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How should acoustics adapt to meet future demands?

Calculation of overall community noise impact due to a change in noise source emissions

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ABSTRACT

When the acoustic amenity of a region changes, either by the addition or modification of a transportation noise source, the overall community noise impact depends on the number of affected receivers as well as the change in noise level at each receiver. This overall impact could be quantified as an arithmetic average of the change in noise level at the affected receiver. However, a simple arithmetic average does not adequately consider the relative significance of the change at the receivers which experience substantial increase or decrease of noise level. For instance, a change of 2 dB(A) is usually regarded as being a barely perceptible change for environmental noise and a change of 10 dB(A) is usually regarded as approximately doubling or halving the subjective sound loudness. A method is proposed whereby a change in noise amenity is quantified in terms of the significance of the change in noise level as a function of the number of affected receivers and the severity to which they are affected. The proposed method is particularly useful in cases where the noise impact from several alternative proposed transportation route options need to be compared as a single-number rating in terms of overall noise impact upon the community. The result would be useful for input into a Multi-Criteria Decision Matrix [MCDM]. Two methods are presented for comparing the overall community noise impact from alternative transportation route options.

INTRODUCTION

When considering the impact on a community from a change in a transportation noise source, the total impact needs to be determined in a way that allows consideration of the fact that some receivers will be more affected by the change than others. A simple arithmetic average of the change in noise level at each receiver does not adequately take into account the difference in the subjective response to the noise impact at the affected receivers. This paper presents two versions of an alternative calculation method to arrive at a single-number rating for the impact from a change in a transportation noise source, both of which inherently consider the importance of receivers that experience a significant change in noise level.

Basis for an alternative approach

The overall impact on a community from a change in a transportation noise source is not well described by a simple arithmetic average of the change in noise levels. Rather, it would be more appropriate to quantify the overall noise impact on a community in terms of an alternative unit of measurement, for instance the change in subjective sound loudness or the change in the acoustic energy.

The general approach followed in all of the methods is to sum the noise impacts at individual receivers and divide them by the number of receivers.

When the ‘impact’ is defined as simply a change in noise level, the overall community impact is simply an arithmetic mean of the change in noise level.

However, by altering the definition of ‘impact’ in the calculation, a different result is obtained for the overall effect on the community. When the ‘impact’ is defined as a change in sound energy, or as a change in sound loudness, the calculation of overall community noise impact effectively applies a weighting penalty for those receivers which experience large changes in noise level.

The two proposed methods are based on calculating the average change in sound energy or loudness, rather than the change in sound pressure level. The methods can therefore be regarded as the ‘acoustic average’ of noise impact rather than the numerical average of a change in sound pressure levels.

NEED FOR THE METHOD

It is considered that this method will be useful during the early phases of a project, such as when undertaking the noise component of a route options comparison study. For instance, the result would be a useful means to compare the community noise impact of two or more alternative routes for a new or upgraded road or railway, for input of the noise component into a Multi-Criteria Decision Matrix.

A method such as described in this paper is required because a simple arithmetic average does not intrinsically provide information regarding the receivers at either end of the distribution table. While other statistical indicators such as the Standard Deviation would provide additional information, this data is questionable since it can be argued that values on a decibel scale are not amenable to numerical analysis as though they were scalars. For instance, a change in received noise level of 10 dBA is not 5 times as significant as a change of 2 dBA, nor is it 2 times as significant as a change of 5 dBA, and yet a scalar analysis would regard it as being so.

Comparatively, a change in 10 decibels represents a consistent change of 10 times the acoustic energy,or an approximate doubling or halving of the subjective sound loudness, no matter the absolute sound pressure levels before and after the change.

The proposed methods therefore enable the quantification of the noise impact from the distribution of the change in noise levels throughout a community, which an average of the basic change in noise level at individual receivers cannot give.

EXAMPLE TYPICAL SCENARIO

A need has been identified for the upgrading of a road corridor through a residential area. The multi-criteria assessment requires that the selection of the preferred route must consider the noise impact on the community as one of the assessment categories. Two new alignments are proposed. These two alignments are being compared against the “future existing” road, which yields the comparative baseline of future noise levels in the area if the road upgrade did not take place. The noise impact of each of the proposed new alignment options need to be compared against the future-existing road.

