ACOUSTICS 2017 PERTH
SOUND, SCIENCE AND SOCIETY

Strategic Mapping of Road Traffic Noise in Auckland, New Zealand

Nick Henrys[(1)]

(1) Resonate Acoustics

ABSTRACT

A model was developed to quantify road traffic noise levels and potential health effects associated with this noise, in Auckland, New Zealand. The model used traffic volume, road geometry and building data as inputs to predict the noise level at the façade of every building in the area of interest. All local, arterial and state highway roads with an average daily traffic volume of 5,000 vehicles or more were included. The results were then post-processed using 2013 census data to determine population statistics. Established relationships for sleep disturbance and annoyance were used to derive the percentage of people affected within each census area, and across the city as a whole. Based on this analysis approximately 27,600 people are potentially highly sleep disturbed and 48,800 people are potentially highly annoyed due to current road traffic noise. This represents approximately 1.95% and 3.45% of the total Auckland population respectively. There is opportunity to further refine the model, for example by including topography, to reduce uncertainty associated with the results.

1 INTRODUCTION

There is a growing body of evidence regarding the health effects of environmental noise, and in particular noise from road traffic (Fritschi, Brown, Kim, Schwela, & Kephalopolous, 2011). Health effects can be direct, such as cardiovascular disease; or indirect, for example resulting from annoyance, sleep disturbance, and interference with communication (Welch, et al., 2013).

A number of studies have formulated exposure response relationships for road traffic noise in urban areas. Relationships for sleep disturbance (Miedema, Passchier-Vermeer, & Vos, 2002) and annoyance (Miedema & Oudshoorn, 2001) are well established and are based on meta-analyses of epidemiological studies with large sample sizes (Figure 1 and 2).

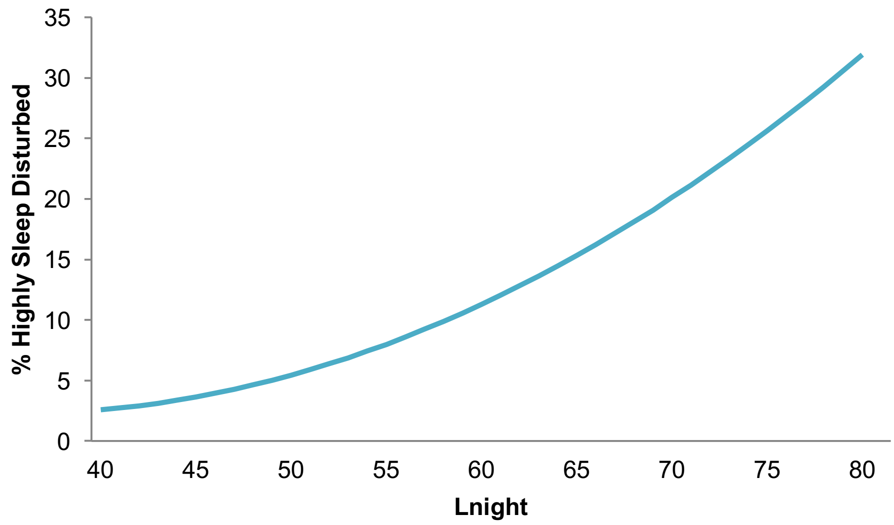

Figure 1: Relationship between L_{night}[1] and percentage of the population highly sleep disturbed due to road traffic noise (Miedema, Passchier-Vermeer, & Vos, 2002)

[1] A-weighted L_{eq} sound level in dB averaged between the hours of 23:00 to 0:700

