Prediction of parking area noise in Australian conditions

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ABSTRACT

The prediction of carpark noise presents a significant challenge to Acoustic Engineers. This paper aims to provide a method for prediction of carpark noise that can predict spectral L_{eq}, L_1, L_{10} and L_{max}. The basis for this method is an application of the Bavarian State Office for the Environment (Bayerisches Landesamt für Umwelt - BayLfU) parking area noise study to Australian conditions. Measurements of carpark noise were made at carparks with low, medium and high rates of turnover per parking space. The noise associated with an individual parking procedure was measured for procedures on smooth bitumen, rough bitumen and coarse gravel. The overall sound pressure level from one parking procedure on a smooth surface was 64dB(A), with a +3dB correction required for rough surfaces. The BayLfU model, a German study into noise emissions from carparks, presents a method for calculating the L_{Aeq} overall sound level. The model does not provide methods for calculating spectra for the noise. Predictions of carpark noise for the BayLfU model are based on a 63dB(A) measurement for one parking procedure. When comparing the noise measurement results with predictions calculated using the BayLfU model, it was found that the BayLfU model slightly under-estimated noise emissions. By correcting predictions made with the BayLfU model to the parking procedure measurements, estimations of carpark noise were very close to the measured levels for medium and high turnover carparks.

INTRODUCTION

Parking area noise presents a significant challenge to acoustic engineers. The transient, random nature of the noise, and the distribution of noise over a large area make prediction difficult. Parking area noise arises from the movements of vehicles within a parking space. Noise sources associated include passing traffic, vehicles shunting into and out of the carpark space, door and boot slams and engine starts. In shopping centres, noise from shopping trolleys must also be considered. Each individual noise source has no fixed location, and most are impulsive in nature.

Parking area noise can vary greatly depending on the time of day. Shopping centre carparks tend to be busy during the day, from 9am till 5pm, whereas carparks associated with licensed premises (clubs, hotels and restaurants) tend to be busy during the evening period. When considering parking area noise, it is best to consider the busiest time period and the relevant regulations.

The type of vehicles using a parking area can also affect noise levels. A parking area frequented by large diesel four-wheel-drives and utilities can generate more intrusive noise than one used mostly by small passenger cars. This is an important consideration when predicting the noise of carparks, and the appropriate corrections must be applied.

Parking areas are regularly positioned in close proximity to other sources of environmental noise. Transport corridors, plant noise and loading dock noise can often mask the more transient parking area noise. Due to high background noise, measurement of parking area noise can be difficult, making prediction methods more important.

The number of parking spaces within a carpark does not directly affect the noise emissions. Rather, the number of movements per carpark, turnover, has a significant influence. This necessitates the use of traffic data to determine the number of vehicles entering and leaving the parking area in a reference period. Limits on length of stay in a parking area can also be used to estimate turnover. Parking areas with high turnover are easier to model than carparks with low turnover.

Vehicle turnover is rarely constant over the entire parking area. Parking spaces closer to shops and businesses tend to have much higher turnover than those on the fringe of the property. The emissions from these high turnover areas are higher than those in low turnover areas, but traffic data does not always model the distribution of high parking space use. As a result, predictions of carpark noise may overestimate noise emissions over the area of the carpark. Preferably, carparks with distinct areas of differing turnover should be modelled as separate sources.

Definitions

When referring to carpark activity, the following definitions will be used;

Movement – a vehicle entering or leaving a parking space.

Procedure – a vehicle entering then leaving a parking space. Each procedure is two parking movements, one entering and one leaving movement.

Event – a parking event is an individual action associated with a parking movement. Events include door and boot slams, engine starts, manoeuvring, tyre noise on pavement and gravel and driving to the parking space.

Turnover – the number of movements per space per hour.

Carpark size – the number of parking spaces associated with a parking area.

Carpark area – the surface area of the carpark in m^2.

Parking Area Classification

In this paper, parking areas are classified either in terms of the number of parking spaces associated with the carpark (the carpark size), the number of movements per hour, or in terms of the turnover per hour (the number of movements per space per hour). When considering the noise levels associated with a parking area, the turnover is the most influential, although the carpark size must also be considered. For comparisons in this paper, parking areas are classified according to Table 1 below.

