A SENSITIVITY ANALYSIS OF THE KEY ENVIRONMENTAL NOISE MODELLING DRIVERS BEHIND MONETISING OF HIGHWAYS SCHEMES

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Accurate environmental noise modelling for road schemes may be required to create monetised noise impact values. The value of noise impacts is driven by how a road scheme impacts receptors that are sensitive to road traffic noise. As an example, the value of noise impacts is a key deliverable for a Highways England road scheme at Project Control Framework (PCF) stages 1 and 2 but the assessment must be proportionate as design is at an early stage. There is an inherent trade-off between model fidelity and the simplifying assumptions used to create it – more simplifications produce less accuracy, but model production consumes less resource. Moreover, while a key deliverable is the value of noise impacts, the need often arises for a breakdown of the distribution of noise impacts to groups of receptors. This can lead to an inefficient working style of analysing the results by request. These issues may be solved by either improving the speed of modelling, and thus providing more time for analysis, or by making analysis more efficient. This paper explores the factors that influence the value of noise impacts such as the distribution of receptors around a road scheme and the changes in alignment of typical road schemes. It is based on previously assessed road schemes and examines their population distribution in relation to roads in rural and urban communities. The primary target of this paper is not to replace environmental noise modelling, but to understand the limitations of applying a simplified method of calculating noise levels within the context of a valuation of noise impacts.

Keywords: road, value, environment, modelling, population

1. Introduction

Route options of road schemes may be assessed for their monetary value, which include both benefit and adverse impacts on the economy. One element of monetisation is the noise impact on receptors. While the value of noise impacts rarely swings the compliance of a route option one way or another, it is part of the process of understanding the relative impacts of different options. However, as the calculation of the value of noise impacts of a road scheme is a single value, it is often not clear which areas are most impacted or would not be impacted with provision of mitigation, without further analysis. This analysis relies on understanding the drivers that influence the value of noise impacts.

Second-order elements to the noise level calculation process have been assessed in the context of several schemes. As a result, a simplified calculation methodology has been derived. This simplified calculation methodology has been shown to be applicable, with varying degrees of accuracy, within a range of different contexts. Further research into this area would be required to achieve greater levels of accuracy, as well as unlocking other efficiencies.
2. Background

There are several standards, methodologies, and processes that must be adhered to in order to undertake a monetising noise assessment of typical road scheme. In an attempt to understand the drivers behind the value of noise impact, previously assessed road schemes are examined to understand any behavioural trends. The projects have been chosen to represent the range of schemes which are monetised, paying particular attention to distribution of population and nature of route alignment.

2.1 Calculation of Road Traffic Noise

In the UK the Calculation of Road Traffic Noise (CRTN) [1] is the recognised approach for calculating the level of noise at receptor locations. Methodology in CRTN involves dividing roads into a number of segments and deriving the $L_{A10,18\text{hour}}$ at 10m from the source line, which corresponds to the source strength of each segment. The source line is located 3.5m from the carriageway edge. The $L_{A10,18\text{hour}}$ at 10m is calculated from traffic, road surface, and gradient information. Receptor levels are calculated based on the contribution of each section by applying corrections for distance, ground absorption, and screening from topography and structures such as buildings or barriers, for which the greater of the corrections of either ground absorption or screening is applied.

2.2 Design Manual for Roads and Bridges

While CRTN provides a methodology for calculating noise levels at receptor locations, the Design Manual for Roads and Bridges (DMRB) [2] explains the protocol for applying CRTN to a road scheme and includes a definition of the study area. This calculation protocol involves applying CRTN four times: to the situation where the road is not going to be built (referred to as the do minimum or DM) and to the situation where the road is going to be built (do something or DS), in both the year of opening and a future year (typically fifteen years after the year of opening). The DM and DS are assessed on the basis of having different traffic information and therefore differences in the $L_{A10,18\text{hour}}$ at 10m. Furthermore, there may be changes to road alignment and screening due to the engineering design.

2.3 TAG Unit A3 Environmental Impact Appraisal

TAG Unit A3 Environmental Impact Appraisal (or WebTAG) [3] sets out a methodology for monetising noise impact. This monetising is derived from studies proving the economic impact noise has on annoyance, sleep disturbance, and health effects.

