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A study on the sound power of Queensland road vehicles

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ABSTRACT

A sound power survey was conducted on Queensland roads to produce a database of vehicle sound power levels categorised on vehicle classification, speed, pavement surface type and driving conditions. The purpose of the study was to compare the local vehicle sound power levels with similar surveys conducted in Europe in application of the Nordic and Harmonoise prediction methods. This paper presents the methodology employed in the study and the locations measured and also outlines the results and analysis.

1.0 INTRODUCTION

Queensland is a state of Australia. In Queensland, as with most other Australian states, road traffic noise has been calculated using the CoRTN [1] methodology and this is unlikely to change in the near future. There are numerous road traffic noise calculation methods available internationally, the most recent being the development of the 'Harmonoise' method for optional use in the European Union (EU). The Harmonoise method is significantly more complicated than the CoRTN method and consequently requires significantly more detailed input data than CoRTN to produce a calculation. The Harmonoise method is similar in concept to the Nordic prediction method by the separation of the source strength and the propagation calculation [2, 3].

Fundamental to all road traffic noise calculation methods is the representation of the road traffic noise source strength. In CoRTN, the road traffic noise source strength is embedded into the 'basic noise level' and its consequent corrections for speed, % commercial vehicles, road gradient and pavement surface. The source strength in CoRTN is an overall dB(A) level. In Harmonoise, the source strength is divided into rolling and propulsion source sound power levels, the sum of the two being the overall sound power of the particular vehicle type at a specified speed, acceleration rate, road gradient, pavement surface type, pavement surface temperature (using air temperature) and road wetness. The source strength in Harmonoise is in 1/3rd octave bands from 25Hz to 10kHz.

In recent years, in-situ measurements of road vehicles have been conducted in Australia using the Statistical Pass-by Method (SPB) [4, 5] and the focus of these studies has been on the road pavement surface effects on vehicle pass-by noise. In order for Queensland to proceed to investigating the use of Harmonoise or Nordic prediction methodologies an understanding of the local vehicle sound power characteristics is required. This study is a step towards developing a local sound power level database of road vehicles in Queensland.

2.0 METHODOLOGY

The sound power of individual vehicles in-situ traffic was measured generally following the method in Nordtest Method 109 (NT ACOU 109) [6]. Figure 1 shows the schematic measurement layout for each site. The investigators and instruments were positioned in a stationary vehicle at a satisfactorily safe distance from the nearest carriageway. A B&K Pulse instrumentation system was used to conduct the measurements, via connection with a laptop and Pulse was linked with a spreadsheet. The system was calibrated before and after each measurement session.

Three microphones were placed at 0.2m, 1.5m and 4.0m above the pavement surface (see Figure 2). The 1.5m microphone height was included to allow the potential to correlate the measured pass-by data with SPB results from previous studies and possibly with data from the TNM methodology [7], however data from the 1.5m microphone is not presented in this paper.

The L_{eq} and L_{max} in 1/3 octave bands from 20Hz to 20kHz of an individual vehicle was measured with a known microphone distance and were recorded directly into a spreadsheet database with details of the vehicle classification and speed for each of the different pavement surface types investigated.

The measured L_{eq} from both the 0.2m and 4.0m microphones were normalised to a Sound Exposure Level (SEL) at 10 m ($L_{E,10m}$) and then converted to L_w using published transfer function values C(v) [8] with speed correction ($L_w = L_{E,10m} + C(v)$). The final L_w for each 1/3 octave band was the highest L_w out of the 0.2m and 4.0m microphones.