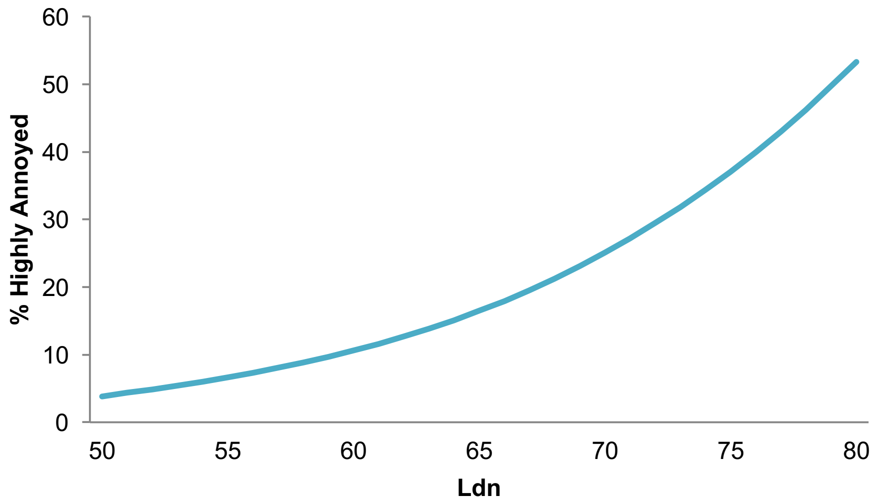

Figure 2: Relationship between L_{dn}[2] and percentage of the population highly annoyed by road traffic noise (Miedema & Oudshoorn, 2001)

It should be noted that the above relationships are based on averaged noise from ‘bulk’ traffic flow, that is, a reasonably continuous stream of vehicles. Individual vehicles can produce elevated noise levels, for example from a modified exhaust, engine brakes, or emergency sirens and the like. This can also result in sleep disturbance and annoyance but is difficult to predict because of the random nature of occurrences.

The body of evidence on the association between road traffic and cardiovascular diseases and cognitive impairment in children is growing. However, exposure response relationships for these health effects are not well defined compared to those for annoyance and sleep disturbance (Fritschi, Brown, Kim, Schwela, & Kephalopolous, 2011).

The European Noise Directive (European Parliament, 2002) required member states to develop action plans to reduce environmental noise, informed by strategic noise mapping for cities with more than 250,000 people. Subsequently computer-based noise models have been developed for many cities in Europe and to a lesser degree in other continents. With advances in computer processing speed and software, the ability to produce noise models covering large geographical areas has improved significantly in the past two decades.

Strategic noise mapping of Auckland’s motorway network has been undertaken in 2009 and again in 2012 (Hannaby, Chiles, Worts, Whitlock, & Haigh, 2014). The focus of these mapping exercises was the motorway and state highway network only, rather than arterial and other local roads, with the intention of identifying priority areas for structural mitigation such as noise barriers.

Whilst the motorway network carries high traffic volumes at relatively high speeds, it is hypothesised that a significant population is exposed to elevated traffic noise from arterial and other local roads for a number of reasons:

- There is limited ability to implement structural mitigation such as barriers due to severance of access;

[2] Day-night equivalent level: A-weighted L_{eq} sound level in dB, averaged over 24 hours with a 10 dB penalty applied to the hours of 23:00 to 07:00.

- Buildings are often found at a higher density and are typically located in closer proximity to local roads compared to motorways;
- Land use planning measures, for example limiting residential development or requiring acoustic insulation to noise-sensitive buildings, has historically been more rigorously applied near the motorway and state highway network in New Zealand;
- The total length of the local road network in Auckland is large compared to the state highway network.

Whilst the ability to implement structural traffic noise mitigation on arterial and local roads is limited, a number of other interventions are available to road controlling and planning authorities to reduce noise exposure in some circumstances, for example:

- Diversion of road traffic away from high population areas;
- Measures to limit traffic speed and volumes, likely implemented in parallel with provision of infrastructure to facilitate alternative transport options such as public transport and cycling;
- Legislating, incentivising and encouraging the use of low noise emission vehicles, for example electric vehicles;
- Land use planning measures to limit new noise-sensitive development near high volume roads, or requirements for minimum levels of acoustic insulation.

For the first time in New Zealand, the present study attempts to quantify road traffic noise levels throughout an entire urban area. These results are used to estimate populations likely to be affected by sleep disturbance and annoyance. These results will be valuable in decision-making processes, in particularly cost-benefit analyses of the above interventions.

