Comparison of rail noise modelling with CadnaA & SoundPLAN

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ABSTRACT

Railway noise in Australia is commonly modelled using the SoundPLAN software package and the Kilde Report 130 calculation methodology. This paper investigates an alternative approach for rail noise modelling using the CadnaA software package and the more recent Nordic Prediction Method 1996. When modelling changes in source noise levels in CadnaA, it is necessary to create separate rail objects for each change. Modelling situations with source corrections due to changing train speeds, curves and track corrections requires different approaches. Processes for modelling rail noise in CadnaA are developed in this paper and the results compared to noise levels calculated using SoundPLAN and Kilde Rep 130. The comparison between the two models demonstrates that CadnaA produces results that are in close agreement with a SoundPLAN - Kilde Rep 130 model. It was found that in some situations CadnaA is capable of modelling noise levels more accurately than SoundPLAN.

1 INTRODUCTION

The Nordic Rail Traffic Noise prediction method: Kilde Report 130 was released in 1984 for use in Scandinavian countries. This methodology has been superseded by the Nordic Prediction Method (NMT) 1996 and Nord 2000. These methodologies allow for the calculation of both L_{eq} and L_{max} noise descriptors which makes them suitable for use in Australia where an assessment of both noise parameters is required.

It has been demonstrated that the more detailed calculation methods of NMT 1996 and Nord 2000 produce results with greater propagation losses than the more simplistic and conservative approach used in Kilde Rep 130 (Deivasigamani and White, 2016; De Lisle and Burgemeister, 2014). Notwithstanding this, Kilde Rep 130 remains the most commonly used methodology for the prediction of rail noise levels in Australia.

Both the Kilde Rep 130 and NMT 1996 methods are available for rail noise modelling in the SoundPLAN software package. Of the Nordic rail prediction methodologies, only NMT 1996 is implemented in CadnaA. This study compares the results of a CadnaA – NMT 1996 rail noise model with a SoundPLAN - Kilde Rep 130 model. Due to differences in how rail objects are implemented in the two software programs, new approaches are required for modelling in CadnaA. Techniques for applying source corrections due to changing train speeds, curves and track corrections are investigated.

This study compared noise emission level differences in the near field to minimise the effect the different propagation algorithms used by Kilde Rep 130 and NMT 1996 had on the results. All results were produced using flat, hard ground models and do not consider other propagation effects such as uneven terrain, shielding and reflections.

2 RAIL NOISE PREDICTION METHODOLOGIES

Both the Kilde Rep 130 and NMT 1996 prediction methods can be used to calculate the equivalent noise level (L_{eq}) from rail traffic over a defined period and the maximum passby noise level (L_{max}) of individual trains.

In the Kilde Rep 130 method, the formulae for the equivalent noise level for a 24-hour period ($L_{eq,24h}$) and the maximum noise level (L_{max}) are as follows:

$$L_{eq,24h} = 50 + 10\log_{10}\left(\frac{l_t.n}{1000}\right) - 10\log_{10}\left(\frac{a}{100}\right) + 23.51\log_{10}\left(\frac{v}{80}\right) + \Delta L_{type-L_{eq}} + \Delta L_{corrections} \quad (1)$$

$$L_{max} = 10\log_{10}\left(10^{\frac{\Delta L_1}{10}} + 10^{\frac{\Delta L_2}{10}}\right) + 30.51\log_{10}\left(\frac{v}{80}\right) + \Delta L_{type-L_{max}} + \Delta L_{corrections} \quad (2)$$

$$L_1 = 92 - 10\log_{10}\left(\frac{a}{10}\right) + 10\log_{10}\left(\frac{\tan^{-1}\left(\frac{l_t}{2a}\right)}{1.37}\right) \quad (3)$$

$$L_2 = 50 - 20\log_{10}\left(\frac{a}{10}\right) + \left(44 - \frac{100}{\sqrt{l_t}}\right)\left(\frac{3}{\sqrt{a}}\right) \quad (4)$$

Where:

l_t = train length, m
n = number of trains in a 24-hour period
a = perpendicular distance from the track centreline, m
v = train speed, km/h

The Kilde Rep 130 noise emission calculations are based on reference noise levels at 100 m for L_{eq} and 10 m for L_{max}. ΔL_{type} corrections are then applied to calibrate the source noise levels of different train types. Other corrections are also applied for factors such as the ground surface, screening and rail roughness. The maximum noise level is comprised of two components, a point noise source for the locomotive (L_1) and a line noise source for the whole train set (L_2). The noise source is located along the track centreline, 0.5 m above the top of rail height.

