Measuring the environmental performance of Melbourne's road network

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ABSTRACT
In 2015, VicRoads commenced a programme to monitor the environmental performance of Melbourne's road network. Three freeways and three arterial roads were selected across metropolitan Melbourne for the installation of noise and air quality monitors. The locations were chosen for their representation of major roads in Melbourne, the availability of actual traffic data and the lack of interference from other sources of pollution. Hourly noise levels are collected continuously and NO_2 emissions are measured by means of diffusion tubes. The monitoring programme is detailed here and results with preliminary findings from the first months of noise monitoring are introduced.

1. INTRODUCTION
Long term noise and air quality monitoring is instrumental to the understanding of trends in noise and air pollutant emission, the validation and improvement of emission mapping and ultimately strategic planning and reporting. While monitoring networks have been in place for many airports, a number of cities around the world have implemented permanent urban noise monitoring. More specifically, Madrid in Spain and Brussels in Belgium have pioneered the development of permanent noise measurements networks (Vincent, Fradet & Porcheron 2009).

A number of 'noise observatories' have been established in Europe. They integrate noise mapping, monitoring and perceptive surveys so as to provide a better understanding of the factors that affect the noise environment, to evaluate benefits and impacts of planning decisions and to inform the public (Vincent et al. 2011, Bruitparif 2014). They are sometimes coordinated closely with air quality studies (Miège et al. 2012).

In response to the increasing concerns about the health impacts of noise and air quality along the road network, VicRoads initiated a monitoring programme. Noise and air quality monitoring stations were installed in November 2015 at six strategic locations chosen for their representation of major roads in metropolitan Melbourne. The monitoring is not for compliance purposes, but to provide a better understanding of network performance in terms of the generation of noise and $N0_2$ (as a proxy of traffic related emissions). The programme is scheduled for a duration of at least 12 months.

This paper summarises the installation of the monitoring stations, and introduces findings from the first months of noise monitoring.

2. MONITORING STATIONS

2.1 Locations
The six monitoring locations were chosen to represent the diversity in typology of major roads in metropolitan Melbourne. They include three freeways (Eastern Freeway, Monash Freeway and Western Ring Road), two inner arterial highways (Ballarat Road, Hoddle Street) and one outer arterial (South Gippsland Highway). Location details are listed in Table 1. The specific locations were selected for their proximity to traffic counters, after consideration of a number of practical factors which included:

- Absence of other sources of pollution that would compromise the data gathered
- Land accessibility (the stations were located on roadside land owned by VicRoads)
- Safe distance from traffic (to allow safe access by the operators, but also to ensure they do not constitute a roadside hazard)
- Sufficient clearance from overhead and underground services

The installation locations and a photograph of a monitoring station are shown in Figure 1. Details of each of the six sites are given in Tables 1 and 2.

Table 1: Installation details

Site	Road and suburb	Distance from road	Microphone Height*	Nearest lane	Notes
1	Eastern Freeway, Balwyn North	15m	3.5m	Eastbound	-
2	Monash Freeway, Chadstone	12m	3.5m	Eastbound	-
3	Western Ring Road, Sunshine West	21m	3.5m	South-eastbound	Road in a cut, curve
4	Hoddle Street, Collingwood	15m	3.5m	Northbound	-
5	Ballarat Road, Footscray	11m	3.5m	Westbound	Curve
6	South Gippsland Highway, Cranbourne	11m	3.5m	Northbound	-

* The height reported here is measured above ground at the location where the monitoring station is installed (it is not the height with respect to the road level)

Table 2: Monitoring locations, road typology and characteristics

Site	Road and suburb	Typology	Speed limit km/h	Daily volume and % Heavy vehicles	Pavement surface
1	Eastern Freeway, Balwyn North	Freeway 2x4 lanes	100	62,000 EB (4%) / 63,000 WB (4%)	Open graded asphalt
2	Monash Freeway, Chadstone	Freeway 2x4 lanes	100	86,000 EB (9%) / 86,000 WB (9%)	Open graded asphalt
3	Western Ring Road, Sunshine West	Freeway 4+3 lanes	100	64,000 SEB (11%) / 64,000 NWB (11%)	Open graded asphalt
4	Hoddle Street, Collingwood	Inner arterial 4+3 lanes	70	40,000 NB (4%) / 34,000 SB (8%)	Dense graded asphalt and stone mastic asphalt
5	Ballarat Road, Footscray	Inner arterial 2x2 lanes	70	18,000 EB (4%) / 18,000 WB (3%)	Dense graded asphalt
6	South Gippsland Highway, Cranbourne	Outer arterial 2+3 lanes	80	17,000 NB (5%) / 17,000 SB (6%)	Spray seal

Figure 1: Distribution of the monitoring sites across the metropolitan Melbourne road network and photograph of a monitoring station

2.2 Monitoring system

The noise monitoring stations consist of Type 1 sound level meters equipped with windshields and remote communication interface and record continuously hourly noise levels. The sound level meters were calibrated to the requirements of IEC 61672-1 (International Electrotechnical Commission 2013) prior to installation. Electrical calibration checks are conducted daily, and field calibration checks are conducted quarterly for two frequencies (250 Hz and 1 kHz) to ensure reliability of the noise level measurements.

