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NOISE CONTROL FOR A BETTER ENVIRONMENT

Identifying low level barrier opportunity areas for high speed rail

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ABSTRACT

A low-level barrier design has been considered as a part of the mitigation strategy for the proposed High Speed 2 (HS2) railway. An analysis of their relative performance in relation to fence type barriers was completed in order to determine their overall feasibility for possible substitution or supplementation. This involved an interrogation of the HS2 multiple source prediction methods and showed that low level barriers would provide similar or improved attenuation in certain scenarios. A set of criteria was established, and a GIS-based spatial analysis was completed to identify opportunity areas along the route for further study.

Keywords: Noise, Environment, Rail
I-INCE Classification of Subject Number: 13, 31, 75, 76

1. INTRODUCTION

High Speed 2 (HS2) is a high-speed railway line connecting London to Birmingham, Manchester and Leeds. It is Europe's largest infrastructure project with the Phase One section from London to Birmingham covering around 225km. Noise mitigation methods for the operational railway are described in the HS2 Phase One Environmental statement (ES) [1]. The design considered in the ES included line side noise barriers and assumed that rolling stock will be specified to generate lower noise emissions than the performance values set in the Technical Specification for Interoperability (TSI) Regulation 1304/2014 [2].

A feasibility study has been undertaken to inform possible supplementation or substitution of the mitigation methods described in the ES. A part of this study included

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an analysis of Low Level Barriers (LLB) and an evaluation of their effectiveness in comparison to standard line side barriers.

LLB can be described as barriers which due to their height can be placed closer to the source of noise. General acoustic principles suggest that the proximity can allow for an increased amount of energy to be absorbed when appropriate materials are selected. Line side barriers in contrast tend to be further from the source and are generally placed at an optimal position between the source and receiver to maximise the overall attenuation. The constraints in regard to the placement of LLB are primarily due to the structural gauge, the minimum distance for the clearance of the passing train.

For conventional rail, LLB have previously been implemented for projects across Europe, such as the Czech Republic. P. Čížková [3] measured insertion losses of around 4 to 8dB at a 6.5m distance at varying height with a LLB at 2m from the centre of the track. While these installations have been shown to be effective in a number of scenarios, their use for high speed train applications remains novel.

The initial analysis described below considers the effectiveness of LLB by interrogating the HS2 multiple source noise prediction methodology. A generalised computational noise model has then been developed to compare the attenuation from LLB and conventional line side barriers in high speed rail applications, and using geospatial analysis, opportunity areas have been identified so that more detailed modelling can be completed along the route.

2. HS2 PREDICTION METHODOLOGY

The acoustic effectiveness of a barrier is largely dependent on the geometry between the source and the receiver. For rail sources, the total noise level is generally dominated by the wheel-rail interface, however at high speed (typically defined as above 250kph) other sources such as aerodynamic sound can significantly contribute to the overall noise level. Marshall et al. [4] describe the derivation of source terms for a five-source model which builds upon the HS1 'Train Noise Prediction Method' (TNPM) developed for the Channel Tunnel Rail Link [5]. The sources include:

1. Rolling noise at a height of 0.0m above the rail head, the sound emitted by the wheels and the track;
2. Body aerodynamic sound at a height of 0.5m above the rail head, which includes sound generated by flow in the lower regions of the train;
3. Starting sound, at a height of 2.0m above the rail head, which includes sound generated by traction and auxiliary systems;
4. Pantograph recess sound, at a height of 4.0m above the rail head; and
5. Raised pantograph, at a height of 5.0m above the rail head.

The contribution of these sources at the receiver varies with speed and the source terms specific to the type of train. For $L_{Aeq,T}$ prediction the speed relationship for each source is described by the HS2 prediction methodology as follows:

$R_{SEL} + 20\log_{10} V$ for rolling sound;
$P_{SEL} + 60\log_{10} V$ for body aerodynamic sound;
$S_{SEL} - 10\log_{10} V$ for starting sound;
$P_{SEL} + 60\log_{10} V$ for pantograph and pantograph recess sound,

where R_{SEL}, P_{SEL}, S_{SEL}, P_{SEL} are constants (the source terms) and V is the train speed in kph.

