Regional detailed transport noise modelling – issues and outcomes

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ABSTRACT

Detailed noise modelling of approximately 34 850 km of major roads and 3 100 km of railways in Queensland, Australia was conducted to support decision making processes for residential buildings in transport noise corridors under the Queensland Development Code (QDC). The modelling is believed to be the largest project of its kind undertaken in the world to date. The project replaces earlier modelling that did not consider terrain and barrier effects, potentially resulting in conservative acoustic requirements for buildings. SoundPLAN software managed high resolution terrain data using a tiling methodology and calculated noise levels on a fine grid. GIS software then produced the required noise category contours from the modelled results. Preliminary analysis of the detailed road modelling shows that the numbers of properties within QDC noise category 4 and noise category 3 mandatory noise corridors were reduced by 28% and 7% respectively State-wide. This should result in significant savings for new residential development. Work has commenced on a second stage of modelling incorporating additional high resolution data. This paper describes the modelling methodology, summarises challenges, issues and solutions, and presents a preliminary analysis of results.

1. INTRODUCTION

Detailed noise modelling on a large scale such as a city or region has only recently become practical through advances in computer and software technology. The European programs in this area are driven by the Europe Union Environmental Noise Directive (2002/49/EC) established in 2002 (END, 2002). The Directive recognises environmental noise pollution as a major health burden and aims to define a common approach across the European Union to avoid, prevent or reduce, on a prioritised basis, the harmful effects of environmental noise exposure. The Directive requires member states to prepare and publish strategic noise maps and noise management action plans for major urban areas, major roads, railways and airports every 5 years. To date, there have been two rounds of noise mapping and action planning (in 2007 and 2012). The European Commission is currently undertaking an evaluation of the END and trying to assess its effectiveness and efficiency, including benefits, costs and hurdles to the implementation of an effective EU noise policy (Juraga, 2015).

Australia has no nation-wide overarching policies that require large scale noise modelling. A draft issue of the National Construction Code (NCC) in 2014 featured the inclusion of measures to address noise intrusion into habitable rooms, but this was abandoned prior to release in 2015 (NCC, 2015). However, if the future NCC reintroduces a noise treatment requirement, it may trigger the need for large scale noise modelling to assist governing authorities with building approvals.

Nevertheless, some large scale noise modelling projects have been undertaken in Australia (Hinze 2015). For example, Adelaide City commissioned Australia's first city noise map for roads in 2006 (Adelaide City Council Fact Sheet 9). VicRoads developed noise maps for the Highways Retrofit Noise Assessment (VicRoads, 2011) and the Victorian Environmental Protection Authority produced the Greater Melbourne Noise Map (EPA Victoria, 2013).

In September 2010, the Queensland Government released a mandatory building code, the *Queensland Development Code Mandatory Part 4.4 – Buildings in Transport Noise Corridors* (QDC MP4.4) (QDC 2010, 2015). The purpose of the code is to ensure that new residential buildings located near roads and railways are constructed in a way that attenuates adverse noise impacts for building users. The code defines four noise categories for roads and railways and stipulates the required acoustic specifications of building materials. To implement the code, transport noise corridors must be declared and the noise category contours must be produced. This requires noise modelling and mapping for all declared roads and railways.

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 also declared in June 2015.

Queensland Department of Transport and Main Roads (DTMR) manages the noise modelling and mapping projects for State-controlled roads and railways. There have been two rounds of noise modelling. The first round involved a flat-earth based spreadsheet approach. The modelling was completed in 2010 for State-controlled roads and in 2014 for railways. The noise mapping results presented as the four QDC noise category contours are publicly available on a government website for use by the public, consultants, development industry and local governments.

The noise results from the first round of modelling are considered to be over-conservative in some circumstances due to the flat-earth assumption and absence of structures such as noise barriers. As a result, developers may accept conservative construction requirements for residential buildings in transport noise corridors or commission their own detailed noise modelling studies. To improve the modelling accuracy, a second round of noise modelling was conducted, incorporating terrain data, existing noise barriers and buildings. The re-modelling was conducted using sophisticated acoustic software. The second round of modelling is separated into stages. For both roads and railways, Stage 1 includes the input of terrain and noise barriers while Stage 2 includes the addition of buildings.