The workbook accompanying the methodology sets out receptor data in a matrix. This shows the number of receptors in a noise exposure category for the DM and DS cases in 3dB bands. For example, if the DM level for a receptor is 55dB and the DS level is 59dB, the receptor would increment the number count corresponding to DM element 54dB to 57dB and DS element 57dB to 60dB. See Table 1 for an example section of a matrix that would be an input to the WebTAG workbook.

There are four matrices which present noise level counts for day and night in the opening year and the future year: night-time levels are typically derived from daytime levels using one of the methods in the TRL study for converting $L_{A10,18\text{hour}}$ to EU noise indices including $L_{\text{night}}$ [4]. The workbook uses these matrices to calculate the so-called Net Present Value of noise impacts which is the sum of the monetised noise impacts for the scheme. Where there are increases in noise from DM to DS, this contributes to a negative net present value of noise impacts and where there are decreases, this contributed to a positive net present value of noise impacts.
Table 1: An example from a WebTAG matrix given with its relative value of noise impacts

<table>
<thead>
<tr>
<th>Without Scheme</th>
<th>With Scheme</th>
<th>Value of noise impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td>54-57</td>
<td>57-60</td>
</tr>
<tr>
<td>54-57</td>
<td>421</td>
<td>36</td>
</tr>
<tr>
<td>57-60</td>
<td>12</td>
<td>308</td>
</tr>
<tr>
<td>60-63</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

2.4 Schemes to assess

Six recently monetised Highways England schemes have been studied to investigate the key drivers behind the value of noise impacts. These schemes were chosen to represent a range of positive and negative impacts, population quantity and distribution, and route alignments. The schemes assessed are shown in Table 2 with relevant statistics to provide context.

Table 2: A list of schemes previously assessed for value of noise impact

<table>
<thead>
<tr>
<th>Value of noise impacts</th>
<th>Scheme 1</th>
<th>Scheme 2</th>
<th>Scheme 3</th>
<th>Scheme 4</th>
<th>Scheme 5</th>
<th>Scheme 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>£1.29m</td>
<td>-£0.21m</td>
<td>-£0.80m</td>
<td>-£11.33m</td>
<td>-£2.08m</td>
<td>£7.20m</td>
</tr>
<tr>
<td>Population Density</td>
<td>791</td>
<td>523</td>
<td>1446</td>
<td>8551</td>
<td>8626</td>
<td>9974</td>
</tr>
<tr>
<td>Diversion Length</td>
<td>3.8km</td>
<td>7.1km</td>
<td>6.6km</td>
<td>3.7km</td>
<td>5.3km</td>
<td>10.4km</td>
</tr>
<tr>
<td>Diversion Distance</td>
<td>0.9km</td>
<td>0.1km</td>
<td>1.8km</td>
<td>(new)</td>
<td>&lt;0.1km</td>
<td>4.4km</td>
</tr>
</tbody>
</table>

3. Driver behind the value of noise impacts

The WebTAG Net Present Value of noise impacts is based on the scalar product of the input matrices with monetising matrices. The input matrices present the distribution of noise levels, showing both numbers of changes in noise bands as well as the absolute level. The monetising matrices are such that the greater the number of changes in noise level band, the greater the monetary value. This is true for both positive and negative changes. Further to this, where there are changes in noise band at higher absolute noise levels, the monetary value is greater than at low absolute noise levels. Therefore, the WebTAG net present value of noise impacts is based on the change in noise level as well as absolute noise level.

3.1 Correlation between changes in noise level and changes in noise band

A monetary value only triggers when there are changes in band and this is not always equal to noise level change. While a DM noise level of 57.0dB and DS noise level of 56.9dB represents a change of 0.1dB and a DM noise level of 59.9dB and DS noise level of 54.0dB represents a change of 5.9dB, as the band boundaries are set at 54dB, 57dB, and 60dB both examples only change by one band and will have the same monetary value. As such, there are statistical phenomena within this model of calculating value of noise impact, therefore the change in noise level at a receptor is proportional to its probability to change noise band, and not equal to the change in noise band. In practice, the quantisation of band ranges is only a factor where there are a small number of receptors all with similar absolute noise levels, or with a small difference between the contribution of noise in DM and DS.