Equation 1. SEL / Speed relationship for LAeq,T prediction

Figure 1 shows the contributions to the Sound Exposure Level (SEL) against speed graphically for each component.

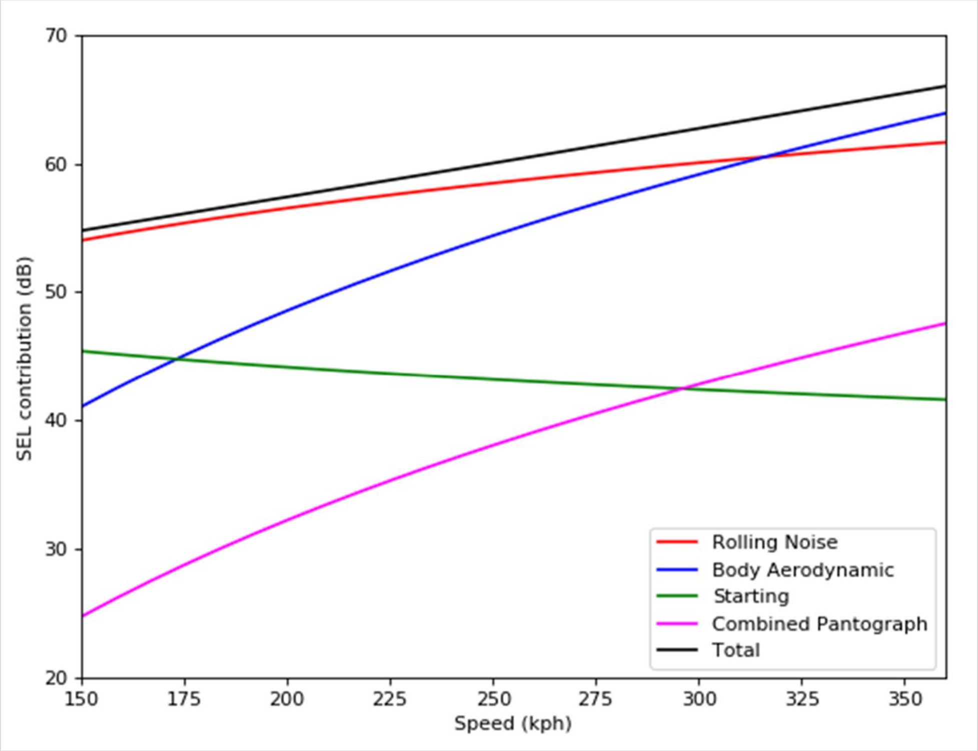

Figure 1: Contribution of sources at 25m / 1.5m height

At slower speeds, the rolling noise of the wheel / rail interface is most dominant, followed by the aerodynamic noise from the body of the train, the engine / traction noise, and aerodynamic noise from the raised pantograph. In this case, the source terms represent mitigated rolling stock, and the aerodynamic noise from the body of train becomes dominant at around 320kph.

The propagation of noise from each source is logarithmically summed at a receptor location to provide a single value with different distance attenuation, air absorption, ground absorption, screening and angle of view for each source. Barrier attenuation is calculated using the following formulae for absorptive and reflective barrier types, with path differences calculated using the approach described in the UK Calculation of Railway Noise (CRN) [6].

Absorptive

$PD < 0: BA = e^{(1.63+12\times PD)}$

$PD \geq 0: BA = 10 \times \log(2.5 + 30(PD + 0.025))$

Reflective

$PD < 0: BA = e^{(1.1958+14\times PD)}$

$PD = 0: BA = 3.3\, dBA$

$PD < 0: BA = 11 \times PD^{0.262}$

PD represents the path difference between the source and the receiver.

Equation 2. Absorptive / Reflective barrier correction

3. INITIAL STUDY

The initial feasibility study for LLB involved an interrogation of the HS2 prediction methods analytically in Python before developing a more comprehensive computational model in the geometric sound modelling software package NoiseMap (version Five).

An absorptive LLB was considered at 1.1m height from the top of the rail (TOR) at various distances from the structural gauge. This was compared against standard line side reflective barriers between 3 – 5m height at a distance of 5.7m from the centre of the track.

Figure 2 shows the results of the Python implementation and the effect of the LLB on the contribution of sources for a receiver at 25m from the rail, at 1.5m height (TOR).

