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Insulation for Construction Noise</td>
<td>Mon-Fri: 0700-0750, Sun: 0800-1100</td>
<td>Same as Crossrail 2002</td>
<td>Same as Crossrail 2002</td>
<td>Same as Crossrail 2002</td>
<td>Same as Crossrail 2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mon-Fri: 0700-0800, Sun: 0800-1100</td>
<td>0700-0750, 0800-1100</td>
<td>0700-0750, 0800-1100</td>
<td>0700-0750, 0800-1100</td>
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<tr>
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<td></td>
<td>Mon-Fri: 0700-0800, Sun: 0800-1100</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Mon-Fri: 0700-0800, Sun: 0800-1100</td>
<td>0700-0750, 0800-1100</td>
<td>0700-0750, 0800-1100</td>
<td>0700-0750, 0800-1100</td>
</tr>
</tbody>
</table>

### Predicted Noise Levels

- Mon-Fri: 0700-0750, Sun: 0800-1100
- 0700-0750, 0800-1100
- 0700-0750, 0800-1100
- 0700-0750, 0800-1100
- 0700-0750, 0800-1100

### Operational Noise

- Groundborne Noise
- Airborne Noise
- Vibration

### Maintenance

- Groundborne noise: 0.35m/s Amax, 0.13m/s Night
- Airborne noise: 65 dB LAeq, 24hr

### Public Access

- Noise intrusion to a practicable minimum

### Vibration Limits for People

- Use BPM for PPs not to exceed: 0.56mm/s - residential/sensitive
- 1.75mm/s - education/offices

### Operational Airborne Noise

- Vibration Limits for Buildings
- Groundborne Noise

### Construction Vibration Limits for Buildings

- Use BPM not to exceed 5mm/s at foundation of buildings

### Operational Groundborne Noise

- Underfloor noise to incorporate CWR and resilient track to the greatest extent practicable
- Regard given to achieving lower levels where reasonable and practicable for particularly sensitive buildings

### Operational Airborne Noise

- The Appellants will abide by NRR 1996 (as amended)

### Construction Noise

- Use BPM for PPs not to exceed: 0.4m/s - day

### Operational Groundborne Noise

- Underfloor noise to incorporate CWR and resilient track to the greatest extent practicable
- Regard given to achieving lower levels where reasonable and practicable for particularly sensitive buildings

### Vibration Limits for People

- Use BPM for PPs not to exceed: 0.13m/s - dwellings
- 0.8m/s - commercial

### Operational Airborne Noise

- The track to incorporate CWR (and resilient track for underground sections) to the greatest extent practicable
- Regard given to achieving lower levels where reasonable and practicable for particularly sensitive buildings

### Vibration Monitoring

- Permanent monitoring during activities where high levels may be caused.
APPENDIX D

CONSTRUCTION NOISE, TRIGGERS FOR SIGNIFICANCE, NOISE INSULATION AND TEMPORARY RE-HOUSING
CROSSRAIL

CONSTRUCTION NOISE

Triggers for significance, Noise Insulation and Temporary Re-housing

Note by Rupert Taylor
14 June 2004

Revised 6 July 2004 and 16 February 2005 (PSE)

This paper considers the appropriateness of the system developed for triggering “significance” and noise insulation and temporary re-housing in the noise for the noise and vibration assessment.

The system of determining significance originated in the construction noise specialist report prepared by Arup Acoustics for the Channel Tunnel Rail Link ES. It is as follows:

<table>
<thead>
<tr>
<th>Assessment Category and threshold value period $L_{eq}$</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIGHT-TIME (2300-0700)</td>
<td>45</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Evening and weekends*</td>
<td>55</td>
<td>60</td>
<td>65</td>
</tr>
<tr>
<td>Daytime (0700-1900)</td>
<td>65</td>
<td>70</td>
<td>75</td>
</tr>
</tbody>
</table>

*1900-2300 weekdays, 1300-2300 Saturdays and 0700-2300 Sundays

1. Category A: threshold values to use when ambient noise levels (when rounded to the nearest 5 dB) are less than these values.
2. Category B: threshold values to use when ambient noise levels (when rounded to the nearest 5 dB) are the same as category A values.
3. Category C: threshold values to use when ambient noise levels (when rounded to the nearest 5 dB) are higher than category A values.
4. The category (A, B, or C) is to be determined separately for each time period and the lowest category is then used throughout the 24-hour cycle. (E.g. a site which is category A by day and category B or C in the evening and night will be treated as category A for day, evening and night)

Note 4 was added by Thameslink 2000 to deal with anomalies caused by sites near main line railways that had high whole-night ambients due to rail traffic during operating hours, but low ambients between operating hours.

