Regional detailed transport noise modelling – railway methods and outcomes

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ABSTRACT

To support the application of the Queensland Development Code (QDC), noise mapping of Queensland road and rail transport noise corridors was conducted. The initial road modelling has been described previously (Zhang et al, 2016). The railway noise modelling of approximately 3 100 km of railway corridor is one of the largest projects of its kind in the world. The project considers attenuation due to terrain, noise barrier and building effects. SoundPLAN software managed the detailed models and calculated noise levels on a 5 m grid. Geographic information system processing of the noise category contours collated the results into a suitable format. The noise category contours present accurate representation of noise impacts for new residential development. Work has commenced on a second stage of rail noise modelling incorporating additional high resolution terrain and building data. This paper describes the modelling and post processing methodology, presents noise contour results, discusses challenges and solutions.

1. INTRODUCTION

The Queensland Development Code (QDC) includes Mandatory Part 4.4 (MP4.4) (Department of Local Government and Planning, 2010, Department of Local Government and Planning, 2015) which requires noise mapping of Transport Noise Corridors (TNC) to support its function. QDC MP4.4 uses noise mapping results to set default building construction requirements that minimise amenity issues associated with noise emissions from State-controlled roads and railways. The mapping results are used directly to determine the impact and associated mitigation for individual dwellings. This differs in implementation from international approaches. For example both the European Union (Environmental Noise Directive 2002/49/EC) (END, 2002) and the United States of America (USA) use noise mapping results to develop broad scale action plans to supplement a country's historical mitigation approaches and gauge general community exposure (DEFRA, 2014) (Hintzsche & Heinrichs, 2016) (US DoT, 2017). Other states within Australia define noise categories within guidance documents (Department of Planning, 2008) (Department of Planning, Transport and Infrastructure, 2013) based on traffic attributes and setback distances. These documents are support by state government mapping layers (i.e. traffic flow in New South Wales) and planning overlay maps (i.e. defined area and road types in South Australia).

The QDC railway noise modelling project is one of the largest of its kind in the world (Hepworth et al, 2013, Zhang et al, 2016). It incorporates approximately 5 400 km of railway track located on approximately 3 100 km of rail corridor, a significant portion of the railway network in Queensland (refer Figure 1). The modelled railway tracks represent corridors which are typically used at a higher capacity.

To implement QDC MP4.4, transport noise corridors must be declared with noise category contours based on modelled results. Transport noise corridors for State-controlled roads were declared in August 2010, with mandatory and voluntary noise corridors introduced in June 2015. Transport noise corridors for selected railways were first declared in June 2015 based on flat earth modelling (Round 1). The revision of railway transport noise corridors (Round 2) considers attenuation of terrain, noise barriers and buildings. It is being conducted in two stages. Overall, the modelling approach as presented in this paper is similar for both Round 2 stages. However, more detailed terrain and building data is included within the later stage. This paper focuses on the first stage of Round 2 railway noise modelling and noise category contour generation.

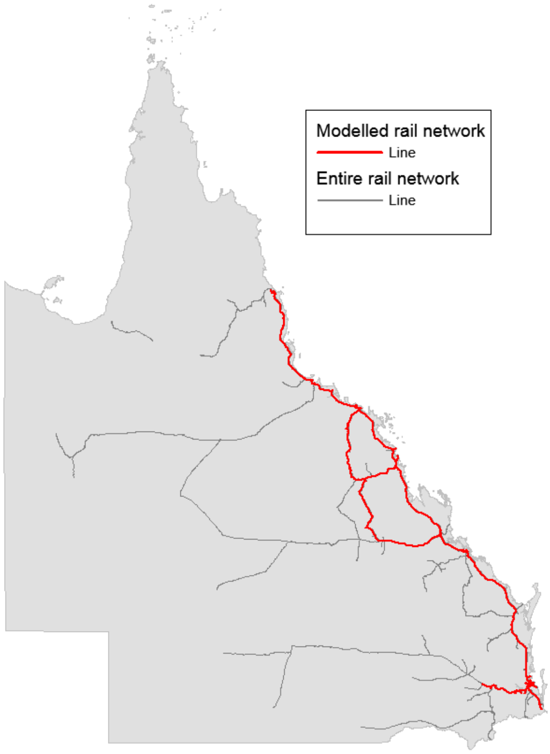

Figure 1: Queensland Railway Network

2. PROJECT METHODOLOGY

2.1 Modelling basis

Railway noise modelling was conducted using the Nordic Kilde 67/130 (Kilde) algorithm (Ringheim, 1984) for railway traffic and the ISO 9613 2:1996 algorithm for railway facility operations. While the Nordic models have evolved into more recent versions (NMT96, NORD2000) (Nordic Council of Ministers, 1996) (Jonasson et al, 2001), Kilde was selected as it has been historically preferred by rail operators in Queensland and the correction factors for train types are readily calculated, based on existing data.

