A review of road traffic noise indicators and their correlation with the $L_{A10(18hour)}$

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ABSTRACT

This paper outlines a study to determine the correlation between the $L_{A10(18hour)}$ and other road traffic noise indicators. It is based on a database comprising of 404 measurement locations including 947 individual days of valid noise measurements across numerous circumstances taken between November 2001 and November 2007. This paper firstly discusses the need and constraints on the indicators and their nature of matching a suitable indicator to the various road traffic noise dynamical characteristics. The paper then presents a statistical analysis of the road traffic noise monitoring data, correlating various indicators with the $L_{A10(18hour)}$ statistical indicator and provides a comprehensive table of linear correlations. There is an extended analysis on relationships across the night time period. The paper concludes with a discussion on the findings.

1. INTRODUCTION

Over the last 50 years, many indicators have been developed and proposed for the assessment of road traffic noise. The present research does not intend to analyse all of these, but rather focuses on specific statistical and energy based indicators and their relationships with the $L_{A10(18hour)}$. This study firstly discusses the need and constraints on the indicators and the nature of matching a suitable indicator to the various road traffic noise dynamical characteristics. A statistical analysis of a large database of road traffic noise monitoring data is then presented, correlating various indicators with the $L_{A10(18hour)}$ statistical indicator and concludes with a discussion on the findings.

2. INDICATORS

Before selecting an indicator, one first needs to determine what needs to be indicated. In road traffic noise, an indication of subjective and/or objective indicators may be of interest. Subjective indicators include annoyance, health, sleep disturbance and sleep awakening. Objective indicators such as change of ambience, average levels and statistics, energy levels and statistics, and peak or maximum levels. Often it has been the case to use a form of objective indicator as a subjective indicator by attempting to determine relationships with a subjective human response via field or laboratory trials. In other words, it has become international practice to use a quantitative indicator, usually with the units of decibels to determine a predicted subjective response.

For assessing subjective annoyance, there are two forces driving the development and use of an objective road traffic noise indicator. These two forces were outlined by Rice (1978) and paraphrased in Schultz (1982): (1) the indicator must be sensitive to changes in the physical characteristics of the noises under consideration, and (2) the ability of the indicator to produce equal numerical values for judged conditions of equal noisiness or annoyance i.e. the selected indicator should reduce the scatter of subjective responses.

There are other constraints which drive the selection of a road traffic noise indicator such as (1) instrument capabilities (instrument must be capable of measuring the selected indicator or its components); (2) instrument cost (it must be relatively cost effective in order for the selected indicator to be widely accepted and measured); (3) indicator presentation (the selected indicator must have some ability to be presented to and reasonably understood by non-acoustic professionals and also the public). As road traffic noise is a common issue, the need to present results through community consultation and deliberation requires an indicator which is relatively easy to describe and understand, and (4) indicator calculation (it must be possible to predict the selected indicator, either directly through a defined calculation methodology or indirectly by calculating an intermediary indicator and using accurate adjustments).

Thus, it is the pragmatic forces which ultimately decide which indicator or indicators to be used. It is not sensible to develop a policy, using an indicator which can not be measured or calculated within the bounds of sensible quantities of work, or does not provide any significant improvements in the assessment and management of road traffic noise. This is supported by the European Commission (European Commission 2000) where it is stated; "*…the purpose of an indicator is to reduce this large volume of information which is still meaningful but easier to handle. It is inevitable that information about individual contributions will be lost, but this has to be accepted. This can be done in much the same way that indicators are made for stock markets and the state of the global climate (based on average annual temperature).*"

2.1 Summary of some recent events in Europe

The World Health Organisation (WHO) Guidelines for Community Noise (GCN) in 1999 (World Health Organisation 1999) use the L_{Aeq} and L_{Amax} indicators for continuous noise and event noise, respectively. Criteria *guideline* values were set as the lowest noise level that may produce an adverse health effect for the general population. The European Commission followed their green paper with a 'Position Paper on EU noise Indicators' (European Commission 2000). The purpose of the report was to recommend "*physical indicators to describe noise from all outdoor sources for assessment, mapping, planning and* *control purpose and to proposed methods of implementation.*" This paper succinctly summarised different types of indicators into basic, composite and complex indicators. *Basic* indicators are useful when dealing with complaints and unusual situations. They include the SEL, L_{Amax} and $L_{Aeq.}$ The SEL and L_{Amax} are single event descriptors and have a weak correlation with long term effects. Another basic indicator is the Rise time (dB/sec) which is correlated with startle effects. A *Composite* is useful for overall policy to reduce the number of affected persons and assists land use planning, mapping zoning, simplifying estimation of dose/response effects and is more easily understood by the public, politicians and planners and so on. Examples of *Composite* indicators are the L_{den}, L_{Night}, L_{A10} (e.g. $L_{A10(18hour)}$) and other percentiles. *Complex* indicators are used for comparisons between countries, regions, cities or parts of a city or of different kinds of sources. Examples of *Complex* indicators are the number of events over criteria, the surface area over criteria, conflict maps, and population exposure indicators (number of people annoyed).

The paper (European Commission 2000) provided some very useful insight into the selection of the L_{den} and L_{Night} where it was recognised that the L_{den} and L_{Night} are neither superior nor inferior indicators to many other existing indicators and the main reason for suggesting the L_{den} and L_{Night} indicators is for the harmonisation of methods and assessments in Europe. Also, it not intended by the European Commission to abolish local assessment practices where they do not conflict with the harmonisation policy. The paper goes on to state that the L_{Night} indicator is used only to satisfy the assessment and reporting process where it specifically relates to sleep disturbance.

