Acoustics 2008
Geelong, Victoria, Australia 24 to 26 November 2008

Acoustics and Sustainability:

How should acoustics adapt to meet future demands?

Is CoRTN an L_{eq} or L_{10} Procedure?

Dr Simon Kean

Research and Development, Bassett Acoustics | AECOM, Sydney, Australia

ABSTRACT

This paper investigates from theoretical analysis and field data, sources of error in using the Calculation of Road Traffic Noise (CoRTN) procedure to predict L_{eq} noise levels. Particular attention has also been given to providing a possible theoretical explanation for the L_{den} conversion factors obtained by Transport Research Laboratory (TRL). The equations in CoRTN have been compared with established relationships for L_{eq} noise levels. The investigation focused on equations involving traffic volume, distance and speed which theoretically contribute to a change in the relationship between L_{10} and L_{eq}. It was found that most of the equations in CoRTN are valid for predicting L_{eq} and that the correction equations derived by TRL for predicting L_{den} introduce additional complications and the potential for significant error. Revised equations are proposed.

INTRODUCTION

Background

The Calculation of Road Traffic Noise algorithm (CoRTN 1988) has been criticised by some (Steele 2001) as a ‘quasi L_{10}’ procedure that incorrectly adds and subtracts L_{10} statistical parameters. Some (Steele 2001) also regard it as obsolete given that in many regions criteria have shifted to L_{eq} descriptors.

However the Australian experience is that it is robust, still relevant and can, with a number of adjustments, be used to successfully model both L_{eq} and L_{10} noise levels. In Australia CoRTN is commonly used over varied terrain ranging from sparsely populated rural areas to city environments.

The CoRTN algorithm, while robust, is currently used well beyond its intended use with many corrections, assumptions and modifications to fit data. It is also being used to model road traffic noise levels at distances beyond which it was intended. For example the night time new road criteria in NSW is 50dBA (EPA, ECRTN), this combined with high flow rates, in the order of 14,000 Average Annual Daily Total (AADT) with night time heavy vehicle percentages of up to 50%, requires the modelling of distances up to 300m for standard Dense Grade Asphalt road surfaces or even up to 600m for Portland Concrete Cement road surfaces.

The accuracy of CoRTN has been evaluated a number of times. This has typically been undertaken by comparing the differences between measured and predicted noise levels at all receivers and reporting the error distribution. However this does not provide a sensitivity analysis of the contributing parameters in road traffic noise. It may be that the spread of the error distribution is partially determined by factors such as distance. For example there may be a bias towards over prediction at a closer distance and and bias towards under-prediction at greater distances.

Based on the authors experience in NSW predicting road traffic L_{eq} noise levels, it appears that the measured noise levels are underestimated at distance using the standard CoRTN procedure with standard Australian source level corrections. It is also apparent that this error increases with distance.

Even though it is recognised that there will always be modelling and measurement error it is still worthwhile for the mean to be as accurate as possible at all distances. An example of this is CoRTN is now often used down to one decimal point to determine which residences receive noise mitigation. In some cases a decimal point or two can increase or reduce mitigation costs to the client by dollars measured in six figures and rule out the treatment of worthy residences. In order to do the best by the client and the general public we need to make sure that our predictions are as accurate as possible even though we know that there is always a spread between predicted and measured data.

The CoRTN algorithm was developed to model L_{10} noise levels based on empirical and theoretical relationships. The method involves the estimation of a basic noise level which is corrected to take into account many aspects including but not limited to topography, geometry, ground effects, speed and vehicle mix.

These corrections however, are not necessarily mathematically correct as statistical percentile parameters can not be added and subtracted unless either the entire statistical data set or distribution is known or all data sets have a common spread and statistical distribution. This aspect is commonly overlooked by acoustic consultants due to necessity, for example the requirement by NSW legislation to predict overall

L_{10} construction noise levels when the only available data is individual L_{10} noise levels for each individual source. It is technically incorrect to add these together but there is often no feasible alternative.

While we are discussing corrections it should be noted that there are three types of corrections. These are:

1. Source level corrections which adjust the noise level at all locations to an equal degree
2. Propagation loss corrections which adjust the rate of decibel change with distance
3. Noise level corrections at the receiver which linearly multiply the overall calculated noise level by a constant such as developed by Transport Research Laboratory (Abbott and Nelson 2002)

Transport Research Laboratory (TRL) (Abbott and Nelson 2002) has developed a couple of conversion equations to convert the L_{10} outputs from CoRTN to L_{eq} noise levels. These have been implemented in SoundPLAN but have a number of potential issues. It has been the authors experience that SoundPLAN results using these equations have on occasions differed significantly from measured data.

Conversion Equations

The equations that are currently used in SoundPLAN to convert L_{10} outputs from the CoRTN procedure into L_{eq} levels were derived by TRL. A feature of these equations is that they relate either predicted or measured L_{10} noise levels with measured L_{eq} noise levels for Motorway and Non-Motorway roads. There is little doubt that the relationships are valid for the data set that they were derived for, however they appear to make little sense as conversion factors for obtaining L_{eq} levels from CoRTN predicted L_{10} noise levels in the general case.