In the NMT 1996 method, formulae are provided to calculate the sound power radiated per meter of track for the equivalent noise level (L_{Wo}) and the maximum noise level (L_{Wt}) as follows:

$$L_{Wo} = a.log_{10}\left(\frac{v}{100}\right) + 10\log_{10}(l_t.n) + b + \Delta L_{corrections} \quad (5)$$

$$L_{Wt} = a.log_{10}\left(\frac{v}{100}\right) + 10\log_{10}(v) + 43.8 + b + \Delta L_{corrections} \quad (6)$$

Where:

a, b = are constant values in octave bands for a given train type

Unlike Kilde Rep 130, the NMT 1996 method calculates noise levels in octave bands between 63 Hz and 4 kHz. The noise levels in octave bands are A-weighted and summed to produce an overall result. Corrections are applied to L_{eq} and L_{max} noise levels, including propagation effects such as divergence, air absorption and the ground effect. There are multiple noise source heights between 0.5 m and 2 m which are frequency dependent. The NMT 1996 makes a distinction between L_{maxM} (prediction method based on the energy average value using formula 6) and L_{maxF} (prediction of maximum level obtained with the fast meter setting, calculated by applying a correction to formula 6). All maximum noise levels in this study have been calculated using the L_{maxM} method.

3 RAIL NOISE SOFTWARE PACKAGES

The railway noise modelling in this study has been undertaken with SoundPLAN 8.0 and CadnaA 2019.

In SoundPLAN, the properties of a railway object are defined at each of its nodes. Consequently, the noise emission level can be changed over the length of a single railway object. In CadnaA, the noise emission properties are constant for a railway object. Therefore, rather than inserting a new node when the source noise level changes (as would be done it SoundPLAN), in CadnaA a new railway object must be created. The “break into pieces” function in CadnaA can be used to easily create a rail alignment made up of a series of railway objects of equal length.

To calculate the L_{eq} noise level at a receiver, both modelling programs divide rail objects into elements which are treated as point sources. The noise levels from all rail elements are then summed energetically to calculate the L_{eq} noise level, as per the Nordic methodologies.

The maximum passby noise level at a receiver is calculated by treating the train as a moving line source in both modelling programs. A line source the length of the train is iterated along the length of each rail object. Once the position that produces the highest noise level is found, this is used to calculate the L_{max} noise level. The noise levels from multiple rail objects are not summed together.

As a rail alignment in a CadnaA model usually consists of multiple rail objects, separated where there is a change in source noise levels, situations occur in which a rail object is not long enough to calculate the L_{max} noise level from a full train length. Consequently, CadnaA has an “extrapolate trains to ½ length on both sides of rail” calculation option that projects the L_{max} line source half a train length beyond the ends of each rail object.

4 MODEL SETTINGS AND CALIBRATION

The calculation settings and modelling parameters used in the CadnaA and SoundPLAN models for this study are provided in Table 1.

Table 1: Settings used for the SoundPLAN and CadnaA models

Setting	SoundPLAN - Kilde 130	CadnaA – NMT 1996
Ground conditions	Flat, hard ground (G = 0)	Flat, hard ground (G = 0)
Receiver height	2 m above ground	2 m above ground
Top of rail height	0.6 m above ground	0.6 m above ground
Train type corrections	L_{eq} = +2.4, $L_{max,wagons}$ = +2.6	N-Pass
Train length	120 m	120 m
Number of trains in 24h	100	100
Order of reflections	3	3
Noise levels calculated	$L_{Aeq,24h}$ and L_{Amax}	$L_{Aeq,24h}$ and L_{AmaxM}
L_{max} sampling interval	0.125 s	0.1 s

For the CadnaA model, the train type correction values (a, b) were set to the N-Pass electric train values provided in Appendix B of the NMT 1996 report. The Kilde 130 correction values were then set such that the noise emission levels in the two models matched as closely as possible.