The noise levels from the future-existing road and both alignment options can be predicted using a method such as CoRTN, and be presented as a noise level at each receiver.

DISCUSSION OF LINEAR AVERAGE METHOD

Typical approach – Linear (arithmetic average)

The most straight-forward approach to calculate the overall community noise impact for a route option would be to sum the change in noise levels and divide by the number of receivers as shown in eq. (1).

$$\mathrm{CNI}_{tot} = \frac{\sum_{n=1}^{N}\left(L_{n_k} - L_{n_{FE}}\right)}{N} \qquad (1)$$

where:
N is the total number of receivers
CNI_{tot} is the total Community Noise Impact
L_{nk} is the noise level at the n^{th} individual receiver from route option k.
L_{nFE} is the noise level at the n^{th} receiver from the “Future Existing” noise source.

This is a straight arithmetic average of the change in noise level in decibels.

However, this method is flawed, since the decibel unit of measurement of sound pressure levels is not suitable for analysis using the same approach as would be suitable for scalar units of measurement. For instance, a change in noise level from 60 to 66 dB does not represent a 10% increase in the subjective importance of this change in noise level, yet the arithmetic averaging procedure intrinsically makes this assumption.

PROPOSED METHODS

The proposed methods have been designed to more accurately represent the change in sound quality with an approriately scaled unit of measurement representing the change in sound quantity.

Method 1 - Energy

One option to describe the change in noise impact would be to consider the change in acoustic energy at each receiver.

We convert the change in noise level to an energy basis for each receiver, calculate the average of these values, and then convert back to a scalar of comparable magnitude to the linear method for comparison purposes. The general form is shown below:

$$CNI_{tot} = 10\times\log_{10}\left(\sum_{n=1}^{N}\left(\frac{10^{\frac{\Delta L_n}{10}}-1}{N}\right)+1\right) \qquad (2)$$

Where

DL_n is the change in noise level at the n^{th} receiver

N is the number of receivers

CNI_{tot} is the community noise impact for a cluster of receivers

Method 2 - Loudness

It is known that a change in level of 10dB is perceived as an approximate doubling of the loudness. Using this principle a similar equation is presented for calculating the impact on a loudness basis:

$$CNI_{tot} = 10\times\log_{2}\left(\sum_{n=1}^{N}\left(\frac{2^{\frac{\Delta L_n}{10}}-1}{N}\right)+1\right) \qquad (3)$$

Where

ΔL_n is the change in noise level at the n^{th} receiver

N is the number of receivers

CNI_{tot} is the community noise impact for a cluster of receivers

However, in order to balance the averaging for both positive and negative values, it is necessary to adopt a parameterised approach.

We need an increase in noise levels to result in a positive energy ratio, and a decrease in noise levels to be quantified as a negative value.

That is, an increase of 10 times the acoustic energy needs to give the same scalar value as a decrease to a value 1/10th of the acoustic energy, but with the opposite sign, so that the averaging calculation is equally balanced for both positive and negative values of the change in noise level.

For the purposes of explanation we will coin the term *Community Noise Impact* CNI_n. This is the part of the equation which is the numerator within the sum.

The parameterised section of the energy method equation is shown below in equation 4:

$$
\begin{aligned}
CNI_n &= \left(10^{\Delta L_n/10}-1\right), && \Delta L_n > 0\\
&= 0, && \Delta L_n = 0\\
&= -\left(10^{-\Delta L_n/10}-1\right), && \Delta L_n < 0
\end{aligned}
\tag{4}
$$

The parameterised section of the loudness method equation is shown below in equation 5:

$$
\begin{aligned}
CNI_n &= \left(2^{\Delta L_n/10}-1\right), && \Delta L_n > 0\\
&= 0, && \Delta L_n = 0\\
&= -\left(2^{-\Delta L_n/10}-1\right), && \Delta L_n < 0
\end{aligned}
\tag{5}
$$

Where:

ΔL_n = the change in noise level at receiver *n*

CNI$_n$ = Community Noise Index at receiver *n*

Parameterised approach

As discussed above, since it is important to ensure that a beneficial change in impact is regarded with equal weighting as a detrimental change in impact, it is necessary to adopt a parameterised approach.