Correction for Motorway Roads

The Motorway roads equation was obtained by relating measured L_{eq} noise levels with predicted L_{10} noise levels using CoRTN. This is similar to the field testing the author undertook where L_{eq} noise levels were measured and compared with the predicted L_{eq} levels from CoRTN (Obtained from L_{10} minus 3dB and without the low volume correction). The equation obtained by TRL is:

$$L_{\mathrm{Aeq,1hr}} = 0.94 L_{\mathrm{A10,1hr}} + 0.77\mathrm{dB} \qquad \text{Eq. (1)}$$

When this is applied to the outputs from CoRTN there are a number of potential issues:

- Conservation of energy laws are violated and so are established acoustic principles and theory.
- It is possibly site specific.
- Established Australian correction factors (eg road surfaces) become a function of volume and distance as a minimum.
- There is no discussion of the range of validity in TRL's paper.

The conservation of energy laws are violated as a factor of 10 increase in source strength no longer corresponds to a factor of 10 increase in noise level. While the error may be small for the typical changes in volume that are modelled between existing and future cases the error may be large when applied to other variables that impact more significantly within the practical range of parameter values used in modelling, such as distance from source, speed corrections and volume corrections.

It is considered likely that the derived relationship is site specific in terms of geometry, buildings, experimental error and traffic conditions given that it does not correlate with basic acoustic theory, when applied to CoRTN.

The net result of TRL's equation is that established (within each state, country etc) Australian correction factors, such as road surface corrections, artificially become functions of distance, volume and speed (in some cases the existing constants are only such over a finite speed range). This is because it is the overall predicted noise levels that are corrected rather than the source generation and individual correction factors within CoRTN.

The equations do not state a range for parameters in which the equations are valid. Note that while not stated directly in SoundPLAN the Non-Motorway equation is intended to be used for volumes and distances that use the low volume correction within CoRTN.

Corrections for Non-Motorway Roads

The correction for Non-Motorway Roads should be applied to traffic flows that would normally have the low volume correction applied. The equation is:

$$L_{\mathrm{Aeq,1hr}} = 0.57 L_{\mathrm{A10,1hr}} + 24.46\mathrm{dB} \qquad \text{Eq. (2)}$$

There are three major issues with this equation, these are:

- The relation is derived from an experimental relationship between L_{10} and L_{eq}
- It essentially undoes the existing CoRTN low volume correction
- All of the issues with Equation 1 for Motorway roads.

RELATIONSHIP BETWEEN L_{10} AND L_{EQ}

The purpose of this paper is not to define the relationship between L_{10} and L_{eq} but to investigate, from theoretical analysis and field data, sources of error in using CoRTN to predict L_{eq} noise levels. Particular attention is given to trying to understand the relationship obtained by TRL. TRL when publishing their relationship between L_{10} and L_{eq} referenced the work by Barry and Reagan (1978), whom produced a theoretical curve over extended time periods. This is illustrated in Figure 1 where L_{10}-L_{eq} is shown to be a function related to hourly traffic volume, q, distance to receiver in meters, d and vehicle speed V in km/h.

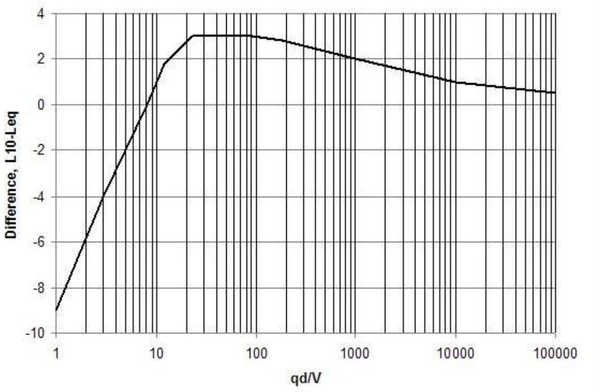

Figure 1. Theoretical Difference between L_{10} and L_{eq} Barry and Reagan (1978)

For the case of road traffic noise within certain ranges of traffic flow (*qd/V* 20 to 1000) the relationship in Figure 1 indicates that the relationship between L_{10} and L_{eq} values is nearly constant (differs by 2 to 3 dB). This provides validity to the L_{10} based empirical and theoretical relationships in CoRTN as it appears that the data sets may have had similar spread and distribution if they were derived within certain ranges of *qd/V*. Therefore it may be reasonable to add and subtract the terms for L_{10}. This also implies that, with the exception of the low volume correction, the relationship between L_{10} and L_{eq} within CoRTN may be constant. Therefore the standard CoRTN method may be valid for predicting L_{eq} levels with a single constant (perhaps –3dB) provided that the CoRTN correction factors (both theoretical and empirical) can be shown to have a constant value of L_{10}-L_{eq}.

The correction factors may be shown to have a constant relationship between L_{10} and L_{eq} if they can be shown to be similar to functions that are valid for L_{eq}. If the correction factors within CoRTN (referenced from CoRTN Charts 2 to 16) deviate from similar known functions that are valid for L_{eq} then the CoRTN functions may include a correction for the L_{10}-L_{eq} relationship.