Table 1: Parking Area Classification

Size/Turnover	Small/Low	Medium	Large/High
Parking spaces	< 30	30 – 100	> 100
Movements/hr	< 50	50 - 150	> 150
Mov/space/hr	< 0.5	0.5 – 1.5	> 1.5

MEASUREMENT OF PARKING AREA NOISE

Measurement of Parking Events

To determine the L_{Amax} power level for parking related noise sources, the sound pressure levels for individual parking events were measured. Events measured included door and boot slams, engine starts, acceleration from rest and travel at a constant speed. Measurements were conducted 10m from the source, at a height of 1.5m and the duration varied depending on the nature of the source. For each event type, the loudest event was used for calculations.

Measurement of Parking Movements

Measurements were made to determine both the spectral and overall sound power levels associated with movements involving a range of vehicles representative of the Australian vehicle market. Each measurement involved a vehicle entering or leaving a parking space, with associated door slams, engine starts and tyre noise. Measurements were taken perpendicular to the parking space, 7.5m from the central axis. The receiver was positioned at a height of 1.5m. An average of the measurements for all vehicle types was used for comparison with the BayLfU levels. The average levels associated with parking movements are summarised in Table 2.

Figure 1: Parking Movement Spectra

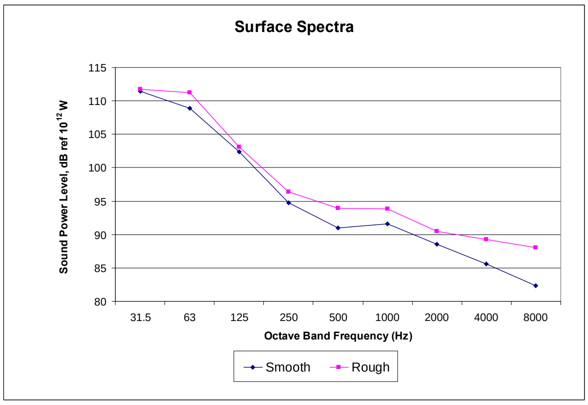


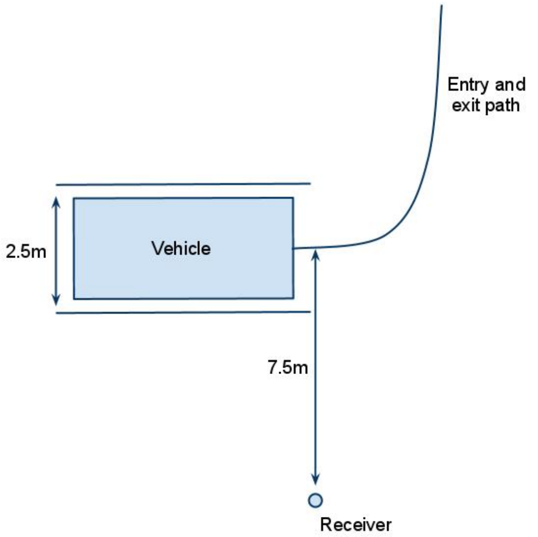
Table 2: Parking Movement Sound Power Levels - Smooth and Rough Surfaces, dB L_w ref 10^{-12} W

Surface	Frequency (Hz)							
	63	125	250	500	1k	2k	4k	8k	L_{Aeq}
Smooth	109	102	95	91	92	89	86	82	97
Rough	111	103	96	94	94	91	89	88	99

Measurement Procedure

An illustration of the measurement procedure for simulated movements is shown below in figure 2.

Figure 2: Measurement Procedure



Surface Correction

In addition to measurements taken on smooth surfaces, measurements of parking movements were performed in carparks with rough surfaces, such as gravel and loose bitumen. These measurements were used to determine an overall correction for rough surfaces of +3dB.

Vehicle Type

Measurements of parking movements involving a range of vehicle types were performed to determine the effect different vehicle types have on overall emission level from parking areas. Vehicles measured included small hatchbacks, large sedans, sports utility vehicles (SUVs) and large four-wheel drive vehicles.