Following the EU Position Paper on EU Noise Indicators (European Commission 2000) the European Commission released its directive (European Commission 2002a) relating to the assessment and management of environmental noise. The key elements of the directive are (1) it is necessary to establish common assessment methods for environmental noise and a definition for limit values, in terms of harmonised indicators for the determination of noise levels; (2) limit values are determined by each member state to suit the situation or local needs; (3) the L_{den} is selected to assess annoyance; and (4) the L_{Night} is selected to assess sleep disturbance. Thus, member states in the EU are required to report environmental noise exposure statistics using the L_{den} and L_{Night}.

Also in 2002, the European Commission released their "Position paper on dose response relationships between transportation noise and annoyance" (European Commission 2002b). The purpose of their position paper was to synthesise available research to develop dose-response curves to estimate the number of annoyed or highly annoyed people based on an external noise level. The dose-response curves were based on the L_{den}. Dose response curves that are based on the L_{Night} have been outlined in the European Commission "Position paper on dose-effect relationships for night time noise" (European Commission 2004).

Another recent document to be issued by the WHO is the "Night Noise Guidelines for Europe" (World Health Organisation 2009) which is stated by WHO to be an extension of their "Guidelines for Community Noise" (World Health Organisation 1999). The main summary points from the 'Night Noise Guidelines" as they pertain to European countries are as follows:

- Although several countries have night noise guidelines, there is insufficient information on actual exposure and effects on the population.
- On noise indicators, an indicator must have the ability to predict an effect. For different health conditions, different indicators could be selected.
- Long term effects of noise such as cardio-vascular disease are best correlated with long term average noise levels, such as the L_{Night}.
- Short term effects such as sleep disturbance are better correlated with a maximum noise level per event, for example, L_{Amax}.
- Indicators should be easy to explain to the public and be consistent with existing practices and legislation.
- L_{Night} is the indicator of choice from both a scientific and practical perspective.

2.2 Types of indicators

There are two main type of indicators; (1) statistical and (2) energy based. In this paper, derived statistics are often related to standard Queensland Environmental Noise practice, being Day (6:00am to 6:00pm), Evening (6:00pm to 10:00pm) and Night (10:00pm to 6:00am). This is different from European practice that defines Day (7:00am to 7:00pm), Evening (7:00pm to 11:00pm) and Night (11:00pm to 7:00am).

2.2.1 Statistical indicators

The most commonly used statistical levels are percentiles. Percentile levels are the percentage of time, above which the noise level is exceeded and thus need to be referenced to the duration of the measurement or calculation. In road traffic noise, 1 hour or 15 minute periods of measurement are generally the smallest time duration investigated. The most commonly used percentile indicators are the L_{A10} (often used as a quick quantifier of the average maximum noise level) and L_{A90} (often used to quantify background noise levels).

The $L_{A10(18hour)}$ was presented in the 1975 version of the Calculation of Road Traffic Noise (Department of Transport Welsh Office 1975) and has been adopted by many road authorities since. The $L_{A10(18hour)}$ (Eq a) is the arithmetic average of the values of the $L_{A10(1hour)}$ for each of the eighteen one-hour periods between 6am (0600 hours) and midnight (2400 hours). This indicator is calculable through the use of the CoRTN method, which can derive the $L_{A10(18hour)}$ directly. The CoRTN method can also directly calculate the $L_{A10(1hour)}$.

$$L_{A10(18hour)} = \frac{1}{18} \sum_{6am}^{midnight} L_{A10(1hour)} \tag{a}$$

Instrumentation is easily available to measure $L_{A10(1hour)}$ levels and consequently the $L_{A10(18hour)}$ is easily determined from measurements. Also in use in the State of Queensland is the $L_{A10\ (12\ hour)}$ which is the arithmetic average of the values of the $L_{A10(1hour)}$ for each of the twelve one-hour periods between 6am (0600 hours) and 6pm (1800 hours). This indicator has been used in criteria for open space passive recreation areas.

Another statistical indicator is the L_{Amax} which is the highest sound pressure level measured over a defined measurement period. It is often used to quantify the magnitude of a noise event. Several forms of the L_{Amax} can be derived from standard measurement data such as the $L_{Amax,max(Day)}$, $L_{Amax,max(Eve)}$ and $L_{Amax,max(Night)}$ which are the maximum $L_{Amax(1hour)}$ of each of the one-hour periods between the Queensland day, evening and night periods respectively. Also the $L_{Amax,av(Day)}$ $L_{Amax,av(Eve)}$ $L_{Amax,av(Night)}$ is the arithmetic average $L_{Amax(1hour)}$ of each of the one-hour periods for the respective Queensland time periods.

2.2.2 Energy indicators

A common energy based indicators is the L_{Aeq} which contains the same quantity of sound energy over a defined time period as the actual time varying sound level and is a similar concept as the root mean square (rms) level of a fluctuating electrical signal. Common time periods in use for the L_{Aeq} are the $L_{Aeq(1hour)}$ and the $L_{Aeq(24hour)}$.

The L_{den} described above is a derived indicator from the L_{Day} (12 hours from 7am to 7pm), L_{Eve} (4 hours from 7pm to 11pm) and L_{Night} (8 hours from 11pm to 7am). Thus it is an indicator which takes into account the fluctuating noise level of the whole day period and thus avoids some of the criticism aimed at shorter time frame indicators like the $L_{A10(18hour)}$. Some difficulties arise with the L_{den} as it can not be measured easily as it is based on a yearly average exposure. The weightings need to be applied to measured or predicted values which increase the difficulty in explaining the indicator concept to the public and non-acoustic professionals. The weightings in the L_{den} have been included to fit the indicator better to predicting annoyance, not for the perspective of protecting sleep quality (World Health Organisation 2009).