The main functions that should be investigated are all functions that use *q*, *d* and *V* as these variables are the most significant in the influence over the L_{10}-L_{eq} relationship. These functions are:

- Basic Noise Level Calculation (*Chart 2*) (*Chart 3*)
- Vehicle Speed (*Chart 4*)
- Heavy Vehicle Percentage Correction (*Chart 4*)
- Correction for Gradient (*Chart 6*)
- Distance Correction (*Chart 7*)
- Ground Absorption (*Chart 8*)
- Barrier Loss (*Chart 9*)
- Angle of View Correction (*Chart 10*)
- Low Volume Correction (*Chart 12*)

As shown by Barry and Reagan the relationship between L_{10} and L_{eq} is most significantly determined by the traffic volume, speed and distance from the road. It is also influenced to a certain extent by vehicle distribution and mix. The relationship between L_{10}-L_{eq} is commonly plotted in terms of *q*, *d* and *V*:

$$L_{10} - L_{eq} = function\left(\frac{q \times d}{V}\right) \qquad \text{Eq. (3)}$$

This can be understood physically as a function of vehicle spacing and distance to the receiver:

$$\left(\frac{q \times d}{V}\right) = \frac{\text{Cars per hour} \times \text{Distance to receiver}}{\text{Kilometres per hour}} \qquad \text{Eq. (4)}$$

$$= \frac{\text{Cars per hour}}{\text{Kilometres per hour}} \times \text{Distance to receiver}$$

$$= \text{Cars per Kilometer} \times \text{Distance to receiver}$$

The relationship between L_{10}-L_{eq} and vehicle spacing (Cars per kilometre) makes sense if one considers a noise time trace at a receiver as a vehicle drives by (See Figure 2 and Figure 3). The time averaged noise levels are due to noise emission from moving point sources. At low volume the L_{10} is less than L_{eq} as the L_{10} levels are dominated by quiet periods. As the traffic density increases the L_{10} becomes dominated by the waveform of the drive by event and is greater than the L_{eq} noise levels. At high volumes the vehicle spacings are close together and the L_{eq} and L_{10} values converge. A summary plotted against *qd/V* is shown in Figure 4.

L_{10} and L_{eq} noise levels converge with increasing distance. Consider a finite length road string. At a receiver the noise level time trace is produced by the change in proximity of the source to the receiver as the source moves along the road traffic string. At large distances the percentage change in source to receiver distance as the source travels along the road string is less than at close distances. This results in reduced noise level fluctuations and a convergence of the L_{10} and L_{eq} levels.

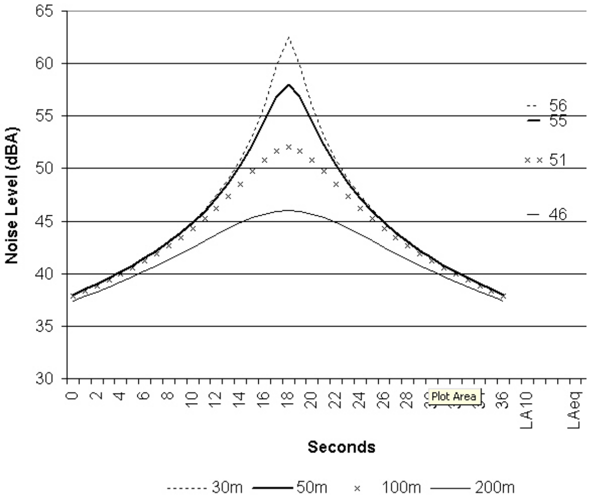

Figure 2 Theoretical time trace of one car travelling at 100km/h at various distances

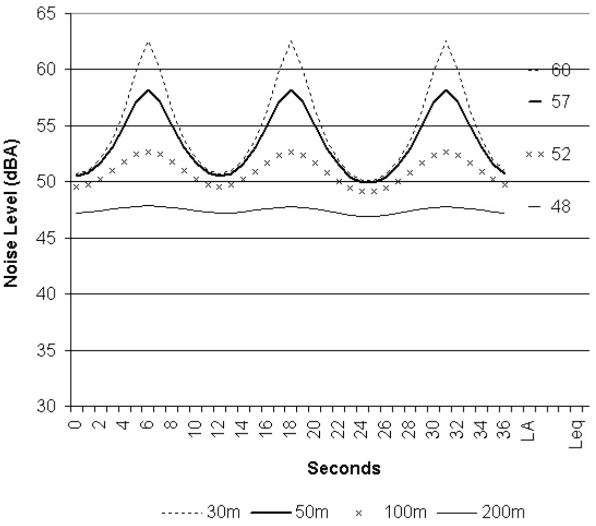

Figure 3 Theoretical time trace of three evenly spaced vehicles travelling at 100km/h at various distances

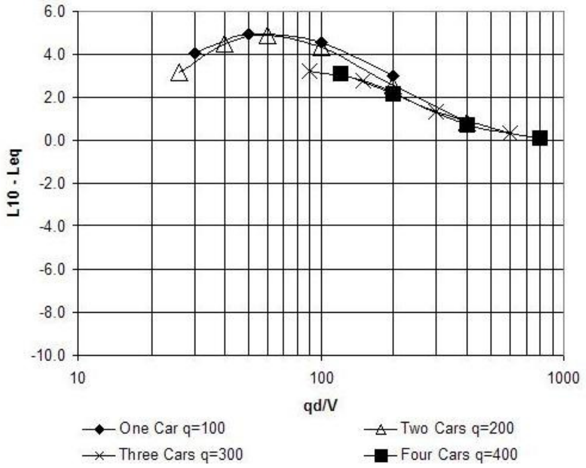

Figure 4. Theoretical relationship between L_{10} and L_{eq} for various traffic volumes with evenly spaced vehicles travelling at 100km/h at various distances over 36 seconds based on relationships in Figure 1 and Figure 2

Other factors that may influence the L_{10}-L_{eq} relationship are vehicle spacing, vehicle mix including heavy vehicle percentage and variations between vehicles within each class. Note that for the same vehicle volumes and mix the L_{eq} is constant and not influenced by vehicle distribution, only the L_{10} level is affected.