The L_{eq} and L_{max} noise levels at 15 m were calculated manually using the Kilde 130 and NMT 1996 formulas in Section 2. The change in noise emission levels with speed is shown in Figure 1 and Figure 2. The results were verified using straight track calibration models in CadnaA (using NMT 1996) and SoundPLAN (using both Kilde 130 and NMT 1996).

The Kilde 130 and NMT 1996 L_{eq} noise levels are almost identical for speeds above 60 km/h. NMT 1996 produces higher noise levels at low speeds compared to Kilde 130 (up to 0.5 dB at 50 km/h). For L_{max} NMT 1996 predicts lower noise levels below 80 km/h (up to -0.4 dB at 50 km/h) and higher noise levels above 80 km/h (up to 0.3 dB at 100 km/h). The L_{max} speed correction for NMT 1996 follows approximately a 33.5log(v) relationship, whilst the Kilde 130 method follows a 30.5log(v) relationship.

All presented noise levels are A-weighted.

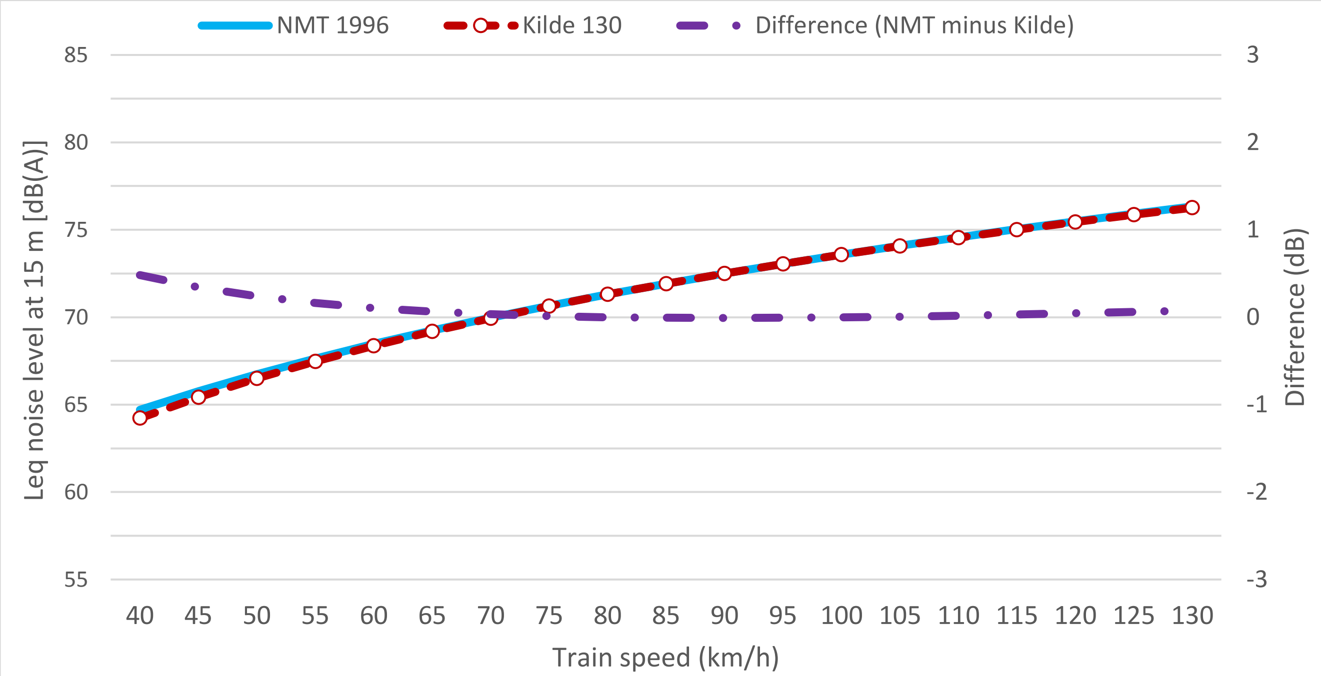

Figure 1 L_{eq} noise level versus train speed for Kilde 130 and NMT 1996

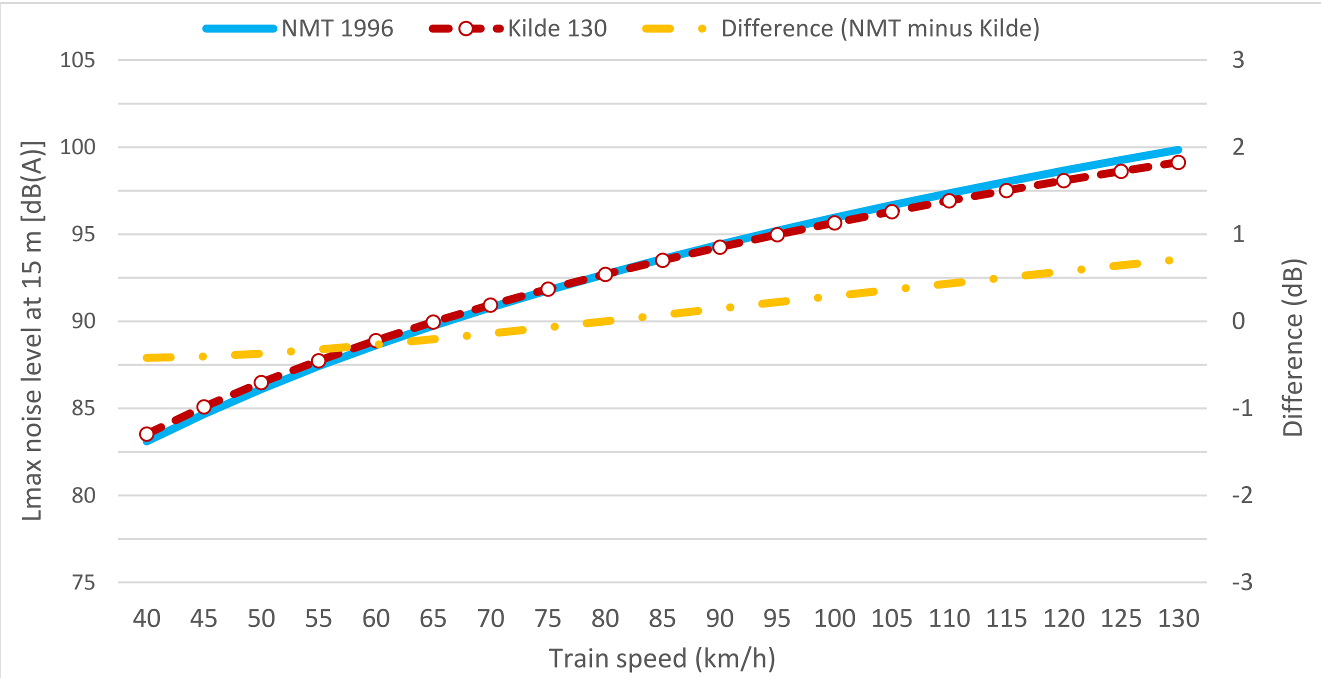

Figure 2 L_{max} noise level versus train speed for Kilde 130 and NMT 1996

5 COMPARISON OF CADNA-A AND SOUNDPLAN RAIL MODELLING

Several common rail modelling scenarios have compared in CadnaA and SoundPLAN. Each scenario features complexities associated with changes in source noise levels. This study presents the results of modelling with the two software programs and suggests approaches for modelling these situations in CadnaA.

5.1 Speed profile

A typical train speed profile has been modelled in both SoundPLAN using the Kilde method and CadnaA using the NMT method. The speed profile used was applied to straight track, 2,500 m long and entered into the models in 5 m increments. In SoundPLAN, the train speed was entered at a node placed every 5 m while in CadnaA, the alignment was split into separate 5 m long rail objects. Receivers were placed 15 m from the track centreline, at 5 m increments along the rail line. The CadnaA extrapolate setting described in Section 3 was turned on so that the line source was extended to the length of a train when calculating L_{max} noise levels.