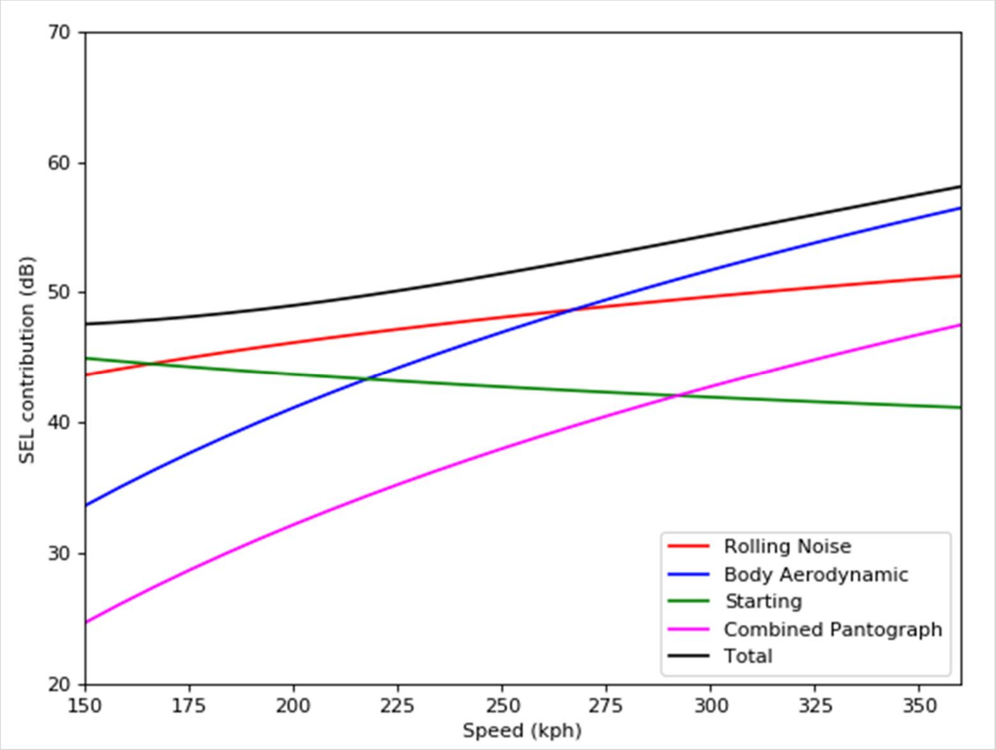

Figure 2: Contribution of sources at 25m / 1.5m height with LLB

Figure 2 can be directly compared with Figure 1, showing that the rolling noise component has been attenuated more than the body aerodynamic component. The body aerodynamic noise therefore becomes dominant at a lower speed of around 260kph. Also, the starting / traction noise is more dominant at lower speeds, as it is not screened by the LLB.

3.1 NoiseMap modelling

NoiseMap is capable of directly implementing the TNPM procedures with the updated requirements for the HS2 prediction methodology. It allows for a more complex simulation and includes a number of additional parameters and assumptions. While the Python implementation considers a single train type and single track, the full service pattern can be included as a part of a computational model. The contributions from the source terms of each train type and the related number of services are combined on each track. The model also computes the overall barrier attenuation in three-dimensions, and combines the result from each geometric sound ray at the receiver, which creates a more realistic assessment.

A set of receivers between 25 and 600 metres at varying heights were inserted into the model in order to determine the effect of the LLB over distance. The calculation was repeated over a number of scenarios and the full results, which included the details of each correction applied, were exported to a spreadsheet. The exported results were split by source contribution for each train service at each receiver. This approach enabled the ‘front-loading’ of the propagation calculation and allowed for changes to the assumptions (such as train speeds, source terms etc) to be investigated without needing to recalculate the full 3D model.

In order to calculate the contributions from each source at different speeds, a set of results were calculated by correcting the speed term of the individual sources. These were then combined at each receiver and summarised as a set of insertion losses for each scenario.