Air quality is assessed utilising passive sampling tubes which are collected monthly to measure nitrogen dioxide (NO_2). Additionally, the monitoring equipment includes weather stations that record temperature, atmospheric pressure, wind speed, wind direction and rainfall. The weather stations have been calibrated to the requirements of AS/NZS 3580.14 (Standards Australia 2014).

Traffic data is collected by counters that record the number of vehicles in each individual lane and provide speed estimations in specific ranges. Due to the resolution of the speed ranges that are concentrated on values around the speed limit, these estimations are of limited accuracy when traffic speeds are much lower or are higher and should be considered as indicative only.

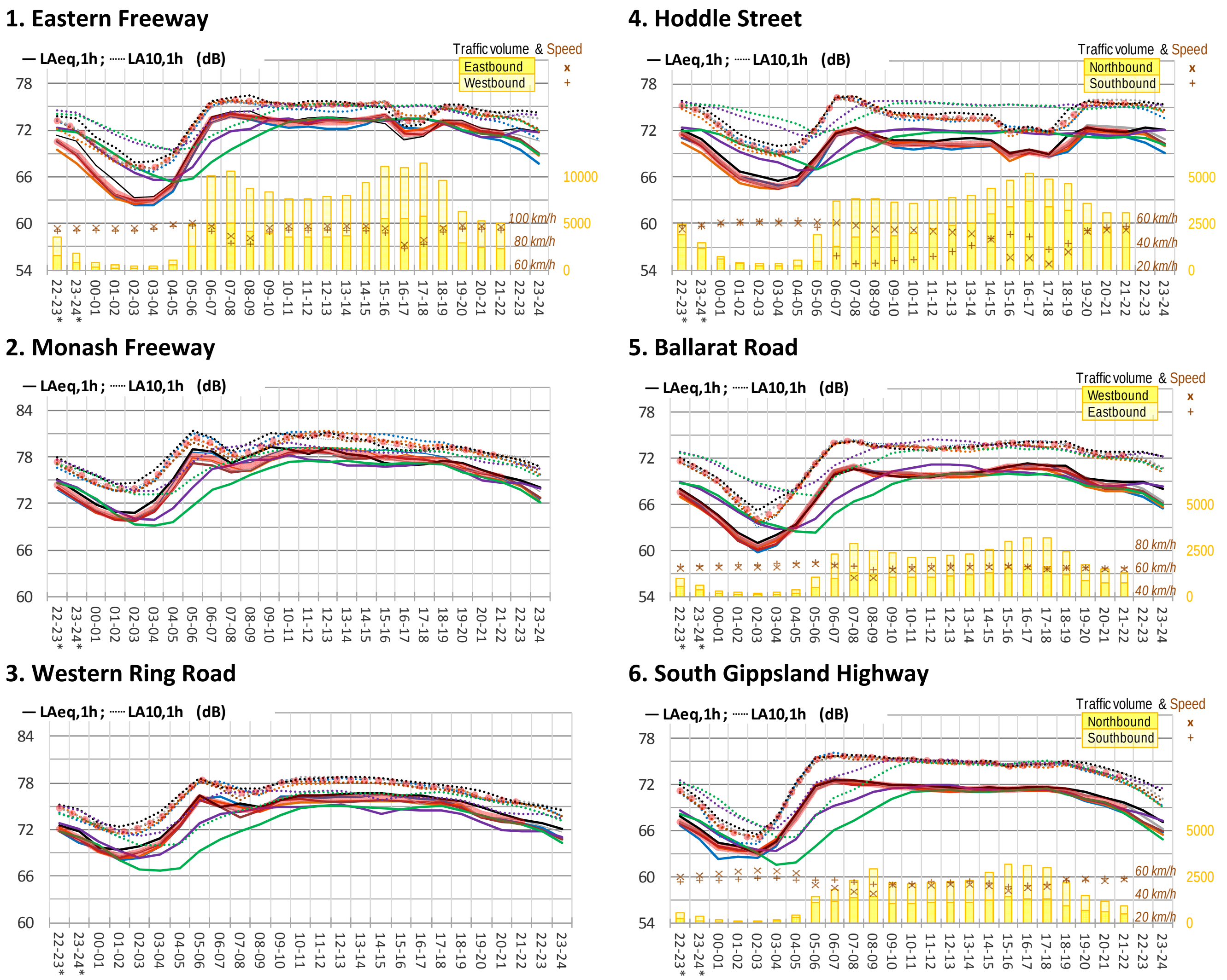
3. PRELIMINARY OBSERVATIONS

This section presents noise data collected between February and May 2016. To ensure better consistency across the data, only measurements undertaken on 'normal' working week days outside school and public holidays are considered for the analysis presented in this paper. Noise data that may have been affected by weather conditions (rain or wind likely to generate extraneous noise at the microphone) have been discarded during post processing.