INVESTIGATION OF CORTN EQUATIONS

As discussed in the previous section the relationship between L_{10} and L_{eq} is most significantly influenced by *V*, *q* and *d*. Therefore the functions in CoRTN containing these terms were investigated to determine if they were equivalent to known functions that were valid for L_{eq} or whether they had a relationship that would influence the difference between L_{10} and L_{eq}.

Upon inspection it was identified that most of the correction charts were equivalent to known functions that were valid for L_{eq}. The following charts were identified as valid for L_{eq} but may differ by a constant:

$$L_{eq} \approx +\sum_{n=2}^{3} K_{Chart_n} + \sum_{n=6}^{7} K_{Chart_n} + \sum_{n=9}^{10} K_{Chart_n} \qquad \text{Eq. (5)}$$

Low Volume Correction

Given that the majority of functions, with perhaps the exception of ground absorption, are functions that are applicable for L_{eq}, a correction is required within CoRTN to predict L_{10} levels with large vehicle spacing. This is applied with the low volume correction:

$$K_{Chart12} = -16.6\left(Log\left(\frac{30}{d'}\right)\right)\left(Log\left(\frac{q}{200}\right)\right) \qquad \text{Eq. (6)}$$

Where *d'* is less than 30m and *q* is between 50 and 200 vehicles per hour. This relationship is however only valid for the range of vehicle speeds for which it was derived as it does not include a term for vehicle speed. Since it does not include a term for vehicle speed the resulting L_{10}-L_{eq} relationship is not a function of vehicle spacing and is likely to produce an error when used to predict L_{10} noise levels.

The low volume correction should never be used when predicting L_{eq} noise levels with the L_{10} method as it is a correction to convert essentially L_{eq} noise levels as calculated by CoRTN into L_{10} noise levels.

When using the L_{den} module in SoundPLAN the correction for Non-Motorway Roads is applied to traffic flows that would normally have the low volume correction implemented. The equation is:

$$L_{Aeq,1hr} = 0.57L_{A10,1hr} + 24.46\text{dB} \qquad \text{Eq. (2)}$$

The use of an experimental relationship between L_{eq} and L_{10} noise levels rather than the predicted L_{10} noise levels to correct the output of CoRTN introduces additional error into the methodology as it retains the inherent error in the CoRTN algorithm.

A spreadsheet calculation using CoRTN with the low volume correction enabled is presented in Table 1. This shows that the experimentally derived equation simply undoes the low volume correction. The example in Table 1 assumes 50, 100 and 200 cars an hour at a distance of 10m.

Table 1 Comparison between L_{10}-3dB and L_{eq} method

Cars per Hour	**L_{10}**	**L_{eq} (L_{10}-3dB)**	**L_{eq} Eq. 2**	**Difference L_{10}-3dB vs. Eq. 2**
50	58.7	55.7	55.2	0.5
100	61.7	58.7	58.3	0.4
200	64.7	61.7	61.3	0.4

The net result of applying the low volume correction and applying the Non-Motorway correction is an equation of the form:

$$L_{Aeq,1hr} = 1.02L_{A10,1hr} + \text{Constant dB} \qquad \text{Eq. (7)}$$

This equation includes the overall error in using CoRTN to predict L_{10} and site specific factors relevant to the data set used to obtain the relationship for Non-Motorway roads. Given that this equation undoes the low volume correction it would have been simpler and more computationally efficient to remove the low volume correction from CoRTN altogether. This would also result in less overall error.

Also note that SoundPLAN 6.4 appears to have not implemented the combined Non-Motorway roads and low volume correction correctly in the L_{den} module. This can result in significant error.

Vehicle Speed and Heavy Vehicle Percentage Correction

It is established within the literature that mixed traffic flows influence the relationship between L_{10} and L_{eq}, therefore it is possible that the CoRTN correction for vehicle speed and mix may contain a function that influences the difference between L_{10}-L_{eq}. The equation is:

$$K_{Chart4} = 33Log\left(V + 40 + \frac{500}{V}\right) + 10Log\left(1 + \frac{5p}{V}\right) - 68.8 \quad \text{Eq. (8)}$$

Where p is the percentage of heavy vehicles.

For non-mixed traffic flows or traffic flows that are significantly dominated by either heavy or light vehicles it is likely that the *Chart 4* relationship is based on q, d and V rather than differences in individual vehicles. This appears to provide validity for the use of multiple source height string models with vehicle percentages set at either 0% or 100% as is common in NSW. In addition provided that the equations have been derived from empirical data with developed traffic flow it is likely that the relationship between L_{10} and L_{eq} (at 0% and >70%, at 70% truck contribution is greater than 10dBA above the car contribution) is practically constant and sufficiently close to a difference of 3dBA so as to use the *Chart 4* correction for L_{eq} corrections.