The maximum noise level Lmax is required to be modelled to meet the QDC MP4.4 requirements. The following formula represents the base Lmax calculation using the Kilde algorithm:

$$\mathrm{L} = 10\log(10^{L1/10} + 10^{L2/10}) \tag{1}$$

In this formula:

$$L1 = 92 - 10\log\left(\frac{a}{10}\right) + 10\log\left(\frac{\arctan\left(\frac{lt}{2a}\right)}{1.37}\right)$$
$$L2 = 50 - 20\log\left(\frac{a}{10}\right) + (44 - 100/\sqrt{lt})(3/\sqrt{a})$$

lt is the train length including locomotive (m).
a is the perpendicular distance from the track (m).

L is the overall maximum sound pressure level, corrected for a train running at 80 km/h on continuously welded rails (CWR). L1 represents the maximum noise level, with the emission being assumed as a finite line source, an example of which is wheel-rail emission. L2 represents the maximum noise level, with the emission being assumed as a moving point source, for example the locomotive exhaust of a freight train.

L1 and L2 present different attenuation rates. Figure 2 shows L1 and L2 calculations where they are corrected to be equal at a location 25 m from the track. As presented in Figure 2, L2 attenuates more rapidly than L1 with increased receiver distance from the track. For example, for distances of over 25 m, L2 shows a reduction of 10 to 12 dB per doubling of distance while L1 shows a reduction of 4 to 5 dB per doubling of distance. The attenuation rate for L1 is more comparable than L2 to those presented in FTA, 2006 which vary from 3 to 6 dB per doubling of distance and measurements in New South Wales which concluded approximately 4 dB per doubling of distance (SLR, 2015).

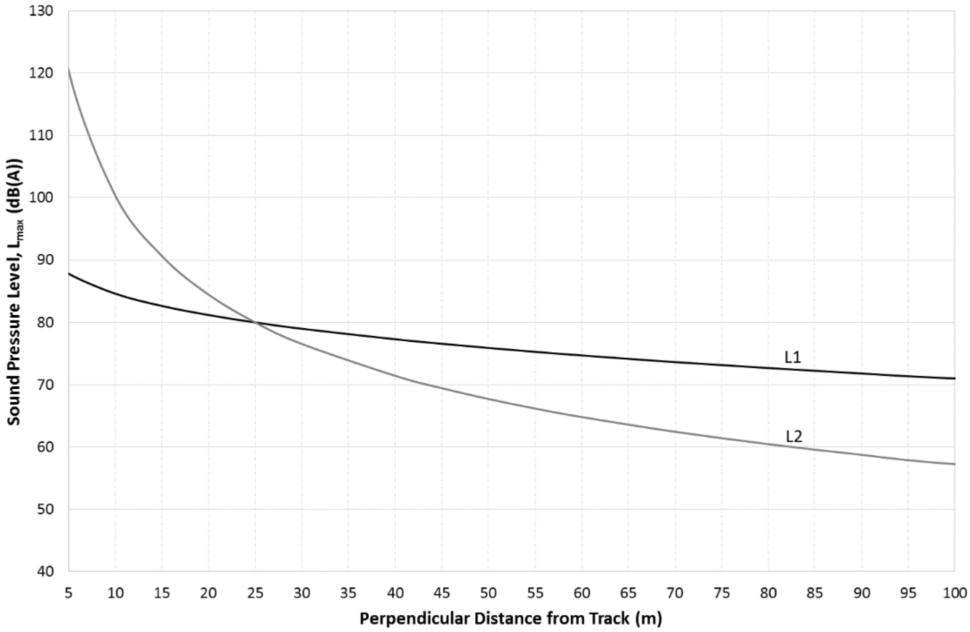

Figure 2: Kilde L1 and L2 predicted noise levels

While acknowledging that the L2 formula is not generally a standalone factor, it was excluded from the Round 2 modelling with the focus on using L1 contribution only. Based on the assumption that L1 forms the basis for calculation, the correction of the L1 base level is required to be calculated for train types in Queensland. To derive the L1 corrections, noise modelling is carried out for specific train types at a speed of 80 km/h on a continuously welded rail track, with hard ground on flat terrain. The modelling result is then compared against measurements at 25 m from the track. The measurement data was provided by train operators in Queensland for the modelled train types. Table 1 presents the derived L1 corrections for the modelled train types. For all train types, L2 is set as -100 to totally remove its contribution.