4. MODELLED RESULTS

Figure 3 shows the calculated insertion losses for the LLB compared with a 3m high line side fence barrier at 320kph for receivers at 1.5m height. The insertion losses are determined by comparing calculated levels at the receiver with and without the barrier in place. It can be seen that the LLB provides less attenuation for receptors nearer to the track than standard line side barriers, however at greater distances (in this case around 150m), the LLB becomes more effective. Insertion losses of LLB and line side barriers were compared in order to determine the crossover in effectiveness for LLB for each of the modelled receiver heights and distances.

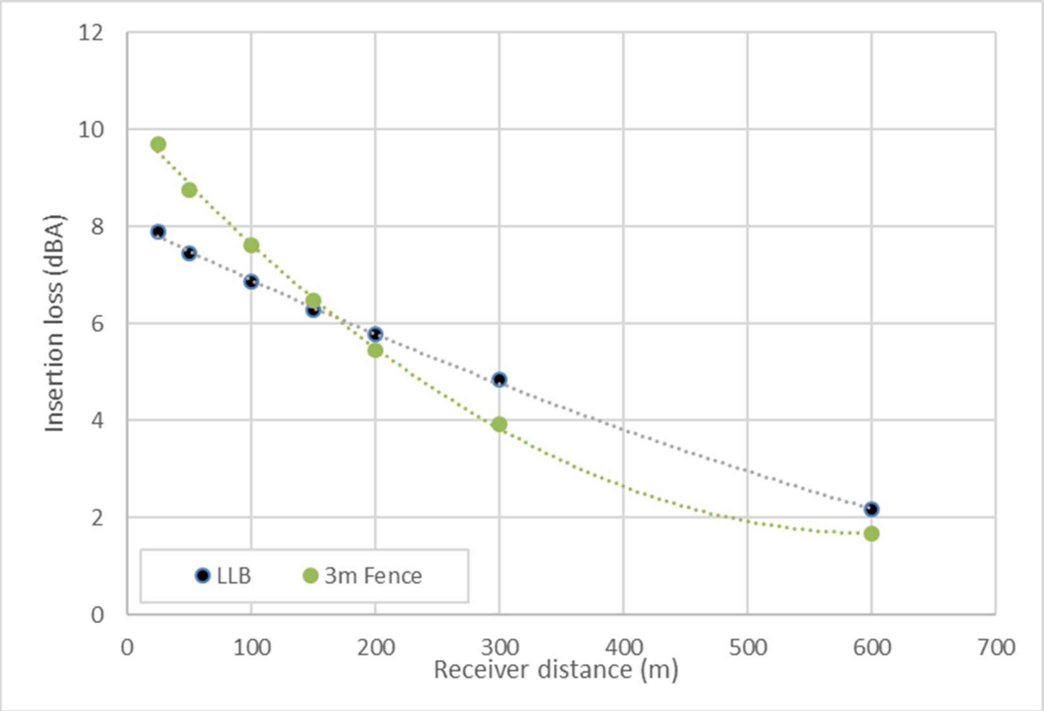

Figure 3: Insertion losses for LLB and 3m line side barrier at 320kph

Figure 4 shows the comparison of LLB insertion loss against distance relative to the performance of line side barriers at 3, 4 and 5m heights and a train speed of 320kph. Negative values equate to reduced attenuation for the LLB in comparison to line side barriers. The distance of the crossover in effectiveness at which LLB becomes more effective than line side fence barriers is greater for taller line side barriers, and as distance increases, the height of the receiver becomes a stronger factor, with receivers above and below the rail height diverging.

