A VEHICLE MAXIMUM NOISE LEVEL STUDY

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Abstract

The RTA is currently embarking on a program of fixed speed camera (FSC) installation throughout NSW and has developed draft selection criteria for their installation. In response to community concern regarding perceived increases in noise levels and more particularly, the perceived increases in the number of noisy engine brakes, research has been undertaken to evaluate whether installation of FSC's and warning signs contribute to impacts, and whether site selection criteria should address noise issues. The assessment concentrates on evaluating the effects of FSC installation on changes in the application of audible engine brakes, 'A' weighted night-time $L_{eq(9hour)}$ traffic noise levels and L_{max} vehicle noise events. It was found that the prototype "Mad Max" software package currently being developed by Wilkinson Murray P/L provided a credible definition and protocol for interpreting single vehicle noise events where multiple vehicle pass-bys are common. Research suggests that external noise events below 65 dB(A) are of reduced concern in terms of maximum noise level impacts but all events should be identified to ensure a normal distribution of data and therefore statistical validity. None of the road types investigated showed a significant increase in audible engine brake application or noise impact. However, some further research is needed to capture all road geometry scenarios. Where traffic is comprised of primarily light vehicles a significant benefit can be expected due to a reduction in vehicle speed.

Introduction

The NSW Roads and Traffic Authority (RTA) is currently embarking on a program of fixed speed camera installation throughout NSW and has developed draft selection criteria for their installation. The *Draft Criteria for Selection of Speed Camera Locations* (2000) [1], addresses accident and injury rates for a range of road classifications, severity of accidents, speed profile and practical fixed speed camera (FSC) installation. At the present there are no FSC site selection criteria addressing noise impacts.

Numerous engine and vehicle manufacturers have stated that the near unanimous buyer preference for ancillary braking systems in Australian heavy trucks is the engine brake. Engine brakes consist of a device built into the diesel engine to change valve timing such that the engine is converted from a power-generating machine into a large compressor (Close 2001) [2]. The exhaust valves are opened near top dead centre on the compression stroke and the resulting blowdown of the compressed gas to atmospheric pressure prevents the return of its energy to the engine on the expansion stroke (*Austroads* 1993) [3]. Engine brakes, when not adequately silenced, generate a staccato 'bark' noise. On most trucks, additional 'tuned' muffling is required, and must be maintained to bring engine brake noise into or near equality with maximum engine powered exhaust noise (Close 2001) [2].

The characteristic loud, low frequency tone and impulse like nature of the engine brake noise emissions contribute to the annoyance expressed by affected residents, particularly at night time when people are sleeping and background noise levels are at their lowest.

Transport South Australia has recently installed a prototype 'engine brake noise camera' developed by the Sound Thinking Group P/L and Acoustic Research Laboratories P/L using the 'noise modulation' monitoring & assessment protocol developed in partnership with the National Transport Commission (*NRTC* 2003) 4]. It is hoped that development of this protocol will lead to enforcement activity in this area.

Current literature concerning sleep disturbance due to noise indicates that the main noise characteristics that influence sleep disturbance are: the number of noisy events heard distinctly above the background noise level; the peak level emergence; and the time of onset of these events (EPA 1999) [5] and Carter et al (2000) [6].

This study was undertaken in response to concerns that there may be an increase in the maximum noise level events that occur as heavy vehicles use engine brakes to 'wash off' speed on the approach to a traffic calming devices such as a FSC installation (*Austroads* 1993) [3]. The primary objective of this Study was to evaluate the need for specific noise criteria for FSC site selection. However, it is believed the findings will be useful in the development and application of a wide range of environmental impact maximum noise level assessments.

Data Collection and Analysis

Monitoring Site Selection & Site Characteristics

The Study sites were selected from a number of locations where it was proposed to install FSCs, with a criterion that the heavy vehicle volumes were greater than 100 heavy vehicles per night, and that there was a cross-section of sites representing varying road geometry and speed conditions. Standard design dictates that there are three warning signs on the approach to the FSC and the monitoring sites were selected in the vicinity of the

2nd warning sign (200 – 300m on the approach side to the camera). The selected study sites were:

Pacific Highway, New Italy – The FSC site was located on a straight section of 100 km/h single, two-lane carriageway with a minor curve some distance beyond the FSC.