Stage 1 declared road modelling (Road Stage 1) is complete and the results after consultation are expected to be published in November 2016. Stage 1 declared rail modelling (Rail Stage 1) is also complete with the results yet to be published. Stage 2 for declared roads and railways are expected to be completed in late 2016 and late 2017 respectively.

This paper focuses on the second round of noise modelling for declared roads. While railway noise modelling uses a different noise calculation method from roads, the noise mapping processes and issues encountered are very similar. This paper describes the modelling methodology, summarises challenges, issues and solutions, and presents the findings of a preliminary analysis of the modelling outputs.

Key terms and acronyms used in this paper are summarised below for convenient reference:

AADT - Annual Average Daily Traffic
ALOS - Advanced Land Observing Satellite
ALS - Airborne Laser Scanning
ArcMAP - Main component of Esri's ArcGIS suite of geospatial processing programs
BHM - Building Height Model
CoRTN - Formulae for the Calculation of Road Traffic Noise developed in the United Kingdom
DGM - Digital Ground Model
DTMR - Queensland Department of Transport and Main Roads
GIS - Geographical Information System
LGA - Local Government Area
MapInfo - GIS software developed by Pitney Bowes.
MLS - Mobile Laser Scanning
NCC - National Construction Code of Australia
Point cloud - A set of data points in a coordinate system representing the surface of objects
QDC MP4.4 - Qld Development Code Mandatory Part 4.4 – Buildings in Transport Noise Corridors
Qld - The State of Queensland, Australia
SoundPLAN - Noise modelling software by SoundPLAN GmbH
SRTM - Shuttle Radar Topography Mission

2. METHODOLOGY FOR ROAD NOISE MODELLING

For road traffic noise modelling, the United Kingdom Department of Transport Calculation of Road Traffic Noise (CoRTN) algorithm 1988 version was adopted. The CoRTN algorithm is well tested in Queensland and corrections for Queensland conditions were utilised in the project (Noise Code, 2013, Saunders et al 1983). The model can be represented by the following formula:

$$L = L_0 + \sum_i C_i \tag{1}$$

In this formula:

L is the calculated noise level, described by $L_{A10\ (18h)}$.

L_0 is the basic noise level, related to 18 hours traffic volume in a reference environment.

C_i are additional linear corrections, related to factors such as vehicle speed and heavy vehicle percentage, road gradient, road surface pavement type, propagation distance, angle of view, ground absorption, barrier screening and reflection.

CoRTN assumes the source of traffic noise is a line 0.5 m above the carriageway level and 3.5 m in from the nearside carriageway edge.

The following data from the DTMR data repository relating to the noise emission source was collated for both rounds of road noise modelling - annual averaged daily traffic (AADT) and growth rate, sign-posted speed, percentage of heavy vehicles and road pavement surface type. The AADT and growth rate were used to project traffic volumes for noise predictions for a 10-year horizon, as required by the QDC. This is 2020 for the first round of noise modelling and 2025 for the second round of noise modelling.

Spreadsheets can be used to carry out CoRTN calculations for simple situations, for example, those having limited road sections and simple attenuation features. Specialised software packages such as SoundPLAN are more capable in applying the various correction factors and modelling complex terrain in CoRTN.

2.1 Methodology for the first round of modelling

A spreadsheet approach was used in the first round of noise modelling. It consisted of three steps: data preparation, noise calculation and noise mapping. The data related to the noise emission source was collated and attached to the road centrelines as attributes. Assumptions were made for some road sections to correct unsustainable traffic growth rates when predicting future traffic volumes.

Noise calculations were conducted using a spreadsheet. A simplified version of the CoRTN formula, considering only the emission data, gradient and receptor distances, was coded using Visual Basic to calculate the noise category extents from each road centreline. The calculated extents were then imported into GIS software (MapInfo) to produce the four noise category contours by creating buffers around the road centrelines.

The spreadsheet approach assumed noise was emitted from a road section with an infinite length and perpendicular to the receptor location. It did not consider the contributions from other road sections. The receptors had an angle of view of 180 degrees. The height of the receptors was 1.8m above the ground. Hard ground was assumed for the ground absorption. Low traffic flow correction was not considered.