The triggers for the determination of NI and TRH, which originated in preparation of the first Crossrail Bill, were as follows:
4.7 Noise insulation (or grant) will be offered to eligible buildings where the predicted total noise level exceeds either the trigger level for insulation set out in the Table, or a figure 5 dB above the existing airborne noise level for the corresponding times of the day, whichever is the higher, for more than 10 out of 15 consecutive working days or for a total of days exceeding 40 in any six month period.

4.8 In the exercise of its discretion under Section 28 of the Land Compensation Act 1973, CLRL will offer temporary re-housing where the predicted total noise level exceeds either the trigger level for temporary re-housing, or a figure 10 dB above the existing airborne noise level for the corresponding times of the day, whichever is the higher, for more than 10 out of 15 consecutive working days or for a total of days exceeding 40 in any six month period."

**TABLE 4.7 AIRBORNE NOISE TRIGGER LEVELS FOR NOISE INSULATION AND TEMPORARY RE-HOUSING**

<table>
<thead>
<tr>
<th>Time</th>
<th>Relevant Time Period</th>
<th>Averaging Time T</th>
<th>Noise Insulation Trigger Level LA_{eq,T}</th>
<th>Temporary Re-housing Trigger Level LA_{eq,T}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday to Friday</td>
<td>07.00 - 08.00</td>
<td>1 hr</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>08.00 - 18.00</td>
<td>10 hr</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>18.00 - 19.00</td>
<td>1 hr</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>19.00 - 22.00</td>
<td>3 hr</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>22.00 - 07.00</td>
<td>1 hr</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Saturday</td>
<td>07.00 - 08.00</td>
<td>1 hr</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>08.00 - 13.00</td>
<td>5 hr</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>13.00 - 14.00</td>
<td>1 hr</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>14.00 - 22.00</td>
<td>3 hr</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>22.00 - 07.00</td>
<td>1 hr</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Sunday and Public Holidays</td>
<td>07.00 - 21.00</td>
<td>1 hr</td>
<td>65</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>21.00 - 07.00</td>
<td>1 hr</td>
<td>55</td>
<td>65</td>
</tr>
</tbody>
</table>

Both the significance thresholds and the NI/TRH triggers are plotted in Figures 1. and 2. for daytime. The plots ignore the fact that daytime for the significance thresholds is 0700-1900 while the daytime NI/TRH trigger are for 0800-1800. If the lower triggers for the two shoulder hours are taken into account, it lowers the trigger levels by 0.5 dB. In addition to the above, the relative attenuations provided by various glazing types/window states relative to external levels and effects are described in the table at the end of this paper.

The primary discussion which follows is about daytime. The considerations for other periods including night-time are addressed subsequently. All levels referred to are façade levels.
There are four notable features about Figures 1. and 2. Firstly, the significance threshold is saw-tooth in shape at the lower end. This is a consequence of the 5dB rounding that is required, and it is an advantage when assessing large schemes for which measured ambient data are not universally available. It reduces the uncertainty which results when estimates of ambient noise category are made. However, when measured data are available, it produces the saw-tooth effect which is otherwise unjustifiable.
Construction noise triggers

The second feature of the figures is that the Noise Insulation trigger is lower than the significance threshold when the ambient is from 67.5 to 71.6 LAeq. This is a consequence of the fact that the significance thresholds are written in terms of levels of construction noise only, whereas the NI/TRH triggers are written in terms of the total noise level, i.e. construction noise and ambient LAeq levels combined. This is anomalous.