Bruxner Highway, Alstonville – The FSC site was located on a straight, level section of single, two-lane carriageway after an approach with a steady incline for approximately 3 km. The posted speed limit changed from 100 to 60 km/h on approach. This site was used to analyse light vehicle maximum noise levels only due to inadequate heavy vehicle numbers.

New England Highway, Tenterfield – The FSC site was located on a straight level section of single, two-lane carriageway at the top of a 1% gradient either side of FSC monitoring site. There were right angle bends within 1 km of both the approach and departure to the FSC monitoring site with a speed change from 100 to 80 to 60 km/h on approach. The monitoring equipment could not be adequately screened from driver view at the Tenterfield site and it was perceived there was heavy vehicle driver behaviour bias during the pre-installation phase of the Study. Biased results were excluded from the analysis.

Pacific Highway, Korora The FSC site was located on the crest of a hill with a 3 to 5% gradient on either side of a 4-lane dual carriageway. The posted speed limit changed from 60 to 80 to 100 km/h on approach. The road geometry had a propensity for low numbers of engine brake occurrences.

Pacific Highway, Sexton Hill The FSC was located on an 80 kph, 4-lane dual carriageway with an approximate 8% downhill gradient in the target direction at the monitoring site and an approximate 5% uphill gradient at the approach to the FSC warning signs. Additionally an engine brake noise advisory sign was sited at the approach to the FSC. The post FSC installation study was not undertaken.

Data Analyses

Software Verification

"Mad Max" software developed by Wilkinson Murray P/L (Murray 2001) [7] was used to produce a real time histogram of the vehicle pass-by noise. Should a vehicle or group of vehicles produce a noise defined by the software as an 'event', a point on the graph history is automatically circled, as shown in Figure 1. This allows visual identification when a defined event has occurred. The "Mad Max" defined event parameters were set to:

- Maximum noise level ≥ 65 dB(A)
- Separation time between any other maximum noise level by at least three seconds
- Separation from any other maximum noise level by an intermediate drop in level of at least 5 dB(A)
- Event does not last longer than 25 seconds.

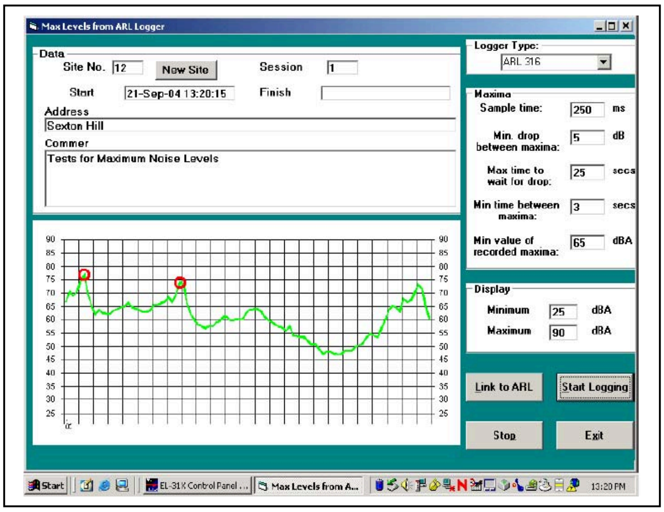

Figure 1. Mad Max Software Display

Comparisons were made with operator observed events, the source of the event and the recorded events. The results showed 100% comparison between the operator identified events and the recorded events at 65 dB(A) or above. The study team is of the opinion that the software quantitatively and qualitatively provides an excellent representation of human perception of discrete vehicle noise events, however site selection was found to be of paramount importance as studies have found that in scenarios where measurements are made in close proximities to residences that road traffic noise may be responsible for as little as 36% of peak noise level events (Samuels & Parnell 2004) [8].

Night time $L_{eq(9hour)}$ Noise Level

The $L_{Aeq(9hour)}$ pre and post FSC installation noise levels were recorded and corrected to remove confounding effects attributable to differences in traffic volume and composition by applying simple noise modelling techniques (*FHWA* 1998) [9]. A change in noise level greater than 2 dB(A) was considered significant (*RTA* 2001) [10].