This approach produced noise contours parallel to the road centrelines. While they are easy to understand, the results tend to be conservative in some circumstances due to lack of consideration of the noise attenuation effects along the noise propagation path.

2.2 Methodology for the second round of modelling

The second round of noise modelling aimed to improve the modelling accuracy by considering terrain, existing noise barriers and buildings. SoundPLAN Version 7.4 was selected as the modelling tool to implement the CoRTN algorithm. The noise re-modelling process is shown in Figure 1. It consisted of three steps: data preparation, noise modelling and post processing.

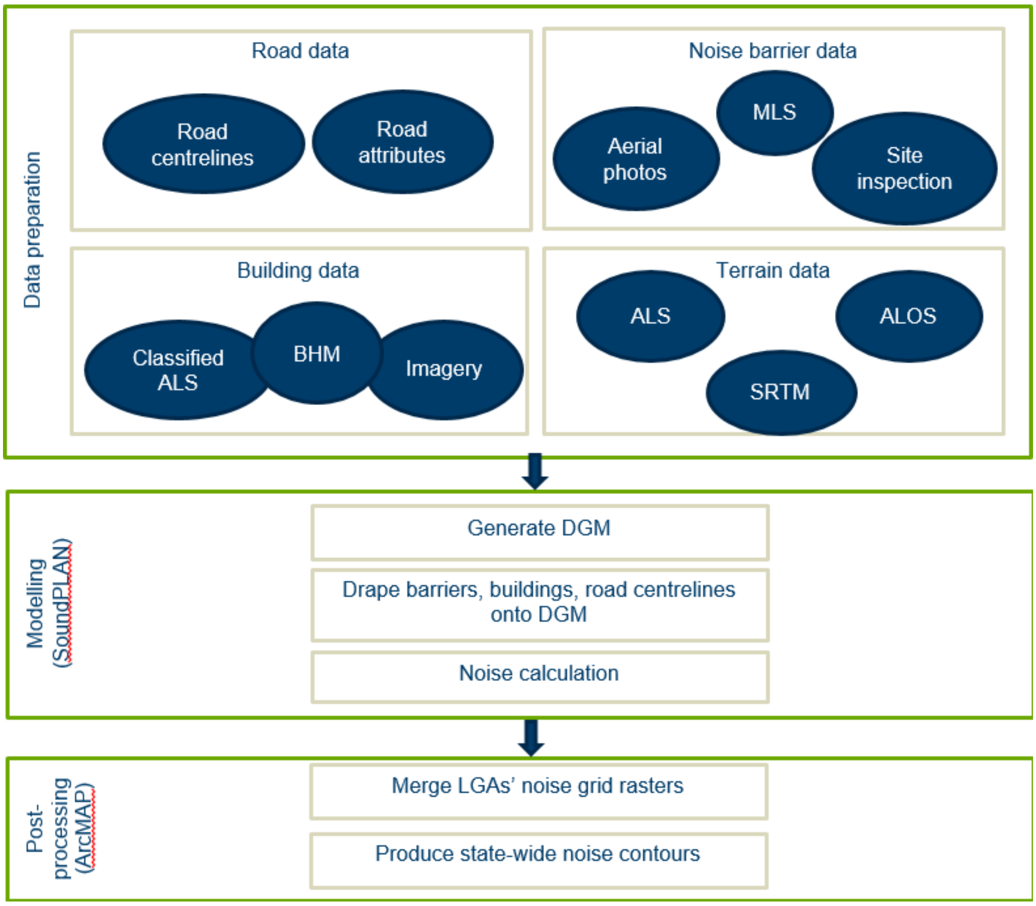

Figure 1: Process for road noise modelling and mapping

2.2.1 Data preparation

The input data for re-modelling contained four elements: road data, existing noise barriers, existing buildings and terrain data. The road data was prepared in the same way as the first round of modelling. It was collated and processed if necessary, then attached as attributes to the centrelines of the State-controlled roads.

Existing noise barrier data was collected mainly from desktop studies. MapInfo was used to digitise noise barrier alignments as polylines based on aerial photos, DTMR video records and cadastral boundaries. The barrier heights were also estimated in the process. Some barrier information was collected from site inspection during barrier condition surveys. Both DTMR and developers' noise barriers were identified as far as possible and included in the modelling.