At the time of writing, traffic data for the Monash Freeway and the Western Ring Road was not available and therefore is not presented here.

3.1 Hourly noise levels

The diagrams in Figure 2 show the average values of the hourly A-weighted equivalent sound pressure level ($L_{Aeq,1h}$) and the hourly 90th percentile sound pressure level ($L_{A10,1h}$) across each 24 hour day of the week. The data for the last two hours of each preceding day is repeated (intervals '22-23*' and '23-24*') to provide a better understanding of the night time noise patterns. Further insight into these patterns is given in Figure 3. Where traffic data is available, the hourly volumes and indicative speed averaged across normal working week days are also shown for reference.



Time interval (hours)
(* refers to the preceding day)

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Legend

Mean hourly noise levels: — $L_{Aeq,1h}$; ···· $L_{A10,1h}$

— Monday ; — Tuesday ; — Wednesday
— Thursday ; — Friday ; — Saturday
— Sunday
— Average weekday

Average weekday hourly traffic data

Nearest lanes direction: Volume; x Speed
Farther lanes direction: Volume; + Speed

Figure 2: Mean traffic noise level patterns (outside school or public holidays). Noise levels are expressed in terms of $L_{Aeq,1h}$ (solid lines) and $L_{A10,1h}$ (dotted lines) and are shown for the 26 hour period starting at 22:00 the day before and ending at 24:00 on the considered day. The average values across the working week days (Monday to Friday) are shown by thick red lines and, where available, are compared to the average traffic volumes (yellow columns) and indicative average speed estimates (brown crosses)

The standard deviation of the hourly $L_{Aeq,1h}$ varied from 0.3 to 3.5 dB for the Eastern Freeway, from 0.5 to 3.9 dB for the Monash Freeway, from 0.2 to 2.5 dB for the Western Ring Road, from 0.7 to 3.3 dB for Hoddle Street, from 0.8 to 3.0 dB for Ballarat Road and from 0.2 to 1.6 dB for the South Gippsland Highway. The higher values in these standard deviation ranges are likely to relate to extraneous noise or single noisy events that were not discarded during data processing. Standard deviations for $L_{A10,1h}$ are found to be marginally lower to those for $L_{Aeq,1h}$.

Comparing the noise level distribution between the different days of the week, it is clear that Saturdays and Sundays show a different pattern than that observed for weekdays. However, a specific trend is observed between 22:00 to 24:00 with late Sunday noise levels having similar values to those for weekdays; and the levels for the last two hours of Fridays appearing to take different values (and to show a similar pattern to that for Saturdays). Although not detailed here for brevity, traffic volumes show similar patterns: while typical traffic volumes for the late hours of Sundays are consistent with those for weekdays, those for late Fridays and Saturdays are somewhat different.

It can therefore be concluded that when characterising noise levels for a given day, the applicable night time period should start from the late hours of the preceding day (e.g. 22:00 on Sunday for Monday night time noise levels and 22:00 on Thursday for Friday night time noise levels) and finish in the early hours of the considered day (ie 06:00 for $L_{Aeq,8h}$). While this approach differs from the common practice of considering the early morning (00:00 to 06:00) as part of the previous day's night time period, its relevance is obvious when comparing the evolution of noise levels across the night time period, as shown in Figure 3.