Mean Vehicle Event Noise Levels

Differences of pre and post FSC installation mean vehicle event noise levels >2 dB(A) were defined as significant. It was generally considered that a sample pool of less than 30 was associated with inadequate statistical power.

Audible Heavy Vehicle Engine Brakes

Significant differences between pre and post FSC installation occurrence of audible engine braking were calculated to the 95% confidence level. The *Theory of Significance of Differences in Proportions* (Spiegel 1992) [11] was applied where the sample pool was ≥ 30.

Maximum Vehicle Event Noise Levels

(Spiegel 1992) [11] was also applied to the comparison of pre and post sign installation L_{max} events.

Results & Discussion

Change in L_{eq} traffic noise levels

Table 1: Change in L_{eq} traffic noise levels

Site	Change in Noise Level (dB(A))
New Italy $L_{eq(9hour)}$	(-1)
Alstonville $L_{eq(9hour)}$	(-1.47)
Tenterfield $L_{eq(9hour)}$ [1]	N/A
Tenterfield $L_{eq(short\ term)}$ [2]	(-0.4)
Korora $L_{eq(9hour)}$	(-2.75)
Sexton Hill $L_{eq(9hour)}$ [3]	N/A

1. Classified traffic data not recorded during pre-FSC monitoring
2. Manual traffic counts during attended monitoring
3. No post-FSC monitoring

Table 1 shows a trend to lower noise levels at all sites where pre & post FSC installation data was recorded. A significant reduction in night time noise level was recorded at the Korora Site.

Having accounted for variables relating to traffic density and composition and the potential influence of background noise, the only remaining explanation for the quieter noise level is a reduction in speed and corresponding mean vehicle event noise levels.

Change in Audible Engine Brake Occurrence

Table 2: Manually tallied engine brake occurrence compared to heavy vehicle pass-bys

Test Description	P_2	P_1	Sig. Dif.?
New Italy approach lane (northbound) [1]	0.25	0.25	No
Alstonville[2]	N/A	N/A	N/A
Tenterfield approach lane (southbound) [1, 3]	0.02	0.26	N/A
Korora approach lane (northbound) [1]	0.00	0.03	No
Sexton Hill outbound (southbound lane)[4, 5]	0.28	N/A	N/A
Tenterfield Post FSC vs New Italy Post FSC	0.25	0.26	No
Tenterfield Post FSC vs New Italy Pre FSC	0.25	0.26	No
Tenterfield Post FSC vs Sexton Hill Pre FSC	0.24	0.26	No

1. No engine brake occurrences along outbound lane(s)
2. Insufficient heavy vehicle sample pool
3. Data provided for information only and no conclusion due to bias during control phase
4. Post sign installation results not conducted
5. No engine brake occurrences along approach lanes

The data in Table 2 show that the installation of FSC warning signs did not result in any significant change in audible engine brake occurrences. The Tenterfield result was ignored due to bias during the course of pre installation e monitoring. The Korora site only had one engine brake occurrence, which occurred during the experimental phase. This is attributable to the site being located on top of a hill thereby not being conducive to driver hesitation resulting in automatic application of the engine brakes.

Interestingly, comparison of sites where road geometry is conducive to even the smallest driver hesitation or behavioural change (such as minor road declines or distant minor bends) indicates that 25% of drivers will apply engine brakes at the 95% confidence level. This result was not affected by road location, traffic volume or the percentage of heavy vehicles. Also, comparison of engine brake occurrence between sites, tends to suggest that the engine brake noise advisory sign installed at the approach to the FSC at the Sexton Hill Site had no effect on heavy vehicle driver behaviour.

L_{max} Events $\geq$ 65 dB(A)

From Table 3, there was no change in the number of maximum noise level events found at Tenterfield or Korora at the 95% confidence level. At the Alstonville site, there was a significant reduction in vehicle noise events.

At New Italy, there was no significant effect on heavy vehicle noise events but there was a significant increase in the number of light vehicles noise events. This result was unexpected and not supported by any of the results of other attributes investigated.