The L_{Night} indicator is the L_{Aeq} over an 8-hour period of the night. It does not contain a weighting like the L_{den}. The L_{Night} is used as an indicator in studies to predict the long term effects of noise on sleep, not the short term effects (World Health Organisation 2009).

3. SIMILAR RESEARCH

There have been a number of studies aimed to develop relationships between different road noise indicators usually of the form $L_{A10} = L_{Aeq} + \phi$ (Brown 1989; Burgess 1978; Huybregts and Samuels 1998).

The UK developed the $L_{A10(18hour)}$ indicator and more recently is now required by the European Commission to conduct wide scale noise mapping based on L_{den} and L_{Night}. Thus, the Transport Research Laboratory (TRL) reviewed various means on how the UK could conduct predictions of the L_{den} and also prepared an analysis to compare the differences between the $L_{A10(18hour)}$ and the L_{den} (Abbott and Nelson 2002). The TRL developed several relationships and a method of converting the $L_{A10(18hour)}$ to produce indicators according to EU preferred indicators.

4. RELATIONSHIPS WITH THE $L_{A10(18HOUR)}$

The remainder of this paper is concerned with determining Queensland based relationships between the $L_{A10(18hour)}$ and other indicators indentified above. There is a particular emphasis on comparing the results across the night time period. The night time period in Queensland is defined as being between 10pm and 6am the following morning.

A database of road traffic noise measurement results was collated so that statistical analysis could be performed to determine the relationships between various noise indicators. To ensure a representative cross-section of road types in the database, the noise measurements were carried out on a variety of road sizes and types, with traffic flow rates ranging from multi-lane, heavy flow motorway traffic, to single lane rural road traffic with lower traffic flows but a higher percentage of heavy vehicles.

The road traffic noise data was mostly from measurements carried out in the south-east Queensland area. However data was also gathered from areas such as Townsville, Cairns and Rockhampton. The measurement data was sourced from both the Transport and Main Roads (TMR) databases, and also from road traffic noise measurements performed by external consultants commissioned by TMR. Once completed, the database comprised 404 measurement locations, and 947 individual days of valid noise measurements conducted between November 2001 and November 2007. Figure 1 shows the approximate locations of the measurements included in the database. The measurement locations exhibit a range of data as shown in Table 1. Prior to entering the final database for analysis, data of each day was visually checked for consistency with known traffic noise characteristics. The daily data was charted over its 24 hour period, and any days that demonstrated clear examples of extraneous noise, that is, such as spikes in the L_{Aeq} were removed from the data set.

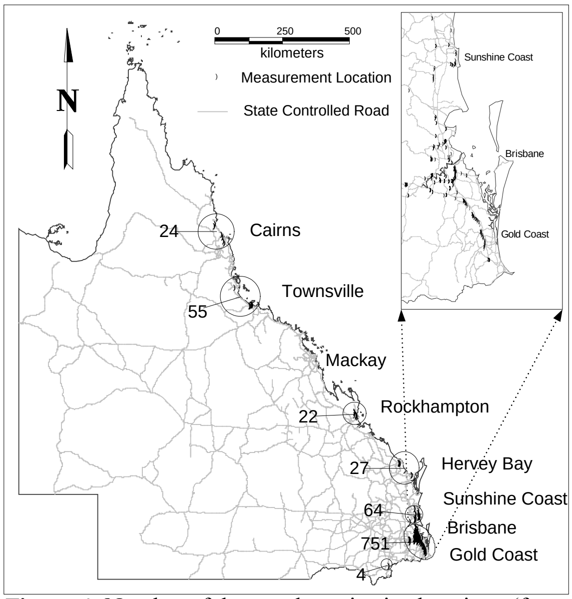

Figure 1: Number of days and monitoring locations (from Naish, Tan and Demirbilek 2011)

5. RESULTS

In the following analysis it is assumed that all of the indicators are approximately normally distributed and correlation between two variables was assumed to be linear. The consequent discussion has a general focus on night time noise considerations.

5.1 Indicator relationships with $L_{A10(18hour)}$

To determine various indicator relationships with the $L_{A10(18hour)}$ the method of least squares analysis was conducted with the $L_{A10(18hour)}$ being the independent variable. Table 2 presents the indicators analysed and the straight line best fit regression equation with a two standard deviation tolerance and the correlation coefficient, R^2. In the following discussion, an equation number refers to the corresponding equation number in Table 2.

Table 1: Variable ranges across the monitoring sites

Pavement	No.	Speed km/hr	No.	% C.V.	No.	Dist, m	No.	AADT (veh/day)	No.
Unknown	170	*Unknown*	91	*Unknown*	433	*Unknown*	87	*Unknown*	87
Bitumen Spray Seal	6	60	196	1-3	23	1-51	467	0-9999	89
Boral Lo Noise*	26	70	74	3-5	132	51-101	132	10k-19k	81
Chip Seal	26	80	56	5-7	89	101-151	90	20k-29k	78
Concrete	34	90	82	7-9	117	151-201	69	30k-39k	125
Dense Graded Asphalt	587	100	391	9-11	67	201-251	26	40k-49k	64
Open Graded Asphalt	65	110	57	11-13	48	251-301	31	50k-59k	51
PMB Spray Seal	3			13-15	17	301-351	12	60k-69k	164
Sprayed Seal	14			15-17	12	351-401	10	70k-79k	105
Stone Mastic Asphalt	16			17-19	4	401-451	6	90k-99k	3
				19-21	5	501-551	8	100k-109k	65
						901-951	2	>110k	35
						>1001	7		
Total	947	Total	947	Total	947	Total	947	Total	947