Adopting a parameterised approach ensures that the magnitude of an increase the noise impact is weighted equally with a decrease of the same magnitude, whether the chosen quantity is the acoustic energy or the subjective loudness.

Without adopting a parameterised approach, the relationship between the change in noise level at a particular receiver and the Community Noise Index [CNI$_n$] is shown in Figure 1.

As shown in Figure 1, the exponential terms in eqs. (2) and (3) result in asymmetrical factors for an increase or a decrease in noise level.

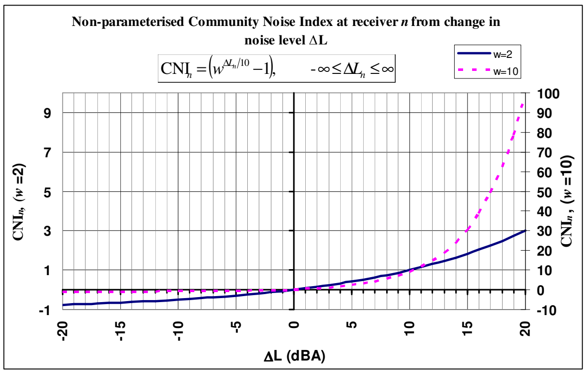

Figure 1: **Non-parameterised form of Community Noise Index CNI$_n$**

However, by extracting the negative sign to outside the parenthesis when the change in noise level is negative, an increase or decrease of noise level of the same decibel value results in a CNI$_n$ value of equal magnitude but opposite sign.

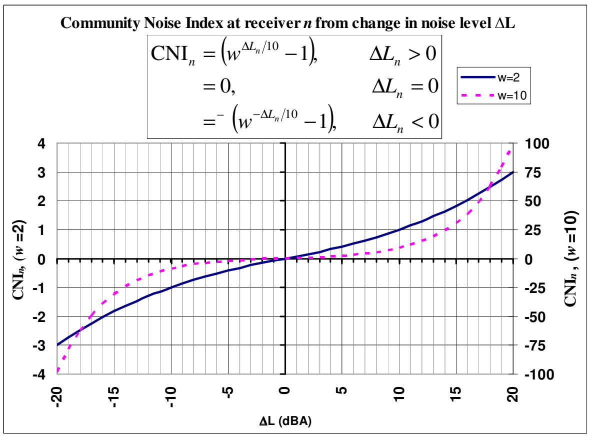

Figure 2: **Parameterised form of Community Noise Index CNI$_n$**

The second area which needs parameterisation is the conversion back into a comparable scalar after the averaging calculation. This involves taking 10 times the logarithm (either base 10 or 2 for the respective methods) of the average. We are unable to take the logarithm of a negative number, so we will remove the sign from the average and apply it outside the logarithm.

For the Energy method:

$$
\begin{aligned}
CNI_{tot} &= 10\times\log_{10}\left(CNI_{avg}+1\right), && \mathrm{CNI}_{avg} > 0\\
&= 0, && \mathrm{CNI}_{avg} = 0\\
&= -10\times\log_{10}\left(-\left(CNI_{avg}-1\right)\right), && \mathrm{CNI}_{avg} < 0
\end{aligned}
\tag{6}
$$

For the Loudness method:

$$
\begin{aligned}
CNI_{tot} &= 10\times\log_{2}\left(CNI_{avg}+1\right), && \mathrm{CNI}_{avg} > 0\\
&= 0, && \mathrm{CNI}_{avg} = 0\\
&= -10\times\log_{2}\left(-\left(CNI_{avg}-1\right)\right), && \mathrm{CNI}_{avg} < 0
\end{aligned}
\tag{7}
$$

COMPARISON OF THE METHODS

The robustness of the methods can be tested and their relative effectiveness can be compared by three types of examples, which also provide validation of the methods:

- Symmetrical distribution of change in noise levels, (Example 1)
- Identical change in noise levels at all receivers, (Example 2)
- Asymmetrical distribution of change in noise levels (Examples 3 and 4)

A comparison of the methods shows the following generalisations.