3.2 The causes of change in noise level

An observation of the results gathered from this study is that there is a strong correlation between the change in receptor noise level and the change in L_{A10,18hour} at 10m of its dominant source. Receptor levels were within 0.1dB of the change in L_{A10,18hour} at 10m of the dominant source in 62% of cases, with 80% and 93% within 0.2dB and 0.5dB respectively.
3.3 Drivers behind absolute noise level

According to CRTN, the noise level at each receptor arises from multiple sources, with the appropriate losses applied to each. For the schemes in this study, however, it was noted that most receptors were impacted by only one source: for 77% of receptors, the contribution of the dominant source was within 3dB of the L_{A10,18hour}. This means that the contribution of the dominant source is equal to or greater than the contribution of all other sources combined. As such, the contribution of the L_{A10,18hour} at 10m of the dominant source may be considered a lower bound estimate of the noise level at each receptor. Where receptors are very close to one road, this lower bound estimate is highly accurate.

Losses must be applied to L_{A10,18hour} at 10m of each source based on distance correction, ground absorption, and screening to calculate noise levels at each receptor. In general, for the schemes in this study, screening had a limited impact on noise levels at each receptor. It was found that in rural areas 85% of receptors were within 3dB as those for which screening effects had been ignored and 98% were within 6dB. In urban areas these values decrease to 65% and 88% respectively. The difference is likely to be due to the higher levels of screening that occur in urban environments. As such, the calculation without screening may be considered an upper bound estimate of the noise at each receptor. As with the assessment demonstrating the dominance of one source for the schemes in this study, the accuracy of the upper bound estimate decreases with distance from the dominant source. The correlation was less strong where there were sections that included environmental or engineering design screening.

4. Simplified CRTN methodology

A simplified method for calculation of noise levels is proposed based on the observations in Section 3. As the traditional method is time consuming and gives a single value outcome, there may be multiple benefits from employing an alternative method, such as locating areas within the study area that are most impacted, pertaining to a key driver of the value of noise impacts. This method considers the dominant source for each receptor to be the only source of noise for that receptor and that screening is negligible; and for receptors far from its dominant source, the negative effect on the noise level due to screening is counter-balanced by the positive effect on the noise level due to additional sources. This method for calculating noise levels is investigated within the context of assessing the value of noise impacts using WebTAG methodology and contains receptor distribution simplifications.

4.1 Areas of interest

As illustrated in Section 3.2, the change in noise level at each receptor generally corresponds to the change in L_{A10,18hour} at 10m of the dominant source. Furthermore, as illustrated in Section 3.3 the effects of screening are second-order in most cases. Therefore, the locations at which two sources produce equal noise levels may be calculated using Charts 7 and 8 of CRTN such that:

\[ L_{A10,18hour_1} - L_{A10,18hour_2} = \frac{2}{5} (25 + 13I) \log_{10} \left( \frac{d_1^{'}}{d_2^{'}} \right) \]

(1)

where \( L_{A10,18hour_1} \) and \( L_{A10,18hour_2} \) are L_{A10,18hour} at 10m from two different sources, \( I \) is the proportion of absorbent ground, and \( d_1^{'} \) and \( d_2^{'} \) are the distances from each source line to receiver. This equation has been derived by equating two CRTN equations where all losses have been ignored except distance correction and ground absorption. This equation assumes that the receptor height is significantly smaller than the distance from the source line, which in general is true for situations where more than one dominant source is present. This equation may be applied to generate geographical polygons which would encapsulate the receptors for each source. This exercise must be completed for both the DM and the DS, and if necessary for daytime and night-time, opening year and future year, as they will not necessarily align. Where they do not align the areas of interested must be sub-divided. Due to the proportionality relationship between change in noise level and change in noise band discussed.
in Section 3.1, areas of interest with a difference in $L_{A10,18 \text{hour}}$ at 10m between the DM and DS of less than 0.2 dB and population below 100 were ignored, as these were found to have negligible values of noise impact and were variable to error when attempting to calculate using the simplified method.