*(proprietary product)

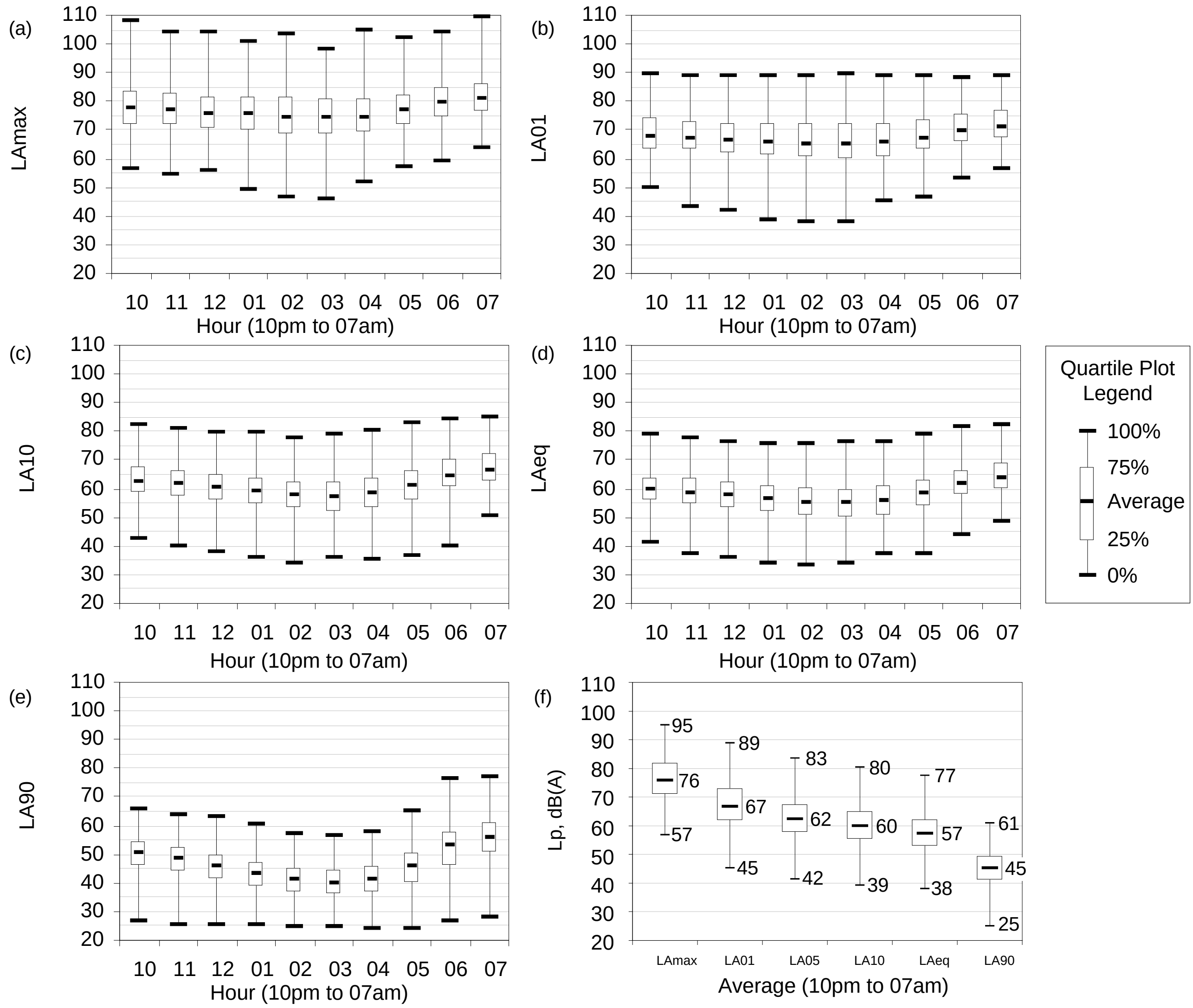

Figure 2: Spread of night time noise levels, hourly quartile and average plots of L_{Amax} (a), L_{A01} (b), L_{A10} (c), L_{Aeq} (d), L_{A90} (e) and nightly average quartile and average plots of all assessed indicators (f).