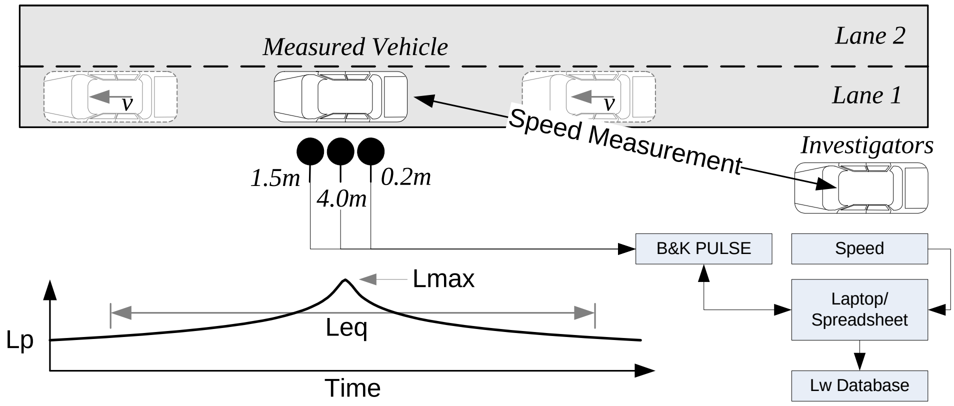

Figure 1: Schematic instrumentation and measurement arrangement

Figure 2: Typical field measurement microphone arrangements

Vehicle speed was measured with a laser type speed gun and measured at the vehicle as it passed the microphone locations. In most sites, two pass-by lanes were included in the database, except for one site which included a third lane. The measured L_w results are compared with the reference pavements from the Harmonoise [9] database of L_w values.

While recording the measurements, vehicles were initially classified according to AS2702 [10] vehicle classifications. These classifications were correlated with corresponding categories for Harmonoise [9], TNM [7], CoRTN [1] and the Austroads 12 bin classification system [11]. In this paper only the Harmonoise classifications are used to analyse results, and more specifically only the major classifications of; Category 1 = Light (e.g. cars); Category 2 = Medium (e.g. trucks or busses); and Category 3 = Heavy (e.g. trucks and busses). The vehicle speed was recorded in integers and consequently placed in bins of 5km/hr span for example, 97km/hr falls into the 95km/hr bin (spans 92.5 to 97.5km/hr). Pavement surface temperature was also measured with a laser pointed temperature meter at regular intervals during the measurements, but this data has not yet been used in this study.

3.0 MEASUREMENT SITES

The measurement sites were all flat grade roads with speed limits ranging from 60km/hr to 110km/hr. The pavement surface types were dense graded asphalt (DGA), bituminous seal (chip seal – CS), stone mastic asphalt (SMA), open graded asphalt (OGA) and transversely tyned Portland cement concrete (PCC). In total, 9 measurement sites were included in the database, and their approximate locations around South-east Queensland are shown in Figure 3. This study has not obtained detailed information on the condition of the pavement surfaces such as core samples or maintenance histories of the pavements but this is intended to be obtained in future studies. This study has focused on obtaining establishment of the method and initial comparisons between pavements and the databases already established in Europe and is not intended to be conclusive. The number of vehicles measured at each site is presented in Table 1.

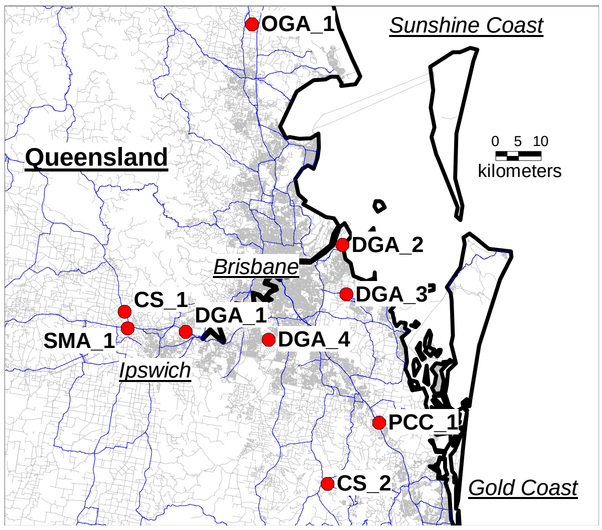

Figure 3: Measurement locations surrounding Brisbane

In total, the database comprises of 2241 vehicles (71% Category 1, 8% Category 2, 20% Category 3). The DGA pavement surfaces contributed to 38% of the sample followed by 23% (CS), 18% (SMA), 12% (OGA) and 10% for PCC.

