Road Surface Noise Corrections 2023

Research Note

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Foreword

The purpose of this research note is to gather findings from multiple research outputs and to describe the process through which a new set of road surface noise corrections was finalised. This note also provides miscellaneous new analyses where the core research outputs identified unresolved risks with the methodology. It is not a summary of the full methodology or findings.

This note is not the official publication of the corrections and should not be referenced as the source.

Abbreviations and Definitions

AC	Asphaltic Concrete
cars	Used colloquially in reference documents for light vehicles generally (cars, utes, vans)
CPX	Close proximity measurement of tyre/road noise
CRTN	Calculation of Road Traffic Noise – road-traffic noise modelling algorithms used in NZ
$L_{Aeq(t)}$	Equivalent continuous sound level, in dB, over period, *t*
LN*x*	Surface classification for a high-performance low-noise surface with nominal reduction *x* dB
%HCV	Percentage heavy vehicles (trucks, as defined below), equivalent to CRTN's *p*
R_c, R_t	Previous surface correction terms (in dB) for cars and trucks respectively
SEL	Sound Exposure Level – representing all the noise energy from a single event, in dB L_{AE}
SH	State Highway
SPB/CPB	Statistical or Controlled Pass-By measurements, of single vehicles at the wayside
trucks	Used colloquially in reference documents for heavy vehicles (MCVs, HCVs, busses)

This document makes frequent reference to earlier outputs of the surface corrections research programme, particularly the "Part 1" [1], "Part 2" [2], and "Part 3" [3] reports.

Any reference to CRTN's "charts" implies usage of the corresponding equation rather than the chart itself.

[1] Jackett R (2021) *Road Surface Noise Corrections Part 1: Large CPX Survey of Road Surfaces*, WSP report 5-27858.01 10CAR-1

[2] Jackett R, Lester T, McIver I (2022) *Road Surface Noise Corrections Part 2: Light Vehicles*, WSP report 5-27858.01 10CAR-2

[3] Jackett R (2022) *Road Surface Noise Corrections Part 3: Heavy Vehicles*, WSP report 5-27863.01 10HCV

1 Introduction

1.1 Background

Over the last 30 years, Waka Kotahi has investigated how the road surface materials and design contribute to road-traffic noise emission, how to quantify the effect of different road surfaces on noise, and how to optimise surface specifications to reduce noise. This body of research is detailed on the Waka Kotahi noise and vibration research webpage:

https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/environment-and-sustainability-in-our-operations/environmental-technical-areas/noise-and-vibration/noise-and-vibration-research/

Road surface noise corrections provide a quantification of the road-traffic noise emission from different road surface types. In noise modelling, these “surface corrections” are used alongside traffic data (e.g. AADT, %HCV) and geometry information to improve the accuracy of noise predictions for both existing and proposed road designs. The range of the surface corrections is over 10 dB from the quietest to the noisiest surface types, making it arguably the most influential modelling input (c.f. a 10-fold increase in traffic volume is equivalent to +10 dB). It follows that the other primary application of the surface corrections is to identify and formalise surface specifications than can be used to mitigate noise effects from roading projects.

In recent years Waka Kotahi has conducted research and road surveys using its CPX noise measurement system (a trailer-based system for measuring the tyre/road noise emission directly, and able to collect large amounts of noise data at highway speed). This has enabled both a better quantification of noise from existing surfaces on the SH network and accelerated the development of high-performance low-noise surface classifications.

1.2 Purpose

It has been nearly 30 years since the CRTN noise model had last been calibrated for NZ, and during this time both the road surfaces and the traffic fleet have changed significantly. New high-performance low-noise surface specifications have been developed and trialled over the last few years, which required formal surface corrections to enable their broader usage. Conversely, the existing asphalt reference surface around which the previous corrections were defined is now effectively gone from the network (from high-speed roads at least).

Therefore, the new corrections have been designed to embody a 2023 recalibration of CRTN, to represent the full set of NZ surface types (including the newest high-performance low-noise surfaces), and to be independent of any particular reference surface or surfaces.

The extensive CPX data allow for development of new surface corrections that are based on large surveys of the SH network, rather than on a few spot measurements.