Table 2: Relationships of various indicators with the $L_{A10\,(18\,hour)}$

Eq.	Dependant Variable	Standard Equation	Regression Equation (ref $L_{A10(18hour)}$)	± R^2
1	$L_{A10(12hour)}$	$=\frac{1}{12}\sum_{6am}^{6pm} L_{A10(1hour)}$	$=1.02\ L_{A10\,(18\,hour)}+0.3$	±1.5 (0.99)
2	$L_{Aeq,av(24hour)}$	$=\frac{1}{24}\sum_{6am}^{6am} L_{Aeq(1hour)}$	$=0.93\ L_{A10\,(18\,hour)}+0.3$	±1.8 (0.98)
3	$L_{Aeq(24hour)}$	$=10Log_{10}\left[\frac{1}{24}\sum_{6am}^{6am} 10^{\frac{L_{Aeq(1hour)}}{10}}\right]$	$=0.89\ L_{A10\,(18\,hour)}+4.8$	±2.3 (0.96)
4	$L_{Aeq,\max(1hour,Day)}$	$=Max\left[L_{Aeq(1hour)}\right]_{6am}^{6pm}$	$=0.78\ L_{A10\,(18\,hour)}+15.6$	±5.0 (0.82)
5	$L_{Aeq,\max(1hour,Eve)}$	$=Max\left[L_{Aeq(1hour)}\right]_{6pm}^{10pm}$	$=0.84\ L_{A10\,(18\,hour)}+8.9$	±3.6 (0.91)
6	$L_{Aeq,\max(1hour,Night)}$	$=Max\left[L_{Aeq(1hour)}\right]_{10pm}^{6am}$	$=0.88\ L_{A10\,(18\,hour)}+4.8$	±5.8 (0.81)
7	L_{Day}	$=10Log_{10}\left[\frac{1}{12}\sum_{6am}^{6pm} 10^{\frac{L_{Aeq(1hour)}}{10}}\right]$	$=0.90\ L_{A10\,(18\,hour)}+5.6$	±2.6 (0.96)
8	L_{Eve}	$=10Log_{10}\left[\frac{1}{4}\sum_{6pm}^{10pm} 10^{\frac{L_{Aeq(1hour)}}{10}}\right]$	$=0.87\ L_{A10\,(18\,hour)}+4.5$	±2.9 (0.94)
9	L_{Night}	$=10Log_{10}\left[\frac{1}{8}\sum_{10pm}^{6am} 10^{\frac{L_{Aeq(1hour)}}{10}}\right]$	$=0.91\ L_{A10\,(18\,hour)}-1.5$	±4.8 (0.87)
10	L_{den}	$=10\log_{10}\left[\frac{1}{24}\left(12\times10^{\left(\frac{L_{Day}}{10}\right)}+4\times10^{\left(\frac{L_{Eve}+5}{10}\right)}+8\times10^{\left(\frac{L_{Night}+10}{10}\right)}\right)\right]$	$=0.88\ L_{A10\,(18\,hour)}+9.3$	±3.3 (0.93
11	$L_{den(QLD)}$	$=10\log_{10}\left[\frac{1}{24}\left(12\times10^{\left(\frac{L_{Day}}{10}\right)}+4\times10^{\left(\frac{L_{Eve}+5}{10}\right)}+8\times10^{\left(\frac{L_{Night}+10}{10}\right)}\right)\right]$	$=0.89\ L_{A10\,(18\,hour)}+4.9$	±3.1 (0.94)
12	$L_{A\max,\max(1hour,Day)}$	$=Max\left[L_{A\max(1hour)}\right]_{6am}^{6pm}$	$=0.54\ L_{A10\,(18\,hour)}+54.6$	±12.7 (0.25)
13	$L_{A\max,\max(1hour,Eve)}$	$=Max\left[L_{A\max(1hour)}\right]_{6pm}^{10pm}$	$=0.73\ L_{A10\,(18\,hour)}+35.9$	±12.2 (0.39)
14	$L_{A\max,\max(1hour,Night)}$	$=Max\left[L_{A\max(1hour)}\right]_{10pm}^{6am}$	$=0.79\ L_{A10\,(18\,hour)}+30.9$	±10.6 (0.50)
15	$L_{A\max,av(1hour,Day)}$	$=\frac{1}{12}\sum_{6am}^{6pm} L_{A\max(1hour)}$	$=0.73\ L_{A10\,(18\,hour)}+33.6$	±6.3 (0.71)
16	$L_{A\max,av(1hour,Eve)}$	$=\frac{1}{4}\sum_{6pm}^{10pm} L_{A\max(1hour)}$	$=0.88\ L_{A10\,(18\,hour)}+21.7$	±7.8 (0.70)
17	$L_{A\max,av(1hour,Night)}$	$=\frac{1}{8}\sum_{10pm}^{6am} L_{A\max(1hour)}$	$=1.03\ L_{A10\,(18\,hour)}+8.9$	±5.9 (0.85)
18	$L_{A90,avg10-6}$	$=\frac{1}{8}\sum_{10pm}^{6am} L_{A90(1hour)}$	$=0.36\ L_{A10\,(18\,hour)}+20.8$	±11.0 (0.16)
19	$L_{A90(18hour)}$	$=\frac{1}{18}\sum_{6am}^{midnight} L_{A90(1hour)}$	$=0.59\ L_{A10\,(18\,hour)}+15.6$	±8.1 (0.49)

The $L_{A10(12hour)}$ is, as expected, highly correlated with the $L_{A10\,(18\,hour)}$ (Equation 1, $R^2 = 0.99$) with a tolerance of ± 1.5 dB(A). The $L_{A10(12hour)}$ is of no interest for night time consideration as it is an average of day time levels only. However it is presented here to demonstrate the relatively constant levels obtained when measuring road traffic noise using the L_{A10} statistic. Additionally, the $L_{A10(1hour)}$ levels from 6pm to midnight are expected to be less than between 6am and 6pm but not less by large amounts. Consequently, there is little difference expected between the $L_{A10(18hour)}$ and the $L_{A10(12hour)}$.

The $L_{Aeq(24hour)}$ is also highly correlated with the $L_{A10(18hour)}$ (Equation 3, $R^2 = 0.96$) with a tolerance of ± 2.3 dB(A). This demonstrates that there is a high level of confidence that a measured or predicted $L_{A10(18hour)}$ level can be converted to an $L_{Aeq(24hour)}$ using Equation 3. The $L_{Aeq,av(24hour)}$ is not often used, but Equation 2 demonstrates that there is also a very high correlation ($R^2 = 0.98$, ± 1.8 dB(A)).