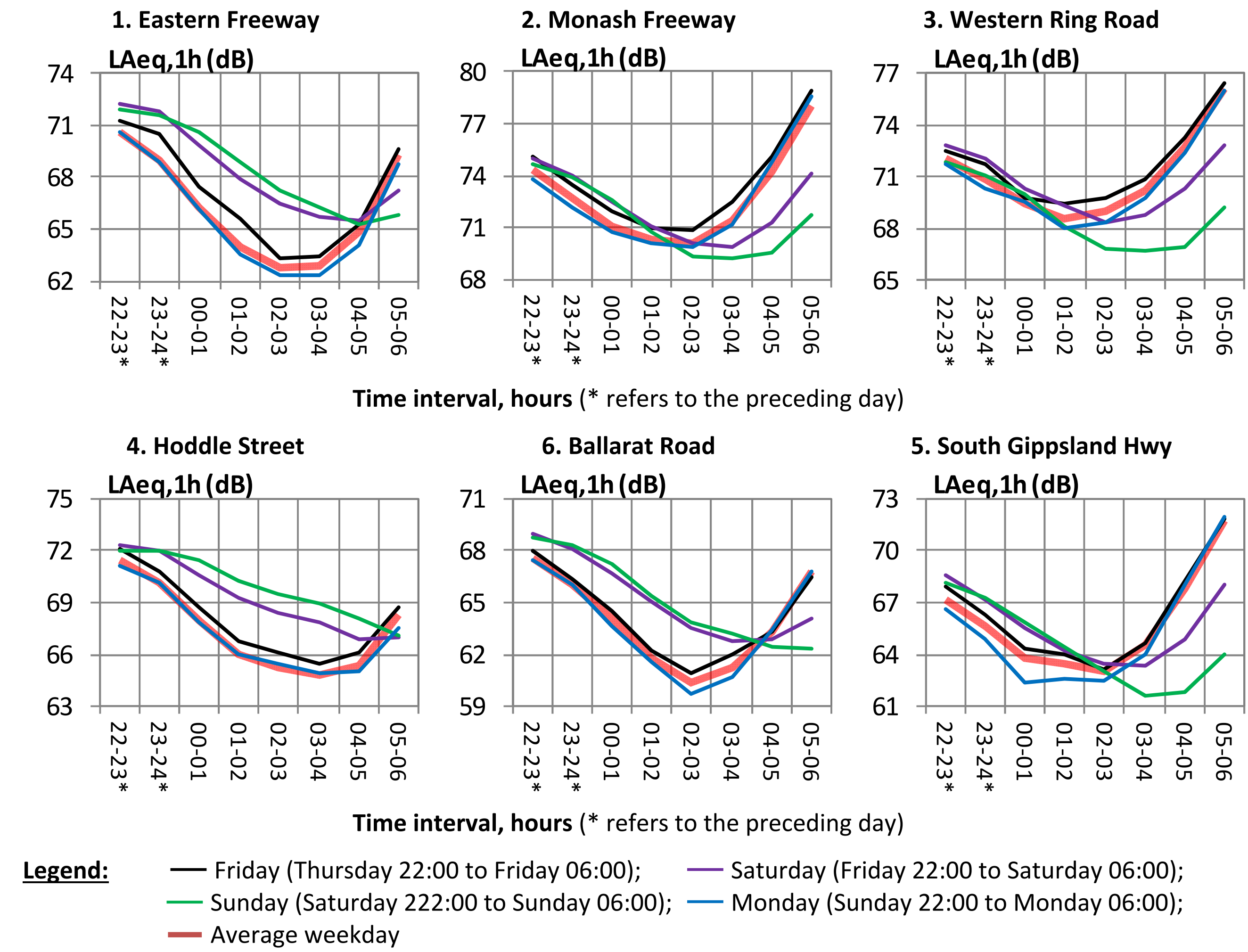


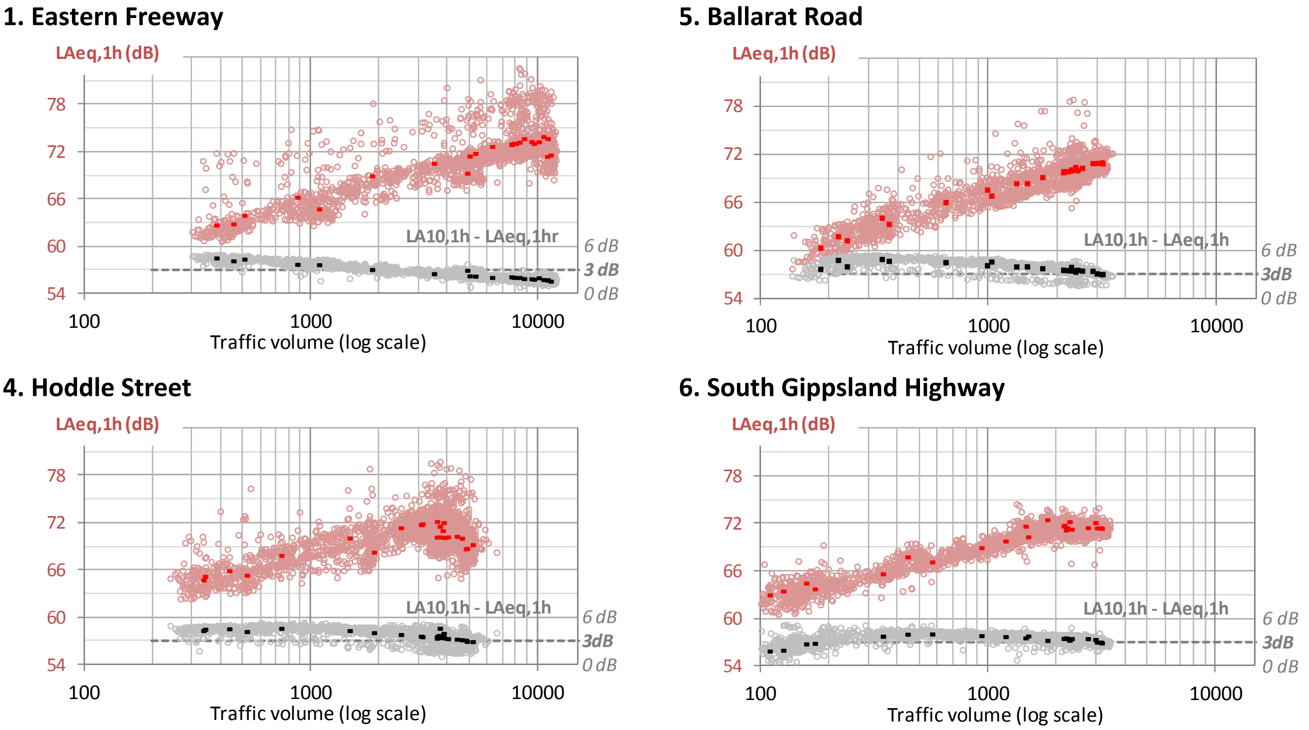
Figure 3: Evolution of the mean traffic noise level $L_{Aeq,1hr}$ across the night time period (from 22:00 on the preceding day to 06:00 on the considered day) for Friday, Saturday, Sunday, Monday and the average weekday