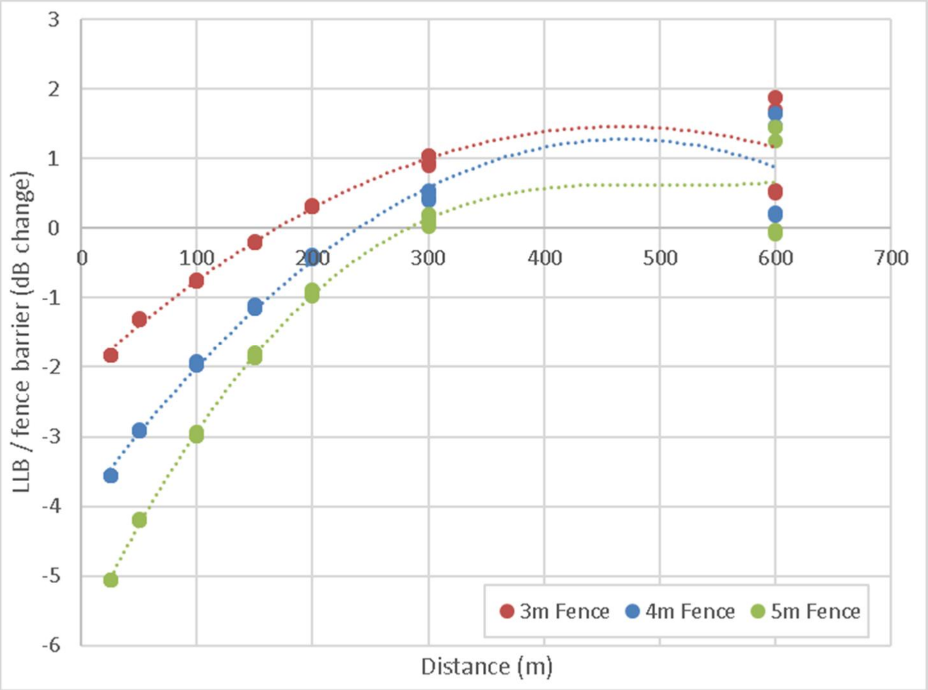

Figure 4: Insertion loss comparison / distance at 320kph

Quadratic regression was then used to calculate the distance at which the LLB becomes more effective (the ‘crossover distance’). Figure 5 shows the crossover distance against speed for each barrier height. Comparison of Figure 5 with Figure 2 shows that the LLB is most effective for speeds between around 175kph and 275 kph. This is because in this speed range the rolling noise source term (which is attenuated by the LLB) is dominant. Below 175 kph the traction (starting) source becomes dominant and above 275 kph the body aerodynamic source becomes dominant; at these boundaries the LLB starts to become less effective. Both the traction and body aerodynamic sources are situated at greater height than the rolling noise source, so are not affected by the LLB to the same extent.

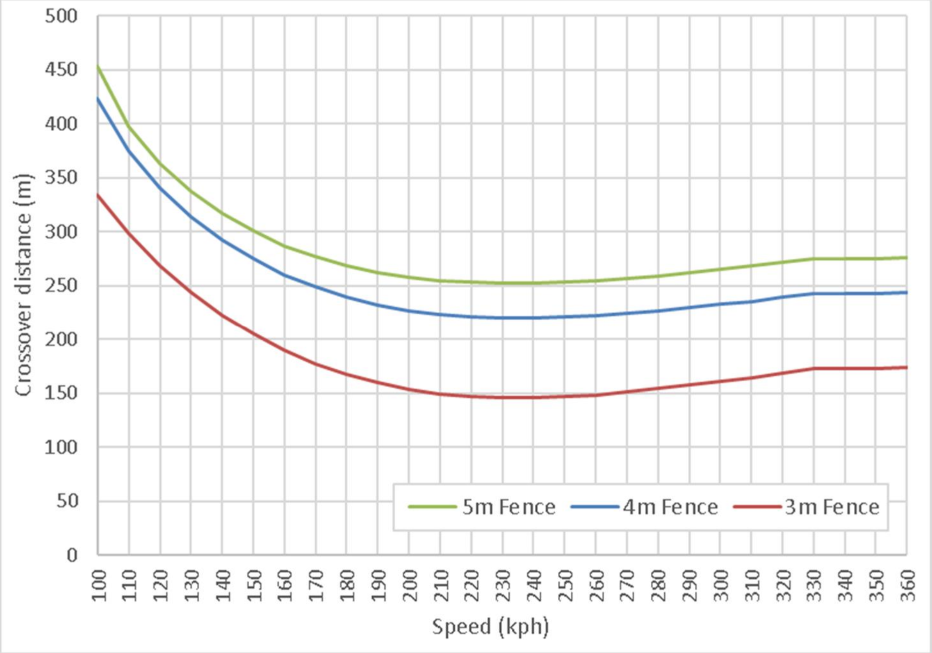

Figure 5: Crossover distance / speed

Figure 5 shows that the LLB are most effective for train speeds at around 240 kph. Figure 6 shows the difference in insertion loss at this speed. In comparison to Figure 4, the crossover distances are reduced, and the effectiveness of the LLB is increased overall.

