



Maximum pass-by noise levels from vehicles in real road traffic streams: comparison to modeled levels and measurement protocol issues

Eric Schreurs¹, Lex Brown², and Deanna Tomerini³

^{1,2,3} Urban Research Program, Griffith School of Environment

Griffith University, Nathan QUEENSLAND, 4111 AUSTRALIA

ABSTRACT

The noise signal from an individual vehicle or succession/platoon of vehicles within a road traffic stream is highly variable and in reality identifying a representative sample of the population of the noise level maxima of vehicle pass-by for the range of real road traffic noise conditions (combinations of vehicle speed, vehicle type, road surfaces, propagation path) is an expensive and time-consuming measurement task. This paper reports on a secondary analysis of a large sample of maximum pass-by noise data that was collected in Brisbane, Australia. The data set provides the noise level maxima (L_{AFmax}) of the pass-by of some 85,000 vehicles in service on urban arterials and motorways. Concurrent attended monitoring of vehicle type has allowed an analysis of the distribution of the noise level maxima according to some road characteristics and for the range of the different types of vehicle.

There have often been suggestions that road traffic noise criteria should include, in addition to integrated energy measures such as L_{eq} , L_{den} or similar, some metric of the individual noise events (L_{AFmax} , SEL) or number of noise events, generated by individual noisier vehicles within the traffic stream. Apart from selecting such a metric in terms of its relationship to health impacts, such as sleep disturbance, that metric needs to be able to be measured reliably, and preferably able to be predicted. The aforementioned monitoring program identified that, whereas field measurement of descriptors such as L_{eq} have a well-established protocol, there is no similar protocol for the in-situ measurement of noise events. This paper enumerates the issues relevant to the measurement of noise events in road traffic streams.

1. INTRODUCTION

Environmental noise researchers and road transport authorities are both interested in understanding the temporal variation of environmental noise at a resolution that is valid to their cause (which might be the accurate prediction of acute health effects or the practicable management of road traffic noise). These causes are constrained by an incomplete understanding of noise events. In addition, some road transport authorities are developing noise management approaches that require both the identification of a single noisy vehicle and a legally acceptable way to measure the noise event.

In 2007, Austroads, the Australian association of road transport and traffic authorities, commented on the increasing community reaction from night-time noise due to increased operations of freight traffic [1]. Here it was recognised that there is a major and negative community reaction to the noise made by heavy vehicles on urban roadways, particularly during the night when many trucks prefer to travel because of lower levels of congestion and timely access to markets. This reaction is related to the properties of truck noise, which can be identified as being single noise events where a

¹ e.schreurs@griffith.edu.au

² lex.brown@griffith.edu.au

³ d.tomerini@griffith.edu.au

high peak level emerges from and diminishes to the background level. However, current noise measurement techniques and noise indicators do not readily accommodate the assessment of this discontinuous noise of large vehicles travelling at night. This is a problem if the effect of transport noise on human sleep depends more on the maximum noise level L_{AFmax} and number of noise events in the traffic stream than it does on integrated energy measures such as L_{eq} , as suggested in recent studies by Griefahn [2] and Pirrera [3].

Still, most noise measurement studies focus more on the time averaged measures. For instance in Australia, measurements of road traffic noise are usually represented by the equivalent noise level L_{eq} or the 10th percentile level L_{10} . These single-number metrics used to represent the fluctuating traffic noise signal generally de-emphasise, and are insensitive to, the noise caused by single noisy vehicles. A study by Brown et al. [4] showed that the noise of road traffic alongside a traffic lane, where heavy vehicles were restricted during the measurement period, did not result in significant changes of the L_{eq} or L_{10} levels, whereas the level and incidence of the L_{AFmax} measurements tended to show a change after the restriction of heavy vehicles.

The research reported in this paper forms part of a research project at Griffith University that is examining the relationship between noise events in road traffic and conventional measures of road traffic and L_{eq} . The project is using micro-simulation of road traffic streams and then modelling the noise emissions from vehicles in these streams. Input to the modelling requires information on noise emission levels of different types of vehicles in practice. This paper reports a secondary analysis of data from a study in which maximum pass-by noise levels from over 85,000 vehicles were recorded at urban motorways and arterial roadways in the Brisbane area, and then compares these to modelled levels from the European IMAGINE/HARMONOISE packages [5]. The paper also raises issues with respect to the measurement of L_{AFmax} levels from vehicles operating under real conditions on roadways in the field (non-experimental, non-controlled conditions), and the need for the development of protocols for such measurements.