2 METHODOLOGY

2.1 Inputs

Traffic and road data were sourced from the New Zealand Road Assessment and Maintenance (RAMM) database for each carriageway section in the Auckland Region as follows:

Table 1: Noise model input data

Data	Details
Traffic volumes	Average daily traffic (ADT) derived from counts or estimates. Where available, 7-day averages were used rather than weekday averages. ADT is assumed to be approximately equivalent to average annual daily traffic (AADT) for the purpose of this study.
Heavy commercial vehicles (HCV)	Expressed as a percentage of total traffic volume in ADT
Road surface	Road surface and grade (for example two-coat chip seal grade 4/6; asphaltic concrete (AC) grade 10; open graded porous asphalt (OGPA) grade 10)
Road width	Total width of all traffic lanes in metres

Traffic speed data could not be obtained and were therefore assumed to be the typical posted speed limit of 50 km/h for local roads and 100 km/h for State Highways. An assumed speed limit of 50 km/h for local roads will likely underestimate noise exposure as some arterial routes have higher speeds.

The road geometry was provided as a shapefile representing the centreline of each carriageway section. Roads were filtered to remove any with an ADT of less than 5000 vehicles per day to reduce calculation time. The extent of the remaining network can be seen in Figure 3 and represents some 1534 km of road, 402 km of which is classified as state highways.

Building footprint and height data were supplied by Auckland Council and were originally derived from aerial photography and LiDAR surveys carried out between 2008 and 2013.

Whilst terrain elevation data are available at high resolution for the study area, road elevation data including locations and heights of bridges and overpasses could not be obtained. Manual entry of these features was considered excessively time consuming. Incorrect or inaccurate definition of these features can lead to high road slopes, which in turn can result in significant errors in road traffic noise calculation. On this basis a 2.5D model with a flat terrain and extruded buildings was produced.

Comprehensive data containing the locations and heights of noise barriers were also unavailable, so these were not included in the noise model. This will likely result in over-estimation of exposure from some state highway sections.

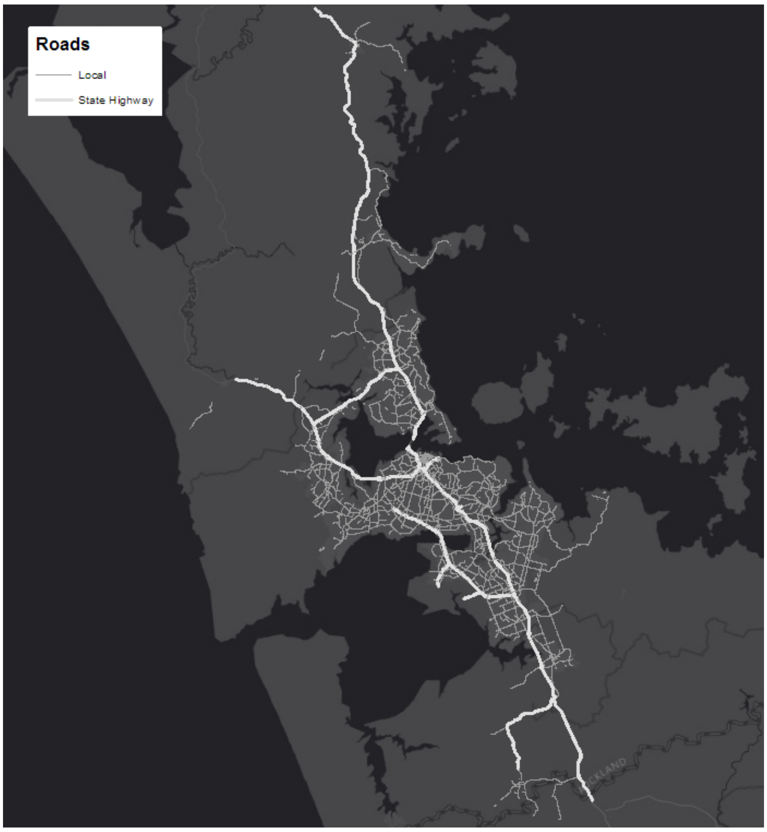

Figure 3: Auckland road network, ADT greater than or equal to 5000 vehicles per day

2.2 Noise model

Road traffic noise modelling was conducted using SoundPLAN 7.4 software implementing the UK Calculation of Road Traffic Noise (CoRTN) calculation algorithm (DoT, 1988). This calculation method is widely used in New Zealand, Australia and the United Kingdom, although other methods are commonplace elsewhere, for example the NMPB method in France and the German RLS method (Murphy & King, 2010).The CoRTN method takes into account the average daily traffic volume, the percentage of heavy vehicles, road gradient, and road surface. Propagation effects such as screening (for example from buildings), reflections and ground absorption are also included. A road surface adjustment specific to New Zealand conditions was made in accordance with (Dravitzki & Kvatch, 2007).