The differences between the CadnaA NMT and the SoundPLAN Kilde results are shown in Figure 3. For L_{eq} the model results are within 0.3 dB of each other. The largest difference is when CadnaA NMT produces higher noise levels at low speeds, consistent with the relationship shown in Figure 1. The CadnaA L_{max} noise levels were between 0.4 dB below and 0.9 dB above the results calculated in SoundPLAN. The CadnaA model predicted lower levels when train speeds were low and steady, which is a result of the difference in Kilde and NMT speed corrections shown in Figure 2. The CadnaA model predicted higher noise levels on sections where the train is accelerating or braking. This is because rail objects with higher speeds have been extrapolated across objects with lower speeds and resulted in higher L_{max} levels at receivers.

The extrapolate setting essentially recreates the real-world condition of the train traveling the same speed over its entire length. As such, a CadnaA model has the potential to be more accurate than an equivalent model in SoundPLAN.

The CadnaA model was also run with the extrapolate setting turned off. This resulted in L_{max} noise levels 9 dB lower than the SoundPLAN model. Evidently, it is necessary to have the extrapolate setting turned on when modelling a speed profile in CadnaA.

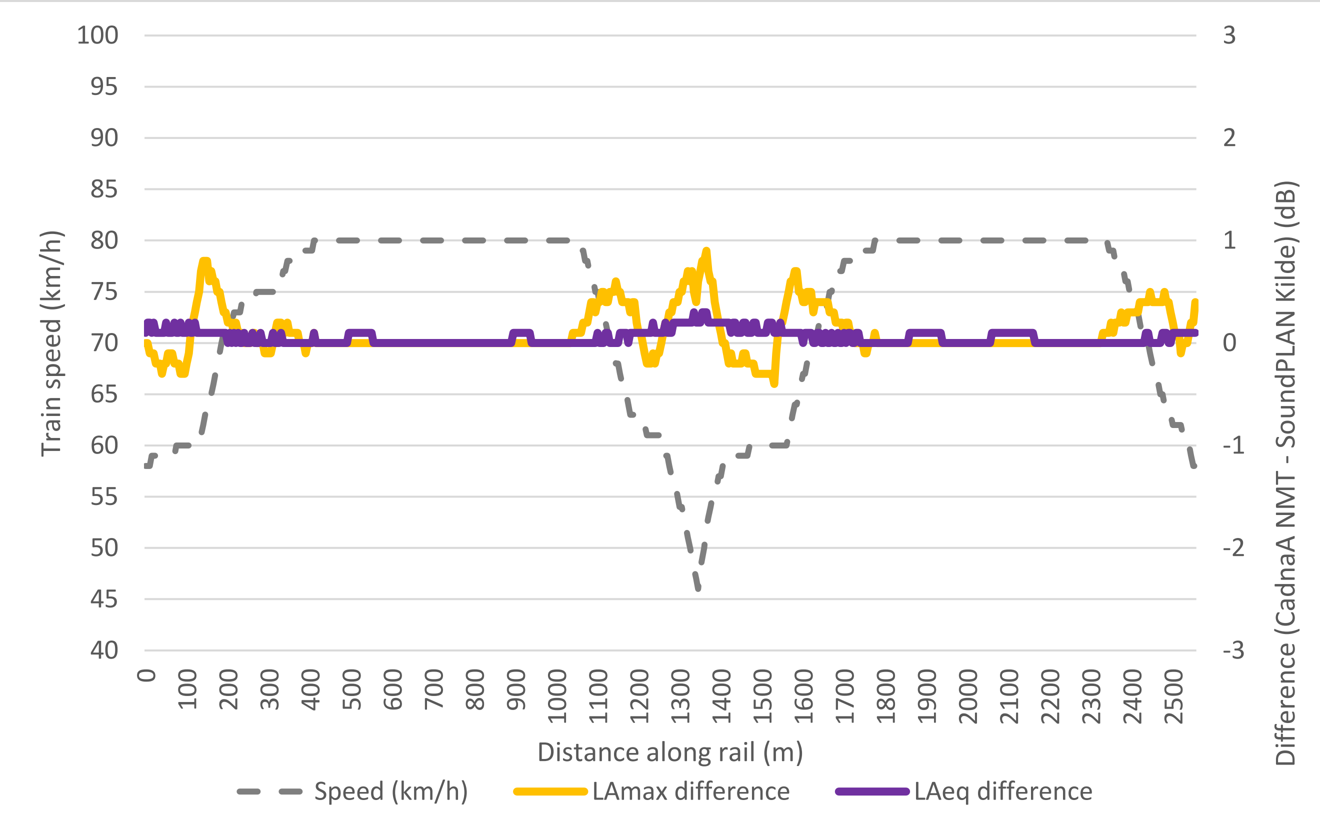

Figure 3 Difference in L_{eq} and L_{max} noise levels over a typical speed profile