2. L_{AFmax} FROM VEHICLES IN SITU

2.1 Measurements

For this study, measurements were performed at ten different sites in the Brisbane Metropolitan area. Four sites were adjacent to two-way urban arterial roadways (four to six lanes with posted speed limits of 60 or 70 km/h) and six beside dual carriageway urban motorways (two lane carriageways with posted speeds of 80, 90 or 100 km/h). These roads were all paved with dense graded asphaltic concrete (DGAC). Actual vehicle speeds could not be measured at these sites, so for the analysis the posted speed limits were used as a proxy for the vehicle speed.

The microphones at the measurement sites could not be placed at a consistent distance from the roadway; this distance from the microphone to the centreline of the respective carriageway carrying freely-flowing vehicles ranged from 13 m to 38 m, with the median distance being 16 m for vehicles on the near carriageway and, 27 m for vehicles on the far carriageway. Measurements were conducted between 10 pm and 5 am. These night-time hours were dictated by the original purposes of the truck management study, but they had advantages for vehicle pass-by measurement in that vehicle movement on the roadways was not constrained by congested flow conditions. The receivers were set to record the L_{AFmax} during noise events according to the following operational characteristics:

- sampling period 200 ms
- minimum value of recorded maxima 60 dB(A)
- required drop in level before next maximum 5 dB(A)
- maximum wait time for above drop in level 25 s
- minimum period before next maximum 3 s

When the measurement equipment detected a noise event under this protocol, operators identified the vehicle type responsible for the event (a judgement as to which passing vehicle was acoustically dominant) and the direction in which the vehicle was travelling. The demands of visually

identifying the vehicle responsible for each noise event resulted in some events being unassigned, and these have been excluded from further analysis. Exclusions can be considered random in terms of vehicle type.

2.2 Secondary analysis of the measurement data

Three adjustments have been made to the measured maximum levels in the results reported below. Firstly, corrections were made for façade effects. Secondly, as variation in the terrain between vehicle source and microphone at the different sites will have influenced the measured levels (depending on terrain and the flow resistivity of the ground surface between source and microphone) these have been adjusted to free-field conditions. This adjustment was made, independently for each carriageway at each site, using the propagation effect-of-terrain component of the Nord2000 model. The model identifies a Fresnel-zone of reflection on the intervening ground surface [6] and estimates the terrain effect based on 1/3 octave bands. This adjustment resulted in an estimate of the level at the measurement location that would have resulted from spherical divergence alone from the vehicle source (no ground effect or shielding effect). Thirdly, all levels have been standardised to a distance of 15 m from the centreline of vehicle flow. The choice of 15 m approximates the median propagation distance (in Australian cities) between dwelling facades and the nearest roadway lane: Brown and Lam [7] reported the median distance from facades to roadway kerbs as 13 m.

After this processing, of the 85,000 vehicles measured, the results of around 71,000 of them were deemed useful. These results can be compared with each other, divided in four different vehicle types (Cars, non-articulated trucks, articulated trucks, and motor cycles). These categories are comparable with the classification used by Imagine (light vehicles, medium heavy vehicles, heavy vehicles and two-wheelers) [5]. Imagine distinguishes between buses with 2 axles (medium heavy) and with 3-4 axles (heavy), however for this study all buses were considered to be non-articulated, as most buses are considered to be medium-heavy in Australia. The results are summarized in Table 1, where for the five different posted speed limits the mean value, the median value and the standard deviation (σ) of all the L_{AFmax} levels are provided. Also the total number n of observations is given.

Table 1 - Mean, median and standard deviations of the distributions of noise level maxima (dB)

Vehicle Type		Posted Speed Limits (km/h)				
		60	70	80	90	100
Cars (n = 37,686)	Mean	67	69	69	72	71
	Median	67	70	69	72	73
	σ	4.6	5.1	3.5	4.4	6.7
Non-Articulated Trucks (n = 6832)	Mean	71	73	75	76	76
	Median	72	73	74	76	77
	σ	5.1	5.5	4.4	5.1	7.3
Articulated Trucks (n = 25,527)	Mean	73	76	77	79	77
	Median	75	77	77	80	80
	σ	6.0	5.7	4.1	6.0	9.0
Motorcycles (n = 990)	Mean	69	72	75	75	75
	Median	69	72	75	75	75
	σ	5.5	5.3	5.8	5.1	8.0

The variance of the levels within all vehicle classes is high, with the L_{AFmax} of some 90% of the vehicles of each type extending over a range of between 12 and 20 dB on roadways with posted speeds of less than 100 km/h, and up to 30 dB where the posted speed limit was 100 km/h. The large variance in the levels from each class of vehicle results in the distributions of their maxima overlapping extensively. This means, for example, that while the very noisiest of events at any location is likely to be from the passing of an articulated truck, some cars and non-articulated trucks will have L_{AFmax} higher than those from articulated trucks. Figure 1 shows noise maxima categorised by vehicle type for two posted speed limits: 60 km/h and 100 km/h. For 60 km/h roadways, L_{AFmax} of up to 72 dB were generated predominantly by cars, and maxima above this predominantly by articulated trucks. For 100 km/h roadways, this transition occurred above 78 dB.