Existing buildings adjacent to the State-controlled roads were identified from classified Airborne Laser Scanning (ALS) data and imagery. Polygons representing the building footprints were built using a combination of automated extraction from the classified ALS and manual digitising. A Building Height Model (BHM) was generated using the difference between the mean height within the building footprint and the adjacent bare earth Digital Ground Model (DGM).

Terrain data preparation was the most time consuming task in the data preparation process. The terrain elevation data was collected from different sources. For Road Stage 1, year 2014 ALS data was used in the coastal areas and year 2000 Shuttle Radar Topography Mission (SRTM) Version 1.0 data was used in the inland areas of Queensland. The data was processed in ArcMAP software to generate a DGM. The DGM has stepped resolutions for the corridor up to 500 m each side of the road, with 1 m spacing from 0 to 25 m, 2.5 m spacing from 25 m to 50 m, and 5 m spacing from 50 m to 500 m. The terrain was produced in a comma separate value (CSV) file format, with each line identifying a height at a specific coordinate. The SRTM data will be replaced by Advanced Land Observing Satellite (ALOS) data in Stage 2. The input data used for each round of noise modelling are summarised in Table 1.

Table 1: Input data for each round of noise modelling

Round / Stage	Roads	Barriers	Buildings	Terrain
Round 1	2D	No	No	No
Round 2: Stage 1	3D	Yes	No	ALS and SRTM
Round 2: Stage 2	3D	Yes detailed	Yes	ALS and ALOS

2.2.2 Noise modelling

Noise modelling was conducted in SoundPLAN 7.4 for each Local Government Area (LGA). The terrain data was imported into SoundPLAN and triangulated to produce a DGM that extended into any adjacent LGAs to ensure the road traffic noise level contribution from outside the LGA was considered. Road centrelines, noise barriers and buildings were then set on the DGM to assign appropriate base heights. Quality assurance (QA) was conducted to make sure the ground and above ground objects matched.

Noise calculations were carried out using the SoundPLAN Grid Noise Mapping module to produce noise levels on 5 m spaced grids. Noise calculations were completed via a suite of quad core modelling computers. Calculation times for each LGA ranged from approximately 2 hours to 2 days, depending on the size of the LGA terrain data.

The tiling function of SoundPLAN was adopted in the modelling process for preparing DGM data in the Geo-Database module, calculating noise levels in the Calculation Kernel and visualising results in the Graphics module. The tiling function allows sections of a large model to be loaded to complete the above mentioned tasks without the need to load the entire model.

2.2.3 Post-processing

The grid based calculated noise levels were exported from SoundPLAN in a raster form. ArcMAP was used to process the raster data by interpolating the raster pixel values and generate the four QDC noise category contours.

3. MODELLING RESULTS

3.1 Terrain models

Incorporating terrain and noise barriers is expected to have significantly improved the accuracy of the noise results in the second round of noise modelling. Sufficient QA was performed to ensure the accuracy of the terrain model and also the accuracy of noise barrier alignment. Figure 2 presents a snapshot of the terrain with noise barriers in a modelling area. It demonstrates that the noise barriers are placed at the appropriate locations, i.e. road edges and the top of the road cutting.