Table 1: Kilde Train Type L1 Model Corrections (80 km/h, CWR)

Train Type	L1 Correction (dB)
Diesel Locomotive (Dual) – Notch 6	+4.4
Freight Consist (Wagons)	-6.5
Passenger Electric (EMU, 6 Car)	-4.6
Passenger Electric (IMU, 6 Car)	-7

According to the Kilde algorithm, using L1 contribution alone with the correction of L1 at 25 m from the track theoretically results in conservative noise prediction and mitigation for all practical development situations adjacent to a rail corridor. This approach may be revisited if further attenuation data becomes available, particularly for diesel locomotives.

Further model corrections for freight consist and electric passenger trains, not for locomotives, were required to account for the wheel track interactions. These corrections are presented in Table 2. They are taken to be cumulative where multiple corrections are required. These values are based on those used historically in Queensland as well those documented in Kilde (Ringheim, 1984) and NMT96 (Nordic Council of Ministers, 1996) documentation.

Table 2: Wheel Track Interaction Model Corrections

Track Attribute	Condition Correction (dB)
Jointed Track	+3
Switch (10 m track length)	+6
Level Crossing	+5
Track Radius < 300m	+8
Track Radius ≥ 300m & < 500 m	+3
Bridge - concrete (including viaducts) with parapets	+1
Bridge - concrete (including viaducts) without parapets	+3.5
Bridge - steel with concrete parapets	+4
Bridge - steel with a box or lattice girder	+9
Bridge - wooden	+5
Bridge - unknown	+6

The modelling of facilities used the formulae within the ISO9613 algorithm. A moving point source with a sound power level of 130 dB(A), representing the noise equivalent to a typical coupling slack bang of shunting, was used to represent the track lines and estimate noise emissions from railway facilities. The sound power level was selected as it adequately represents the loudest noise emission sources which may occur within facilities.

2.2 Data preparation

The terrain data preparation and methodology for Round 2 rail noise modelling is similar to that for road noise modelling as presented by Zhang et al (2016). Terrain data used in Round 2 includes a combination of Airborne Laser Scanning (ALS), Shuttle Radar Topography Mission (SRTM) Version 1.0 and Advanced Land Observing Satellite (ALOS) data. Buildings will be included in Stage 2 of the Round 2 noise modelling.

The railway track lines were an amalgamation of available data from rail operators and the Department of Transport and Main Roads. Additional datasets to annotate the track lines were also generated by the Department of Transport and Main Roads. These included track curve radius, switch points, level crossings, tunnels, bridges, bridge type (where available), track type (e.g. jointed) and speed (where available). The correction factors for these track attributes are presented in Table 2. A minimum speed of 80 km/h was used where speed data was not available or the posted speed was less than 80 km/h. The noise level correction for train speed is as per Kilde 67/130.

2.3 Noise modelling

Kilde 67/130 and ISO9613 algorithms as implemented within SoundPLAN version 7.4 were used to model the railway and railway facility noise levels at the surrounds. The terrain data covered approximately 500 m either side of the track lines. The State-wide data was split and modelled within 28 model domains. The model domains were based on local government area (LGA) and Universal Transverse Mercator (UTM) zone. In total, railway tracks within 26 local government areas were modelled. As two LGAs were located on the border of zone 55 and 56, these LGAs were analysed in relation to both zones to accommodate changes in UTM zone projection. The model domains extended 1 km into adjacent domains to ensure that model results could be readily trimmed and merged at the boundaries.

The railway track data was split by speed and train type prior to being imported into SoundPLAN. In addition overpasses were separated from the main tracks to ensure they retained their height over the main lines. These data sets were imported into SoundPLAN separately to facilitate the addition of emission attributes. Once imported and attributed, the railway tracks were merged by train type. This allowed for a seamless track line which included all the complex emission characteristics. The wheel track interactions (Table 2) were annotated and summed for each railway link segment. This data was automatically imported into SoundPLAN with the link geometry and included as a total condition correction.