5.2 Curves

The effect of a curved track on a rail alignment modelled as 5 m sections as described in Section 5.1 was investigated. A 300 m radius curve was modelled with a constant train speed of 80 km/h. Receivers were placed between 10 and 40 m from the track centreline on the inside and outside of the curve. In the CadnaA model, the extrapolate setting for L_{max} was turned on. The model layout is shown in Figure 4.

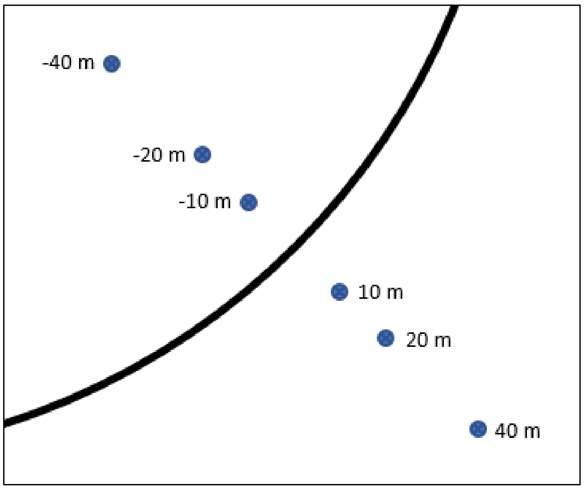

Figure 4 Layout for tight radius curve model

The difference between the CadnaA NMT and the SoundPLAN Kilde results are shown in Table 2. For L_{eq} the model results are within 0.1 dB at all positions. At a 10 m distance on the outside of the curve, the CadnaA L_{max} result is 2 dB higher than the SoundPLAN model. When calculating the L_{max} noise level with the extrapolate setting turned on, CadnaA extends the noise source in straight line from the vertices at either end of the rail object. The resulting line source is not curved but rather V-shaped. This results in an overprediction of L_{max} noise levels on the outside of the curve. This effect is visualised in Figure 5.

The significance of this effect is increased by either smaller radius curves or longer trains. The suggested approach when modelling in CadnaA is to model curved geometries as a single rail object when the magnitude of this effect is considered too large (e.g. greater than a prediction uncertainty of 2 dB).

Table 2 Difference in L_{eq} and L_{max} noise levels on the inside (-) and outside (+) of a tight radius curve

Distance from track centreline (m)	CadnaA NMT - SoundPLAN Kilde difference (dB)	
	L_{eq}	L_{max}
-40	0.0	0.1
-20	0.0	0.2
-10	0.1	0.3
+40	0.0	1.9
-40	0.0	0.6
-20	0.0	0.1