Table 3: L_{max} events $\geq$ 65 dB(A)

Site	Vehicle Noise Event Category	Z	Sig. Diff.?
New Italy	Light Vehicles	(2.59)	More
	Heavy Vehicle	(1.01)	No
Alstonville[1]	All Vehicles	(-2.51)	Less
Tenterfield[1, 2]	All Vehicles	(-0.5)	No
	Heavy Vehicles	(-0.11)	No
Korora	All Vehicles	(-1.59)	No
	Heavy Vehicles	(-0.75)	No
Sexton Hill Outbound[3]	All Vehicles	N/A	N/A
	Heavy Vehicles	N/A	N/A

1. Heavy vehicles not analysed as inadequate sample pool
2. Analysis is conservative due to heavy vehicle operator bias during control phase
3. Post-installation monitoring not conducted

Assuming a normal distribution, a significant reduction in mean vehicle event noise level could result in a reduced number of events over a given noise range, however, if the vehicle noise levels are constantly less than 65 dB(A), then the normal distribution will be truncated. This could have the effect of artificially raising mean event noise level compared to what it would otherwise have been, thereby biasing the significance of increased impact towards a greater effect.

If there is a substantial increase in traffic density, it is expected that this would result in a more continuous traffic flow and consequently less vehicle noise events.

The effect of event distribution and traffic density at the Alstonville and New Italy sites are now analysed.

Alstonville

Figure 2 shows that the L_{Amax} noise event data resembles a truncated bell shaped curve. It can bee seen that the mode and the slope of the curve for the experimental phase has shifted to the left by at least 4 dB(A) indicating a general but significant lowering vehicle event noise levels. It is also apparent that the truncated portion of the distribution for the experimental phase includes the mode of the curve.

The translation of the bell curve appears to reflect a decrease in the mean vehicle velocity, particularly those vehicles travelling at or above the posted speed limit. The result is particularly pronounced because heavy vehicles are almost totally absent from the sample pool.

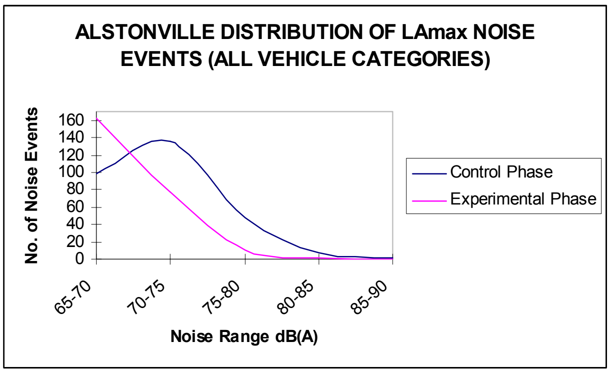

Figure 2: Distribution of L_{max} vehicle noise events ≥ 65 dB(A) 15m from the road centreline

A large portion of the L_{max} noise levels caused by pass-bys of single vehicles or multiple vehicles are lower than 65 dB(A) at this site which is expected to result in a significant lowering of mean vehicle event noise levels (discussed later). Conversely however, this effect would be minimised by a tendency for the mean vehicle event noise level to be artificially raised due to events below 65 dB(A) being excluded from the analysis.

New Italy

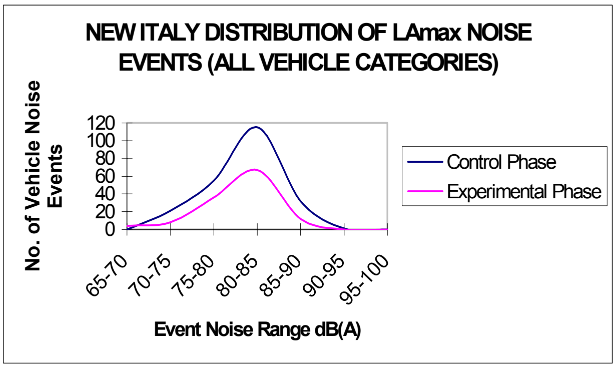

Figure 3: Distribution of L_{max} vehicle noise events ≥ 65 dB(A) 20m from the road centreline

Figure 3 shows that the L_{Amax} noise event data closely approximates a bell shaped normal distribution, albeit slightly skewed to the right with the overall number of events being less in the experimental phase compared to the control phase. It can be seen that noise levels from individual pass-bys are almost all ≥ 65 dB(A) at 20m from the road centreline – a result that is considered representative of a major highway with high posted speed limits. From analysis of the data, the slight skew to the right can be attributed to the number of light vehicle events within the lower noise range. It was therefore speculated that the L_{Amax} noise event distribution was not the cause of the increase in the number of light vehicle noise events ≥ 65 dB(A).