Experience by the author in Australia indicates that at freeway speeds source level corrections of -1.7dBA may be applicable to traffic flows with predominantly light vehicles (<20% heavy) during the day time period and +0.5 to +1dBA to vehicle source emissions when traffic flows are predominantly heavy vehicles (near 50%) during the night time period. This indicates that *Chart 4* could be updated for Australia's vehicle fleet. Note that temperature changes ($\Delta 10°C$) partially account for the observed differences between day and night corrections. These may account for up to 1dBA in correction as tyre source emissions increase as the temperature falls (Jonasson et al. 2004) (Sandberg and Ejsmont 2002).

Also note that the Pasquill Stability Category may also change between the day time and night time period. This may also account for differences in day time and night time correction factors.

Ground Absorption Equation - Comparison of *qd/V* for TRL Conversion Equations and Ground Absorption of 1.0 and 0.75

The ground absorption correction equation in CoRTN within the height range of:

$$0.75 \leq H\frac{d+5}{6} \quad \text{Eq. (9)}$$

Where H is the average height of propagation and I is the proportion of absorbent ground is:

$$K_{Chart8} = 5.2ILog\left(\frac{6H - 1.5}{d + 3.5}\right) \quad \text{Eq. (10)}$$

Reviewing the equations in CoRTN indicates that there is no other correction for air absorption. Considering the ground absorption correction was probably derived from empirical data it is likely that the equation also includes air absorption. However if the ground is set to hard with I equal to 0 CoRTN propagation calculations reduce to geometric spreading without air absorption. Comparative calculations using geometric spreading over hard ground and either air absorption from ISO 3891 or ISO 9613 indicate that the proportion of soft ground in the CoRTN ground absorption equation should never be set to less than 0.3 if air absorption is to be included.

Logging by the author in NSW at distances ranging from 13m to 200m indicates that for L_{eq} modelling the proportion of soft ground should be set to 0.75 in CoRTN as a propagation loss correction.

A check was completed to see if the differences between *Chart 8*, with ground absorption set at 1.0 for grassy fields, valid for L_{10}, differs from the measured relationship used by the author for L_{eq} modelling of 0.75 due to difference in L_{10}-L_{eq} with increasing *qd/V.*

This is indicated in Figure 5 where an initial difference of 3dB at 13.5m was chosen as this is commonly measured on noise loggers. The traffic volume was 1000 vehicles per hour. Provided also for comparison is the difference between L_{10} and L_{eq} noise levels predicted using TRL's correction equation.

The trend for the differences in ground absorption of 1.0 and 0.75 in Figure 5 correlates with the theoretical difference between L_{10} and L_{eq} calculated by Barry and Reagan. This indicates that the differences between the CoRTN procedure, which states that for grass fields ground absorption should be set to 1.0, and the measured relationship for grassy fields of 0.75 for L_{eq} levels may be due to differences between L_{10} and L_{eq} for increasing *qd/V*. The equation by TRL for Motorway Roads also shows the correct trend except it differs by a constant.

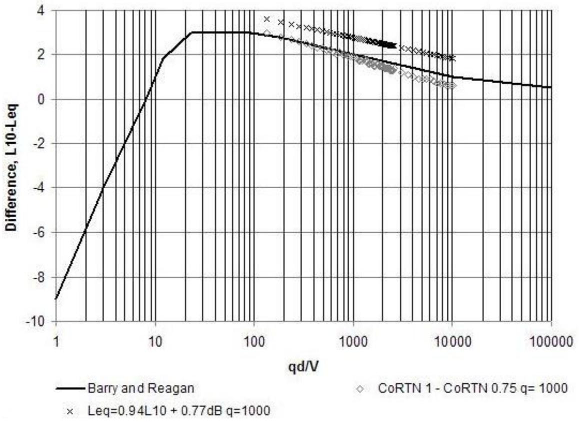

Figure 5. Comparison between *qd/V* using ground absorption 0.75 for L_{eq} modelling and 1.0 for L_{10} modelling with TRL Motorway Roads equation, assumed L_{10}-L_{eq} difference of 3dB at 13.5m and q of 1000.

Similar trends are seen in Figure 6 for traffic volumes of 200 vehicles per hour, note that the data fits best with an offset of 4dB for this flow rate rather than the 3dB assumed for 1000 vehicles per hour. Note however that this data follows the same trend line as for 1000 vehicles per hour with a 3dB offset. The equation by TRL shows the correct trend but differs by a constant.

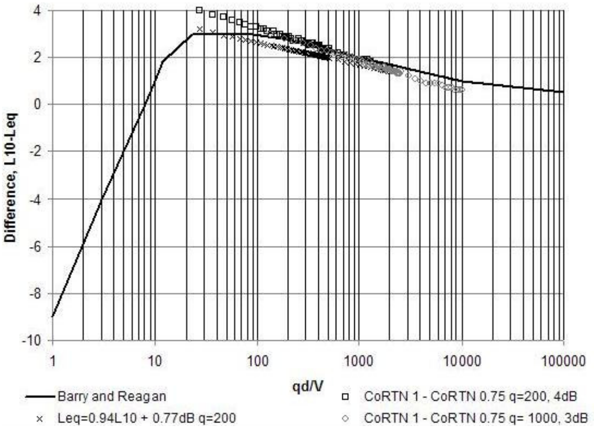

Figure 6. Comparison between *qd/V* using ground absorption 0.75 for L_{eq} modelling and 1.0 for L_{10} modelling with TRL Motorway Roads equation, assumed L_{10}-L_{eq} difference of 4dB at 13.5m and q of 200.