It is observed from Figure 2 that for all locations, the evolution of noise levels is generally consistent with the traffic pattern, with a dip during the night time followed by a peak in the early morning hours (between 06:00 and 08:00 for the Eastern Freeway, Hoddle Street and Ballarat Road; and between 05:00 and 07:00 for the Monash Freeway, the Western Ring Road and the South Gippsland Highway). This morning peak is more pronounced for the Monash Freeway, the Western Ring Road and Hoddle Street.

A decrease in noise levels is observed in the mid to late afternoon for the Eastern Freeway (between 16:00 and 18:00) and Hoddle Street (15:00 and 18:00). It is expected that this is a consequence of congestion, with high traffic volumes and a remarkable reduction in vehicle speed which results in lower noise levels. A somewhat similar decrease in noise levels can be observed for the Monash Freeway for some weekdays (Friday and Tuesday), and for Saturdays on the Western Ring Road. Comparison with traffic data for these locations, when they will be available, will confirm this trend and the potential relation to congestion.

Inversely, the afternoon peak results in slightly higher noise levels for Ballarat Road (15:00 to 18:00), which suggests that this location is not subject to congestion. The South Gippsland Highway also seems to be somewhat less affected by congestion. The average speed estimates at this location appear to be relatively low (about 60 km/h) with regards to the speed limit (80 km/h) which may relate to the proximity of controlled intersections.

Figure 4 provides further insight into the relationship between traffic volumes and noise levels, with plots of the individual measurements of $L_{Aeq,1h}$ against the traffic volume (on a logarithmic scale) for the Eastern Freeway, Hoddle Street, Ballarat Road and South Gippsland Highway. The average values (that were shown by red lines in the diagrams in Figure 2) are represented by red squares.



Legend: $L_{Aeq,1h}$: ○ Individual measurement ; ▪ $L_{Aeq,1h}$ average weekday

$L_{A10,1h}$: ○ Individual measurement ; ▪ $L_{A10,1h}$ average weekday

Figure 4: Hourly noise levels as a function of traffic volumes. Pink circles indicate the individual measurements of $L_{Aeq,1h}$ taken during working week days plotted against the traffic volume counted during the period of measurement. Red squares represent the average hourly values across the working week days. Grey circles show the difference between the individual measurements of $L_{A10,1h}$ and $L_{Aeq,1h}$. Black squares show the average difference across the working week days.

A linear relationship between the noise levels and the logarithm of the traffic volumes is generally observed, as is typically the case for free flowing traffic. Nevertheless, noise levels for the Eastern Freeway and Hoddle Street decrease for the highest volumes, which is consistent with the earlier observations regarding congestion. Noise levels for the South Gippsland Highway appear to reach a plateau at high volumes, which again is probably a sign of milder congestion.

Figure 4 also gives an insight into the difference between $L_{A10,1h}$ and $L_{Aeq,1h}$. The relationship between these two hourly noise scales has been discussed in several studies in the Australian context (Burgess 1978, Brown 1989, Huybregts & Samuels 1998, Kean 2008), as well as internationally (Barry & Reagan 1978, Abbott & Nelson 2002). While a 3 dB difference is considered a generally adequate adjustment factor (Burgess 1978, Abbott & Nelson 2002), it remains a simplification of a relationship which is the function of the density of traffic (traffic volume divided by speed), the distance between the receiver and the road, and site conditions (Barry & Reagan 1978). In presenting a theoretical curve for the adjustment factor between $L_{A10,1h}$ and $L_{Aeq,1h}$.

Barry & Reagan (1978) differentiate two situations. For low traffic volumes, individual pass-bys can be critical to the overall traffic noise levels, with ($L_{A10,1h}$ - $L_{Aeq,1h}$) increasing with traffic density from negative values to up to about 3 dB. For high traffic volumes, individual vehicles have less influence on the noise emissions and the difference between $L_{A10,1h}$ and $L_{Aeq,1h}$ reaches up to about 5 dB and then decreases down to about 1 dB as traffic density increases. It can be observed from Figure 4 that the evolution of the difference between $L_{A10,1h}$ and $L_{Aeq,1h}$ with traffic volume at the different sites investigated, is in general agreement with these theoretical trends.