The change in traffic density during the post-FSC installation phase (experimental phase) compared to the pre-FSC installation phase (control phase) was calculated as 0.67 and 0.71, respectively. These results tend to confirm speculation that the reported significant increase in the proportion of light vehicle events ≥ 65 post-FSC installation could be attributable to lower relative traffic density (ie. traffic more spread out) during the experimental phase. It is considered reasonable to assume that this result is associated with a lower number of noise events being caused by multiple vehicles, thereby resulting in a corresponding relative increase in the number of events caused by single vehicles, and therefore a greater intermittency of traffic.

5.5 Mean Vehicle Event Noise Levels ≥ 65 dB(A)

From Table 4, the results show no significant change in L_{Amax} vehicle event noise levels at New Italy, Tenterfield, & Korora, however, a significant reduction in mean noise levels was recorded at Alstonville. The result at Tenterfield is considered conservative due to the previously reported bias during the control phase.

Table 4: Mean L_{Amax} vehicle noise events ≥ 65 dB(A)

Site	Mean L_{max} Vehicle Events	Change dB(A)
New Italy	All Vehicles	(-1.54)
	Loudest 30%	(-0.65)
	Heavy Vehicles	(-0.91)
Alstonville	Loudest 30%	(-3.59)
	Heavy Vehicles[2]	N/A
Tenterfield	Loudest 30%	1.13
	Heavy Vehicles	(-1.3)
Korora	Loudest 30%	(-0.48)
	Heavy Vehicles	1.33
Sexton Hill Outbound	Loudest 30%	N/A
	Heavy Vehicles [1]	N/A

1. No post sign installation monitoring
2. Insufficient data to provide a result

The results at Alstonville show that the mean of the loudest 30% of Lmax Vehicle Events during the experimental phase was 3.59 dB(A) less than that recorded during the control phase. This confirms the previously made presumption that the shift in the mode of the bell curve of events to the left during the experimental phase, and the large proportion of events less than 65 dB(A) would be associated with a lowering of noise levels.

At New Italy, there was a marginal trend towards reduced mean vehicle event noise levels but no significant effect. Given that the effect of the FSC on vehicle event noise levels at New Italy was not significant, the previously reported significant increase in the number of light vehicle noise events ≥ 65 dB(A) is unexpected and can be reasonably assumed to be attributable to factors not relating to changes in vehicle event noise levels.

This tends to add weight to previous speculation that the significant increase in the number of light vehicle noise events ≥ 65 dB(A) was attributable to lower traffic density during the experimental phase, which would tend to result in reduced multiple vehicle noise events, an increased number of single vehicle noise events, and therefore a marginal lowering of mean vehicle event noise levels.

Maximum Vehicle Noise Events ≥ 65 dB(A) where $L_{max} - L_{eq(1hour)} \geq$ 15 dB(A)

The Environmental Criteria for Road Traffic Noise (ECRTN) (*EPA* 1999) [5] requires that the design of noise control measures is governed by the night time L_{eq} guideline of 55 dB(A) for existing roads or 50 dB(A) for new roads. However, the ECRTN also suggests that when the difference between the maximum and L_{eq} noise level is ≥ 15 dB(A) the number of maximum noise level events should also be considered in prioritising the most appropriate type of noise treatments.

Practice Note iii of the Environmental Noise Management Manual (ENMM) (*RTA* 2001) [10] provides a protocol for assessing maximum noise levels. In essence the protocol requires identification of the number of *emergent* vehicle noise events defined as $L_{max} - L_{eq(1hour)} \geq$ 15 dB(A) where L_{max} noise levels are ≥ 65 dB(A). Analysis is conducted using this protocol.

Table 5 presents the results of a comparison between the monitored vehicle event L_{max} noise levels and the prevailing L_{eq} noise level during attended monitoring, corrected for variations in traffic volume and composition. The results show no increase in the number of *emergent* vehicle noise events following FSC installation. A significant reduction in the number of events occurred at the New Italy, Alstonville & Tenterfield sites.