The source heights assumed in the modelling were 4.0 m and 0.5 m above track height for freight locomotives and electric passenger/freight consist respectively. It is noted that SoundPLAN automatically adds 0.5 m to the source height so the models were configured based on sources 3.5 m and 0.0 m above track height. The length of trains were taken to be 36 m, 144 m and 1000 m for dual diesel locomotive, 6 car electric passenger and freight wagon consist respectively.

The height of the point source for railway facility modelling was 2.0 m. The Stage 1 railway facility noise model included estimated noise barrier locations and heights but did not include terrain, which will be included within Stage 2.

Noise models included receivers at a grid resolution of 5 m for both ground floor and first floor. Ground and first floor receivers were taken to be 1.8 m and 4.6 m in height above ground level. The ground surface was taken to be reflecting (i.e. hard ground) for the modelling domain.

2.4 Noise contour post processing

The generation of transport noise corridor noise category polygons from the SoundPLAN models involved multiple steps. Initially, the results of the various train type modelling (i.e. locomotives, freight wagon consist, electric passenger) were combined, with the envelope maximum being retained. This maximum noise level was then adjusted to include a 2.5 dB facade reflection allowance. The contour results were then exported from SoundPLAN for noise level intervals based on the ranges required by QDC MP4.4 (Department of Local Government and Planning, 2015).

Geographical information system (GIS) software was used to process and combine the 28 modelling domain noise contour results for both receiver heights. Processing was conducted to remove the polygon areas of lower noise categories which overlapped higher noise categories. For example a point within a noise category 4 area would also include noise category 3, 2 and 1 area. Processing allowed a single noise category to represent any given point within the transport noise corridors.

This process may be revised during Stage 2 as the inclusion of buildings within the noise models may add complexity to the results and exceed the capacity of SoundPLAN's inbuilt export options.

3. MODELLING RESULTS

Terrain, noise barriers and buildings are the key elements affecting noise propagation and are essential inputs to detailed noise modelling. At the time of preparing this paper, the project included terrain and noise barriers in the rail noise mapping, with the buildings to be included in Stage 2. Quality assurance was performed to ensure the accuracy of the terrain model and noise barrier alignments. Figure 3 presents a snapshot of the terrain with noise barriers (in green) evident in a modelling area. The terrain model is generated from the ALS data. The snapshot shows that the noise barriers are correctly placed on the top of the cutting of the rail corridor edge. The location was verified by aerial photography and model flythrough.

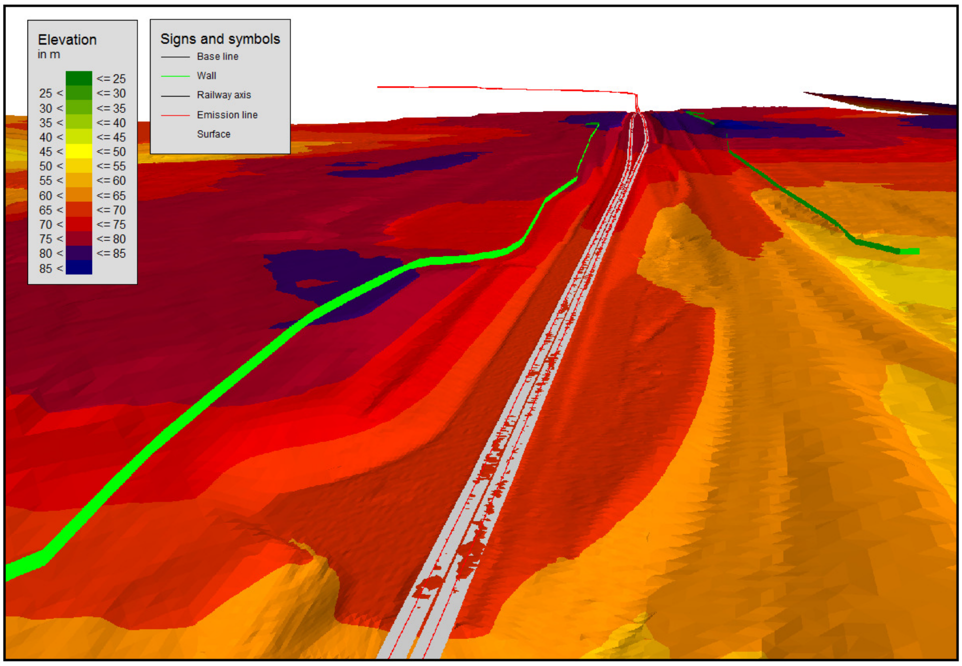

Figure 3: Terrain model snapshot with noise barriers

The modelled noise levels were affected by rail noise emission level, propagation distance, terrain characteristics and barriers. The QDC MP4.4 noise category contours in the Brisbane local government area are presented in Figure 4. For a suburban area, the noise category contours are further presented in Figure 5 for the ground floor and Figure 6 for the first floor.