Sound pressure levels due to road traffic noise emissions were predicted 1m from the centre of each building façade, 1.8m above ground level. Only buildings within 100m of roads carrying average daily traffic volumes of 5000 or more were included in the calculation. It is expected that traffic noise levels at greater distances are lower than the levels typically associated with adverse health effects. Traffic noise levels were not calculated at the façade of buildings with a footprint area of less than 50 m^2, as these are not likely to contain dwellings, although these were still included in the model as they may provide screening or reflection. Noise levels were predicted at a total of 157,734 buildings.

2.3 Post-processing

The CoRTN algorithm produces a noise level in dB $L_{A10(18hr)}$. This can be converted to $L_{Aeq(24hr)}$ using the relationship established in (Nelson, 1987), assuming the majority of traffic flow is between 6:00am and midnight.

$$L_{Aeq(24\,hr)} = L_{A10(18\,hr)} - 3\;dB$$

L_{Night} and L_{den} levels for comparison with sleep disturbance and annoyance relationships can be derived from the $L_{Aeq(24hr)}$ levels if the temporal variation of traffic volumes are known. Hourly traffic data from 2013 to 2014 were collected at an Auckland Harbour Bridge counter site by the New Zealand Transport Agency and are shown below.

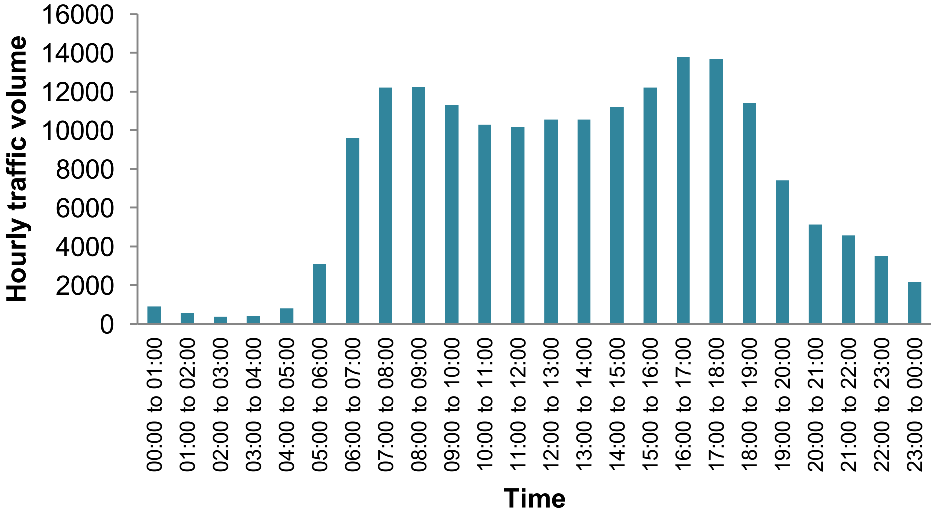

Figure 4: Auckland Harbour Bridge hourly traffic volumes, 2013-2014

Hourly traffic volumes were not available for other locations so the temporal distribution of traffic is assumed to be reasonably similar throughout the network. The percentage of HCVs is also assumed to be constant throughout an average day. Based on these data, L_{night} is 5.2 dB lower than $L_{Aeq(24)}$, on average; while L_{dn} is 3.2 dB higher (due to the 10 dB penalty applied to night time noise for this metric).

Noise modelling results were used to estimate the population exposed to various levels of road traffic noise, using data from the 2013 New Zealand Census (Statistics New Zealand, 2013). Usually resident population per census meshblock[3] were extracted for the study area. This was then divided by the number of buildings in each meshblock to determine a mean population per building. Buildings less than 50 m^2 were also excluded from this analysis for the reasons given previously. Based on this analysis, the buildings included for calculation in the noise model have a total of 495,576 residents, representing approximately 35% of the total Auckland population of 1,415,550 counted as usually resident in the 2013 census.

3 RESULTS

A histogram of modelled noise levels at the most exposed façade of each building, in 1 dB intervals, is shown in Figure 5. A distinctive bi-modal distribution can be seen, with the right peak likely representing first row of buildings adjacent to the road and left peak representing all other buildings set back further from the road and 'shielded' to some degree by the buildings in front. This is demonstrated in Figure 6, where noise levels at the first row of buildings are typically at least 15 dB higher than the next row.