It is important to apply this methodology with a good deal of caution as it is highly susceptible to the smallest changes in ambient noise levels, which may be related to variations in traffic characteristics, or simply variations in non-traffic related environmental conditions.

Table 5: *Emergent* events ≥ 65 dB(A) where $L_{max} - L_{eq(1hour)} \geq$ 15 dB(A) [4]

Site	Vehicle Noise Event Category	Z	Sig. Diff.?
New Italy	All Vehicles	(-3.16)	Less
	Heavy Vehicle	(-3.20)	Less
Alstonville[1]	All Vehicles	(-2.59)	Less
Tenterfield[2]	All Vehicles	(-3.13)	Less
	Heavy Vehicle	(-3.22)	Less
Korora	All Vehicles	(-1.25)	No
	Heavy Vehicles	(-0.98)	No
Sexton Hill Outbound[3]	All Vehicles	N/A	N/A
	Heavy Vehicle	N/A	N/A

1. Heavy vehicles not analysed as inadequate sample pool
2. Analysis is conservative due to heavy vehicle operator bias during control phase
3. Post-sign monitoring not conducted
4. Results corrected for variations in traffic vol. & %

Conclusions

No conclusions are made regarding FSC sites on roads where the pre-existing road geometry is not already conducive to driver hesitation and there is an existing or proposed reduction in posted speed limit, as such a site was not available for the study, unless otherwise stated.

Based on the results of this study:

1. Installation of FSC warning signs do not result in any significant change in audible engine braking at locations where pre-existing road geometry is already conducive to even the slightest driver hesitation or behavioural change (such as minor road gradients or distant minor bends).
2. Where pre-existing road geometry is already conducive to even the slightest driver hesitation or behavioural change, audible engine brakes are applied on 25% of all heavy vehicle pass-bys.
3. Based on the result that the proportions of audible engine brake occurrences were the same at the Sexton Hill site as other roads investigated it is concluded that the engine brake advisory sign installed at the approach to the site also had little effect.
4. The FSC signs did not result in any significant increase in:
   - Night-time $L_{eq(9hour)}$ noise level
   - Vehicle noise events ≥ 65dB(A)
   - Mean L_{max} vehicle event noise levels, and
   - Emergent vehicle noise events.
5. At sites where the traffic make up is comprised of mainly light vehicles, installation of a FSC will result in significantly reduced noise impacts, directly attributable to a reduction in vehicle speed. Where heavy vehicle pass-bys are negligible, this conclusion is expected to apply at all sites, regardless of road geometry.

6. The relationship of $L_{max} \geq 65$ dB(A) vehicle noise events to vehicle pass-bys is dependent upon a number of factors including:
   - Extent of vehicle grouping or 'platooning'
   - Heavy vehicle percentages
   - Actual travel speed
   - Number of carriageways and the distance of each carriageway from the monitoring site.
7. The relationship of total $L_{max} \geq 65$ dB(A) vehicle noise events to total vehicle numbers varied from 34% at Sexton Hill to 85% at New Italy. The relationship of $L_{max} \geq 65$ dB(A) heavy vehicle noise events to total heavy vehicle numbers varied from 70% at Korora to 90% at Tenterfield.
8. The $L_{max} \geq 65$ dB(A) vehicle noise event assessment requires that the data collected is close to normally distributed. This is only possible if nearly all vehicle noise events are ≥ 65 dB(A). This is regularly not the case for light vehicles and at greater setbacks, even some heavy vehicles will be less than 65dB(A). To ensure this does not occur the filtered intervention level for collecting vehicle noise event maximum noise levels should be set to lower than 65 dBA as necessary, so that all vehicle noise events are collected. Care must be taken that the results are not unduly affected by extraneous noises such as from pedestrian traffic, domestic/urban noise or bush sounds. The site selected should be discretely located in a position approximating the near field, close to the road, and sufficiently separated from pedestrian traffic or urban noise influences.
9. *Emergent* vehicle noise event assessment is highly sensitive to changes in ambient noise levels due to changes in traffic volume and composition but also non-traffic related environmental conditions.

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