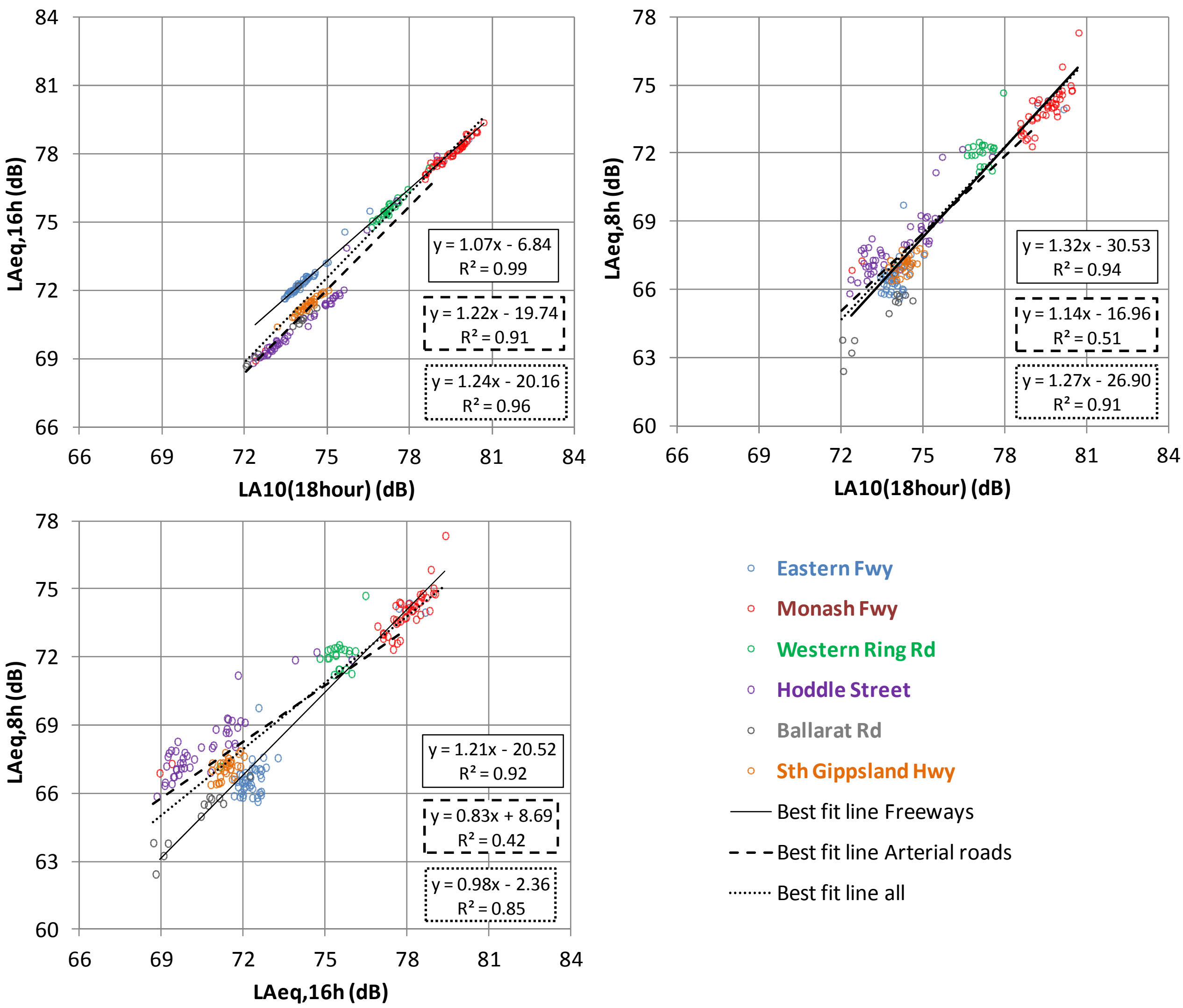


Figure 5: Comparison between noise indices $L_{Aeq,8h}$, $L_{Aeq,16h}$ and $L_{A10(18\ hour)}$

3.2 Noise indices ($L_{A10(18\ hour)}$, $L_{Aeq,16h}$ and $L_{Aeq,8h}$)

Figure 5 shows the comparison of statistical noise index $L_{A10(18\ hour)}$ (the arithmetic average of the eighteen values of $L_{A10,1h}$ measured between 06:00 and 24:00) and the energy equivalent average levels for daytime, $L_{Aeq,16h}$ (06:00 - 22:00), and night time, $L_{Aeq,8h}$ (22:00 - 06:00). Following the observations with regards to night time traffic noise patterns made in Section 3.1 , for a given day $L_{Aeq,8h}$ is determined from 22:00 on the preceding day to 06:00 on the considered day is plotted against $L_{A10(18\ hour)}$ or $L_{Aeq,16h}$ of that day.