Measurement of Parking Area Noise

To validate the method of calculation, measurements of parking area noise were made at a number of sites, ranging from small carparks with low turnover, to large, busy shopping centre carparks. Measurements were taken at a height of 3m, to minimize shielding from nearby vehicles, while ensuring noise from the parking area was still the dominant noise source. Activity within the adjacent carparks was excluded from data (approximately 3.75m radius, or one and a half parking spaces). Locations of measurements varied, with measurements taken both within the parking area and outside the parking area, less than 5m from the carpark boundary. Due to the location of the carparks in the vicinity of roads and other sources of environmental noise, measurements were taken at these distances to limit the extent environmental noise affected results. For each measurement, the number of parking movements and movements of trolleys and patrons were recorded.

MEASUREMENT SITES

Measurements were taken at a number of sites, with a focus on high-turnover shopping centre carparks and carparks with large numbers of vehicles arriving or departing within a short period of time. Measurements were taken at two large shopping centre complexes, and at several parking areas at the University of Queensland, all located within Brisbane. These parking areas were chosen due to the low ambient environmental noise levels compared with other similar carparks.

Site 1: Low turnover (<0.5), large size (approximately 240 spaces). Daily parking area at the University of Queensland, Brisbane. Vehicles at this carpark tended to arrive early in the morning and stay for the day. The carpark filled from empty in 3 hours. There was little activity for the rest of the day.

Site 2: Low turnover (<0.5), large size (approximately 150 spaces). Daily parking area at the University of Queensland. This carpark was similar to the Conifer Knoll Carpark.

Site 3: High turnover (>1.5), large size (approximately 120 spaces). Shopping centre carpark, located in Brisbane, Queensland. Vehicles tended to stay for a maximum of 1 hour. Most carparks saw turnover in a one-hour period, with some high frequency parking spaces having a much higher turnover than the rest of the parking area. Most activity occurred during business hours.

Site 4: High turnover (>1.5), medium sized (approximately 60 spaces). Medium to long term parking area at the University of Queensland, Brisbane. Vehicles tended to arrive early in the morning, and can stay for the day. Most vehicles left after 2 or 3 hours. High carpark activity occurred between 7am and 10am.

Site 5: High turnover (>1.5), medium sized (approximately 40 spaces). Shopping centre carpark, located in Brisbane, Queensland. Vehicles tended to stay for a maximum of 30 minutes. Some parking spaces had high turnover, whilst others had vehicles staying for several hours. Most activity occurred during business hours.

Measurement results, turnover and number of parking spaces are summarised in Table 3 below.

Table 3: Parking Area Noise Measurements

Site	Meas. No.	No. Spc	Mov /hr	Turn-over	Turnover Class	Leq dB(A)
1	1	243	64	0.26	low	57
	2		88	0.36	low	55
	3		72	0.30	low	57
	4		68	0.28	low	57
	5		84	0.35	low	56
	6		64	0.26	low	56
2	1	148	20	0.14	low	53
	2		80	0.54	low	54
	3		56	0.38	low	53
	4		68	0.46	low	54
3	1	120	256	2.13	high	58
	2		232	1.93	high	58
	3		220	1.83	high	58
	4		204	1.70	high	59
4	1	55	124	3.10	high	51
	2		100	1.82	high	52
5	1	40	120	3.00	high	59
	2		148	3.70	high	54
	3		204	5.10	high	57

BAVARIAN STATE OFFICE FOR THE ENVIRONMENT PARKING AREA NOISE

European noise regulations are much stricter than Australian regulations in regards to the noise performance of transportation infrastructure. The Bavarian State Office for the Environment (BayLfU) parking area noise study presents a method for calculating the noise emissions associated with various stationary traffic situations. This study, and its methods for calculating parking area noise, was chosen for examination in this paper due to its inclusion in popular software modelling packages, such as SoundPlan and CadnaA. Methods for calculating noise from petrol stations, truck stops, uncovered parking areas, underground parking areas and ramps and multi-level carparks are included in the study. This paper will focus only on the calculation of noise from uncovered parking areas.

The method presented by the BayLfU study of parking area noise involves the approximation of multiple noise sources to an area source.