Table 1: Sample size for each measurement site

Pavement Surface*	Site Name	Sample Size (number of vehicles)			
		Category 1	*Category 2*	*Category 3*	*Total*
DGA	DGA_1	237	32	110	379
	DGA_2	21	10	111	142
	DGA_3	246	22	14	282
	DGA_4	17	35		52
OGA	OGA_1	197	18	47	262
PCC	PCC_1	170	6	38	214
CS	CS_1	236	17	40	293
	CS_2	201	11	12	224
SMA	SMA_1	273	34	86	393
	Total	1598	185	458	2241

*DGA = dense graded asphalt; CS = bituminous seal (chip seal); SMA = stone mastic asphalt; OGA = open graded asphalt; PCC = transversely tyned Portland cement concrete

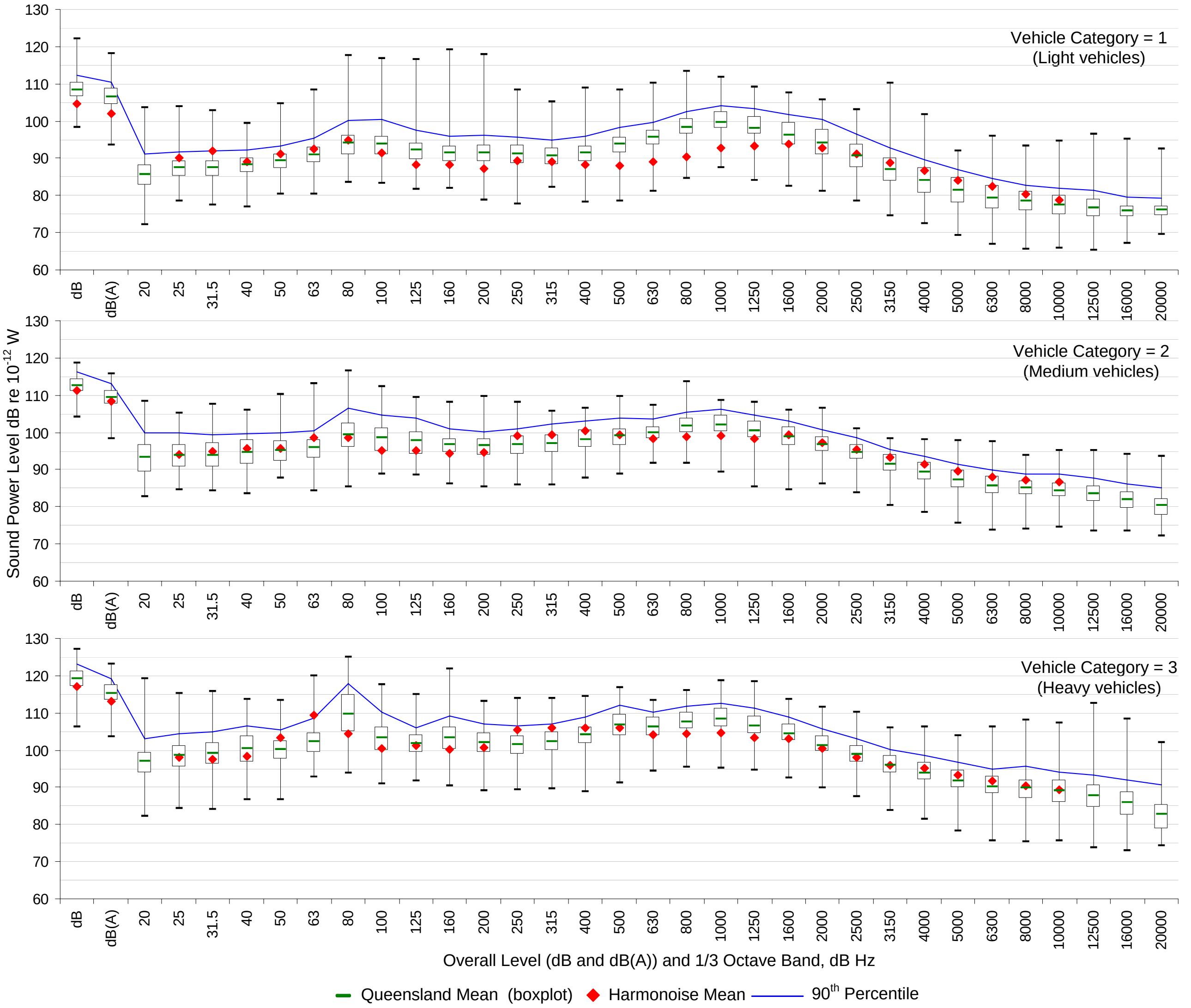

Figure 4: Vehicle category: sound power overall levels and 1/3 octave distribution

4.0 RESULTS

In this paper, the use of “Queensland” simultaneously denotes the State of Queensland and also describes the location that the sound power level data was obtained that is, the database name or description. As an example, “Queensland category 1 vehicles” means category 1 vehicles from this study on Queensland.

The results presented in this paper are only related to those vehicles between the 80km/hr and 110 km/hr speed bins and in the speed analysis only the 80km/hr, 90km/hr, 100km/hr and 110km/hr speed bins. While the sample sizes are not ideal at present, they are likely to be sufficiently large to commence observation of trends in the sound power of Queensland road vehicles. The results are presented in four sections below; Section 1 investigates the frequency variability across the three Harmonoise vehicle categories; Section 2 compares the effects of vehicle speed in the 80km/hr, 90km/hr, 100km/hr and 110km/hr speed bins; Section 3 looks at the effects of the different pavement surface types and the final section presents a tabulation of the overall level sound power separating all three main variables i.e. vehicle category, speed and pavement surface type.

The spread of sound power across the assessed variables is presented in quartiles format for the Queensland data in Figure 4, Figure 5 and Figure 6. The 90th percentile of the measured data (solid line) and the mean Harmonoise sound power level for the scenario under investigation (diamond dots) are also shown in the figures. The 90th percentile is shown to assist in visualising the spectral trend by demonstrating the differences between the loudest sound power and the 75th percentile sound power.