The equation by TRL for Motorway Roads shows good agreement with the theoretical relationship for 350 vehicles per hour only (see Figure 7).

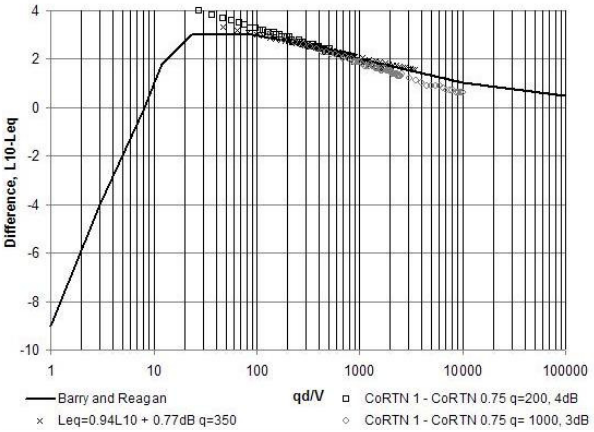

Figure 7. Comparison between Barry and Reagan and TRL Motorway Roads equation with *q* of 350.

The preceding graphs indicate that the apparent difference in ground absorption between the standard CoRTN procedure and the measured ground absorption using L_{eq} may be due to differences between L_{10} and L_{eq} levels over distance.

The graphs also show that the experimental relationships used to obtain the correction for Motorway Roads and the CoRTN ground absorption equation may only be valid for a limited range of traffic volumes, speeds and distances rather than *qd/V* in general. Given that:

- The attenuation of L_{eq} over distance is independent of *qd/V*, we could assume that the measured relationship for ground absorption is valid for all *q*, *V* and *d*

AND

- The relationship obtained by TRL using calculated L_{10} and experimentally measured L_{eq} levels (which is independent of *qd/V*) only correlates with the other data for flow rates of 350 vehicles per hour

It appears that the CoRTN ground absorption equation may only be valid over a limited range of traffic volume and distance. This may be expected as it does not contain the terms for *q*, *d* and *V* which are known to influence L_{10}-L_{eq} relationships.

It is also interesting to note that if the distance losses predicted by CoRTN, including geometric dispersion, are plotted and one assumes that ground absorption of 1.0 is valid for L_{10} and 0.75 is valid for L_{eq} then using the line of best fit for L_{10} versus distance, *d*, from the road is:

$$L_{10} = -6.8379\mathrm{Ln(d)} + \mathrm{Constant}\ 1 \qquad \text{Eq. (11)}$$

And the relationship obtained for ground absorption of 0.75 is:

$$L_{eq} = -6.2672\mathrm{Ln(d)} + \mathrm{Constant}\ 2 \qquad \text{Eq. (12)}$$

If one rearranges to obtain a relationship for L_{eq} in terms of L_{10}, using the two equations above, the following relationship is obtained:

$$L_{eq} = 0.92L_{10} + \mathrm{Constant} \qquad \text{Eq. (13)}$$

This is very similar to the relationship for Motorway Roads and appears to confirm that the differences in observed absorption are due to the comparison between L_{10} and L_{eq} levels, especially given that virtually the same result was obtained by TRL.

$$L_{\mathrm{Aeq,1hr}} = 0.94L_{\mathrm{A10,1hr}} + 0.77\mathrm{dB} \qquad \text{Eq. (1)}$$

However, it must be noted that the constant in Equation 13 above, is only constant for this data set and only accounts for the differences between L_{10} and L_{eq}. It can not be generally applied to changes in traffic flow rates, speed, traffic mix, road surface, gradient corrections etc such as occurs during a road upgrade as this will result in the violation of the law of conservation of energy. It is also believed that this applies to the Motorway Roads equation by TRL.

Also of interest is if the Motorway Roads equation is rearranged to obtain L_{eq}, using Equation 1 above for L_{10} and the geometric dispersion term is subtracted, the ground absorption may be obtained. This is valid as with the exception of the low volume correction all other equations appear to be valid for L_{eq} modelling. The ground absorption value that is obtained is 0.82 which is very close to the authors measured 0.75. This indicates that the 'ground absorption' equation may also have correction terms for the convergence of L_{10} and L_{eq} with distance. The differences between TRL's 0.82 and the authors 0.75 would probably be within experimental error or may be due to different site conditions. Using 0.82 for soft ground would map the authors and TRL's data onto the same line and be in agreement with Barry and Reagan's theoretical relationship (see Figure 8).

It should be noted that this only occurs for TRL's equation when the flow rate is 350 vehicles per hour and that the appropriate value of L_{10}-L_{eq} is selected for values of *q* when CoRTN ground absorption is 0.82.

This is an important difference between the two methods as this indicates that to accurately predict L_{eq} from the L_{10} outputs from CoRTN, TRL's equation requires flow rates to be close to 350 vehicles per hour or a change in the constant. However adjusting the ground absorption for L_{eq} modelling to between 0.75 and 0.82, it appears that (provided the low volume correction is not implemented) CoRTN is an L_{eq} procedure and the outputs are L_{eq} levels that differ by a constant related to the typical difference between L_{10} and L_{eq} in the original CoRTN empirical data.