A simplified calculation method is detailed below;

$$L_{\mathrm{w}} = L_{w0} + K_D + K_S + 10\log N \qquad (1)$$

Where;

$$L_{\mathrm{w}} = \mathit{Overall\ Leq\ sound\ power\ level}$$

$$L_{w0} = 63dB(A) = \mathit{power\ level\ for\ one\ movement/hr}$$

$$K_D = \mathit{Correction\ for\ passaging\ traffic\ noise.}$$

$$K_S = \mathit{Correction\ for\ surface}$$

$$N = \mathit{Number\ of\ procedures\ per\ hour}$$

$$S = \mathit{area\ of\ carpark}$$

The sound power level, L_w, is related to the plane-specific power level, $L_{w''}$, and the length-specific power level, $L_{w'}$, as follows;

$$L_{w''} = L_{\mathrm{w}} - 10\log\frac{S}{S_0} \qquad (2)$$

$$\mathit{where}\ S = \mathit{partial\ area}, S_0 = 1m^2$$

$$L_{w'} = L_{\mathrm{w}} - 10\log\frac{l}{l_0} \qquad (3)$$

$$\mathit{where}\ l = \mathit{partial\ length}, l_0 = 1m$$

For a more detailed explanation of the method of calculation in the BayLfU study please refer to the BayLfU study (Bavarian State Agency for the Environment, 2007).

BayLfU Comparison with Calculated Levels

The BayLfU method uses a L_{Aeq} sound power level level for one parking movement per hour of 63dB(A) L_W. From parking movement measurements, the calculated overall sound power level for one parking movement per hour was 64 dB(A) L_W.

APPLICATION OF BAYLFU TO AUSTRALIAN CONDITIONS

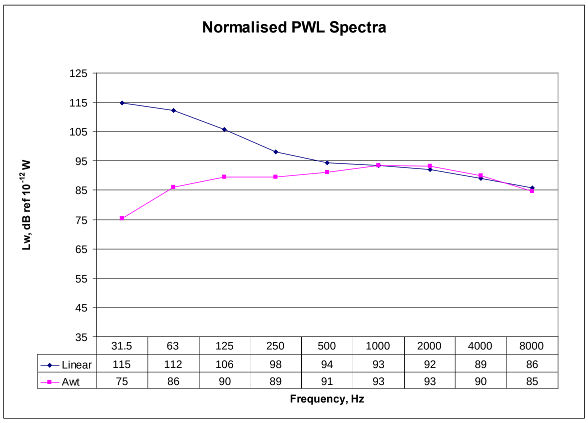
Correction to Australian Conditions

A correction was desired for approximating the level used in the BayLfU method so that results could more accurately represent Australian conditions. In Europe there is a tendency towards small diesel hatchbacks and although these vehicles are gaining popularity in Australia, large cars and utilities still dominate the vehicle market. Comparing the measured sound power level with the level used in the BayLfU method, the addition of a +1 dB correction was required.

Spectral Sound Power Levels

The BayLfU method does not include spectral sound power levels, so the calculated sound power levels from parking movement measurements were used in calculations. The A-weighted and linear spectrum (normalised to 100dB(A)) is shown below in Figure 3.

Figure 3: Power Level Spectra for Parking Movements, dB ref 10^{-12} W



Surface Correction

The BayLfU method provides corrections for surfaces. Not all of these corrections are applicable to Australian conditions. Measurements determined a correction of +3dB for parking on rough, loose surfaces such as gravel. The equivalent correction in the BayLfU method is +2.5dB. The measured correction of +3dB was used for all calculations.

Other Corrections in BayLfU

In addition to corrections for surface type, the BayLfU method includes corrections for parking area type. The correction for parking area type will not be considered in this paper. For more information refer to the BayLfU study (Bavarian State Agency for the Environment, 2007).

L_{Amax} Calculation

The method for calculating L_{Amax} for carparks varies from that used to calculate the statistical noise measures and L_{Aeq}. L_{Amax} is calculated by positioning a point noise source relating to the loudest single event in a parking space close to the nearest noise sensitive receivers. The position of the noise sources should be determined considering separation distance and shielding from intervening structures.