It is evident from Figure 5 that the noise categories are affected by shielding provided by terrain and noise barriers. The inclusion of existing noise barriers in most cases is expected to reduce the noise categories behind the barrier to the next lower category. This is more evident for ground floor receivers. The noise category contours for the first floor have a greater extent. The State-wide noise mapping shows that existing noise barriers are less effective in mitigating noise for the first floor. This is mainly due to the modelled height of locomotive noise emissions, which reduces the barrier attenuation effectiveness.

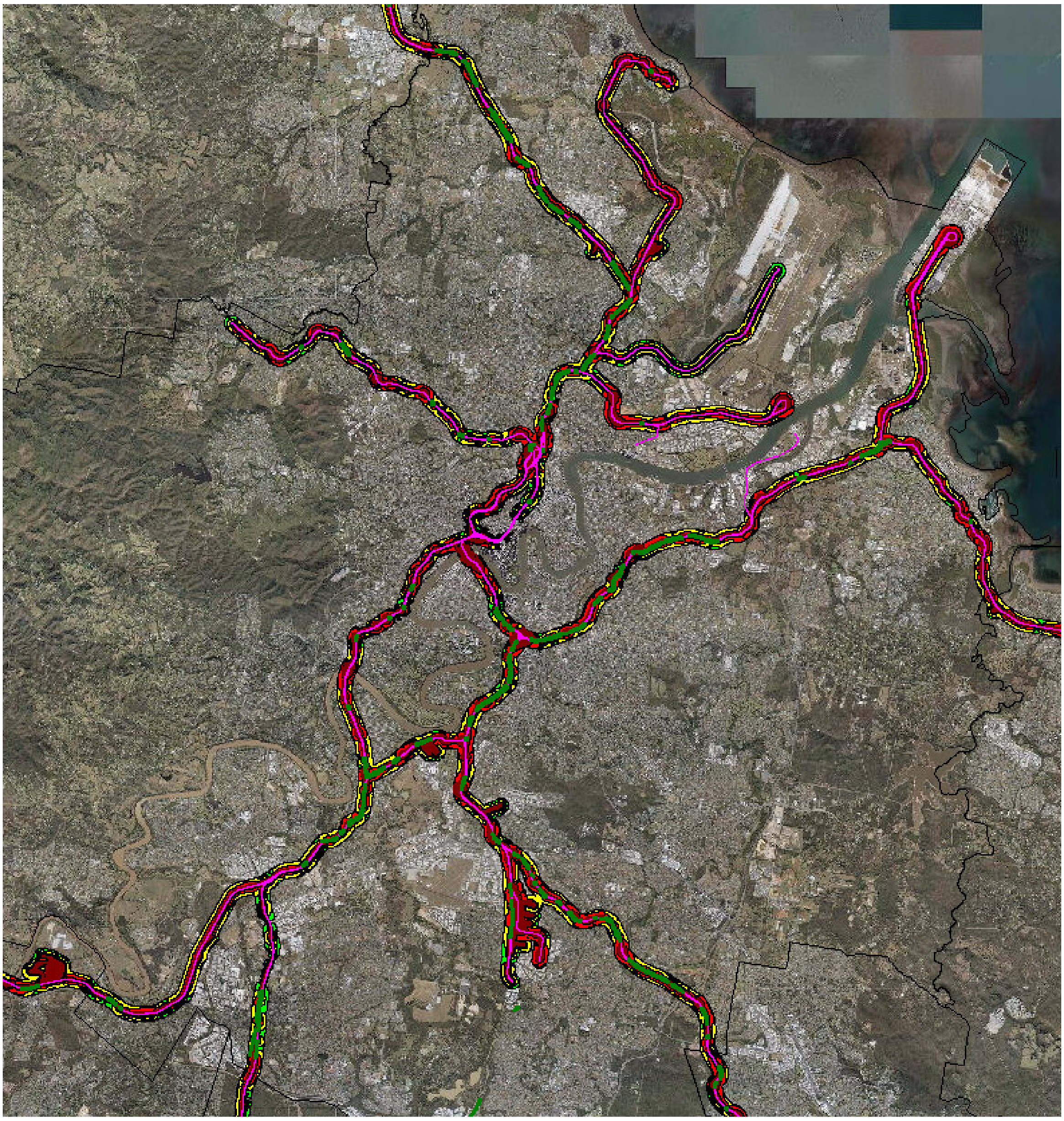

Figure 4: Noise contours in Brisbane

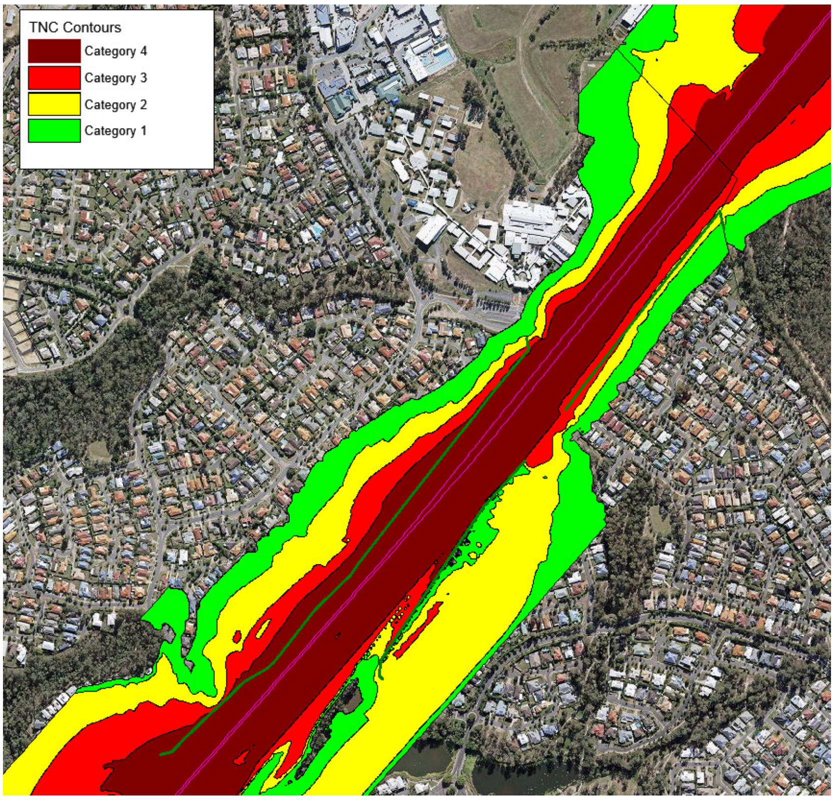

Figure 5: QDC noise category contours for the ground floor

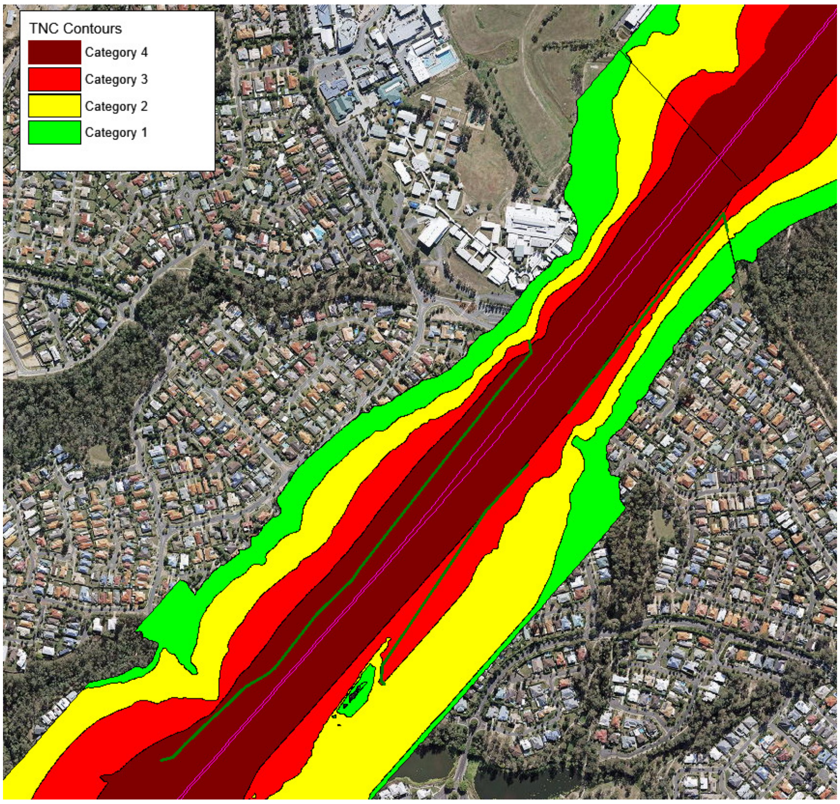

Figure 6: QDC noise contours for the first floor

4. CHALLENGES AND SOLUTIONS

Various challenges were encountered during the project. With learnings and knowledge from the road traffic modelling of the overall project, the known issues were able to be solved to meet the project milestones. The main challenges and solutions are summarised below.

4.1 Managing large dataset

The noise modelling was conducted for a large portion of the rail network across Queensland. Terrain data was prepared up to 500 m on each side of the railway with resolutions stepped from 1 m spacing between 0 and 25 m from the rail track centreline, 2.5 m between 25 m and 50 m, and 5 m between 50 m and 500 m. This resulted in a 31 GB dataset containing over 1.3 billion spot heights.