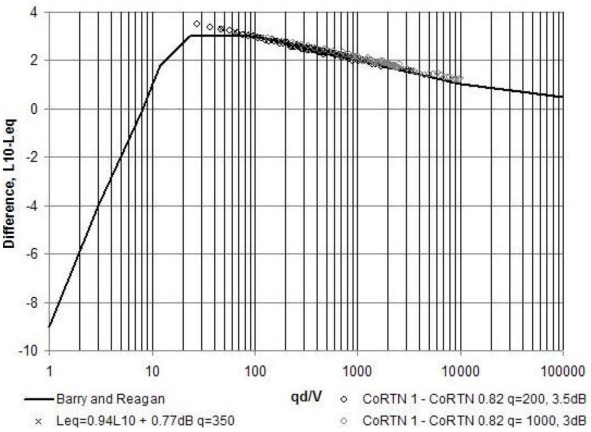

Figure 8. Comparison between Barry and Reagan, TRL's Motorway Roads equation with *q* of 350 and CoRTN with ground absorption set at 0.82 and assumed L_{10}-L_{eq} offsets.

From the data in Figure 8 it appears that the constant should be between -2dB and -3dB. For L_{eq} modelling in CoRTN the value of this constant, once identified, remains just that, a constant valid for all of *q*, *d* and *V*.

This indicates that CoRTN is not good at predicting L_{10}, not surprising given that most of the equations are valid for L_{eq} and the ones that are used to provide correlation with L_{10} do not have all of the required terms.

CONCLUSIONS

L_{eq} prediction using CoRTN

An investigation of all major CoRTN equations that utilise *q*, *d* and *V* was completed. It was found that all major correction factors with the exception of the ground absorption in its current form and the low volume correction were equivalent to functions of L_{eq} and were therefore determined to be independent of any additional relationship between L_{10} and L_{eq}.

It is possible that the differences between calculated L_{10} ground absorption and measured ground absorption using L_{eq} levels were due to weather effects. However the same trend was measured on two sections of the Pacific Highway (total of 10 loggers, distances between 12m and 150m) and on the Princes Highway (total of 8 loggers, distances between 30m and 200m) with logging conducted on both sides of each road. Even if the differences were due to weather effects it is clear that setting ground absorption to 0.75 improves correlation between measured and predicted levels for a wide variety of locations and distances from the road and verifies the findings of TRL for the general case.

If we assume that the measured difference between ground absorption for L_{eq} over a grass field and the relationship in CoRTN is due to the convergence of L_{10} and L_{eq} over distance, the overall relationship derived by the author with ground absorption for open grassy areas set at 0.75 is:

$$\mathrm{L}_{\mathrm{eq}} = 0.92\mathrm{L}_{10} + \mathrm{Constant} \qquad \text{Eq. (13)}$$

The above relationship is very similar to the relationship derived in the UK for motorway roads:

$$\mathrm{L}_{\mathrm{Aeq,1hr}} = 0.94\mathrm{L}_{\mathrm{A10,1hr}} + 0.77\mathrm{dB} \qquad \text{Eq. (1)}$$

Except that it is noted that the constants are only valid for the data sets for which they were derived.

In addition if 0.82 is used for the percentage of soft ground rather than 0.75 then the overall relationship becomes:

$$\mathrm{L}_{\mathrm{eq}} = 0.94\mathrm{L}_{10} + \mathrm{Constant} \qquad \text{Eq. (14)}$$

This is identical to TRL with the same exceptions regarding the 'constants'.

The 'constants' are functions of, but not limited to, vehicle volume, speed, road surface corrections, vehicle mix and distance. These are the standard equations in CoRTN except without the low volume correction.

Therefore it appears that Equations 13 and 14, derived by the author, and Equation 1, derived by TRL, may be rewritten for the general case as Equation 15:

$$L_{eq} = 10\log(q) + Const + \sum_{n=4}^{7} K_{Chart_n}$$
$$+ 0.75K_{Chart_8} + \sum_{n=9}^{11} K_{Chart_n} + \sum_{n=13}^{\infty} K_{Chart_n} \qquad \text{Eq. (15)}$$

Where *Chart 8* is the ground absorption correction factor:

$$K_{Chart8} = 5.2ILog\left(\frac{6H - 1.5}{d + 3.5}\right) \qquad \text{Eq. (10)}$$

and *I* is the proportion of soft ground which in Equation 15 ranges between 100% for modelling of softground and 40% to include air absorption.

This is CoRTN except that:

- The low volume correction has been removed
- A constant, such as -3dB, has been included to take into account typical L_{10}-L_{eq} relationships.
- Ground absorption is multiplied by 0.75 (or perhaps 0.82 or a value in between)

The proposed Equation 15 does not have any of the issues associated with TRL's equation such as violating conservation of energy.

When using a commercial implementation of CoRTN the low volume correction may be prevented from being enabled by multiplying traffic volumes by a suitable factor, such as 10 or 100, and then subtracting an appropriate amount, such as 10 dB or 20 dB, from the road surface correction so as to avoid traffic inputs between $50 \le q \le 200$ vehicles per hour. Note that SoundPLAN does not implement this as per CoRTN as it applies it for vehicle volumes between $0 \le q \le 200$ vehicles per hour.