Example 1: Symmetrical distribution of change in noise level

Where there is no change in noise level at all receivers, as shown in Figure 3, all 3 methods produce the same results as expected, as shown in Table 1.

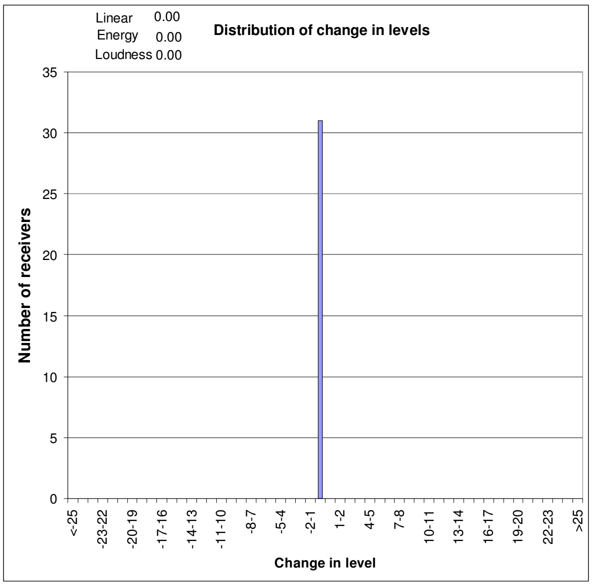

Figure 3: **No change in noise level**

Table 1 – Symmetrical distribution result

Method	CNI_{tot}
Linear	0.00
Energy	0.00
Loudness	0.00

Example 2: Identical change in noise level at all receivers

Where the change in noise level at all receivers is predicted to be identical as shown in Figure 4, all three methods predict the same result, again as expected, as shown in Table 2. This example is representative of a change in the sound power level of the noise source, but no change in the noise source's location.

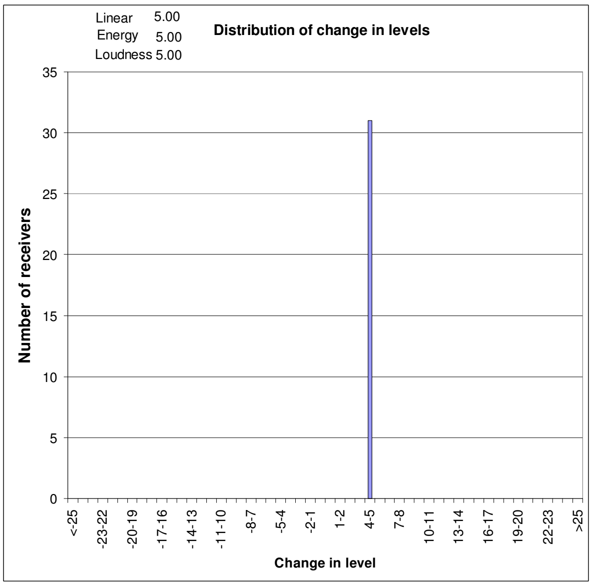

Figure 4: **Identical change in noise level at all receivers**

Table 2: Identical change at all receivers - result

Method	CNI_{tot}
Linear	5.00
Energy	5.00
Loudness	5.00

Example 3: Asymmetrical distribution of change in noise levels

Where the distribution of the change in noise level is asymmentrical either side of 0 as shown in Figure 5, the methods produce different results, as shown in Table 3.