The third feature is the fact that the pure construction noise trigger actually dips down in the region of 70 dB (NI) and 75 dB (TRH). This has rather impracticable consequences. The fourth feature is that the significance trigger is a flat-line above 75 LAeq even when the ambient rises to much higher levels. There is some logic behind this if the ambient LAeq is caused by discrete noise events, e.g. train passages, and conceals a reasonably low background noise between events, whereas construction noise tends to be fairly continuous throughout the day. Construction noise could in those circumstances cause greater intrusion than simple LAeq comparisons would suggest. Against this, it must be noted that more sophisticated environmental noise indicators, now disused in favour of simpler indices, such as Noise Pollution Level (NPL) and Traffic Noise Index operate in the opposite direction, weighting the result upwards, if there is a large difference between the peaks and the troughs in ambient noise. If construction noise were assessed using NPL, in some circumstances it could reduce the resulting level by smoothing out the peaks and the troughs (filling in the troughs).

If the CTRL significance system had not already been established by the process of the passage of the CTRL Bill, it is possible it would not be in use. Its use persists because of the power and convenience of precedent.

In much earlier schemes, there was a tendency to assess construction noise based on the recommendation of the Wilson Report repeated in Advisory Leaflet 72 (still technically a current document) and have a simple threshold of 75 LAeq for busy urban areas and 70 LAeq for other areas. The CTRL system is an advance on that approach, at the lower end of the ambient noise range.

If there were no precedents, a fresh system of assessment would probably look at the marginal increase of total noise over baseline, with a lower cut-off and possibly an upper cut-off as well. The question would be what should the margin be? The figure of 5 dB appears in the NI/TRH triggers largely for enforceability reasons. Any small margin would be much more difficult to measure, given that a NI/TRH policy can be enforced after construction begins. By contrast, environmental assessments are completed before construction begins and are based on prediction alone. Where there are deterministic prediction methods, such as CRTN for highway noise, it is possible to look at quite small margins, like 1 dB, as in the Design Manual for Roads and bridges (that is not to say that CRTN is accurate to within 1 dB – its standard error has been calculated by one authority at 2.8 dB, but the prediction algorithm is repeatable to an accuracy of 0.1 dB). By contrast, because of plant uncertainties, and construction working method uncertainties, construction noise predictions made by two different competent predictors can easily differ by +2.5 dB or so. Consequently the margin should be no less than about 3 dB and 5 dB is not unreasonable. Actual 5 dB increases in LAeq levels for, for example, airport noise, are regarded as significant.
The lower cut-off needs to be at a point where, though there is a 5 dB increase, the resulting ambient noise level is still below significance in impact terms. At the upper end, the cut-off argument would certainly need to take account of the fact that if outdoor noise levels already exceed the “limit of the acceptable”, then any material increase is significant unless there is noise insulation in place. The term “limit of the acceptable” underlies the setting of the noise insulation limits for highways and railways, and the original written parliamentary answer that presaged the introduction of the original highway noise insulation regulations said that 70 dB $L_{A_{10\,18h}}$ was the limit of the acceptable (the reason why the NI trigger was set at 68 is to allow for 2 dB measurement uncertainty). The equivalent in terms of $L_{A_{eq\,16h}}$ is about 68 dB according to PPG 24. This makes the Crossrail significant threshold system, flatlining at 75 dB, supportable, not to say a little generous, which is justified by the finite duration of construction noise.

When the first NI/TRH policy was introduced during the passage of the Jubilee Line Extension Bill, it was explicitly stated that its purpose was to fill the gap left by the presence of Statutory NI schemes for operating roads and railway but the absence of other than a discretionary scheme for construction noise. It is really intended to sit alongside the other statutory schemes for operational transportation. (There are, of course NI schemes for airports, but they differ among different airports).

The statutory NI schemes use, as a margin, 1 dB (with other caveats as well). As explained above, such a small margin would be unworkable for construction noise because of the inherent uncertainty in the prediction process.

The Wilson recommendation was explicitly made on the basis that the sound reduction of a closed single window was 15-20 dB. He talks about “ill-fitting windows”. A large amount of window renewal has taken place since the 1960s, and PPG 24 says that the typical noise reduction of a dwelling façade with windows set in a brick/block wall is 27-30 dB(A) depending on the source. So there is an argument for raising the upper cut-off by at least 7 dB. However, Wilson’s recommendation was 70, not 75. This was based on an internal noise level of 55 dB and windows giving a 15 dB reduction. $L_{A_{eq\,16h}}$ did not exist in Wilson’s time, but he appeared to be assessing a more or less continuous noise level.