The large quantity of terrain data, together with the rail track lines, noise barriers and building profiles, required an effective data management solution. This was achieved through LGA based data preparation and modelling. As stated earlier, the modelled rail network covers 26 LGA areas. This results in 28 noise models being created to represent the 26 LGA's throughout Queensland, with 2 LGA's each split by UTM zone into 2 noise models. It is noted that data extending into a neighbouring UTM zone will distort in shape and position as distance increases outside the projected zone boundary. This is important for noise modelling as the base terrain is required to be representative in both location and extent. Therefore where a modelling domain crosses a UTM zone the domain is split so that distortion effects are limited and data integrity is maintained.

A single terrain dataset for an LGA was found to be too large for SoundPLAN to manage. The tiling function of SoundPLAN was used in the Geo-Database module to divide the terrain of an LGA into multiple tiles of 2 km by 2 km. The same tiling system was also used in the Calculation Kernel to expedite the noise calculations and in the Graphics Module to visualise the modelling results. The tiling function allows data only within the selected and surrounding tiles to be loaded, making it possible to prepare data and present results based a limited tile area.

4.2 QA data and models

The project is to deliver noise contours, to support the implementation of QDC MP 4.4. It is expected that the noise contours have improved accuracy in relation to Round 1 modelling. This poses strict requirements for the quality of input data. Given the scale of the project, it is impossible to verify all site specific information. Indeed, it is out of the project scope to verify site specific information. Field noise monitoring for noise model verification is also out of scope. The project instead focuses on the quality assurance (QA) of the available input data, noise models and noise contour outputs.