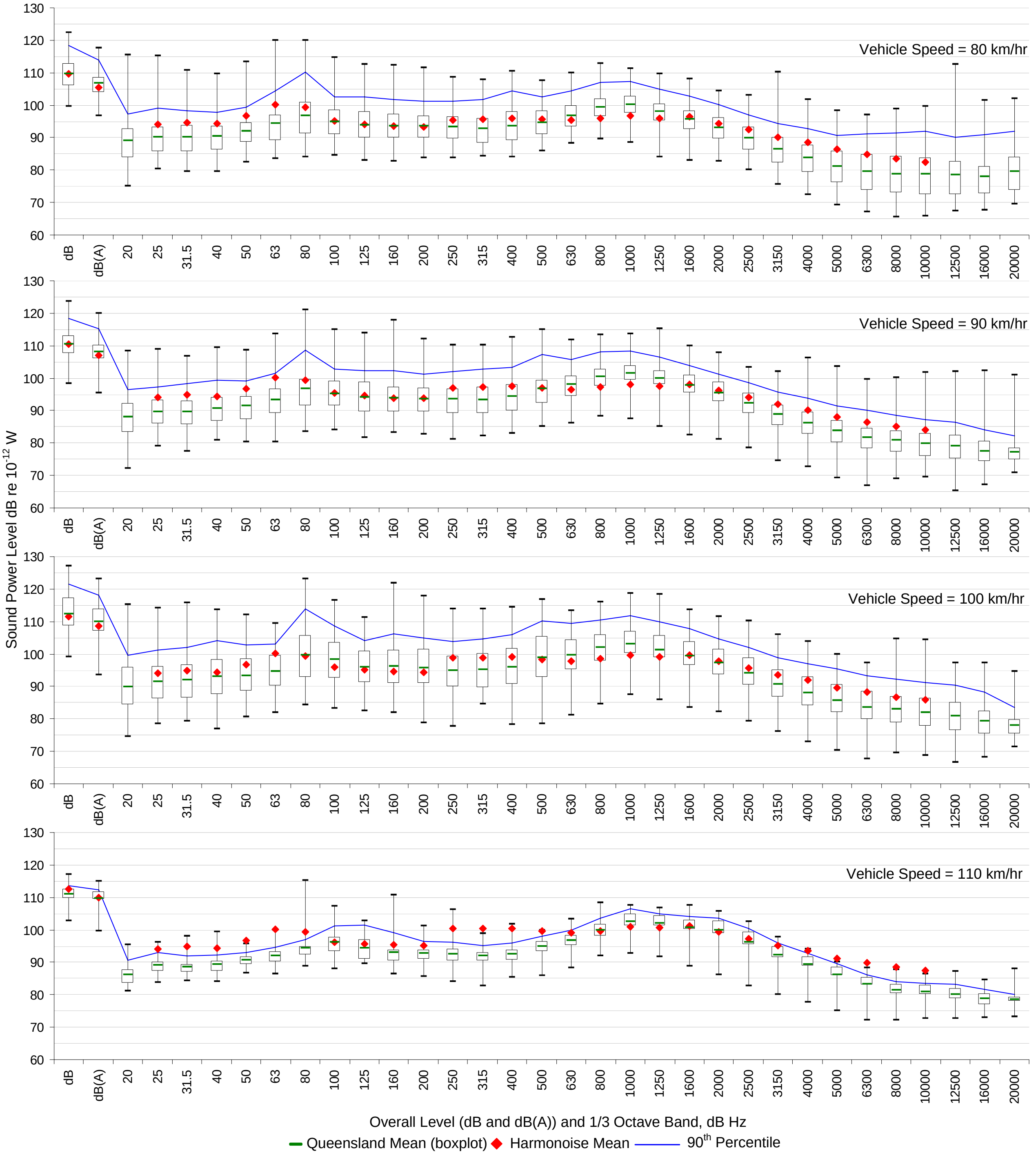

Figure 5: Vehicle speed: sound power overall levels and 1/3 octave distribution

4.1 Vehicle Category Variability

The spread of sound power across the assessed vehicle categories is presented in Figure 4 and the mean Harmonoise sound power level from 80km/hr to 110km/hr (diamond dots) are also shown in Figure 4. These results indicate that category 1 vehicles have the largest variability across the fleet with category 2 having the least variability, however there may be some effect of different sample sizes present. With category 1 vehicles the notable features are the relatively larger variability in the 80Hz and 100Hz bands which is attributed to faulty or modified exhausts (based on site observations). There is also relatively more variability in frequencies ranging from 1600Hz to 6300Hz, which is likely to be mostly due to different pavement surface types such as PCC and OGA (see Section 4.3). Compared with the mean Harmonoise sound power, the sound powers of Queensland category 1 vehicles generally follow the same trend across the 1/3 octave spectrum, although there are some interesting deviations between 400Hz and 1600Hz.

In all three vehicle categories, the influence of the exhaust system is clearly observable, in particular for category 3 vehicles. The largest variability in heavy vehicles is in the 80Hz band, and the mean for Queensland is significantly higher than the mean for Harmonoise. Pavement surface effects would not cause this effect in this frequency band, therefore this indicates that Queensland heavy vehicle exhaust systems produce a different character of noise compared to European vehicles. This effect may need to be noted in future applications of Harmonoise prediction methods in use in Queensland. Between 250Hz and 315Hz, Harmonoise tends to be higher than Queensland, contrary to frequencies between 800Hz and 1250Hz. Queensland category 2 vehicles generally follow the same spectral trends observed in the Harmonoise data.

Despite the comparative difference in the spectral characteristics of Queensland and Harmonoise vehicles, the overall linear and A-weighted levels appear to correlate reasonably for medium and heavy vehicles but not so well for light vehicles. It is possible that the light vehicles in Queensland either have slightly higher propulsion noise than European light vehicles or the pavement surfaces measured are generally noisier than the Harmonoise reference pavement, or both.