### 4.2 Simplified losses

#### 4.2.1 Distance correction

Generally, the distance from a receptor to its dominant source will not change from DM to DS. However, this is not the case where there is a change to the road alignment or there is a new or removed road. See Section 4.2.1.1 and Section 4.2.1.2 for methodology for these approaches.

The distance correction that is applied for each receptor uses the formula $-10 \log_{10}\left(\frac{d'}{13.5}\right)$, where $d'$ is the distance from receptor to source line. While it is a time-consuming exercise to measure the distance of each receptor to its dominant source these distances may be generalised by assuming their distribution. Two methods of simplification have been examined. The first involved measuring the closest and furthest receptor from the source within the area of interest and assuming an even distribution of receptors from the source for the given number of receptors. The second method also involved measuring the closest and furthest receptors from the dominant source, but included an intermediate point at which the sets of receptors either side were given different distributions. The location of the intermediate point depended on the context of the area of interest and was arbitrarily chosen provided there was an obvious change in distribution closer and further away from that point. The distance corrections were calculated using both methods and compared with the actual distance corrections. For the schemes in this study it was found that the first method provided distance corrections within 1dB of those using the actual method in 24% of cases and within 3dB in 78% of cases. The second method was ostensibly more accurate with 86% within 1dB and 99% within 3dB.

#### 4.2.1.1 Alignment change

The generalising methodology cannot be used for changes in road alignment because there are two distances from each receptor to the dominant source. In this case a distance must be measured from each receptor to both the DM road and the DS road. Where there are many receptors it is possible to subdivide the area of interest and generalise the distance from those receptors to both the DM and DS alignments.

#### 4.2.1.2 New roads

Where areas of interest for the DM and DS do not align, each border of the overlapping areas marks a subdivided area of interest. This applies where a noise source is new or has been removed. In situations where the area of interest creates an unmanageable quantity of sub-divided areas of interest, a general noise level may be applied. The $L_{A10,18 \text{hour}}$ is initially assumed to be 50dB where source data is otherwise unavailable. For Scheme 4, the only example project where a new road was introduced, 64% of receptors in the scheme road area of interest were within ±3dB of 50dB in the DM and 93% were within ±6dB.

#### 4.2.2 Ground absorption

Ground absorption corrections are applied for each receptor using the formula $5.2I \log_{10}\left(\frac{6H-1.5}{d+3.5}\right)$ from CRTN where $I$ is the proportion of absorbent ground, $H$ is the height of receptor and $d$ is the horizontal distance from the edge of the nearside carriageway. This may be applied in the same way as the distance correction as ground absorption is a function of distance. As there is no screening, ground absorption is applied in all cases.
5. Results and analysis

The results presented in Table 3 show the value of noise impacts for the schemes in this study using the modelled results as well as the simplified method. These are compared using the difference between value of noise impacts using each of the methods, including a breakdown for existing roads and new roads. The simplified method has been applied on the assumption that the length of the closest road segment of the dominant source is infinitely long and therefore the angle of view is maximum. As such any effects due to road gradient are considered negligible.

Table 3: A comparison between the two methods of calculating value of noise impacts. N.B. The first two rows compare the value of noise impacts from the two methods. The third row gives the difference between the two methods. Rows four, five, and six are the same format as the first three rows but just for existing roads. Rows seven, eight, and nine are the same again but for roads with a route alignment change.