In fact, current practice is to assume a 15 dB reduction for a partially open window. The figure of 75 was introduced to prevent the setting of construction noise limits below those of existing ambients in urban areas near main roads and heavy industrial areas. So an increase in the upper cut-off of the significance thresholds would take us to at least 82 dB (70+27-15=82 or 82-27=55).

An aspect of significance which has to be mentioned is the significance of not being able to open the windows that face the noise source.

There is a step in the curve of significance that occurs at the point where people close their windows against external noise. If they have to do this because of ambient noise in any event, then construction noise will not take them back to the point just before they closed the windows until it is 82 dB or perhaps a little more. There is therefore an argument for adding another category that causes the flatline to be at 80 dB rather than 75 dB.
If the dwelling already has secondary glazing, or even double glazing, then there is an analogous argument for adding yet another category, taking the flatline up to 85 dB.

However, with an ambient above 77.5 (as would be the case to cause a trigger of 85), the total noise level would exceed the upper exposure action value of the proposed Control of Noise at Work Regulations 2005.

A cut-off at the low end of the range of ambient noise levels is required to avoid significance occurring at unreasonably low noise levels. For a permanent noise source, to allow partially open windows, there is an argument that the cut-off should be an external noise level of 55 dB $L_{Aeq}$ in line with the World Health Organization’s guidelines “Guidelines for Community Noise” (1999)

For construction noise, which is of limited duration and subject to a balance between ideal objectives and reasonably practicable achievement, the assumption of a closed window in the façade facing the source would raise the cut-off from 55 to a figure at least 12 dB higher (taking the difference between 15 dB for a partially open window as assumed by WHO and the minimum of 27 dB for windows set in brick/block wall as per PPG24). The historical position in fact leads to the conclusion that the lower cut-off should be the cut-off for category A in the CTRL/TL2K system, i.e. 65 dB $L_{Aeq}$ for daytime.

Evening and night

The arguments for daytime need to be considered anew for night, as the effects are different – being sleep disturbance and annoyance while awake (for any reason) rather than interference with activities. The WHO guidance suggests that sound pressure levels during the evening and night should be 5-10 dB lower than during the day. In fact, the CTRK/TL2K categories go down in 10 dB steps from day through evening to night.

There is more specific guidance for night-time than for evening, and it is helpful to consider night-time first, and then to consider evening. While BS 5228 no longer gives guidance on acceptable daytime noise levels, it is more specific about evening and night: “Hours of work. For any noise sensitive premises some periods of the day will be more sensitive than others. For example levels of noise that would cause speech interference in an office during the day would cause no problem in the same office at night. For dwellings, times of site operation outside normal weekday working hours will need special consideration. Noise control targets for the evening period in such cases will need to be stricter than those for the daytime and, when noise limits are set, the evening limit may have to be as much as 10 dB(A) below the daytime limit. Very strict noise control targets should be applied to any site which is to operate at night. The periods when people are getting to sleep and just before they wake

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1 The guidance advises that, during daytime, few people are seriously annoyed by activities with $L_{Aeq}$ levels below 55 dB; or moderately annoyed by activities with $L_{Aeq}$ levels below 50 dB. Sound pressure levels during the evening and night should be 5-10 dB lower than during the day. Noise with low-frequency components requires even lower levels. It is emphasized that for intermittent noise it is necessary to take into account the maximum sound pressure level as well as the number of noise events. Inside bedrooms the effect considered is sleep disturbance and the guidance values representing the level at which there is no effect, are 30 dB $L_{Aeq,8h}$, 45 dB $L_{A,max}$, fast, for night time, with corresponding outdoor values, window open, of 45 dB $L_{Aeq,8h}$, and 60 dB $L_{L_{A,max}}$, fast.
Construction noise triggers  6 July 2004

appear to be particularly sensitive. Site noise expressed as $L_{Aeq(1 \, h)}$ at the facade of noise-sensitive premises may need to be as low as 40 dB(A) to avoid sleep disturbance."