The key outputs of 2021-22 surface corrections research were:

- A new methodology for recalibrating CRTN and deriving road surface corrections for NZ
- CPX surveys characterised acoustic performance of surface types as they appear on SH network [1]
- CPX data related to wayside noise level (via a pass-by to CPX correlation)
- New reference system proposed: reference equivalent to CRTN’s implicit light vehicle pass-by SEL [2]
- Draft light vehicle corrections derived against the new reference level [2]
- Estimates for heavy vehicle corrections found from pass-by surveys, related to light vehicle SEL
- Draft heavy vehicle corrections related to the light vehicle reference level [3]

1.3 Scope and structure of this document

The research reports[2,3] highlighted risks with the methodology and recommended the draft corrections be reviewed, suggesting that further adjustments may be required. They also recommended that corrections be validated against road-traffic noise measurements prior to being published.

Section 2 of this document applies a sequence of new analyses and measurements to confirm a core assumption and key risk of the methodology: that implicit (theoretical) SELs can be directly compared to measured pass-by SELs.

Then with the methodology for the separate car and truck calibrations confirmed, section 3 describes the process of combining them into a single set of surface corrections applying to a mixed flow of traffic, and section 4 presents the resulting candidate corrections.

Section 5 provides analysis of a set of independent road-traffic validation measurements and CRTN predictions based on the candidate corrections.

Finally, section 6 presents the validated final surface corrections.

2 Equivalence between implicit and measured SELs

Appendix B.2 of the Part 2 report[2] identifies risks associated with the new methodology, particularly in treating the implicit per-vehicle SEL extracted from CRTN as numerically comparable to a measurable pass-by SEL. Following completion of the three WSP research reports, further investigation and analysis has been undertaken to quantify and mitigate those risks, including:

- (§2.1) Redefinition of the L_{AE} parameter (i.e. the reference SEL itself).
- (§2.2) Understanding the compromises in the CRTN empirical model; identifying an SEL precedent.
- (§2.4) Evidence for the validity of computing traffic flow noise from the sum of vehicle pass-by SELs.
- (§2.5) Evidence the SEL sum approach and the modified CRTN approach (c.f. Part 2) are compatible.
- (§2.6) Evidence that CRTN's implicit SEL is directly comparable to measurable pass-by SELs.

2.1 Non-homogeneous vehicle SEL assumption

Appendix A of the Part 2 report derives a relationship between CRTN's chart 2 equation[4] (traffic volume dependence) and pass-by SEL, achieved via a general equation for $L_{Aeq(T)}$ as a function of SEL.

$$L_{\mathrm{Aeq(T)}} = 10\log_{10}\left[n\,10^{\frac{L_{\mathrm{AE}}}{10}}/T\right] \tag{A.0}$$

The text supporting equation A.0 introduces an assumption that all vehicles have identical pass-by SEL, which it denotes L_{AE}. In practice there will always be a distribution of levels, with the upper end of the distribution having outsized effect on $L_{Aeq(T)}$. However, the assumption was unnecessary.

A better definition for L_{AE} in equation A.0 is 'the logarithmic average of all pass-by events occurring during period *T*'. With this definition in place, none of the subsequent equations in the Part 2 report need to change, but the resulting quantities (equations A.12 and A.13) become directly comparable to the Part 2 report's logarithmically-averaged measured SELs. That is, the changed definition for the average of a population of vehicles is evaluated against the average of a sample of vehicles. No further correction for distribution shape is required as it is implicit within the logarithmic averaging of the samples.

[4] DoT, U.K. (1988) *Calculation of Road Traffic Noise (CRTN)*. Department of Transport, Welsh Office, HMSO

2.2 CRTN compromises

Appendix B.2.1 of the Part 2 report identifies risks associated with treating the implicit per-vehicle SEL extracted from CRTN as numerically comparable to a measurable pass-by SEL. Of primary concern was that unknown compromises and simplifications within the 1975 and 1988 CRTN empirical models[5] would lead to a flawed comparison. To aid understanding, additional documents have been sourced.

2.2.1 Delany, Harland, Hood & Scholes's 1976 paper

Further examination has brought a better appreciation of the balances that Delany et al [6] made in the original 1975 model, in terms of how they affect CRTN's scaling of noise level with traffic flow (chart 2).