<table>
<thead>
<tr>
<th></th>
<th>Scheme 1</th>
<th>Scheme 2</th>
<th>Scheme 3</th>
<th>Scheme 4</th>
<th>Scheme 5</th>
<th>Scheme 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelled value of noise impacts</td>
<td>£1.29m</td>
<td>-£0.21m</td>
<td>-£0.80m</td>
<td>-£11.33m</td>
<td>-£4.25m</td>
<td>£7.20m</td>
</tr>
<tr>
<td>Simplified value of noise impacts</td>
<td>£1.33m</td>
<td>-£0.19m</td>
<td>-£1.22m</td>
<td>-£17.03m</td>
<td>-£9.20m</td>
<td>£9.44m</td>
</tr>
<tr>
<td>Difference</td>
<td>£0.04m</td>
<td>£0.02m</td>
<td>£0.43m</td>
<td>£5.70m</td>
<td>£4.94m</td>
<td>£2.25m</td>
</tr>
<tr>
<td>Existing roads modelled</td>
<td>£0.69m</td>
<td>-£0.29m</td>
<td>-£0.20m</td>
<td>-£6.03m</td>
<td>£0.21m</td>
<td>£0.28m</td>
</tr>
<tr>
<td>Existing roads simplified</td>
<td>£0.69m</td>
<td>-£0.26m</td>
<td>-£0.24m</td>
<td>-£6.90m</td>
<td>-£0.13m</td>
<td>£0.01m</td>
</tr>
<tr>
<td>Difference</td>
<td>£0.00m</td>
<td>£0.03m</td>
<td>£0.04m</td>
<td>£0.87m</td>
<td>£0.35m</td>
<td>£0.27m</td>
</tr>
<tr>
<td>New roads modelled</td>
<td>£0.60m</td>
<td>£0.07m</td>
<td>-£0.55m</td>
<td>-£4.43m</td>
<td>-£4.46m</td>
<td>£6.93m</td>
</tr>
<tr>
<td>New roads simplified</td>
<td>£0.64m</td>
<td>£0.06m</td>
<td>-£1.02m</td>
<td>-£11.00m</td>
<td>-£9.06m</td>
<td>£9.43m</td>
</tr>
<tr>
<td>Difference</td>
<td>£0.04m</td>
<td>£0.01m</td>
<td>£0.47m</td>
<td>£6.56m</td>
<td>£4.60m</td>
<td>£2.50m</td>
</tr>
</tbody>
</table>

The results show that in some cases the simplified methodology produces similar results to the fully modelled methodology, but there are some situations where the simplified method is inaccurate. The various reasons for this have been explored as well as a list of possible further studies which may improve the simplified method.

5.1 Existing roads

Where the impact due to existing roads has been monetised using the simplified method, the results are aligned with the modelled method. For each of the six schemes, the value given from the simplified method is within £1m of the modelled results for existing roads. For all areas of interest explored for all schemes, the value given by the simplified method results were of the same sign as the modelled results.

For existing roads, the range of population in areas of interest was 18 to 2,293 receptors. The difference between the modelled value of noise impacts and the simplified value of noise impacts ranged from £4.63 to £1,027.91 per receptor. The mean difference between the two methods was £227.55 per receptor, with no strong correlations to source strength, change from DM to DS, or population density, but generally error decreased with population. This is because for the cases with higher population the population distribution generalisation was more accurate. Furthermore, the statistical phenomena of the probability of band change featured less strongly. This value represents an 11% mean difference between the simplified method and modelled method for roads where there was no change in alignment. This is represented in the Table 3 when comparing the difference between the two methods with the modelled value of noise impacts for existing roads for Schemes 1 to 4. Schemes 5 and 6 however show a greater error between the value of noise impacts for existing roads using the two methods. This is because there were several areas of interest with a low number
of receptors and a low change in road traffic. Therefore, the simplified method was not carried out with the assumption that the effect on the value of noise impact would be negligible. While this is the case when comparing the values of these additional areas of interest (£0.38m and £0.17m for Schemes 5 and 6 respectively) with the value of noise impact for the schemes holistically, this creates results for existing roads which are less accurate. When these areas of interest are discounted from the modelled value of noise impacts of existing roads, the differences between the two methods reduces for each scheme to £0.03m and £0.10m respectively.

For all schemes with the exception of Scheme 4, the value of noise impacts from existing roads was below £1m. This is because each of these schemes included increases and decrease in traffic on the existing road network resulting in a cancellation between the positive and negative impacts, whereas Scheme 4 generally included a greater proportion of increases within the existing road network. Overall, 48% of simplified calculations underestimated the value of the noise impact, and 52% overestimated it. The fact that the monetary value was not more often overestimated confirms that for these cases the assumption that the effects of additional sources and screening cancelled each other, or were negligible. This is confirmed by the lack of correlation between maximum distance of receptor from dominant source and difference between simplified results and modelled results.

5.2 Changes in alignment and screening

While the simplified method for calculating NPV of noise impacts was accurate for existing roads, it was less so for situations where there were changes in alignment, new roads, or changes to screening. In general, the simplified methodology demonstrated the same level of accuracy where there was an alignment change as for where the road alignment is unchanged. However, changes to the engineering design and screening effects from buildings caused greater differences between the two methods.