However, it is also likely that the exclusion of roads with an average volume of less than 5000 vehicles per day has influenced the distribution. Noise levels at the first row of buildings adjacent to these excluded roads are

[3] Meshblocks are defined as "the smallest geographic unit for which statistical data is collected and processed by Statistics New Zealand".

generally 60 dB $L_{Aeq(24hr)}$ or less. The addition of these roads to the model would therefore be expected to reduce the degree of bi-modality. The exclusion of buildings greater than 100m from the nearest road is also likely to have influenced the shape of the distribution.

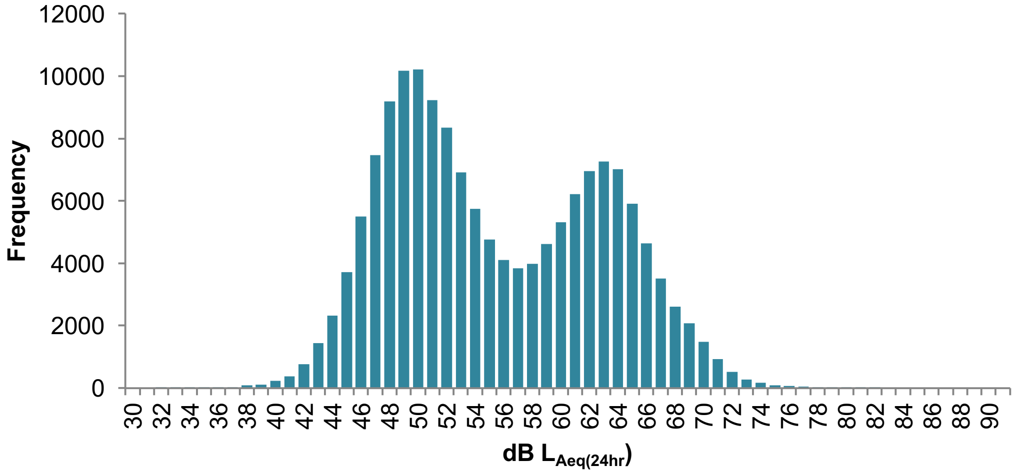

Figure 5: Histogram of road traffic noise levels at the most exposed façade of each building

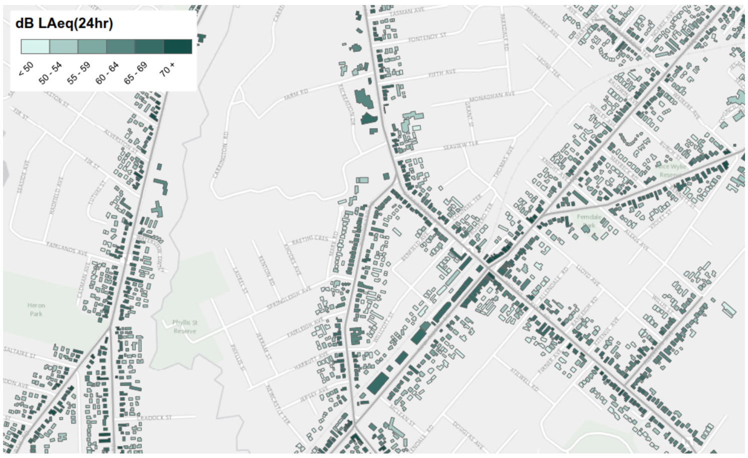

Figure 6: Sample of noise model results, Mount Albert, showing significantly higher noise levels at the first row of buildings.

The results were grouped into 5 dB interval bins, along with the mean population per building and the total population represented in each interval (Figure 7). There is an apparent positive relationship between noise level and mean population per building. This may be due to a tendency in Auckland for densely populated areas to be located close to roads carrying relatively high traffic volumes. These results are also presented in Table 2 along with the corresponding noise levels in L_{Night} and L_{dn}.

Population highly sleep disturbed and highly annoyed were calculated at an individual building level based on the relationships described in (Miedema, Passchier-Vermeer, & Vos, 2002) and (Miedema & Oudshoorn, 2001).