4.2 Vehicle Speed Variability

Comparing all vehicle categories across the nominated speed bins of 80km/hr, 90km/hr, 100km/hr and 110km/hr provides some interesting comparisons between Queensland vehicles and Harmonoise vehicles. In the database, there are 177 vehicles in the 80km/hr speed bin; 307 vehicles (90km/hr bin); 356 vehicles (100km/hr) and 54 vehicles (110km/hr bin). Within these speed bins the there are 239 vehicles with a DGA pavement surface type; 125 vehicles (OGA); 113 vehicles (PCC), 229 vehicles (CS) and 188 vehicles on an SMA pavement. Also within these speed bins there were 637 Category 1 vehicles; 59 Category 2 vehicles and 209 Category 3 vehicles.

Figure 5 presents the charted results. Firstly in the 80km/hr speed bin, the Harmonoise mean is notably higher than the Queensland mean above 2000Hz but is below between 800Hz and 1250Hz. The Queensland mean is a little lower than the Harmonoise mean at 80Hz but significantly lower at 63Hz, which indicates again some differences may exist in the exhaust systems of the two vehicle fleets. These differences noted at 80km/hr are again noted for 90km/hr, 100km/hr and 110km/hr speed bins.

At 110km/hr the distribution of the data is narrowed which is most likely due to the smaller sample size for this speed bin. There is smaller difference between the 25^{th} and 75^{th} percentile in the 80Hz and 100Hz bands than at 100km/hr but it is observed that the frequency of exhaust noise shifts higher at the higher speeds, as expected. The Harmonoise data does not suggest an upward frequency shift, with the 63Hz band containing the respective peak band energy in the low frequency part of the spectrum. Also notable with the 110km/hr data is the relatively smaller variability around the middle frequencies with large variability introduced at higher frequencies above 1000Hz. This later effect is most likely due to the pavement surface noise generation variability. At 110km/hr, the Harmonoise data is significantly louder than the Queensland data below 100Hz.

4.3 Pavement Surface variability

The distribution of sound power over different pavement surfaces including all vehicle categories 1, 2 & 3 and speeds between 80km/hr and 110km/hr are compared with the mean reference pavement Harmonoise sound power from the conditions. The charted results are shown in Figure 6 where in each chart the Harmonoise values are the same and can be used to reference the Queensland data distributions across each chart. This data does not include a sufficient number of samples across the various pavement surfaces to draw strong conclusions on the trends observed and the inferences that can be made from these results, however the observations do match some expectations obtained overall from previous local studies [5].

The spectral means for the study DGA pavement correlate well with the Harmonoise mean which suggests that these pavement surfaces do have similar construction characteristics which produce similar spectral acoustic attributes. The study SMA pavement spectral means are also well correlated with the Harmonoise mean but slightly lower than the Harmonoise mean above 2250Hz.

The study OGA pavement mean is lower in all frequencies compared to the Harmonoise mean. This result is naturally expected as OGA is known to have beneficial acoustic attributes compared to DGA and SMA. The study OGA pavement does demonstrate some significantly lower energy in frequencies at or above 1000Hz and between 250Hz to 400Hz.

In contrast to OGA, the PCC pavement demonstrates consistently higher levels from 800Hz to 2250Hz but follows similar patterns with Harmonoise reference pavement below 800Hz. Likewise the CS pavement follows a similar trend with Harmonoise up to 3150Hz above which it exhibits slightly lower noise emissions.