L_{Aeq} to L_{A1} and L_{A10} Conversion

In addition to the L_{Aeq} and L_{Amax} levels calculated using the BayLfU and above methods, conversion to L_{A1} and L_{A10} is required for some jurisdictions. The conversion is an adjustment added to the L_{Aeq} and is based on L_{A1} and L_{A10} levels measured during parking area measurements. The conversions are summarised in Table 4 below;

Table 4: Conversions to statistical measures

Ln	63	125	250	500	1k	2k	4k	8k	Awt
L1	9	9	10	9	8	9	9	8	8
L10	2	2	2	2	2	2	1	3	2

COMPARISON WITH MEASUREMENTS

To validate the proposed calculation method, results from measurements of parking area noise were compared against predicted levels. Each of the measured parking areas was modelled using the CadnaA software modelling program, and the corrected BayLfU values calculated. A comparison of measured and predicted sound pressure levels for each measurement are shown in Table 5 below. For each site, presented in Figures 4 to 8 are representative spectral graphs plotting the measured and predicted levels in each carpark. The BayLfU model inputs used in Figures 4 to 8 are shown in Table 6.

Table 5: Predicted and Measured L_{eq} for Parking Area Noise

Site	Meas. No.	Turnover Class	Meas. L_{eq} dB(A)	Predicted L_{eq} dB(A)	Difference dB
1	1	low	57	49	-8.0
	2	low	55	51	-4.0
	3	low	57	50	-7.0
	4	low	57	49	-8.0
	5	low	56	50	-6.0
	6	low	56	49	-7.0
2	1	low	53	44	-9.0
	2	low	54	50	-4.0
	3	low	53	48	-5.0
	4	low	54	49	-5.0
3	1	high	58	59	1.0
	2	high	58	59	1.0
	3	high	58	59	1.0
	4	high	59	58	-1.0
4	1	high	51	53	2.0
	2	high	52	54	2.0
5	1	high	59	54	-5.0
	2	high	54	55	1.0
	3	high	57	57	0.0

Table 6: Model Inputs for Presented Comparisons

Fig.	Site	No. Carparks	Turnover (Proc/carpark/hr)	Ks
4	1	243	0.35	0
5	2	148	0.14	0
6	3	120	2.13	3
7	4	55	3.10	0
8	5	40	5.10	0