The WHO guidelines are generally regarded as the most stringent, and while the BS 5228 figure of 40 dB(A) is consistent with an assumption of a wide open window, it is reasonable to take the WHO assumption of a partially open window in which case the external guideline figure is 45 dB $L_{Aeq}$. In contrast to BS 5228, the WHO guidance uses a time base of 8 hours for night-time, but it is coupled to a maximum noise limit equivalent to 60 dB $L_{A_{max, \, F \, external}}$. There thus is support for the cut-off for evening and night being the same as the category “A” figures in the CTRL/TL2K system. The next matter for consideration is the case where the pre-existing ambient modifies the position.

If the pre-existing ambient is higher than the category “A” triggers, it is likely that the resident concerned does not use open windows facing the source of the noise for ventilation. Thus, up to about 55 dB $L_{Aeq, \, 8h \, external}$ (and 70 dB$L_{A_{max, \, F \, external}}$), internal noise levels would achieve the WHO guidelines with windows closed. Above this figure, noise insulation would be required. The question becomes one of determining the marginal increase caused by the construction noise that triggers eligibility for noise insulation. For night-time, it could be argued that a 5 dB margin is too great, and whereas a resident may have undisturbed sleep with closed windows and ventilation from another façade in the house at an external $L_{Aeq}$ of 55 dB, disturbance would occur at an external $L_{Aeq}$ of 59 dB, but noise insulation would not be triggered. One of the main justifications for the 5 dB margin is the accuracy of prediction and the practicality of enforcement/verification and it remains as true for night as for day so that narrowing of the 5 dB margin for night is not appropriate.

However, while the WHO guidance is assessed in terms of $L_{Aeq \, 8h}$, the noise insulation and temporary re-housing trigger is expressed in terms of $L_{Aeq \, 1h}$. Since the night-time ambient will in most cases vary significantly hour-by-hour such that the early hours of the morning are often considerably quieter than the adjacent periods, this overcomes the problem of the need for a narrower margin at night since the adoption of a 1-hour time base rather than an 8 hour time base makes the system more sensitive. While it does not explicitly deal with the WHO $L_{A_{max, \, F \, external}}$ recommendation, $L_{Aeq \, 1h}$ is much more sensitive to maximum noise levels than $L_{Aeq \, 8h}$. The significance triggers need to be in line with the NI/TRH triggers, so if the “saw tooth” framework is to be replaced with a continuous curve, as is appropriate for daytime, the time base needs to be changed to 1 hour for night and 3 hours for evening.

RECOMMENDATIONS

It is recommended that the “saw-tooth” significance threshold system be replaced by a simple test that significance occurs if the total of construction noise combined with ambient noise is 5dB or more greater than the ambient $L_{Aeq}$ for the corresponding period. The periods for significance assessment should coincide with the periods in the NI/TRH policy. There should be a lower cut-off corresponding to the Category “A” figures, but to avoid a dip in the limit for construction noise limit as it approaches the ambient, the cut-off should be stated in terms of the level due to construction noise only, not the combined level due to construction noise and ambient.
The noise insulation trigger should be restated to remove the downward dip as the ambient tends towards 70 dB, as set out below.

Also to remove the dip as the ambient tends towards 75, the TRH trigger should be rephrased in terms of the level of construction noise, not total noise, as set out below. For construction noise levels below the NI trigger, the reported significance becomes the effect of having to close windows facing the source.

For construction noise levels above the NI trigger, the reported significance becomes the effect of having noise insulation rather than the direct effect of noise.

Where total noise levels exceed 85 dB, this should be reported in terms of the effect of causing potential hearing impairment risk for dwellings with balconies or gardens or that people are prevented from being outside for extended periods.

Appropriate wording for the determination of impact is therefore considered to be as follows:

- Noise insulation (or grant) will be offered to eligible buildings where the predicted noise level due to construction exceeds the trigger level for insulation set out in the Table, or the total noise exceeds a figure 5 dB above the existing airborne noise level for the corresponding times of the day, whichever is the higher, for more than of 10 out of 15 consecutive working days or for a total of days exceeding 40 in any six month period.
- In the exercise of its discretion under Section 28 of the Land Compensation Act 1973, CLRL will offer temporary re-housing where the predicted construction noise level exceeds either the trigger level for temporary re-housing, or a figure 10 dB above the existing airborne noise level for the corresponding times of the day, whichever is the higher, for more than 10 out of 15 consecutive working days or for a total of days exceeding 40 in any six month period."