Additionally, the average values for the differences between the three indices are given, together with the standard deviation in Table 3. Differences observed in earlier investigations in New South Wales and Victoria are summarised and compared with the data collected for the present project in Table 4. The average differences across the six sites are in generally good agreement with the results of these earlier studies, and particularly with the conversion factors proposed by Austroads (Austroads 2005). Besides, for freeways, the average difference has the same value (1.6 dB) as that determined for urban roads in New South Wales (Parnell, Wassermann & Samuels 2010).

While it is observed from Figure 5 that daytime $L_{Aeq,16h}$ and $L_{A10(18\ hour)}$ are highly correlated, the relationship between these two indices for arterial roads appears to be somewhat different from that for freeways with $L_{Aeq,16h}$ lower by about 1 to 2 dB for the same value of $L_{A10(18\ hour)}$. This is consistent with a smaller difference between $L_{A10,1h}$ and $L_{Aeq,1h}$ observed for freeways during the daytime period (as illustrated in Figures 2 and 4), which also results in a lower average difference between $L_{A10(18\ hour)}$ and $L_{Aeq,16h}$ (see Table 3).

Night time index $L_{Aeq,8h}$ shows a notably lesser correlation with $L_{A10(18\ hour)}$ than day time $L_{Aeq,16h}$. This is mainly due to inconsistent differences between day time and night time traffic volumes, which results in a wider scatter of the data. This is particularly the case for the arterial roads that bear lower traffic volumes more so than for freeways, and is consistent with observations made in earlier studies (Abbott & Nelson 2002).

It is observed in Figure 5 that the $L_{Aeq,8h}$ noise levels for the Eastern Freeway stand out from those of the other freeway sites and are somewhat more consistent with the levels for arterial roads. Similarly, the night time noise level pattern for Hoddle Street appears to differ from those for the other two arterial roads. The different night time noise level patterns for these two roads are particularly remarkable when comparing $L_{Aeq,8h}$ with $L_{Aeq,16h}$ and are also reflected in the average values of the differences between the $L_{A10(18\ hour)}$ or $L_{Aeq,16h}$ and $L_{Aeq,8h}$ given in Table 3. Whether these trends relate to specific traffic patterns and differences in traffic composition (refer Table 2) will be subject to further investigation.

Table 3: Average and standard deviation (in brackets) of the differences (dB) between $L_{A10(18\ hour)}$, $L_{Aeq,16h}$ and $L_{Aeq,8h}$

Reference	$L_{A10(18\ hour)}$ - $L_{Aeq,16h}$	$L_{A10(18\ hour)}$ - $L_{Aeq,8h}$	$L_{Aeq,16h}$ - $L_{Aeq,8h}$	Number of samples
1. Eastern Fwy	1.7 (0.2)	7.3 (0.8)	5.6 (0.8)	50 / 46 / 46
2. Monash Fwy	1.5 (0.4)	5.5 (0.5)	4.0 (0.7)	48 / 48 /44
3. Western Ring Rd	1.7 (0.3)	5.1 (0.7)	3.4 (0.6)	29 / 23 / 23
1-3 Freeways	*1.6 (0.3)*	*6.1 (1.2)*	*4.5 (1.1)*	*127 / 117 / 113*
4. Hoddle St	3.4 (0.6)	5.9 (0.7)	2.5 (0.7)	49 / 45 / 45
5. Ballarat Rd	3.2 (0.4)	8.6 (0.6)	5.4 (0.4)	13 / 12 / 12
6. South Gippsland Hwy	2.9 (0.1)	7.2 (0.3)	4.2 (0.3)	30 / 27 / 29
4-6 Arterial roads	*3.2 (0.5)*	*6.7 (1.1)*	*3.5 (1.2)*	*92 / 84 / 86*
1-6 All	*2.3 (0.9)*	*6.4 (1.2)*	*4.1 (1.3)*	*219 / 201 / 199*

Table 4: Average and standard deviation (in brackets, where specified) of the differences (dB) between $L_{A10(18\ hour)}$, $L_{Aeq,16h}$ and $L_{Aeq,8h}$ reported in previous studies in Victoria and New South Wales, compared to the data collected for this project