It can be expected that a long term L_{Aeq} will have a correlation with a long term arithmetic average of $L_{A10(1hour)}$ values such as the $L_{A10(18hour)}$. However, quite often legislation and acoustic practice requires the use of the highest L_{Aeq} value over a time period, for example, day, evening or night. Equations 4, 5 and 6 demonstrate the relationships with the $L_{Aeq,max(1hour,Day)}$, $L_{Aeq,max(1hour,Eve)}$ and $L_{Aeq,max(1hour,Night)}$ respectively. The $L_{Aeq,max(1hour,Day)}$ is reasonably correlated with the $L_{A10(18hour)}$ (R^2 = 0.82,± 5.0 dB(A)), however the tolerance indicates the variability can become high. The $L_{Aeq,max(1hour,Eve)}$ is slightly more correlated with the $L_{A10(18hour)}$ than the $L_{Aeq,max(1hour,Day)}$ (R^2 = 0.91,± 3.6 dB(A)). The $L_{Aeq,max(1hour,Night)}$ is the least correlated of these three L_{Aeq} indicators with the $L_{A10(18hour)}$ (R^2 = 0.81,± 5.8 dB(A)). This analysis indicates the limited use of 1-hour L_{Aeq} values at any time over a 24 hour period when predictions are being made using the $L_{A10(18hour)}$. This confirms ancillary concerns over the use of 1-hour L_{Aeq} values in legislation or guidelines where only predictions are possible, such as in the case of a new road. Additional commentary on this is as follows:

- The measurement of the highest 1 hour L_{Aeq} in any time period of a 24 hour period is likely to occur when measurement instrument is unattended as it is not possible for instrumentation to be attended for a full 24 hour period (due to practical, economic, safety and other reasons). It is not always possible with current mainstream instrumentation technology to determine the cause of the highest L_{Aeq} 1 hour value which could be due to extraneous noise sources.
- Unless very accurate knowledge of the traffic volumes and vehicle classification composition is known, including the likely sound power emissions of the vehicle fleet, it is not possible to predict the highest 1-hour L_{Aeq} level in any time period over 24 hours.
- Due to the above points, it is not possible to produce future predicting calculation models which are verified to local conditions, even if these models are capable of prediction 1-hour L_{Aeq} values. This is because, to produce accurate results, the historical traffic data is known and forward predicting traffic data can only be used in future predicting traffic noise models. The accuracy of the future predicting noise models is reliant upon the accuracy of traffic flow data models. It is extremely likely that it is not possible to predict accurately enough future conditions which will satisfy the impacted community.
- Regarding indicators for sleep disturbance, a highest 1-hour L_{Aeq} value neither fits as an indicator for short term sleep disturbance effects from discrete noise sources nor as an indicator for long term sleep disturbance effects.

Thus there is little technical and scientific motivation to adopt a highest 1-hour L_{Aeq} night time noise level as a design level, in any form, advisory, flexible or fixed.

The correlations between the longer term L_{Aeq} values such as the L_{Day}, L_{Eve} and L_{Night} and the $L_{A10(18hour)}$ demonstrate some interesting results. The L_{Day} correlates highly with $L_{A10(18hour)}$ (Equation 7, R^2 = 0.96, ± 2.6 dB(A)). The L_{Eve} correlates with $L_{A10(18hour)}$ similarly well (Equation 8, R^2 = 0.94, ± 2.9 dB(A)), however the L_{Night} does not follow this high level of correlation (Equation 9, R^2 = 0.87, ± 4.8 dB(A)). This is not a surprising trend as the L_{Day} and L_{Eve} are in the same time periods included in the $L_{A10(18hour)}$. These results indicate that the longer term L_{Night} is clearly more correlated than the $L_{Aeq,max(1hour,Night)}$, however there is sufficient variability in the L_{Night} with a tolerance of ± 4.8 dB(A) to warrant caution in its possible use as a night time design level indicator when calculating it as a conversion from $L_{A10(18hour)}$.

The L_{den} and $L_{den(QLD)}$ both demonstrate high correlation with the $L_{A10(18hour)}$. The L_{den} (Equation 10, R^2 = 0.93, ± 3.3 dB(A)) and the $L_{den(QLD)}$ (Equation 11, R^2 = 0.94, ± 3.1 dB(A)) would appear to be suitable indicators which can be calculated easily from an $L_{A10(18hour)}$ conversion.

As the $L_{den(QLD)}$ is slightly more correlated with the $L_{A10(18hour)}$ than the L_{den} there is some justification (albeit not significant) for using the alternative hours used in the calculation of the $L_{den(QLD)}$ as the definition for day, evening and night periods for local conditions in Queensland.

The correlation between the L_{Amax} and the $L_{A10(18hour)}$ is of interest from the point of view that the L_{Amax} is often considered the appropriate indicator to assess short term effects of sleep. As noted in the sections above, the superseded legislation, the EP(N)P 2007 (Queensland Government 1997), contained the L_{Amax} as one of the prescribed planning levels.

Firstly, the highest L_{Amax} in the day, evening and night time periods was compared with the $L_{A10(18hour)}$. The $L_{Amax,max(Day)}$ demonstrated an extremely low level of correlation with the $L_{A10(18hour)}$ (Equation 12, R^2 = 0.25,± 12.7 dB(A)). The $L_{Amax,max(Eve)}$ also demonstrated an extremely low level of correlation with the $L_{A10(18hour)}$ (Equation 13, R^2 = 0.39,± 12.2 dB(A)). The $L_{Amax,max(Night)}$, like the $L_{Amax,max(Day)}$ and the $L_{Amax,max(Eve)}$ demonstrated an extremely low level of correlation with the $L_{A10(18hour)}$ (Equation 14, R^2 = 0.50,± 10.6 dB(A)). Clearly the highest L_{Amax} in any of the time periods is not correlated with the $L_{A10(18hour)}$. This is not surprising as the highest L_{Amax} is the statistic most affected by non-consistent traffic noise or a single noise isolated vehicle.