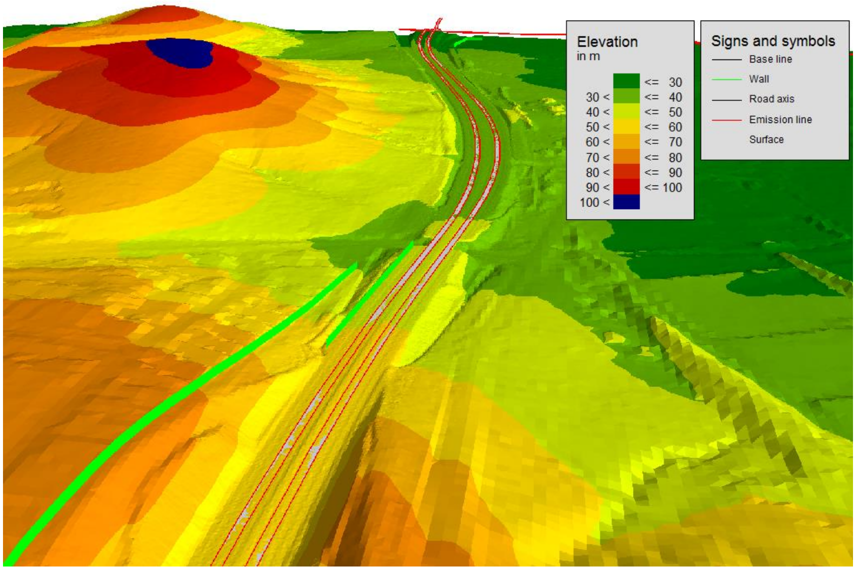

Figure 2: Terrain model with noise barriers

3.2 Noise category contours

The noise levels in the first round of modelling using the flat earth assumption were mainly affected by the road noise emission levels, scaled by propagation distances. The noise levels in the second round of modelling were affected by not only the road noise emission levels and propagation distance, but also the noise attenuation due to terrain and barriers.

For a selected road section, Figure 3 illustrates the QDC noise category contours from the first round of modelling, while Figure 4 represents the second round of modelling.

Figure 3: QDC noise contours from the first round of modelling

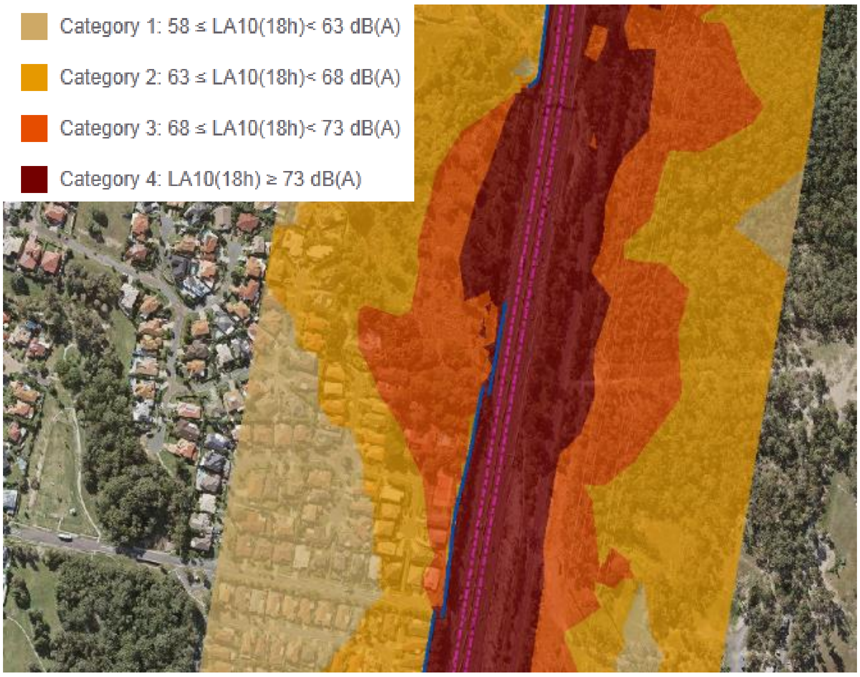

Figure 4: QDC noise contours from the second round of modelling

It is evident from Figure 4 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.

3.3 Comparisons of noise category changes

The second round of noise modelling appears to produce more accurate and realistic acoustic attenuation requirements for the affected properties. As a result of the re-modelling, it was generally found that the number of properties within higher noise categories was reduced. Analysis was conducted to compare the change in the number of properties within the noise categories from the two rounds of modelling for the entire State. Table 2 shows the results for the State for mandatory noise corridors only. The year 2016 study area was taken as a base to ensure the percentages are comparable between round 1 and 2 results.

It was found that State-wide, a 28.5 % and 7.3% reduction was achieved for the number of properties within noise category 4 and 3 respectively. A 38 .5 % and 7.2 % increase was recorded for noise category 1 and 2 respectively. The increase in numbers for noise category 1 was primarily due to the number of properties formerly within higher categories being downgraded to the lower noise categories. These numbers varied within each LGA.