Table 2: Number of buildings, population and percentage of total population in 5 dB intervals

dB $L_{Aeq(24hr)}$	dB L_{Night}	dB L_{dn}	Number of buildings	Mean residents per building	Population
< 50	< 45	< 53	45,471	3.05	138,542
50-54	45-49	53-57	38,126	3.11	118,575
55-59	50-54	58-62	21,186	3.02	64,009
60-64	55-59	63-67	33,175	3.10	102,904
65-69	60-64	68-72	16,780	3.57	60,023
≥ 70	≥ 65	≥ 73	2,984	3.83	11,442
TOTAL			**157,734**	**3.14**	**495,576**

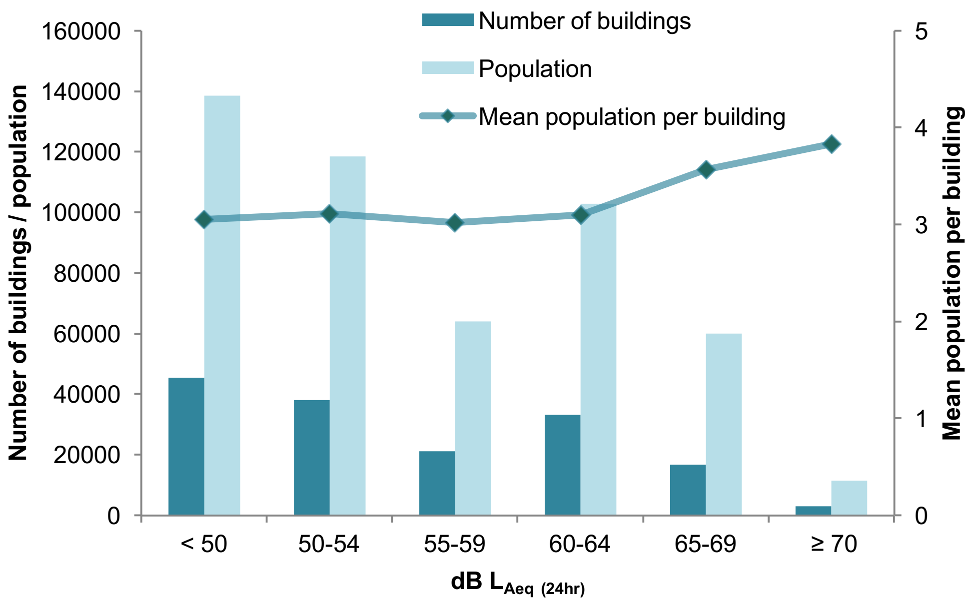

Figure 7: Number of buildings and population in 5 dB intervals

Figure 8: Spatial distribution of population highly sleep disturbed, Auckland Isthmus

The highly sleep disturbed population per census meshblock for an area of the city is shown in Figure 8. As expected, areas with high population density such as the city centre and Newmarket have high concentrations of people affected by road traffic noise. Meshblocks with relatively high numbers of people highly sleep disturbed are not confined to areas adjacent to state highways, but also include many residential areas near arterial roads.

Based on this analysis a total of 27,615 people are highly sleep disturbed and 48,766 people are highly annoyed due to road traffic noise throughout the Auckland region. This represents 1.95% and 3.45% of the total Auckland population of 1,415,550 counted as usually resident in the 2013 census.

4 DISCUSSION

While this study used established methods to calculate the numbers of people highly sleep disturbed or highly annoyed due to road traffic noise, these results should be treated as approximations for a number of reasons:

- The exposure response relationships formulated by (Miedema, Passchier-Vermeer, & Vos, 2002) and (Miedema & Oudshoorn, 2001) are largely based on European studies. There have been no large scale epidemiological studies of this kind which take into account New Zealand conditions, for example any relevant differences in typical dwelling construction compared to European homes. New Zealand houses are generally considered to be poorly insulated (both acoustically and thermally), however in recent years acoustic insulation requirements have been enforced in city centre, mixed use and other areas where there are high ambient noise levels.
- The model assumes flat terrain while in reality Auckland is known to have undulating topography. Topography can affect the noise source level, as traffic noise is greater when vehicles are travelling up a gradient; and by either screening or increasing the exposure of dwellings to noise.
- Some sections of State Highway have noise barriers, which were not included in the model. This is likely to have resulted in overestimation of noise levels at some buildings in close proximity to these areas. Barriers are generally only constructed where multiple buildings are exposed to noise levels from state highways of 65 dB $L_{Aeq(24\ hour)}$ or more.
- The temporal distribution of traffic throughout an average day is based on only one count location (Auckland Harbour Bridge) in this analysis. It is expected that the actual distribution will vary from location to location and in particular between state highways and local roads. The percentage of heavy vehicles is also assumed to be constant throughout the day here, but will likely vary, with a higher proportion of heavy vehicles travelling outside of peak hours.