However, the average L_{Amax} was also considered over each of the time periods. The $L_{Amax,av(Day)}$ (Equation 15, R^2 = 0.71, ± 6.3), the $L_{Amax,av(Eve)}$ (Equation 16, R^2 = 0.70, ± 7.8) and the $L_{Amax,av(Night)}$ (Equation 17, R^2 = 0.85, ± 5.9) all demonstrated a partial correlation with the $L_{A10(18hour)}$. Interestingly the night time average L_{Amax} was found to have the highest correlation of all the $L_{Amax,av}$ periods however the correlation is not sufficiently significant to be useful in the development of a night time noise design level.

Thus the L_{Amax} indicator, either the highest level or average level, does not appear to be an appropriate indicator to use in legislation or design guidelines for a design level for night time noise as:

- The L_{Amax} is highly sensitive to extraneous noise, and therefore measurements during the night time period can not be deemed with confidence to be representative of road traffic noise.
- It is not possible to predict the time or level or location of the occurrence of L_{Amax} event, therefore it is not possible to correlate a measurement to a prediction which ensures there is currently no reliable scientific approach to environmental reporting of the L_{Amax}.

The next analysis which is of interest is how the $L_{A10(18hour)}$ correlates with background noise levels such as the $L_{A90(18hour)}$ and $L_{A90(8hour)}$. It is seen by Equation 18, that the $L_{A90(8hour)}$ is not correlated at all to the $L_{A10(18hour)}$ (R^2 = 0.16, ± 11.0 dB(A)) which implies that the $L_{A10(18hour)}$ can not be used to estimate background noise levels in any way. This is an important conclusion as the emergence of a noise event over the background level can not be established from the $L_{A10(18hour)}$. The $L_{A90(18hour)}$ is more correlated with the $L_{A10(18hour)}$ than the $L_{A90(8hour)}$ (Equation 19, R^2 = 0.49, ± 8.1 dB(A)) however the correlation is clearly poor and greatly unreliable.

The lack of a relationship of environmental road traffic noise to a community's background noise level is an important acknowledgement. It demonstrates that common design level indicators for road traffic noise can not be associated with or reliant upon background levels.

5.2 Indicator Distributions from 10pm to 7am

As this investigation focuses on the night time period, it is useful to first inspect the spread of results per time period and indicator.

Figure 2a shows that the $L_{Amax(1hour)}$ is on average between 75 dB(A) and 80 dB(A). The average is at its minimum between the hours of 2am and 4am which is expected due to these hours carrying the least traffic volumes. The highest recorded $L_{Amax(1hour)}$ (which from unattended data is likely to include a few instances of extraneous noise events) is generally between 100 dB(A) and 110 dB(A). The minimum $L_{Amax(1hour)}$ is just above 45 dB(A) between 2am and 3am but is typically around 55 dB(A) to 60 dB(A) in other hours of the night-time period. The box plots in Figure 2a indicate the very large ranges measured across all sites in the database, for example the average difference between the highest $L_{Amax(1hour)}$ and the 75th percentile $L_{Amax(1hour)}$ is 21.2 dB(A). The average difference between the 25th percentile and 75th percentile in only 11.6 dB(A), whilst the average difference between the minimum $L_{Amax(1hour)}$ and maximum $L_{Amax(1hour)}$ is 50 dB(A).

The L_{A01} can be considered as a representation of the L_{Amax} but being the level exceeded for 1% of the time it will exclude most extreme extraneous noise levels. Inspection of the data in Figure 2b reveals that the $L_{A01(1hour)}$ is 9.0 dB(A) less than the $L_{Amax(1hour)}$ on average between 10pm and 7am. The average $L_{A01(1hour)}$ between 10pm and 7am is generally between 65 dB(A) and 70 dB(A). The $L_{A01(1hour)}$ ranges from approximately 40 dB(A) (1am to 3am) to 55 dB(A) (7am). The average difference between the maximum $L_{A01(1hour)}$ and the 75th percentile is 15.2 dB(A) while the average difference between the 75th percentile and 25th percentile is 11.0 dB(A). The average difference between the maximum and minimum $L_{A01(1hour)}$ is 43.7 dB(A), however only between 1am and 3am the difference is 50.7 dB(A) on average. The maximum $L_{A01(1hour)}$ is remarkably consistent at approximately 90 dB(A).

The $L_{A10(1hour)}$ is the basis of the calculation of the $L_{A10(18hour)}$ between 6am and midnight, and it is expected to be reasonably constant at least between 7am and 6pm. Thus it is of interest to observe how the $L_{A10(1hour)}$ at night behaves. Figure 2c shows the night time trend of the $L_{A10(1hour)}$ during the night. Like the $L_{Amax(1hour)}$ and $L_{A01(1hour)}$, the average $L_{A10(1hour)}$ is at its minimum in the early morning hours of 2am and 3am. The average ranges from 57 dB(A) to 67 dB(A) during the night. The relative consistency of the $L_{A10(1hour)}$ at night is demonstrated by the average difference between the 75th percentile and 25th percentile being less than 10 dB(A). The average range between the maximum $L_{A10(1hour)}$ and the minimum $L_{A10(1hour)}$ is 42.3 dB(A).

The $L_{Aeq(1hour)}$ (Figure 2d) during the night demonstrates statistical characteristics and patterns similar to the $L_{A10(1hour)}$. The average minimises during the hours of 2am and 3am. The average $L_{Aeq(1hour)}$ ranges from 55 dB(A) to 64 dB(A) which is 3 dB(A) less than the $L_{A10(1hour)}$. This gives some credence to the generalised rule that the $L_{Aeq(1hour)}$ is 3 dB(A) less than the simultaneous $L_{A10(1hour)}$. The spread of data around the mean is constrained like the $L_{A10(1hour)}$ with the average difference between the 75th percentile and 25th percentile being 9.3 dB(A). The average difference between the maximum level and minimum level is 39.6 dB(A).