L_{10} was somewhat intentionally treated more like L_{eq} (in terms of summation of levels) and many of the modelled phenomena were found to behave like $L_{10} = K \log_{10}(F)$, where K is a constant and F is a function or variable. In their chapter 7, Delany et al identify four such key relationships and considered values for the coefficient K:

- Summation of multiple sources fell within the range $8 < K < 10$, as observed in experiments. K=10 was preferred, which is at the steady-state end of the range (e.g. high traffic volume and/or far from road).
- Summation by angle of view: K=10.5 was optimal.
- Distance attenuation effect over hard ground: K=10.5 was optimal.
- Dependence on traffic volume, q, the best overall fit was via $L_{10} = 9.0 \log_{10}(q)$, that is K=9.0 was optimal.

Ultimately Delany et al opted to use K=10.0 for all of these effects, in order to achieve internal consistency (that is, to avoid getting different results for the same situation modelled in an arbitrarily different way). It was also a simple value to manipulate.

The best-fit K=9.0 dependence on traffic volume suggests that the chart 2 equation ($L_{10} = 42.2 + 10 \log_{10} q$) contains a compromise in both terms: the q-dependent term is stronger so it follows that the constant is smaller for the same L_{10} noise level. The constant term effectively defines the implicit per-vehicle level (for flows with $q > 50$) so this can potentially inform the current work.

2.2.2 Implications for 2023 recalibration

The derivation of the implicit reference SELs in Part 2 Appendix A is fundamentally about assuming equivalence between two expressions for $L_{Aeq(1h)}$ as a function of traffic volume[7]. Equation A.0 (see section 2.4) and CRTN's chart 2 equation both have a coefficient of 10 to their respective traffic volume terms ($\log_{10}[n]$ in A.0 and $\log_{10}[q]$ in chart 2). The dependence on individual vehicle pass-by SEL arises solely from equation A.0, so there is limited utility in adjusting chart 2 itself.

However, as an informative exercise, we have considered how chart 2 may have looked if a coefficient of 9 had been adopted instead of 10. To achieve comparable noise level predictions for values of q around 500 vehicles/hour it would be similar to $L_{10} = 44.8 + 9 \log_{10} q$. That corresponds to an implicit per-car SEL of 77.9 dB, which is 2.6 dB higher than the value calculated based off the actual CRTN chart 2, and would lead to a set of light vehicle surface corrections that are 2.6 dB lower. The implication is that the current implicit SEL derivation in the Part 2 report could be more likely to overestimate surface corrections than underestimate them, particularly for higher traffic volumes.

More broadly, Delany et al's measurement data pointed to a scaling of noise level that was slower than the theoretical summation of vehicle contributions, suggesting a general tendency for CRTN to overpredict

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5 CRTN was first published in 1975 and was further modified in 1988[4]. The same core 'chart 2' and 'chart 4' equations were used in both, but the 1988 version increased the constant by 1.0 dB and introduced a surface correction term (plus other unrelated changes).

6 Delany ME, Harland DG, Hood RA, Scholes WE (1976) *The prediction of noise levels L10 due to road traffic*, J. Sound Vib. 48(3), pp.305-25

7 Jackett R (2022) *A new methodology for deriving road surface noise corrections for light vehicles in New Zealand*, Conf. Acoustical Soc. NZ, Wellington

at higher traffic volumes (or underpredict at lower volumes, depending on how the constant was compromised). It isn't known how much their use of the L_{A10} parameter would have affected their K=9 vs K=10 finding – there may be a threshold effect and flow dependency associated with this statistical parameter to which the L_{Aeq} parameter is less susceptible.

2.2.3 Abbott and Nelson's 2001 CRTN surface corrections revision

The authors of the 1988 revision of CRTN added surface corrections in 2001 using a method[8] that shares reassuring similarities with that of the Part 2 report. Rather than use a mixed traffic stream, they also derived individual light and heavy vehicle SELs that were "implicit in the CRTN75 formulation". Their derivation followed a similar set of assumptions and produced SELs within 0.2 dB of those derived in Appendix A of the Part 2 report (see reference levels in section 4.1 and assumptions in Annex B).

Abbott and Nelson then compared the implicit vehicle levels (which defined their UK reference surface) against measured light and heavy vehicle pass-by levels to determine surface corrections for a variety of UK surfaces. The Part 2 and Part 3 reports perform a similar process for NZ surfaces, except that the implicit SELs are taken directly as reference levels rather than as indicative of a physical reference surface.