Reference	$L_{A10(18\ hour)}$ - $L_{Aeq,16h}$	$L_{A10(18\ hour)}$ - $L_{Aeq,8h}$	$L_{Aeq,16h}$ - $L_{Aeq,8h}$	Number of samples
Huybregts & Samuels (1998)	2.2 (0.6)	6.7 (1.6)	-	103 / 103 / -
Austroads (2005)	2.0	6.3	4.3	119 / 119 / 119
Parnell, Wasserman & Samuels (2010), urban NSW	1.6 (0.8)	6.8 (4.6)	-	171 / 171 / -
Sites 1-3 Freeways	1.6 (0.3)	6.1 (1.2)	4.5 (1.1)	127 / 117 / 113
Sites 4-6 (Arterial roads)	3.2 (0.5)	6.7 (1.1)	3.5 (1.2)	92 / 84 / 86
All sites (1-6)	2.3 (0.9)	6.4 (1.2)	4.1 (1.3)	219 / 201 / 199

4. CONCLUDING REMARKS

A long term noise and air quality monitoring programme along major roads in metropolitan Melbourne has been introduced in this paper. Preliminary findings for noise levels are presented and provide an insight into the relationships in between different indices used to characterise traffic noise. Comparison with traffic parameters, where available, allows for correlation of noise emissions with traffic patterns and for investigating the influence of congestion on noise levels.

While there is generally good agreement between the noise data collected and results from previous studies in Victoria and New South Wales, specific patterns are observed for some of the roads considered and will be subject to further analysis as the monitoring programme progresses.

It is recommended that when reporting $L_{Aeq,8h}$ noise levels, the assessment period should be treated as part of the following day rather than part of the previous day. For example, the period from 22:00 on Sunday night to 06:00 on Monday morning should be reported as Monday's $L_{Aeq,8h}$ noise level rather than Sunday's level.

5. ACKNOWLEDGEMENTS

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REFERENCES

Abbott PG & Nelson PM 2002, 'Converting the UK traffic noise index $L_{A10,18h}$ to EU noise indices for noise mapping', Project report PR/SE/451/02 (prepared for AEQ division, DEFRA), Transport Research Limited, Crowthorne, UK.

Austroads 2005, 'AP-R277-05, Austroads Research Report, Modelling, measuring and mitigating road traffic noise', Austroads Publication No. AP-R277/05, Austroads Incorporated, Sydney, New South Wales, Australia.

Barry, TM & Reagan, JA 1978, 'FHWA highway traffic noise prediction model', Research report FHWA-RD-77-108, Federal Highway Administration, Washington DC, USA.

Brown, L 1989, 'Some simple transformations for road traffic noise scales', Australian Road Research, Vol. 19, No. 4, pp. 309-312.

Bruitparif 2014, 'How to improve information on noise and operational management in European cities? Methodological Guide - Use of tools developed in the Life Harmonica project', Coordinated by Bruitparif, Paris, France, viewed 1 September 2016, <http://www.bruitparif.fr/sites/default/files/Harmonica%20methodological%20guide.pdf >.

Burgess, M 1978, ‘Relationship between L_{10} and L_{eq} for noise from road traffic’, Australian Road Research, Vol. 8, No. 3, pp. 15-18.

Huybregts, CP & Samuels SE, ‘New relationships between L_{10} and L_{eq} for road traffic noise’, *Proceedings Inter-noise 1998*, Christchurch, New Zealand.

International Electrotechnical Commission 2013, Electroacoustics - *Sound level meters - Part 1: Specifications*, IEC 61672-1:2013, International Electrotechnical Commission, Geneva, Switzerland.

Kean, S 2008, ‘Is CoRTN an L_{eq} or L_{10} procedure?’, *Proceedings of Acoustics 2008*, *Australian Acoustical Society National Conference*, Geelong, Victoria, Australia.

Miège, B, Vincent, B, Vallet J, Olny X, Marquis M, Porcheron, S, Olivier, P, Carra, S J 2012, ‘Territorial coherence between environmental noise and air variables’, *Proceedings Inter-noise 2012*, New York, USA.

Parnell, J, Wassermann, J & Samuels, S 2010, ‘Relationships between noise indices, road traffic noise and criteria in NSW’, *Proceedings of 20th International Congress on Acoustics, ICA 2010*, Sydney, New South Wales, Australia.

Standards Australia 2014, *Methods for sampling and analysis of ambient air - Meteorological monitoring for ambient air quality monitoring applications*, AS/NZS 3580.14:2014, Standards Australia, Sydney, New South Wales, Australia.

Vincent, B, Fradet, F & Porcheron, S 2009, ’The development of a permanent network for measuring environmental noise at the urban-area level’, Version 2, Acoucité, Lyon, France, viewed 1 September 2016, <http://www.acoucite.org/IMG/pdf/Guide-observatoires-misenpage_ENG.pdf>.

Vincent, B, Cristini, A, Vallet, J, Sales, C, Poimboeuf, H, Sorrentini, C & Anselme C 2011, ‘An Urban Noise Observatory: Scientific, Technical, Strategic and Political Challenges; A Systemic Complementary Approach to the New Requirements of the European Directives’, *Proceedings Inter-noise 2011*, Osaka, Japan, viewed 1 September 2016, <http://www.acoucite.org/IMG/pdf/ARTICLE-internoise2011_ENG.pdf>.