It is proposed that the value of the constant is -3dB. This value is arguable but it is likely to be close to the correct value. Typically in NSW freeway modelling this relationship provides agreement to within 1dB of logged results. The benefits of a standardised factor such us -3dB would allow easy comparison of 'Australian Corrections' within Australia and against international corrections.

It also appears that CoRTN may be more valid at predicting L_{eq} noise levels than L_{10} as the equations do not include corrections of the form illustrated in Figure 1.

This suggests that it may be more accurate to predict L_{10} levels by first calculating L_{eq} levels with Equation 15 and then applying the correction in Figure 1, or some other relationship to convert L_{eq} to L_{10}, to estimate the L_{10} noise levels. This could perhaps become a new CoRTN chart correction.

TRL Conversion Equations

The conversion equations violate basic acoustic principles and appear to introduce additional error into the CoRTN procedure. It also appears that the Motorway correction factor is only valid to relate the empirically based L_{10} ground absorption equation in CoRTN measured L_{eq} distance losses rather than as a correction factor for the overall noise level output of CoRTN.

Implementation in SoundPLAN

It appears that SoundPLAN 6.4 while implementing the Non-Motorway equation (low volume) in the L_{den} module to convert L_{10} outputs into L_{eq} noise levels, has not implemented the CoRTN low volume correction. This results in the CoRTN low volume correction being 'undone' by the conversion equation except that the low volume correction has not been applied in the first place.

Revision of CoRTN

L_{eq} Modelling

It is suggested that the current L_{den} method proposed by TRL, using the Motorway and Non-Motorway roads equations, is discarded and a revised L_{eq} procedure implemented. The equation proposed by the author may be used instead of TRL's L_{den} equations.

$$L_{eq} = 10\log(q) + Const + \sum_{n=4}^{7} K_{Chart_n} + 0.75K_{Chart_8} + \sum_{n=9}^{11} K_{Chart_n} + \sum_{n=13}^{\infty} K_{Chart_n}$$

Given that CoRTN appears to be mainly L_{eq} based consideration should also be given to the following equations and modifications:

$$L_{eq} = 10\log(q) + Const + \sum_{n=4}^{7} K_{Chart_n} + K_{CONCAWE,\ ISO?} + \sum_{n=9}^{11} K_{Chart_n} + \sum_{n=13}^{\infty} K_{Chart_n} \qquad \text{Eq. (16)}$$

- CONCAWE or ISO 9613-2 ground and air absorption equations including meteorological conditions rather than *Chart 8*. These methods may be converted from octaves to overall level calculations, to speed up calculations, using a suitable road traffic noise reference spectrum

Neither of these procedures violate conservation of energy or turn established constants, such as road surface types and heavy vehicle corrections, into variables and have a similar overall form to the Motorway Roads equation.

These new procedures also remove the low volume correction and corresponding Non-Motorway Roads correction.

Introducing the ground and air absorption terms from other standards and algorithms also allows meteorological conditions to be modelled. The inclusion of meteorological conditions would improve the correlation at distances greater than 200m due to the inclusion of Air Absorption. This is of importance particularly for new roads where the night time criteria is 50dBA in NSW and traffic volumes may be in the order of 14,000AADT with up to 50% heavy vehicles in the night time period.

It may also be worthwhile investigating if the heavy vehicle and vehicle speed correction equation could be updated for the Australian vehicle fleet and L_{eq} noise levels.

L_{10} Modelling

CoRTN was derived to model L_{10} levels but it appears that it is mainly L_{eq} based and that terms included to improve the correlation with L_{10} do not have the necessary parameters to improve the correlation for the general case. These terms are the ground absorption equation and the low volume correction. This may explain some significant deviations between predicted and measured L_{10} levels with very high traffic volumes.

The L_{10} modelling may be improved by using Equations 15 or 16 to calculate the L_{eq} levels before applying a correction to obtain L_{10} using a theoretical relationship such as derived by Barry and Reagan or from empirical site data. As a minimum the correction should include terms for q, d and V.

REFERENCES

Abbott, P.G. & Nelson, P.M. (2002), *Converting the UK Traffic Noise Index $L_{A10,18h}$ to EU Noise Indices for Noise Mapping,* Transport Research Limited, Crowthorne, UK, Abbott, Project Report REPORT PR/SE/451/02, Prepared for: Project Record: EPG 1/2/37 – Adapt UK Road Traffic Noise, Client: AEQ Division, DEFRA

Barry, T.M. and Reagan, J.A. (1978). *FHWA highway traffic noise prediction model.* Research report FHWA-RD-77-108. Federal Highways Administration, Washington D.C. 20590, Department of Transport, Welsh Office (1988), *Calculation of Road Traffic Noise (CoRTN)*

Environmental Protection Agency (currently Department of Environment and Climate Change), *Environmental Criteria for Road Traffic Noise (ECRTN)*, New South Wales

Jonasson, H., Sandberg, U., van Blokland, G., Ejsmont, J., Watts, G. and Luminari, M. (2004). *Source modelling of road vehicles.* Deliverable 9 of the HARMONISE project. Harmonise Project Report HAR11TR-041210_SP10

Sandberg, U. and Ejsmont, J. (2002). *Tyre/road noise reference book.* Informex, Sweden.

Steele, C. (2001), *A critical review of some traffic noise prediction models*, Applied Acoustics, 62 pp.271-287