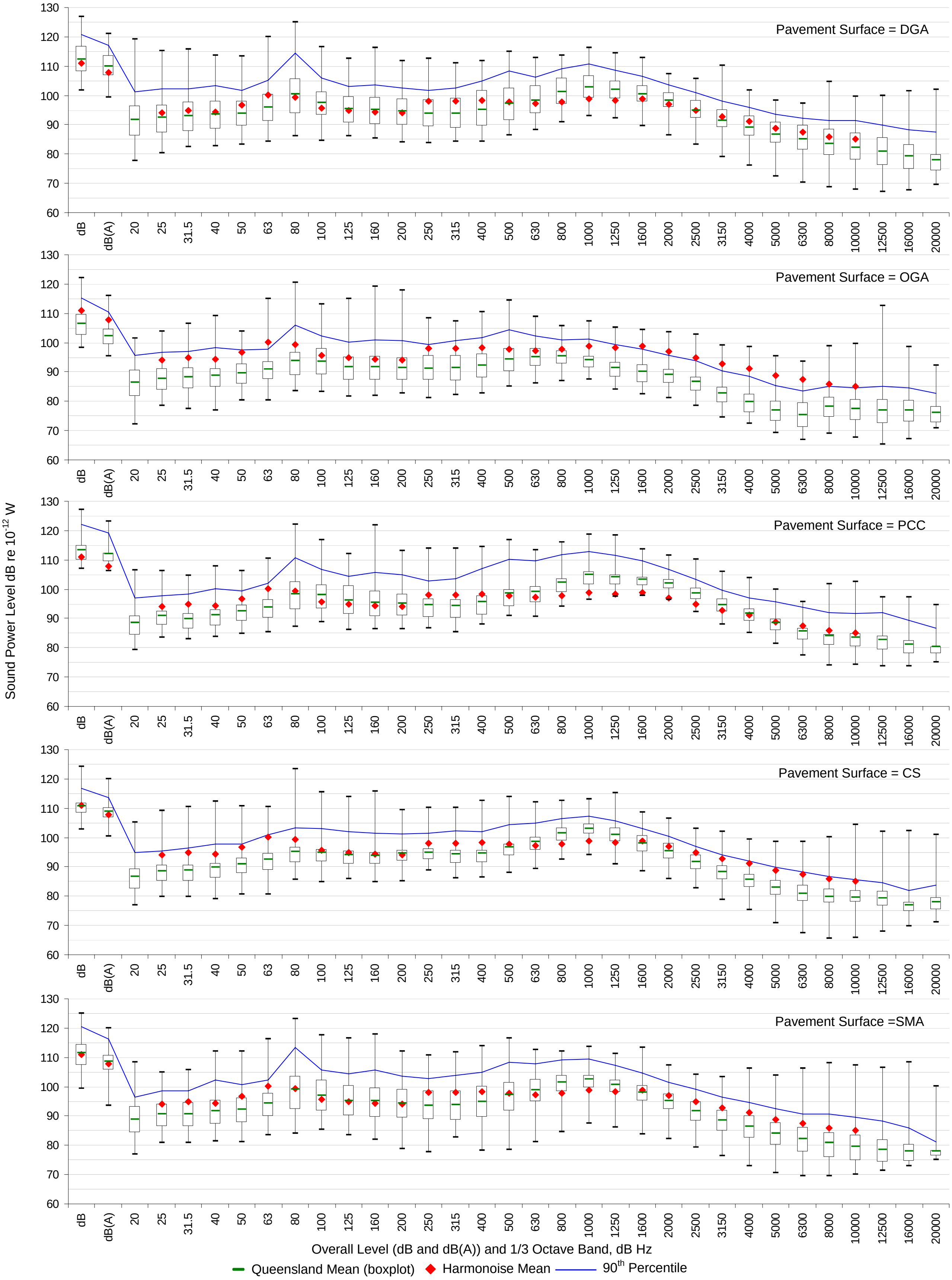

Figure 6: Pavement surface type: sound power overall levels and 1/3 octave distribution (DGA = dense graded asphalt; CS = bituminous seal (chip seal); SMA = stone mastic asphalt; OGA = open graded asphalt; PCC = transversely tyned Portland cement concrete)

Table 2: Mean sound power level dB(A) per measured site vs Harmonoise [9] and DK Nord 2005 [2]