Figure 4: Low Turnover, Large Size – Site 1

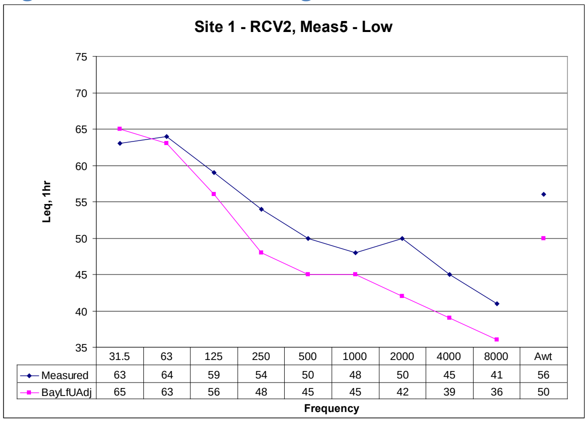


Figure 5: Low Turnover, Large Size – Site 2

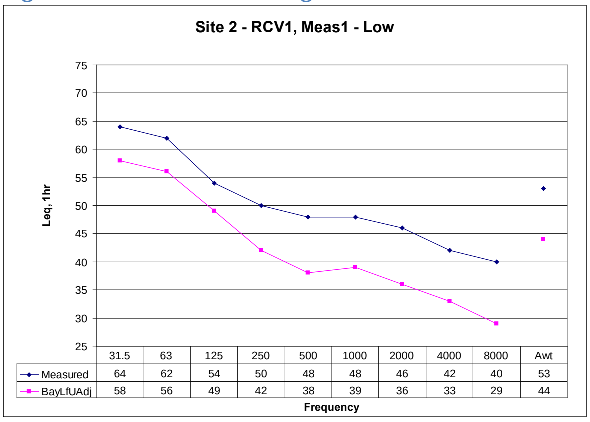


Figure 6: High Turnover, Large Size – Site 3

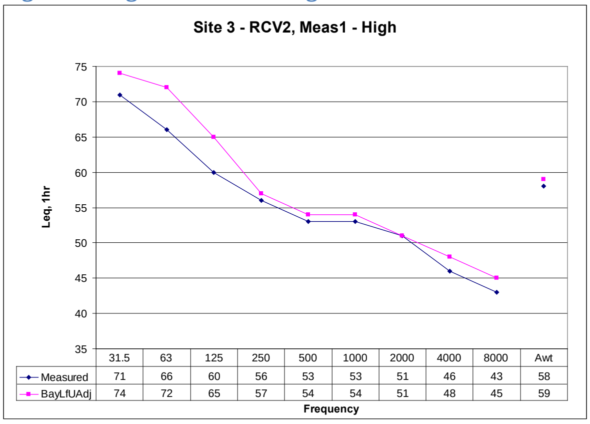


Figure 7: High Turnover, Medium Size – Site 4

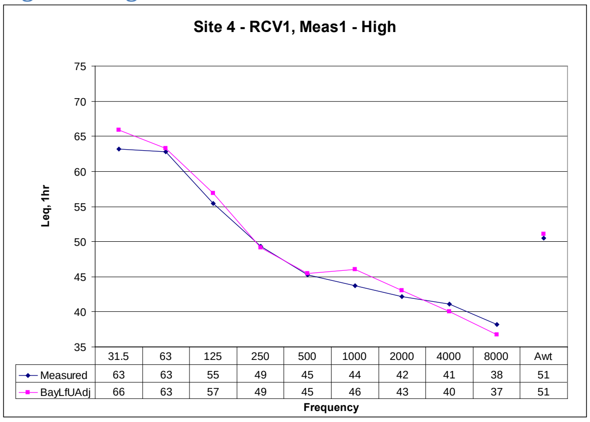


Figure 8: High Turnover, Medium Size – Site 5

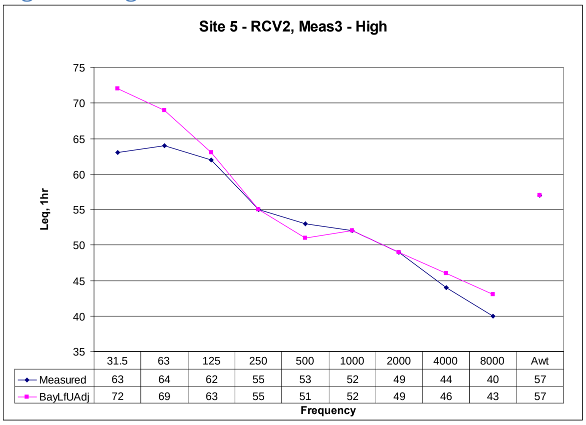


Figure 9: High Turnover Average

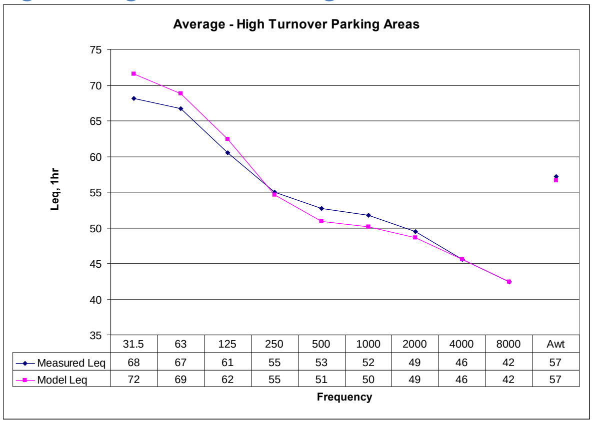


Figure 10: Low Turnover Average

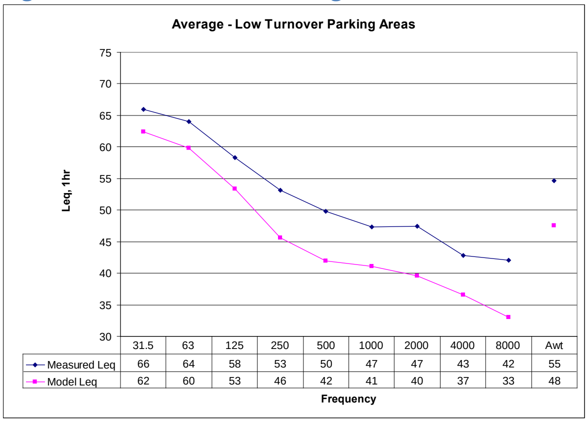
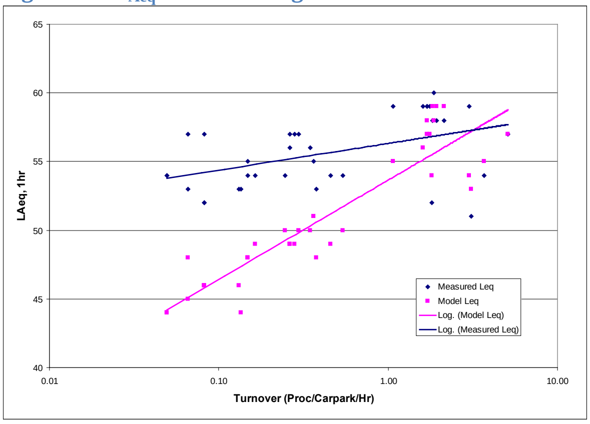


Figure 11: L_{Aeq} for increasing turnover



For carparks with medium and high turnover, there is a close correlation between the overall measured parking area levels and the overall levels predicted using the adjusted BayLfU method. Predicted levels are generally slightly higher than measured levels, desired for a conservative prediction.

The predicted spectrum for medium and high turnover carparks closely matches the spectrum for the majority of measurements. For some receivers, the predicted and measured levels differ at some frequencies. These differences can be explained by slight differences in the surface of the parking area and vehicles present between the predicted model and the measured parking area. These differences are not consistent over the spectrum range.

For some measurements there was a noticeable rise in levels around 1000Hz to 2000Hz that were not present in the individual parking procedure measurements. This could be due to plant noise from refrigerated vehicles, air-conditioning units, and wildlife nearby, noted at the time of measurement. The inconsistency seen in some measurements, even at the same site, demonstrates susceptibility to sources of environmental noise.

Parking areas with low turnover, such as those shown in Figure 4 and 5, are not accurately modelled using the adjusted BayLfU method. Levels for low turnover carparks are generally too low to exceed background noise levels at the location. This makes measurement and prediction of these types of carparks difficult, but also less important.

LIMITATIONS AND IMPROVEMENTS

The method for calculation of carpark noise has shown to be adequate for medium to high turnover carparks, but the calculation is not sufficient for low turnover carparks. This is most likely due to background noise exceeding parking area noise at low turnover parking areas.