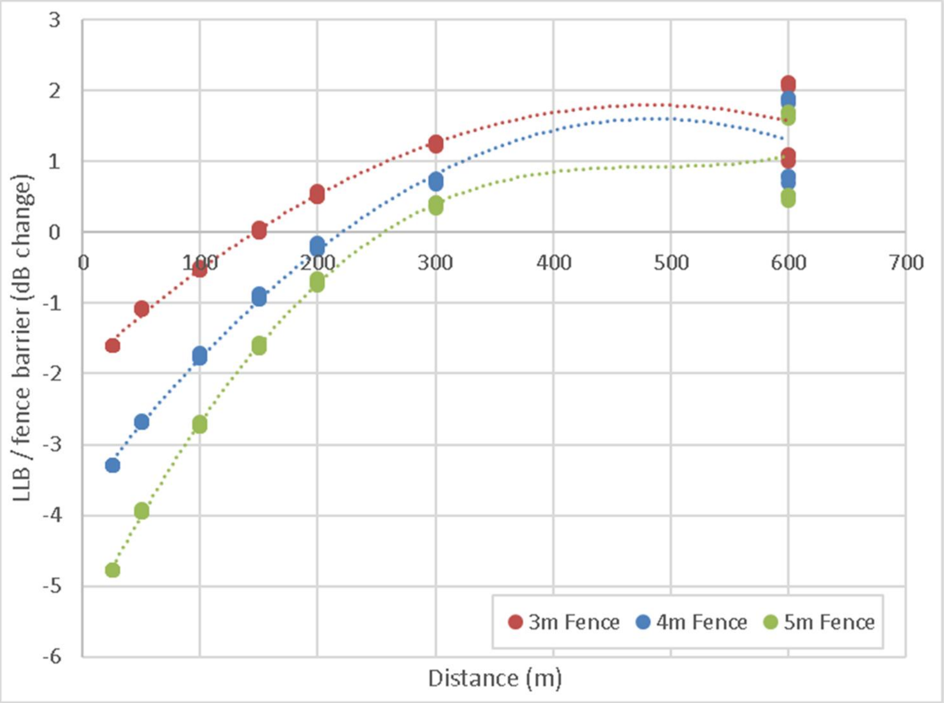

Figure 6: Insertion loss comparison / distance at 240kph

6. GEOSPATIAL ANALYSIS

The ArcGIS geospatial software package (version 10.4) was used to process the modelled results in order to identify LLB opportunity areas. These 'opportunity areas' identified locations with proposed line side barriers that could potentially be substituted or supplemented by LLB. The results from the initial study were expressed and imported as a table of crossover distances against speed and (line side) barrier height.

The inputs also included the following geographic features:

No.	Feature	Description
1	Proposed line side barriers	The line side barriers along with height attributes described in the Environmental Statement
2	Assessment locations	Clusters of noise-sensitive receptors along the route represented by assessment locations.
3	Track alignment	The proposed route split into segments by speed and flow.

Table 1. Geographic features used for LLB analysis

6.1 Processing Steps

A number of tools and functions have been used as a part of the GIS analysis and are summarised below as a set of processing steps:

1. The alignment (3) is split into 10m lengths and segments outside a 10m radius of the proposed barriers (1) are excluded.

2. The alignment (3) is then ‘spatially joined’ to the line side barrier feature (1).

The attributes of the alignment feature included the speed of the track and the height of the nearest line side barrier.

3. The table of results (as crossover distances) are ‘joined’ to the alignment (3) using the track speed as the join attribute.
4. Crossover distances are then assigned using buckets (binning) for the line side barrier heights associated with each alignment segment.
5. The alignment segments (3) are then buffered with the assigned crossover distances.

Figure 7 shows the resulting crossover buffers in blue with the alignment in black and line side barriers in red.