Pavement Surface*	Site Name	Vehicle Category	80km/hr	90 km/hr	100 km/hr	110 km/hr
DGA	DGA_1	1	107	109	110	112
		2	111	114	115	-
		3	118	118	120	-
	DGA_2	1	109	111	-	-
		2	-	-	110	-
		3	118	-	-	-
	DGA_3	1	106	108	-	-
		2	110	-	-	-
OGA	OGA_1	1	101	103	104	105
		2	106	111	109	-
		3	117	115	115	-
PCC	PCC_1	1	109	111	111	112
		2	-	112	115	-
		3	118	119	123	-
CS	CS_1	1	109	110	111	112
		2	-	113	112	-
		3	-	119	121	-
	CS_2	1	107	109	108	-
		2	109	114	-	-
		3	-	117	-	-
SMA	SMA_1	1	106	108	110	107
		2	111	113	112	-
		3	118	119	121	-
Harmonoise	-	1	104	104	105	106
		2	110	111	112	113
		3	116	117	118	119
DK Nord 2005	-	1	106	107	109	110
		2	113	114	115	117
		3	116	117	118	119

*DGA = dense graded asphalt; CS = bituminous seal (chip seal); SMA = stone mastic asphalt; OGA = open graded asphalt; PCC = transversely tyned Portland cement concrete

4.4 Overall Sound Power Level

The overall unweighted mean sound power from each measurement study site, each vehicle category and speed bins 80km/hr, 90km/hr, 100km/hr and 110km/hr are tabulated in Table 2 along with the corresponding values for Harmonoise [9] and DK Nord 2005 [2]. Missing values in the table indicate that there was no sample for that particular scenario on a particular measurement site.

At each measurement site, overall sound powers increased by 1 to 3 dB per 10km/hr speed increment, except for medium and heavy vehicles on the OGA pavement which experience a minor reduction with increasing speed.

The light vehicles on the DGA pavement are 3 to 7 dB higher than the Harmonoise light vehicles on its reference pavement. The light vehicles on the SMA pavement are 1 to 5 dB higher than Harmonoise. The difference between Queensland data and the Harmonoise reference pavement for medium and heavy vehicles on DGA is reduced to -2 to +3 dB and 1 to 3 dB for SMA. Further investigation is required on the exact structure of the measured pavements in comparison to the reference pavement to determine if the high sound power levels for Queensland's data is due to louder vehicles or pavements or a combination of both.

The light vehicles on the PCC pavement are 5 to 7 dB higher than the Harmonoise reference pavement with the medium and heavy vehicles being 1 to 5 dB louder. Similarly the light vehicles on the CS pavement are 5 to 6 dB louder, consistently across all assessed vehicle speeds.

The Queensland data appears to be more closely correlated to the Nordic data, than it is to the Harmonoise data for example light vehicles on DGA are 1 to 4 dB louder than light vehicles on the Nordic reference pavement.

5.0 CONCLUSIONS

This study has demonstrated some initial observational differences between the sound power levels of Queensland road vehicles and the Harmonoise predicted sound power levels The observed differences are notable in some instances but minor in others and clearly more in depth study and analysis required before any strong conclusions are made. The initial summary of the observations are:

1. Queensland vehicle sound power levels generally follow the same spectral characteristic trends as the Harmonoise calculated sound power levels.
2. Exhaust noise in Queensland tends to dominate the 80Hz 1/3 octave band whereas it dominates the 63Hz 1/3 octave band in Harmonoise.
3. There are significant spectral differences between certain pavement surface types.
4. Light vehicles in Queensland appear to be louder than their European counterparts overall, but not consistently across all frequencies. The medium and heavy sized vehicles tend to be more correlated with the sound power of the European equivalents.
5. The sound power of Queensland vehicles appear to be more closely correlated with the Nordic database.

The sound power data obtained from this study can be used in further research into to road traffic noise impacts in

Queensland and Australia. Research into the effects of night time noise or urban street acoustics and building design will all benefit from the results of this study. Future work is proposed to extend the measurements to other sites and expand the database. Additional analysis of the existing database will be conducted with a focus on the combined effects of vehicle category, vehicle speed and pavement surface type.

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