In accordance with QDC MP4.4, a new development in noise category 1 normally requires minimal additional building attenuation above standard construction. Properties within category 2 and above require further noise mitigation measures. For mandatory noise corridors throughout the State of Queensland, the number of residential properties with a noise category of 2 or above was lowered by approximately 8.4 %, equivalent to approximately 15 000 properties.

Table 2: Percentage of allotments within TNC noise categories

TNC Year	Percentage of Allotments within TNC Noise Category (Mandatory Noise Corridors)				
	0	1	2	3	4
2010	6.7%	17.7%	28.1%	24.2%	23.4%
2016	6.3%	24.5%	30.1%	22.4%	16.7%
% Change from 2010	-	38.5%	7.2%	-7.3%	-28.5%

4. ISSUES AND LEARNINGS

It was found that data preparation, particularly for terrain data, accounted for the majority of time and resources of the project. Time required to set up and compute the noise models was not as high as initially expected. The project became more of an exercise in data management, than of noise modelling and mapping.

4.1 Data and file management

Noise modelling was conducted for the entire network of State-controlled roads across Queensland with a total length of approximately 34 850 km. Terrain data was prepared up to 500 m on each side of the roads. This resulted in a 64 GB dataset containing over 4 billion spot heights.

The large quantity of terrain data, together with the road centrelines, noise barrier and building data, required an effective data management solution. This was achieved through LGA based data preparation, use of the tiling function within SoundPLAN and appropriate file management.

- LGA based data preparation

To make data manageable, terrain data was normally prepared and modelled on an LGA basis. State-controlled roads within 65 LGAs were modelled. The Universal Transverse Mercator mapping system divides Australia into zones which each cover 6 degrees of longitude. Where an LGA crossed multiple zones, it was split into multiple terrain datasets. In some cases small LGAs were combined. This resulted in 68 areas being modelled individually in SoundPLAN.

- Tiling function

A single terrain dataset for a 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 on tiles within an LGA.

- File management

The same arrangement of file structures and naming conventions was maintained for each of the LGA datasets and model settings. This consistent approach was of critical importance to maintain data integrity during the entire modelling process from data preparation, modelling to post processing.

4.2 Terrain data processing

Two sources of terrain data were used in the Stage 1 road traffic noise modelling, with ALS data in the coastal area and SRTM data in the inland area. The ALS data has 1 m by 1 m grids and the height of the grid points is considered as the true representation of the bare earth spot height. SRTM data has a 1 arc-second resolution (approximately 30 m by 30 m grids) and the height of the grid points are considered coarse.

Data manipulation was not necessary for the ALS data due to its high level of accuracy. Resampling was applied to the SRTM raster cells from 30 m to 1 m resolution. It produced a terrain model with the same staggered horizontal resolutions in the SRTM areas as in the ALS areas.

The transition from ALS to SRTM areas created a significant terrain discontinuity at the boundary between the two datasets. An algorithm was applied to the transitional zones with the width dependent on the data height difference to maintain a terrain gradient within 5%. An artificial flat surface was also created for the road and verges. This removed the undulation of the terrain due to data variation in the SRTM areas.

4.3 Bridges and culverts

The terrain used in this project was based on the DGM which ignored all features sitting above, such as barriers, buildings and bridges. When the road centreline was set on the terrain, the road sometimes had an incorrect vertical profile. This was particularly the case where bridges or sometimes culverts were present. Where bridges or culverts were not part of the terrain, sharp changes to road gradients may cause unreasonable increases to calculated noise levels.

SoundPLAN functions were explored to correct the terrain in the bridge areas. The gradient detection function was applied to isolate road sections with sharp gradient changes. Then a smoothing function was applied to the subject road sections. This resulted in road sections raised around the bridge but lowered in the neighbouring areas. It was found, however, that the lowering of elevation to the neighbouring road segments sometimes placed the road underneath the local ground surface to an unacceptable level.

The SoundPLAN functions for correcting terrain vertical inaccuracies due to bridges were eventually abandoned and a manual method was adopted. Where a section of road was located on a man-made structure or below an overpass or bridge, this section of road was adjusted to be consistent with the surrounding road elevation.