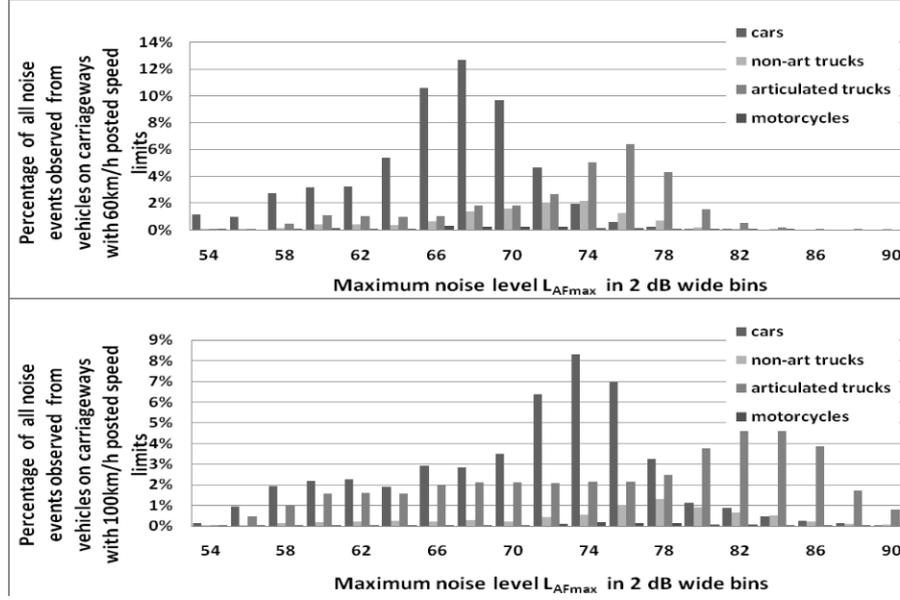


Figure 1 - The distribution of maxima (L_{AFmax}) by vehicle type on roadways with posted speed limits of 60 km/h (top) and 100 km/h (bottom)

3. COMPARISON WITH THE EUROPEAN HARMONOISE/IMAGINE MODELS

Using the median values from the distributions of the noise level maxima of each vehicle type, shown in Table 1 the Sound Power Level of the vehicles can be estimated. As the L_{AFmax} are free-field levels at 15 metres from the centreline of vehicle travel, they can be converted to Sound Power Levels L_W [8]:

$$L_W = L_{A_{max,15m}} + 10\log(4\pi 15^2) = L_{A_{max,15m}} + 34.5 \quad (1)$$

Sound Power Levels estimated from the current measurements at each posted speed limit are shown in Table 2.

The IMAGINE/HARMONOISE model has been developed in the EU over the last 10 years in order to create a single harmonized method for noise mapping in all of the EU member states [5]. Source modelling in IMAGINE is divided in two parts: rolling (tire/pavement) noise (L_{WR}) and propulsion noise (L_{WP}). The Sound Power Level of the vehicle sources in these models, L_W , comprises two terms:

$$L_W = 10\log(10^{L_{WP}/10} + 10^{L_{WR}/10}) \quad (2)$$

The propulsion and rolling noise terms respectively are dependent on the vehicle speed s and coefficients A and B :

$$L_{WR} = A_R + B_R \log\left(\frac{s}{s_{ref}}\right) \quad (3)$$

$$L_{WP} = A_P + B_P \frac{s - s_{ref}}{s_{ref}} \quad (4)$$

With the coefficients A_R , B_R , A_P and B_P known, and the s_{ref} being 70 km/h, L_W can be calculated using the equations 2 to 4.

The HARMONOISE model uses the same equations to calculate the Sound Power Levels, yet the propulsion and rolling noise coefficients have different values [9]. It is assumed that the IMAGINE coefficients are more up-to-date than the HARMONOISE coefficients, but for this study both of the source models will be used, so the measured sound power levels can be compared to two modelled results.

The estimated Sound Power Levels of vehicles with IMAGINE/HARMONOISE source modelling are shown in Table 2 along with the median sound power levels from the present study. These levels are very close to those of the IMAGINE levels (a mean difference of +0.3 dB across all speeds and vehicle types, with a maximum difference of -3 dB), but somewhat lower than those of the older vehicle source strengths from the HARMONOISE model (a mean difference of -1.6 dB across all speeds and vehicle types, with a maximum difference of -5 dB).

Table 2 - Comparison of the estimated Sound Power Levels (dB) of cars, non-articulated trucks and articulated trucks in the present study with those predicted by the IMAGINE and HARMONOISE models.