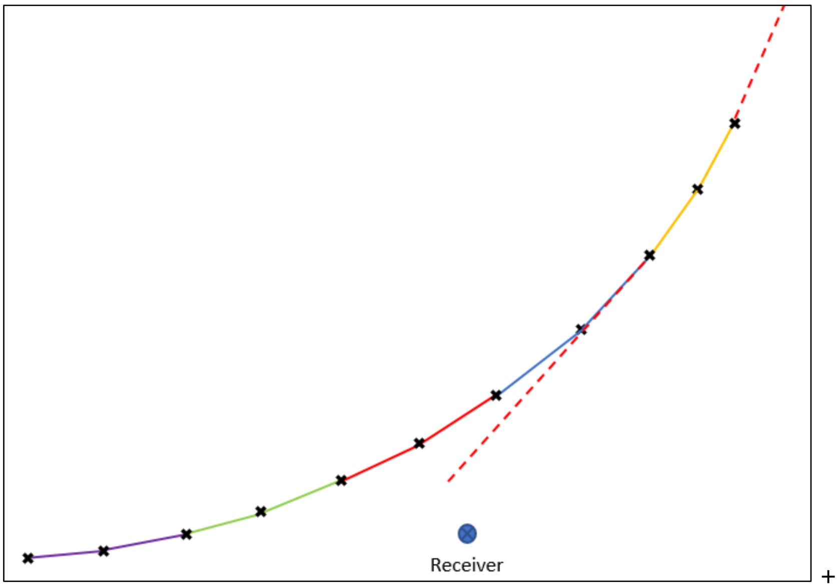

Figure 5 Example demonstrating how CadnaA's L_{max} extrapolation on a segmented, curved geometry can result in overpredictions on the outside of the curve.

5.3 Track corrections

Corrections for track condition are included in the Nordic methodologies when the alignment differs from a ballasted track with smooth continuously welded rails. Track corrections are commonly applied for features such turnouts, track joints, bridges, small curve radii or increased rail roughness. Different approaches for modelling a turnout have been investigated.

In SoundPLAN, the rail alignment is modelled as a continuous rail object and source level corrections are applied to nodes at the relevant positions. The layout of the SoundPLAN model is shown in Figure 6, with a 10 m long turnout correction applied in-line with the standard track. A constant speed of 80 km/h is used and a turnout correction of 6 dB is applied (Schulten et al. 2015). Two receivers were placed at 15 m from the track centreline.

All results have been compared to a baseline model with no correction (Model 0 in Table 3). The turnout scenario shown in Figure 6 modelled in SoundPLAN with the Kilde 130 (Model 1) and NMT 1996 (Model 2) algorithms. The two Nordic methodologies were found to produce the same results.

The situation shown in Figure 6 was also modelled with CadnaA NMT (Model 3). The L_{eq} noise levels are in close agreement with the SoundPLAN results. The L_{max} levels are 1-2 dB lower than those produced by SoundPLAN. This is because the L_{max} noise level is calculated from the highest of the three rail objects in the model and their noise contributions are not combined. The L_{max} results for this model is less than the baseline (Model 0) because each rail object is only a partial length. It is not suitable to use the extrapolate option in this situation as this will increase the length of the 10 m turnout to an entire train length, resulting in a significant overprediction.

An alternative approach is to model a continuous rail in CadnaA and place an additional 10 m rail object with the turnout correction applied on top (Model 4: Figure 7 with the two objects overlaid). This results in a similar L_{max} underprediction as described above. In addition, this method has the potential to overpredict the L_{eq} noise level as the rail noise along the length of correction is included twice.

Table 3 L_{eq} and L_{max} results for modelling a turnout track correction

Model #	Model	L_{eq} noise level		L_{max} noise level	
		Receiver 1	Receiver 2	Receiver 1	Receiver 2
0	No correction (CadnaA & SoundPLAN)	71.3	71.3	92.7	92.7
1	SoundPLAN Kilde (Figure 6)	71.9	73.4	93.3	95.0
2	SoundPLAN NMT (Figure 6)	71.9	73.4	93.3	95.0
3	CadnaA NMT (Figure 6)	71.8	73.4	92.3	92.6
4	CadnaA NMT (turnout overlayed)	71.8	73.4	92.7	92.7
5	CadnaA NMT (separate models & sum)	71.8	73.4	93.3	95.1

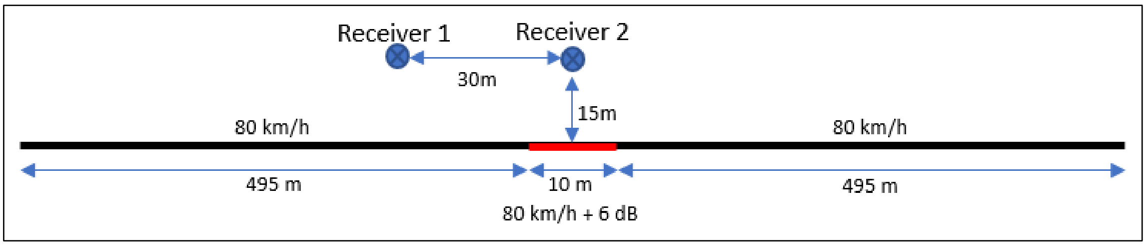

Figure 6 Model layout for a turnout track correction placed in-line with the rail alignment