- Traffic volume data from the RAMM database are based on counts collected at different times of year, and many sections are only estimates based on neighbouring counts. It would be preferable to use continuous traffic monitoring data (including average vehicle speeds) collected over at least a year although the cost of collecting this data is likely prohibitive for a study area of this scale.

Overall the above factors may either increase or decrease the total number of individuals affected by road traffic noise in different areas. The citywide results are considered to be in the correct order of magnitude, although further work, possibly including verification measurements, may be required to more accurately quantify the margin of error.

On the basis of these results alone, there is a strong case for investigation of road traffic noise mitigation options in some areas, including traffic calming measures, land use planning tools, and measures to increase the adoption of quieter vehicles. In the short term, implementing acoustic insulation requirements for new noise sensitive activities near high volume roads is likely to be achievable.

In the medium to long-term, increasing numbers of electric vehicles is expected to reduce traffic noise levels near low speed urban roads. The reduction is negligible near high speed roads where tyre noise is dominant over engine noise. Land use planning measures are therefore an appropriate tool to limit noise sensitive development in the vicinity of state highways. Further investigation into the health effects of road traffic noise in Auckland and other urban centres is recommended. Ideally this would include other known health effects such as cardiovascular diseases and cognitive impairment in children, in addition to further work to verify the number of people sleep disturbed and annoyed.

5 CONCLUSIONS

The population highly sleep disturbed and highly annoyed by road traffic noise in Auckland has been estimated using established calculation methods and exposure response relationships. A considerable number of people are likely to be adversely affected, warranting investigation into noise mitigation measures or at the very least, inclusion of road traffic noise as an important factor in transport and land use planning decisions.

Further research could include quantification of other known road traffic noise health effects not considered in detail in this study, such as cardiovascular disease. This work could also include other cities in Australasia, where there has been very little strategic noise mapping programmes implemented to date. There is also potential for further refinement and validation of the calculation methodology.

REFERENCES

DoT, U. K. (1988). Calculation of Road Traffic Noise (CoRTN). Department of Transport (Welsh Office), HMSO, London.

Dravitzki, V. K., & Kvatch, I. (2007). Road Surface Effects on Traffic Noise: Stage 3: Selected Bituminous Mixes. Land Transport New Zealand.

European Parliament. (2002). Directive 2002/49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. Official Journal of the European Communities, 189, 2002.

Fritschi, L., Brown, L., Kim, R., Schwela, D., & Kephalopolous, S. (2011). Burden of disease from environmental noise: Quantification of healthy years life lost in Europe. World Health Organisation.

Hannaby, R., Chiles, S., Worts, C., Whitlock, J., & Haigh, A. (2014). State highway noise mapping: Auckland motorways case study. ARRB Conference, 26th, 2014, Sydney, New South Wales, Australia.

Miedema, H. M., & Oudshoorn, C. G. (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environmental health perspectives, 109, 409.

Miedema, H. M., Passchier-Vermeer, W., & Vos, H. (2002). Elements for a position paper on night-time transportation noise and sleep disturbance. TNO Inro.

Murphy, E., & King, E. A. (2010). Strategic environmental noise mapping: Methodological issues concerning the implementation of the EU Environmental Noise Directive and their policy implications. Environment international, 36, 290-298.

Nelson, P. M. (1987). Transportation noise reference book. (P. M. Nelson, Ed.) Butterworth-Heinemann.

Statistics New Zealand. (2013). Census usually resident population counts. Statistics New Zealand.

Welch, D., Shepherd, D., Dirks, K. N., McBride, D., Marsh, S., & others. (2013). Road traffic noise and health-related quality of life: A cross-sectional study. Noise and health, 15, 224.