		Posted Speed Limit (km/h)				
		60	70	80	90	100
Cars	This Study	102	104	103	106	107
	IMAGINE	101	102	104	105	106
	HARMONOISE	102	103	103	104	105
Non-articulated trucks	This Study	104	107	109	110	110
	IMAGINE	107	108	109	110	110
	HARMONOISE	108	109	110	111	112
Articulated trucks	This Study	109	111	112	115	114
	IMAGINE	110	111	112	113	113
	HARMONOISE	114	115	115	117	118

4. ISSUES REGARDING MEASUREMENT OF VEHICLE PASS-BY NOISE MAXIMA IN SITU IN ROAD TRAFFIC STREAMS

In some circumstances, the measurement of maximum pass-by noise levels within road traffic noise will be needed as a supplement to the commonly used time-averaged noise levels. Measuring time-averaged sound levels can use unattended noise meters that can measure continuously alongside roadways (an example is the noise monitoring program by the Dutch National Institute for Public Health and the Environment [10]). However, when measuring L_{AFmax} , some issues that exclude the use of unattended monitoring need to be considered.

The significant overlap of the $L_{Afm\max}$ distributions by vehicle categories indicates that valid identification of the true source (vehicle type) of each $L_{Afm\max}$ level is important. A single $L_{Afm\max}$ level is meaningless if no further information of the source is known. Vehicle type, speed, accelerating or braking, sports exhausts and mufflers, which traffic lane the vehicle is travelling on, are all aspects that can influence the resulting maximum noise level.

The number of $L_{Afm\max}$ identified during any measurement period will be highly dependant on the settings of the measurement equipment. There is a need for careful consideration and justification of the specifications that will trigger the equipment to record a noise maximum (choice of sampling rate, the minimum value of the recorded maxima, the required drop in level before the next maximum, maximum wait time before the next maximum). In some circumstances, it may be necessary to record the entire noise signal to allow for post-processing using a variety of specifications to identify and 'count' the noise maxima.

5. CONCLUSIONS

This analysis of this road traffic noise data has elicited both substantive and methodological findings.

It was shown that the median values of traffic noise maxima measured in situ on Brisbane roads are comparable to those predicted by the European IMAGINE/HARMONOISE models.

Furthermore it was shown that the distribution of the L_{AFmax} levels is broad for all the vehicle types: the standard deviation found in the measurements overlap all the median values found for the vehicle types; the highest L_{AFmax} levels are not necessarily produced by the heaviest vehicles. This might be an issue for noise management approaches that rely on the assumption that prohibition of heavy vehicles on residential roads will significantly reduce community reaction to noise.

A protocol for the measurement of road traffic noise maxima in situ is needed to provide consistency in equipment specifications and in the identification and categorization of the vehicle or vehicles related to each measured L_{AFmax} .

REFERENCES

- [1] Austroads, "Strategies for Reducing the Environmental Impacts of Increased Night-Time Operation of Road Freight: A Scoping Study." AP-R315/07. Sydney, Austroads Incorporated (2007).
- [2] B. Griefahn, A. Marks and S. Robens, "Noise emitted from road, rail and air traffic and their effects on sleep." *Journal of Sound and Vibration*, 295, 129-140 (2006).
- [3] S. Pirrera, E. de Valck and R. Cluydts, "Nocturnal road traffic noise: A review of its assessment and consequences on sleep and health." *Environment International*, 36, 492-498 (2010).
- [4] A.L. Brown and D. Tomerini, "Distribution of the Noise Level Maxima from the pass-by of vehicles in urban road traffic streams." *Road and Transport Research Journal* (under review)
- [5] B. Peeters and G. v. Blokland, "The Noise Emission model for European Road Traffic." Deliverable 11 of the IMAGINE project. www.imagine-project.org (2007). Retrieved in 2011.
- [6] B. Plovsing and J. Kragh, "Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 1: Propagation in an Atmosphere without Significant Refraction," DELTA Acoustics & Vibration, Report AV 1849/00 (revised), Hørsholm. (2006).
- [7] A.L. Brown and K.C. Lam, "Can I play on the road Mum? - Traffic and homes in urban Australia." *Road and Transport Research*, 3(1), 12-23 (1994).
- [8] L.L. Beranek, "Noise and Vibration Control", McGraw-Hill, New York, (1971).
- [9] H.G. Jonasson, "Acoustical source modelling of road vehicles." *Acta Acustica United with Acustica*, 93, 173-184 (2007).
- [10] E.M. Schreurs, E.N.G. Verheijen, C.P.M. Potma and J. Jabben, "Noise Monitor 2009: Measurements and validation of Environmental noise." RIVM Report 680700004, Bilthoven, (2010).