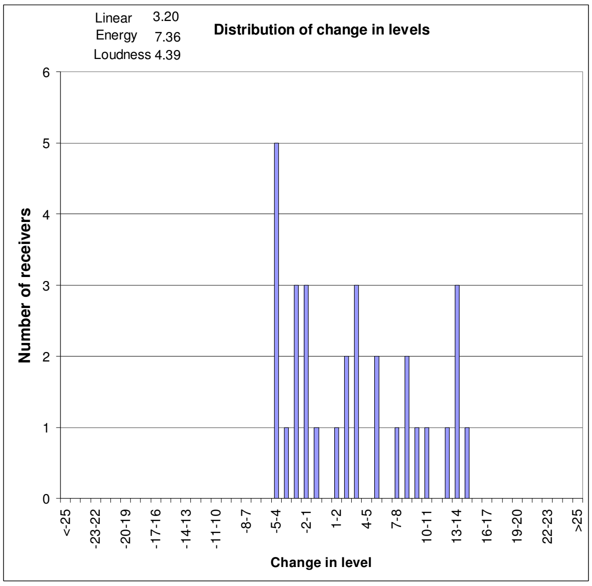

Figure 5: **Asymmetrical distribution of change in noise levels**

Table 3: Asymmetrical distribution of change - result

Method	CNI_{tot}
Linear	3.20
Energy	7.36
Loudness	4.39

As shown in Table 3, both the Energy method and the Loudness method yield results greater than the Linear (arithmetic average) method. For the distribution shown in Example 3, the Energy method produced a higher result than the Loudness method.

Example 4: Many small negative and one large positive

When the majority of the community experiences a small reduction in noise level, but a small number of receivers experience a large increase in noise level as shown in Figure 6, the three methods yield substantially different results, as shown in Table 4. Example 4 is calculated based on 30 receivers having a reduction of 1dB and 1 receiver having an increase of 10dB.

Table 3: Many small negative and one large positive - result

Method	CNI_{tot}
Linear	-0.32
Energy	5.96
Loudness	0.39

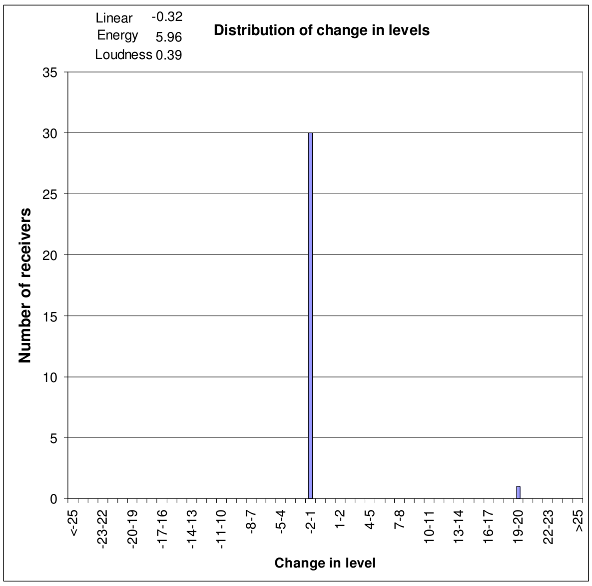

Figure 6: **Many small negative and one large positive**

BENEFIT OF THE METHOD

As shown in Example 4, where the distribution varies widely, the Energy Method highlights receivers that experience a large change in noise level. The linear method shows an overall community noise impact reduction of -0.32 the Loudness method shows an overall community noise impact increase of 0.39 and the Energy method shows an overall community noise impact increase of 5.96.

In this way, the Energy method and the Loudness method both incorporate an allowance for the large impact experienced by a single receiver even though the majority of the community experienced a small reduction in noise level. As shown, the Energy method has a higher sensitivity than the Loudness method.

Example Scenario

The following example shows the change in noise levels for two alignments against the future existing case for a proposed road corridor. The arithmetic average is the same for both cases however, the Energy and Loudness methods both show different results.

Figures 6 and 7 show the change in noise levels for 100 receivers along the two alignments when compared with the future existing alignment, including consideration of background noise.

The results of the methods are compiled in Table 3.

Table 3: Alignment 1 vs Alignment 2

	Alignment 1	Alignment 2
Linear	0.2	0.2
Energy	-0.28	0.34
Loudness	0.02	0.03

In this case the linear averaging system shows no difference between the alignments. The Energy method shows that the selection of Alignment 1 will reduce the noise impact on the community. The Loudness method shows that Alignment 1 will have lower impact on the community than Alignment 2.

The benefit shown in this example is that the Energy method reflects the greater impact on receivers that experience a greater change in noise level, compared with the linear average method. The Loudness method also shows a higher sensitivity than the linear average method towards receivers that experience a greater change in noise level, but not to the same extent as the Energy method.