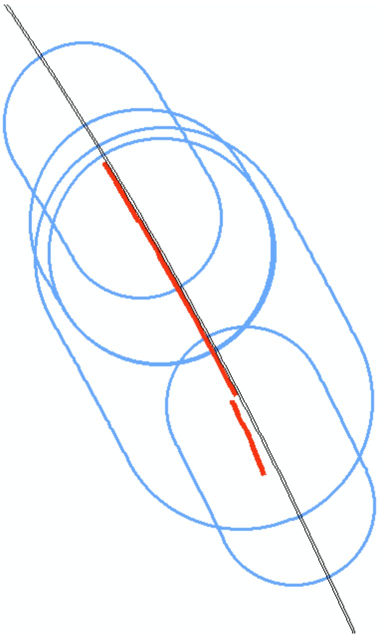

Figure 7: Crossover buffers with line side barriers / alignment

The receptors outside of the blue buffer may experience an equivalent or increased attenuation from LLB if it were substituted in place of the proposed line side barrier. The percentage of the affected receptors that are expected to benefit from this substitution can be calculated.

6. The assessment locations (2) are ‘spatially joined’ to the alignment (3) and the line side barrier (1) and the distances subtracted to show receptors directly affected and not directly affected by the barrier.
7. The assessment locations (2) are then duplicated for each of the crossover buffers and the affected assessment locations are summarised for each barrier to find the total number of assessment locations for each.

The total number of assessment locations that would benefit from a line side barrier, and also situated inside and outside the LLB crossover distance for each barrier location forms the criterion for scoping: a percentage of receptors that would experience a benefit from LLB substitution.

6.2 Scoping criteria

Around 80% of the affected assessment locations were found to be outside the crossover areas, which indicated that the LLB could be equivalent to line side barriers in a large number of locations. However, the ES mitigation requirements are largely determined by receptors nearest to the line side barriers (ie those who would otherwise be most affected by noise), and as such opportunity areas were initially identified in locations where all of the receptors (100%) would experience an equivalent or beneficial effect. This criterion was developed further in order to account for certain limitations of the study, particularly the cumulative effect of line side barriers (ie the combined benefit of multiple barriers along the alignment, when considered at a given receptor) which was not taken into consideration. This involved a manual process to either include or exclude barriers in which a cumulative beneficial effect would be likely to occur.

Figure 8 shows an example of a location which does not meet the scoping criteria. In this case it is likely that line side barriers would be more appropriate.

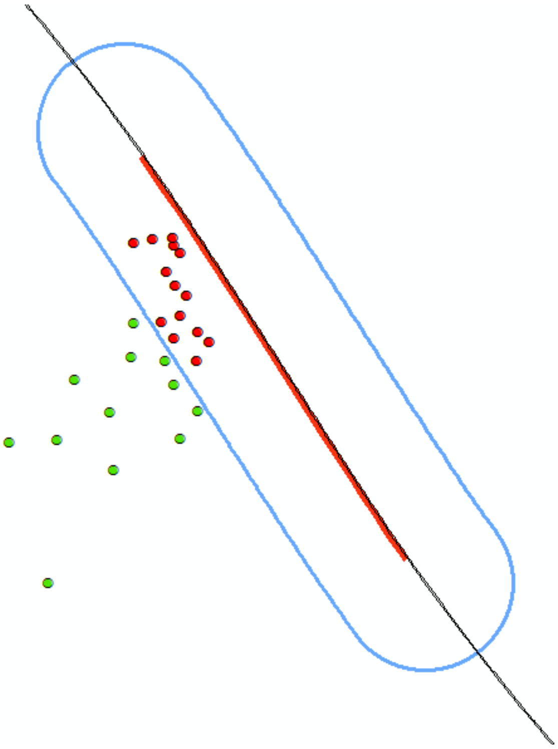

Figure 8: Line side barrier / LLB crossover showing receptors within the crossover area

Figure 9 shows an example of a location which does meet the criteria, as all of the receptors are outside the crossover area. An opportunity area was identified for more detailed modelling of an LLB in this location.