Approximating parking area noise source to an area source has limitations, as the approximation assumes equal turnover over the entire carpark. Modelling separate sections of the parking area using multiple area sources can alleviate the problem. For low turnover carparks it is recommended that individual vehicle noise be used to predict overall carpark noise, as opposed to the area source approximation proposed.

There tends to be a large variability in levels associated with a single carpark due to limitations of the measurements. When making counts of vehicle and patron activity in a parking area, it can be unclear what constitutes the limits of the measurement area. Activity occurring a significant distance from the measurement point may be masked by environmental noise. Activity close to the measurement point dominated results. Ideally, measurements of carpark noise should be performed at periods of low background noise, and with simulated carpark activity.

The type of vehicle using a parking area can influence the emission levels. Large vehicles, such as four-wheel-drive cars and trucks generate more noise than small passenger cars. A correction could be added to the model to account for this difference, based on the proportion of large vehicles using a parking area.

CONCLUSION

Using an application of the BayLfU Parking Area Noise Study, a method was determined for predicting parking area noise that can predict spectral L_{eq}, L_1, L_{10} and L_{max}. Measurements were made for parking procedures on smooth bitumen, rough bitumen and course gravel. Corrections to L_1 and L_{10} from L_{eq} were calculated based on measurements of parking area noise. The BayLfU Parking Area Noise Study provided a method for calculating parking area noise, and this was combined with the parking procedure measurements to correct the method to apply to Australian conditions. The method also includes corrections for parking area surface type. Levels calculated using this method were compared with measured levels at carparks with low, medium and high rates of turnover per parking space. Parking areas with low turnover were not accurately predictable using the model. There was a close correlation between the predicted and measured level, in both overall and spectral calculations, for parking areas with medium and high turnover.

REFERENCES

Bavarian State Agency for the Environment 2007, *Parking Area Noise*, 6th Edition, Bavarian State Ministry for the Environment, Germany.