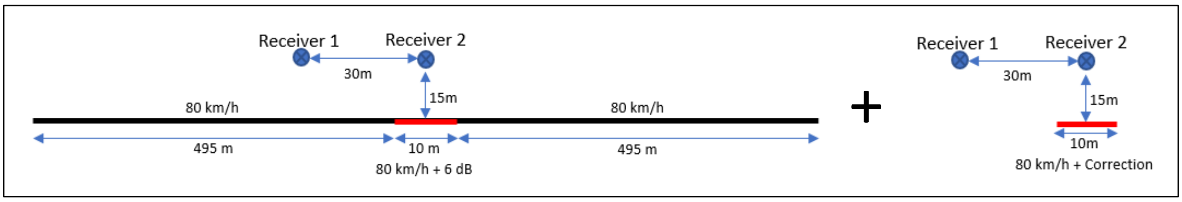

Figure 7 Modelling the rail alignment and turnout correction separately, either overlaid in one model (Model 4) or the result summed after calculation (Model 5).

The suggested approach is to model the rail alignment and track corrections separately and sum the calculated results together. The track correction can be adjusted using formula 8 so that the rail noise contribution is not included in the result twice. For the example above, the turnout rail object would be given a correction of +4.7 dB which results in an overall addition of +6 dB at the turnout. The results for this method (Model 5 in Table 3) are in close agreement with the SoundPLAN models. Modelling the rail alignment and corrections separately has the additional advantage of being able to run the alignment with the extrapolate setting turned on and the corrections objects with the setting turned off.

$$L_{Wt} + \Delta L_c = 10log_{10}\left(10^{\frac{L_{Wt}}{10}} + 10^{\frac{L_{Wt}+\Delta L_{adj}}{10}}\right) \tag{7}$$

Where

L_{Wt} = maximum passby noise emission level without track corrections

ΔL_c = desired track condition correction to be applied to the result (+6 dB for the turnout example above)

ΔL_{adj} = adjusted track correction to be entered into the correction object in the model

Which simplifies to:

$$\Delta L_{adj} = 10log_{10}\left(10^{\frac{\Delta L_C}{10}} - 1\right) \quad (8)$$

This methodology can also be applied to other track correction situations such as bridges and curves.

6 CONCLUSIONS

This study has investigated common rail noise modelling situations which include speed changes, small curve radii and track corrections in CadnaA and SoundPLAN. The near-field L_{eq} and L_{max} noise levels have been compared between a CadnaA - NMT 1996 model and SoundPLAN - Kilde Rep 130 model. As changes in source noise levels must be modelled as separate rail objects in CadnaA, new approaches are required for modelling rail noise with this software. From the results of this investigation the following conclusions can be made:

- In all the modelling situations it was found that CadnaA models produced L_{eq} noise levels that were in close agreement to an equivalent model in SoundPLAN.
- When modelling a speed profile in CadnaA, turning on the extrapolate setting will result in L_{max} noise levels within 0.5 dB of a SoundPLAN Kilde model for constant train speeds and within 1 dB where the trains are accelerating or braking. The CadnaA modelling results may be more representative of real-world conditions, compared with an equivalent SoundPLAN model.
- When modelling a curved track in CadnaA with rail object segments there is the potential for CadnaA's extrapolate setting to overpredict maximum noise levels on the outside of the curve. This effect should be considered when the radius of a curve is small, and the length of the train is large. An alternative approach is to model curved geometries as a single rail object.
- The suggested method for applying track condition corrections in CadnaA is to model the uncorrected rail alignment and the track corrections separately and sum the calculated results together. This method has been demonstrated to produce noise levels that match a SoundPLAN model.
- All the presented variances between the models are considered minor and within normal tolerances for rail noise modelling. The NMT 1996 report suggests that the accuracy of predicted levels at distances less than 30 m is usually ±2 dB for L_{eq} and ±3 dB for L_{max}.

Using appropriate modelling techniques, it is feasible to use the CadnaA software program to implement the NMT 1996 rail noise prediction methodology and calculate results that are in close agreement with a Kilde Rep 130 model made in SoundPLAN.

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