Large efforts and extensive time were spent on the preparation of the terrain data. Two sources of terrain data were used in the Stage 1 rail noise modelling, with high accuracy ALS data in the coastal area and Shuttle Radar Topography Mission (SRTM) data in the inland area. The transition from ALS to SRTM areas created a terrain discontinuity at the boundary between the two datasets in places. An algorithm was applied to the transitional zones with the width dependent on the data height difference to maintain a terrain gradient within 5 %.

Terrain data was checked before being imported into SoundPLAN. To facilitate this, terrain contours with a height difference of 0.25 m were produced. Anomalies were identified through a visual check of the 2D terrain contour lines in a GIS software environment. The terrain data was further checked in SoundPLAN. Anomalies were easily identified in the 3D environment with the produced Digital Terrain Model (DTM). Anomalies in terrain data include spikes, trenches and walls caused by raw input data faults or terrain data preparation process.

Separate QA processes were also applied in preparing track lines and noise barriers. The attributes of the track lines used as the input to the Kilde model were based on raw data provided and verified by the rail authority. Noise barriers were digitised from a 3D video tool to determine the alignment and height. Once imported into SoundPLAN, the alignments of the noise barriers were checked further. A common error occurred when barriers were incorrectly placed in relation to the top of a retaining wall. This was easily identified in the SoundPLAN 3D environment.