The consequential thresholds and triggers are shown in Figures 3. to 8. As far as the shoulder periods in the NI/TRH policy either side of the core working day are concerned, it is inappropriate to devise significance thresholds for them as construction planning detail would not be available in sufficient detail.
Figure 3. Recommended revised significance triggers and NI/TRH thresholds – core daytime working period

Figure 4. Recommended revised significance triggers and NI/TRH thresholds – Saturday core daytime working period
Figure 5. Recommended revised significance triggers and NI/TRH thresholds – Saturday afternoon/evening

Figure 6. Recommended revised significance triggers and NI/TRH thresholds – evening
Figure 7. Recommended revised significance triggers and NI/TRH thresholds – Sunday

Crossrail trigger levels - Sunday

Figure 8. Recommended revised significance triggers and NI/TRH thresholds - night

Crossrail trigger levels - night
<table>
<thead>
<tr>
<th>External daytime noise level: (Notes 2, 3 and 4)</th>
<th>Window state</th>
<th>Ventilation state</th>
<th>Internal Noise Level (Note 5)</th>
<th>Effect: (Notes 1 and 3)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤55</td>
<td>Open</td>
<td>natural</td>
<td>≤40</td>
<td>Few people seriously annoyed per WHO</td>
<td>0</td>
</tr>
<tr>
<td>55-65</td>
<td>Partially Open</td>
<td>natural</td>
<td>40-50</td>
<td>Some people seriously annoyed per WHO - at least 5dB better than Wilson/AL72</td>
<td>1</td>
</tr>
<tr>
<td>65-75</td>
<td>Closed single</td>
<td>from another facade if available</td>
<td>35-48</td>
<td>Some people seriously annoyed at upper end - at least 7dB better than Wilson/AL72 - ventilation problems</td>
<td>2</td>
</tr>
<tr>
<td>75-85</td>
<td>Noise Insulation</td>
<td>Forced noise-attenuated ventilator unit</td>
<td>36-51</td>
<td>Some people seriously annoyed at upper end - at least 4dB better than Wilson/AL72 - ventilation problems</td>
<td>3</td>
</tr>
<tr>
<td>&gt;85</td>
<td>House unoccupied through TRH</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>Dislocation</td>
<td>4</td>
</tr>
</tbody>
</table>

Note 1: WHO recommends 40 dB to achieve few people seriously annoyed; 35dB to achieve few people moderately annoyed. The latter figure appears in their table of guideline values for community noise in dwellings except bedrooms. WHO guidance is about characterless noise such as traffic noise, but is in terms of $L_{Aeq 10hours}$.

Note 2: External noise level triggers are the minimum thresholds for daytime. They rise in areas of high pre-existing noise level to the point where construction noise (only) is 5 dB more than the pre-existing ambient. This can cause WHO/Wilson/AL72 guidance to be well exceeded, but if it were not introduced would result in the project having to insulate properties on account of not caused by the project. A smaller margin than 5 dB would be impracticable.

Note 3: All levels reduced by 10 dB at night. This gives up to around 10 dB above WHO's guideline value of 30 dB in bedrooms, but for an 8-hour averaging time, whereas the Crossrail night time averaging time is 1h.

Note 4: Noise levels are dB $L_{Aeq 10hours}$ for daytime, this becomes 1h for night (see Notes 1 and 3)

Note 5: Noise reductions for single glazing and secondary glazing are taken from PPG 24, which does not list construction noise as a source, so the range for the sources given is used above.
APPENDIX E

SPEED PROFILES
Crossrail

Eastbound speed profile used for groundborne noise contours

Crossrail

Westbound speed profile used for groundborne noise contours
Crossrail Whitechapel to Pudding Mill
Eastbound speed profile used for groundborne noise contours

Crossrail Whitechapel to Pudding Mill
Westbound speed profile used for groundborne noise contours
APPENDIX F

GROUNDBORNE NOISE AND VIBRATION PREDICTION VALIDATION ON DLR GREENWICH