The L_{A90} is a commonly used descriptor to represent the 'background' or 'ambient' sound level. The $L_{A90(1hour)}$ statistical distribution throughout the night time period shows (Figure 2e) different characteristics than the $L_{Amax(1hour)}$, $L_{A01(1hour)}$, $L_{A10(1hour)}$ and $L_{Aeq(1hour)}$ in that there is a significant reduction in average $L_{A90(1hour)}$ in the hours of 2am and 3am (40.3 dB(A)) compared with the 10pm and 6am/7am hours (52.5 dB(A)). The average $L_{A90(1hour)}$ over the entire night period is approximately 46 dB(A) and the range is 15.6 dB(A). The average difference between the maximum $L_{A90\,(1\,hour)}$ and minimum $L_{A90(1hour)}$ is 38.8 dB(A). The average difference between the 75th percentile and 25th percentile is 9.5 dB(A) which indicates the narrowness of spread in the $L_{A90(1hour)}$ data. However, on closer inspection the $L_{A90(1hour)}$ is more widely spread in the hours between 5am and 7am than it is between 10pm and 4am.

It is observed in the sections above that the $L_{Amax(1hour)}$ and the $L_{A01(1hour)}$ tend to be fairly constant and concentrated around the mean, but exhibit a large range across the night time hours. The mean becomes more variable for the $L_{A10(1hour)}$, $L_{Aeq(1hour)}$ indicators. The $L_{A90(1hour)}$ demonstrates the most variability at night of all the indicators analysed. This is to be expected considering the data analysis processes behind the calculation of these indicators that is, the indicators representing the higher noise levels (for example, $L_{Amax(1hour)}$, $L_{A10(1hour)}$) are based on less noise data events than the indicators representing lower noise level (for example, background noise data , $L_{A90(1hour)}$).

The average of each indicator discussed above is graphically presented in each hourly period from 10pm to 7am in Figure 2f. This figure shows the variability each indicator over the night time hours and most notably is the range of averages. It is observed there is typically 20 dB(A) difference between the average and the maximum level for each indicator over the night time period. The difference between the 75th percentile and the 25th percentile is also fairly constant across the indicators, ranging from 10.7 dB(A) for the L_{Amax} to 8.1 dB(A) for the L_{A90} while the L_{A01} demonstrated the highest spread with 11.1 dB(A) difference.

The analysis on the statistical and L_{Aeq} indicators above shows proven that road traffic noise levels will vary significantly across Queensland. In any of the wide range of indicators, there will be a wide range of levels and consequently a wide range of exposures of Queensland's population. Although the situation is further complicated by the wide ranging sensitivities of people towards road traffic noise, this will not be discussed here.

6. DISCUSSION & CONCLUSIONS

The European Commission currently requires its member states to report community transport noise in the L_{den} and L_{Night} indicators. In order to calculate these indicators accurately, a specialised calculation methodology has been developed, which requires the prediction of 1 hour L_{Aeq} levels over an entire 24 hour period. In order to calculate 1 hour L_{Aeq} levels accurately it is necessary to have accurate traffic volume and vehicle classification data, and in addition to this, each vehicle classification requires knowledge of its sound power level for a wide range of speeds, road gradients and pavement surface types.

Using the equations in Table 2 ensures that a reasonable approximation of the L_{den} and L_{Night} can be made, from using existing CoRTN $L_{A10(18hour)}$ calculation methodologies.

The numerous relationships between the $L_{A10(18hour)}$ and other road traffic noise indicators determined that some indicators are highly correlated with the $L_{A10(18hour)}$ and others have little or no correlation at all. The $L_{A10(18hour)}$ is found to be reasonably correlated with indicators using the L_{Aeq}, but it is not well correlated with indicators of short term noise events such as the L_{Amax}. Interestingly, the $L_{A10(18hour)}$ is reasonably correlated with 24 hour energy averages such as the $L_{Aeq(24hour)}$. This concludes that the $L_{A10(18hour)}$ is capable to a certain extent of representing noise levels over the night time period, despite some concerns that the indicator ignores the night time period.

The relationships obtained between the $L_{A10(18hour)}$ and L_{den} and L_{Night} have already been used in another study on estimating the annoyance rates and health related costs of Queensland's population subject to road traffic noise (Naish, Tan and Demirbilek 2011).

Although some reasonable correlations are found with some indicators, a particular note of the tolerance values is also required. Caution needs to be taken when transforming the $L_{A10(18hour)}$ to another indicator when compliance matters are being investigated. For example, even the highly correlated indicator, the $L_{A10(12hour)}$ experienced a tolerance of ± 1.5 dB(A) which is a very high deviation when considering that an acoustic professional may need to design mitigation to optimum values. The tolerances for the L_{Aeq} based indicators likewise are large (L_{Day} ± 2.6 dB(A); L_{Eve} ± 2.9; L_{Night} ± 4.8 dB(A)) when considering the scales needed for acoustic mitigation e.g. noise barriers. The L_{den} tolerance (± 3.3 dB(A)) when placed in perspective, is equivalent to more than double or half of the AADT which contributes to the $L_{A10(18hour)}$. Clearly, the tolerances on other L_{Amax} and L_{A90} indicators suggests that confidently transforming the $L_{A10(18hour)}$ to these formats can be considered inappropriate. Consequently, it can be concluded that the correlations of some indicators is possible, but kept within the acoustic planning domain, not the acoustic compliance domain.

Finally, the data presented in this paper is not to be used as a substitute for direct noise measurements, unless otherwise approved in relevant policy.

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