4.4 Road alignments

The road centrelines were taken from DTMR horizontal alignment mapping. It was found that occasionally the road centreline strings were displaced horizontally and failed to match the terrain underneath, which sometimes caused sharp increases in gradients. Manual adjustments were applied to bring the road strings to the right locations.

The road centrelines initially had nodes spaced at variable distances with straight lines between nodes. When placing these nodes on the DGM, the undulating terrain between the nodes could rise above or fall below the straight road segments. This could potentially impact the road traffic noise from those road sections. To resolve this issue, additional nodes at 30 m intervals were introduced into the 2D road polylines and the roads were re-set to the DGM to ensure the road segments followed the variation in height of the ground surface.

4.5 Noise barriers

Noise barrier data was mainly collected from desktop studies. The barrier alignments were digitised as polylines in MapInfo. The barrier heights were also estimated during the same process. While great efforts were made to maintain the accuracy of the horizontal alignment of barriers, misalignment can happen due to human error and distortion in the base aerial photographs. This is accentuated when the noise barrier sits on a retaining wall, mound or near steep changes in terrain height. A minor shift could place the barrier much lower than where it should be and result in reduction of noise attenuation effects. All the noise barriers were reviewed in a GIS environment together with the 3D terrain to ensure the correct footprint locations.

5. FUTURE DEVELOPMENT

The following issues were identified from the development of Stage 1 road traffic noise modelling and are expected to be addressed in Stage 2.

5.1 Improvement of input data

The road centrelines and road data were subject to strict QA checking when being collected by DTMR. They are normally accepted for modelling without a requirement for ground truthing. However reasonable assumptions were made to adjust some of the data, for example adjusting the traffic growth rate to make the future AADT reasonable.

Using more accurate terrain is more likely to be of benefit for result accuracy, particularly for the inland area of Queensland. In Stage 2, the SRTM data will be replaced by ALOS data with an improved accuracy and horizontal data grid spacing of 5 m by 5 m.

5.2 Inclusion of additional data

In Road Stage 1, through carriageways are modelled, but not the ramp roads. Major ramp roads, particularly those adjacent to residential areas will be included in Stage 2. Traffic data for ramp roads are generally not collected by DTMR. A manual process will be used to estimate ramp data by reference to the adjacent major carriageways.

Concrete safety barriers were excluded from Stage 1, but known to have noise attenuation effects. The same process used for identifying noise barriers is to be applied for existing concrete safety barriers to include them in Stage 2 modelling.

The technology of Mobile Laser Scanning (MLS) offers another option for extracting noise barrier data. The MLS point cloud data includes the points for the top strings of noise barriers. When extracted, the top strings represent the actual barrier alignment and height. However MLS is unable to capture any barrier sections obscured by vegetation, resulting in fragmented point cloud data for barrier top strings. The missing sections of the barriers need to be added manually. Where noise barrier information is available from point cloud data, it will be incorporated into the noise model.

5.3 Modelling outputs

Road Stage 1 generates the noise category contours at the building ground levels only. There is a need to prepare noise contours for both ground floors and first floors. This will be achieved in the coming modelling stages for both road and rail, with no extra resources expected except increased computing time. For a development with multiple storeys, site-specific acoustic assessment would normally be required to identify noise levels for all the floors.

6. CONCLUSIONS

A detailed noise modelling project for the State-controlled road network has been completed for Queensland. The modelling is continuing to another stage to incorporate additional data to further improve the modelling accuracy. A similar approach is also being applied to a major part of the state railway system.

The large scale noise modelling covers all the State-controlled roads across Queensland and is believed to be the world's largest detailed noise mapping exercise. The input data for the project came from different sources. Collecting and processing these data needed collaboration from a team with expertise in both acoustics and GIS. Major 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 were the keys to the success of the project.

The results of the modelling provides direct support for the implementation of QDC MP4.4 for the building industry. The output is also expected to find use in much wider areas. In DTMR, the noise contours and the data collected through the project should assist in the daily management of transport noise issues. For example, they can be used in evaluating the effectiveness of existing noise barrier heights, managing and planning of noise barrier assets, assisting in the assessment of development applications, and management of noise complaints. Externally to DTMR, 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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