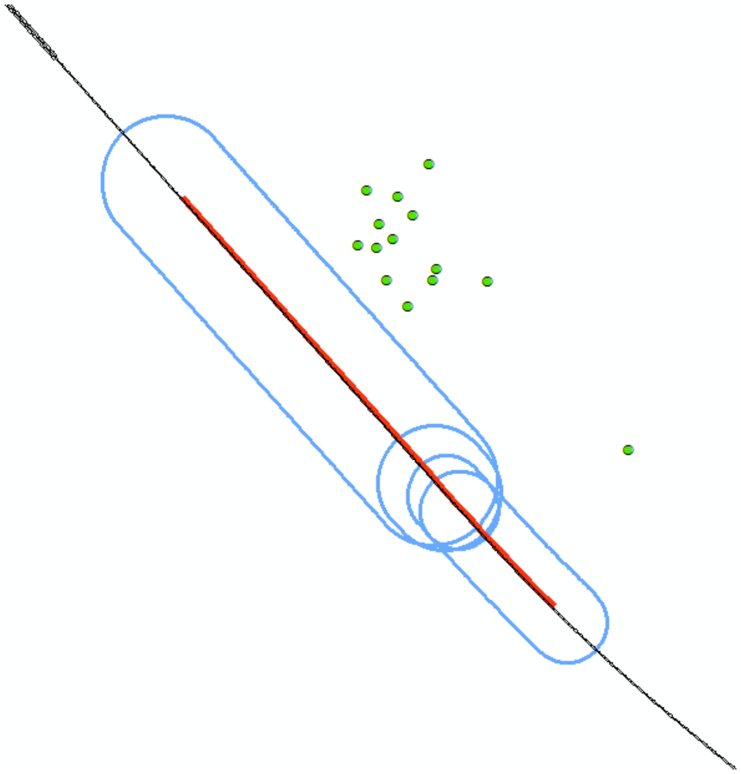

Figure 9: Line side barrier / LLB crossover showing receptors outside the crossover area

5. ASSUMPTIONS AND LIMITATIONS

5.1 Modelling

The following assumptions relate to the performance of LLB and have not been considered during the modelling process:

- The performance of a LLB will be frequency dependant and the spectra of noise sources may vary depending on the speed.
- Turbulence effects due to the passage of the train, and the associated acoustic scattering may degrade the performance of LLB at high speed.
- The barrier may affect the expected source terms, particularly the body aerodynamic noise, which may be increased by turbulent airflow around the LLB.
- Indicative (equal) barrier lengths for both the LLB and line side barriers were used for modelling and comparison. The length of the barrier may alter the LLB crossover distance due to additional corrections for 3D path differences in NoiseMap.

The modelling approach generalised a section of track, and therefore the effects of topography were excluded. Topography will ultimately have a large impact on the effectiveness of LLB. For example, existing screening (in the baseline) may reduce their performance, and taller barriers may be more appropriate. The approach taken is likely to result in a larger number of areas for further study than would otherwise be identified.

5.2 Geospatial analysis

The effects of noise propagation are not considered as a part of the geospatial analysis. GIS serves only to query geographic features based on the provided parameters, in this case the statistical results from noise modelling.

The assessment locations are ‘joined’ to each barrier based on their proximity in order to identify those affected by each barrier. This assumption discounted the cumulative effect of the barriers, which was identified as a factor to consider in the identification of the opportunity areas. A largely manually process was then used to either include or exclude barriers in which a cumulative effect was considered to be likely to occur.

5. CONCLUSIONS

LLB offer a potentially-useful mitigation measure for rail noise, which has not yet been widely-adopted. Their use in conventional speed railways remains relatively limited, and there are very few known examples of applications to high speed rail.

This study has presented a geospatial analysis approach used to identify opportunity areas for LLB substitution for conventional line side fence barriers, for potential application within the UK HS2 high speed rail project. The approach aims to reduce the overall calculation time by highlighting key areas for more detailed modelling. Interrogation of the HS2 prediction methodology and analysis of modelled results provided a set of ‘crossover’ distances at which the LLB was found to become as or more effective than standard line side barriers. It was found that the crossover distance depends on the train speed, the height of the line side barrier being substituted, and the height of the receptor location being considered.

Statistically-derived results were then applied geographically in order to determine opportunity areas along the route. These opportunity areas were selected using criteria developed to ensure that a given proportion of receptors at each substitution location would be expected to benefit from LLB compared conventional line side barriers.

This study indicates the potential effectiveness of LLBs, and demonstrates the usefulness of GIS-based techniques in analysing acoustic performance benefits of noise mitigation measures for a large number of receptors.

6. REFERENCES

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