Consistencies were required across LGA modelling. The model settings, file structures and naming conventions were consistently applied for each model domain. This approach was of critical importance to maintain data integrity during the entire modelling process from data preparation to modelling and post processing, allowing QA to be consistent.

4.3 Calculation speed

Noise calculation for railways using Kilde 67/130 as implemented in SoundPLAN is processor intensive. It was noted that this modelling process provided greater load per kilometre on computer hardware than road traffic noise modelling. In order to minimise the calculation time, the tiling function and distributed calculation function were used. Completion of calculations for a single LGA package varied from 0.5 to 4 days when conducted on a cloud platform with 12 CPU cores. This extended calculation time makes it difficult to regularly revise and trial run the model at a LGA level. However localised changes can be easily made for affected tile areas.

4.4 Noise contour generation

Calculated grid noise maps throughout the LGAs need to be reclassified into five distinct Lmax noise level categories and combined at the State level. The noise category boundaries range from 70 dB(A) to 85 dB(A) with a 5 dB increment, to meet the requirements stipulated in the building code and QDC MP4.4. Once finalised, these noise level contours are hosted on a publicly accessible website. The noise categories need to take the form of polygons to allow a user to select a point and for a single noise category value to be returned.

SoundPLAN offers a number of options for exporting grid noise maps including a direct export as polygons. Initially, a direct noise contour polygon export from SoundPLAN was not considered practical, mainly due to concern over the size of the export file for an LGA wide model. The grid noise levels were exported in a raster format, with a pixel value equal to the calculation resolution. The raster was then processed in a GIS environment to re-generate State-wide noise contours. It was found, however, that the regeneration of the contours yielded discrepancies from SoundPLAN contour results. Ultimately, the direct export of noise contour polygons was adopted. Once exported, the contours were further processed by trimming and cutting without alterations to the noise contour polygon geometry. This produced results which compared well with those visualised in the SoundPLAN Graphics Module.

5. FUTURE DEVELOPMENTS

At the time of writing this paper, the development of Stage 1 of the rail modelling project has been completed and QDC noise category contours are planned to be published soon.

Development of Stage 2 of the project is underway. It will be based on the Stage 1 model domains but incorporate building data and improved terrain in the majority of SRTM areas. Once completed, the contours are expected to be more accurate but also more complex. Buildings are likely to dramatically change the contour geometry in dense residential areas near the rail corridor. A finer resolution of noise grids, for example, 2 m instead of the 5 m grid calculated for Stage 1, could be required. The finer grid would be expected to be particularly beneficial for smooth presentation of noise contour lines in the vicinity of buildings and barriers.

In the long term, once the project is completed, the rail noise contours may be required to be updated regularly in the future. The delivered LGA based modelling packages from the project provide a good foundation to facilitate any necessary updates. The SoundPLAN tile functions prove to be beneficial where partial remodelling is required as localised information, such as noise barriers and buildings, becomes available. The noise model would only be required to be re-run for the affected tiles to reflect the changes. Alternatively, the input data may be updated regularly and the noise models across the State be re-run to generate the latest noise contours as funding is made available.

6. CONCLUSIONS

Stage 1 of a detailed noise modelling project for selected railways has been completed for Queensland. The project is progressing to Stage 2 that will incorporate additional building and terrain data to further improve the modelling accuracy.

The noise modelling covers a large portion of the rail network across Queensland and is believed to be one of the world's largest detailed railway noise models. The input data for the project came from various sources. Collecting and processing these data needed collaboration from a team with expertise in both acoustics and GIS. As with the road traffic modelling portion of the overall project, insurmountable technical difficulties were not encountered in setting up the noise models and conducting calculations. This was due to the power of modern computers, efficiencies achieved through the tiling function of SoundPLAN and the extra resources available through distributed computing. Effective management of terrain data and segregation of the noise modelling domains by LGA and UTM zone was critical to the success of the project.

The results of the modelling provide direct support for the implementation of QDC MP4.4 for the building industry. The output may also find use in wider areas. In the Department of Transport and Main Roads, the noise contours and the data collected through the project will assist in the daily management of transport noise issues. For example, they can be used to assist in the assessment of development applications.

Externally to the Department, the noise contours could be used for other purposes. For the public, the contours form part of an educational tool for improving the awareness of transport noise and its impact. For other government agencies, for example health departments, the results could be used to assess the noise exposure for people adjacent to the transport system and estimate the health burden due to noise.

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