5.2.1 Screening within engineering design

Schemes 2 and 5 were schemes to improve the existing route and were therefore online improvements. Scheme 3 was divided into two areas of interest: an online section where the alignment of the route had a minimal change, and an offline route which, as specified in Table 2 deviated from the existing road by 1.8km. For the online section of Scheme 3 (Scheme 3 online) and Scheme 5, the engineering design included screening such as lowering the route into a cutting and grade separated junctions. While the changes in alignment and therefore changes in distance correction were minimal and accounted for, the calculation of value of noise impact using the simplified method calculated noise levels that were £1,241.07 and £1,487.14 per receptor overestimated for Scheme 3 online and Scheme 5 respectively. Furthermore, for Scheme 2, another scheme with an online improvement, the error was £127.19 per receptor. The difference between Scheme 2 and Scheme 3 online and Scheme 5 is that Scheme 2 had minimal engineering changes. As the only variable within the modelled calculation method that had changed was the impact due to screening in the DS, this accounts for the overestimation in the simplified method. This shows an example of a situation where the changes in the contribution of other noise sources at receptors are negligible but the changes in screening are non-negligible. As a result, a method for generalising or simplifying screening is required in order to use the simplified method to a higher degree of accuracy where the engineering design includes changes to screening.

5.2.2 Building screening for new roads

The effects of screening from the existing topography and buildings have not given rise to significant differences between the simplified method and the modelled method. However, in situations where there are new roads, this is not the case.

While strictly Scheme 6 does not have a new road in the same way that Scheme 4 does, the new alignment is 4.4km from the existing route alignment, so for receptors in close proximity to the new road, the existing route was not the dominant source for the DM. However, the DM was calculated
in different ways for Schemes 4 and 6. For Scheme 4, the sub-division of the areas of interest methodology created an unmanageable number of areas of interest and so 50dB method discussed in Section 4.2.1.2 was used, however for Scheme 6 the subdivision was applicable. As such, both calculated a set of generalised DM noise levels that demonstrated high levels of accuracy. However, both of these areas of interest overestimated the DS using the simplified method, producing values of noise impacts that were £7,618.27 and £2,401.75 per sensitive receptor overestimated for Schemes 4 and 6 respectively. Both include screening due to the engineering design and therefore overestimates due to phenomena discussed in Section 5.2.1 are present. Furthermore, there is additional screening from buildings and topography which did not impact the DM situation, as this was either generalised or calculated from local roads. The two reasons that Scheme 4 was overestimated to a greater extent than Scheme 6 are that Scheme 4 has a greater population density within the study area of Scheme 4, therefore greater screening from buildings, and the contribution of the dominant source was greater for Scheme 4 than Scheme 6.

5.3 Additional study

This paper has examined the ways in which simple calculations may be used to estimate the value of noise impacts of a scheme. While this method has given results to a reasonable degree of accuracy there are areas in which it may be improved.

5.3.1 Generalised screening for engineering design

For the simplified method used in this paper screening from engineering design has been ignored. The way in which screening could be applied to the simplified method is by breaking the screening down into components and generalising the impact. This would involve increasing the number of areas of interest for areas of engineering change. There is a trade-off between increasing resolution and time spent generating a simplified model and so a methodology that includes the effects of screening must be proportionate. This may also be applied when factoring mitigation into engineering design.

5.3.2 Generalised urban screening

In the same way that the lack of consideration for engineering design shows inaccuracies within the simplified method, screening from buildings in highly populated areas must also make use of generalisation in order to be considered. It is anticipated that a combination of hypothetical and real-world situations will need to be assessed before generalised rules are applicable.

6. Conclusions

An investigation has been carried out to assess a simplification of the method to determine the value of noise impacts using Highways England road schemes as examples. The simplified method for deriving noise levels at sensitive receptors discounted the effects of screening and was used to generate the value of noise impacts. It was accurate for existing roads, however, for roads with engineering changes the method was less accurate. If a method is derived that incorporates screening in a general way then this methodology may be more accurate.

REFERENCES