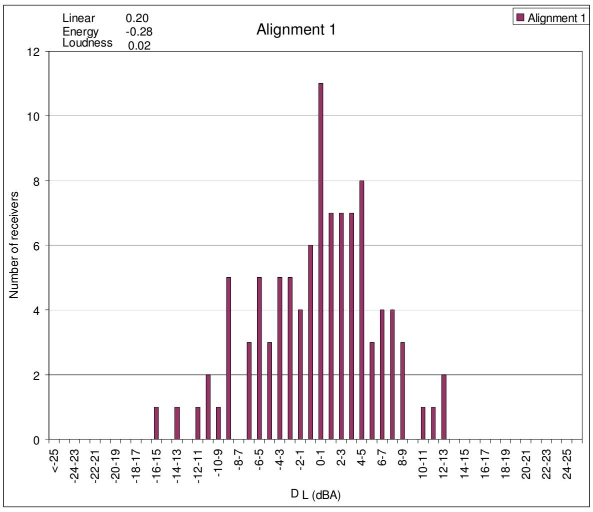

Figure 6: **Alignment 1**

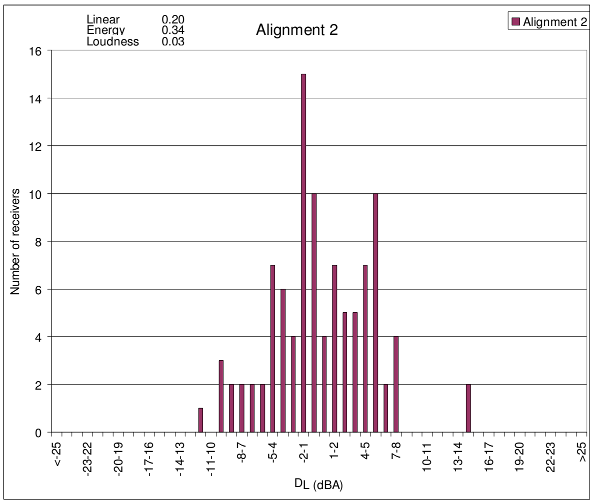

Figure 7: **Alignment 2**

The Energy method shows that the community will benefit from a net average reduction in sound energy from alignment 1, but a net average increase in sound energy from alignment 2.

The Loudness method shows that both alignments will result in a net average increase in sound loudness, with alignment 1 having lesser impact than alignment 2.

Both proposed methods show better sensitivity towards receivers that are subject to a greater change in noise levels than a simple arithmetic average of change in noise levels would indicate. It is this sensitivity which is the greatest benefit of the methods for use in a multi-criteria decision matrix.

BACKGROUND NOISE

When implementing this method in practice, it is considered essential that background noise be included in the calculations of the future noise levels.

Outputs from noise prediction software are typically provided in terms of component noise level, and generally do not take into account the background noise levels at the receiver. This limitation needs to be addressed in order to correctly predict the change in noise levels at receivers. When undertaking the procedure described in this paper it is considered important that background noise levels be incorporated in the predicted noise levels.

The background noise level is required to be added logarithmically to the predicted noise level, otherwise the result will be an over prediction of the benefit of a reduction in component noise level.

This is because: if the calculated noise levels of a route option are less than the future existing and are close to or lower than the background noise (which is normally considered to be the measured L_{A90}), then the acoustic amenity benefit obtained from the component noise level reduction is not as great as the numerical difference between the future existing and the route option's component noise levels.

Therefore, inclusion of background noise consideration will provide a more comprehensive understanding of the proposed noise environment.

Example:

The background noise level at a receiver is 45dB(A), the noise calculated for a route option is 40dB(A) and the noise level from the future existing road is 50dB(A). Without consideration for the background noise level, the change in component noise level would be 10dB(A). However, we know that the noise from the route option and the background noise will be combined giving a total noise level for the option of 46.2 dB(A) which is only a benefit of 3.8dB(A), not 10dB(A).

REFERENCES

Harris, CM 1998, *Handbook of Acoustical Measurements and Noise Control*, Acoustical Society of America, Melville, NY

Beranek LL & Ver IL 1992, *Noise and Vibration Control Engineering*, John Wiley & Sons, Inc

Bies DA & Hansen CH 2003, *Engineering Noise Control*, Spon Press, New York, NY