2.3 Heavy vehicles

The distinction between heavy and light vehicles in CRTN is determined entirely by the chart 4 equation, and is effectively a fixed delta. The Part 3 report[3] found that CRTN's delta of $\Delta L_{AE,CRTN}$ = 8.9 dB under reference conditions was closely replicated by 2022 field measurements of light and heavy vehicles on an AC surface. The heavy vehicle reference level will therefore remain +9 dB relative to the light vehicle reference level under reference conditions, defined for a light vehicle SEL of 75 dB L_{AE}.

The heavy vehicle statistical pass-by and controlled pass-by surveys of the Part 3 report put the heavy vehicle surface correction at approximately 0.65 times the light vehicle correction for any given surface, $R_t = 0.65\, R_c$. This general and approximate relationship has been used to derive the heavy vehicle correction terms R_t in section 3.

2.4 Internal consistency of L_{AE} sum and CRTN-based predictions

Section 2.2 identified that the general equation A.0 has the same dependency on traffic volume as CRTN's chart 2. Equation A.0 is explicitly a sum of individual vehicle contributions and chart 2 is implicitly a sum of individual vehicle contributions.

This suggests that for simple site layouts where average site L_{AE} have been measured and the traffic speed is close to the reference speed (because Eq. A.0 has no speed term), there should be good agreement between predictions based on Eq. A.0 and those based on CRTN using a surface correction specific to the site (i.e. $R_c = L_{AE} - 75.3$ dB, $R_t = 0.65\, R_c$).

When applied to real hourly traffic data from four sites where L_{AE} had been measured (see Annex A) the models' predictions of $L_{Aeq(1h)}$ differed by 0.04 dB on average (sd=0.6 dB, n=58). The small average error is evidence that the new surface correction methodology is internally consistent.

2.5 L_{AE} sum versus measured traffic L_{Aeq}

The methodology of the Part 2 report depends on the validity of the general equation A.0 for $L_{Aeq(1h)}$ as a function of L_{AE} when applied to measured road traffic noise and pass-by levels, respectively.

This has been tested via noise monitoring at four sites previously visited for SEL measurements (see Annex A). Traffic noise levels in dB $L_{Aeq(1h)}$ were measured at the same or similar positions as previously, and traffic counts for light and heavy vehicle categories were performed.

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[8] Abbot PG, Nelson PM (2001) *Revising CRTN road surface correction for medium and high-speed roads*, TRL, PR/SE/289/2001

Predictions of traffic noise in dB $L_{Aeq(1h)}$ were derived from previously measured average car pass-by SELs and extrapolated truck pass-by SELs according to the hourly traffic counts (equivalent to Part 2 equation A.7). The predictions were compared with hourly noise measurements and the error[9] computed as the difference.

Across the four sites the average error was +0.2 dB (overprediction). The error varied significantly between sites (sd = 2.2 dB), some of which appears to be due to genuine differences between visits and traffic speeds different to the reference speed (discussed in Annex A), but much should be attributed to unavoidable and unquantifiable sources of prediction and measurement[10] error. At the hourly level, with $q > 50$, the mean error in $L_{Aeq(1h)}$ was -0.1 dB (sd=2.7 dB, n=49).

In general, the magnitude of the error suggests that it is viable to estimate road traffic noise from the sum of average pass-by levels, at least within the range of traffic volumes surveyed.

2.6 L_{AE}-based CRTN corrections versus measured traffic L_{Aeq}

Section 2.4 showed that the L_{AE} sum hourly predictions (Eq. A.0) are numerically consistent with CRTN hourly predictions using site-specific surface corrections based on L_{AE} measurements. Section 2.5 suggested that the L_{AE} sum approach corresponds reasonably well, on average, with wayside noise level measurement. By extension, using L_{AE}-derived surface corrections in CRTN prediction should produce results that are comparable with measurement, and therefore suitable for adoption as correction values.

This has been tested using L_{Aeq} measurements and predictions from the four sites described in Annex A. The surface corrections were the generic unrounded corrections for each surface type from Table 2, not site-specific corrections. Section 3 details the consolidation of car and truck corrections into a single value for each surface type. The consolidated corrections were used in this analysis, after also temporarily removing the intentional 75th percentile surface bias (section 5.4.1) to obtain a like-for-like comparison.

The error between each measured site L_{Aeq} and its CRTN prediction was +0.7 dB on average (overprediction, sd=0.7 dB). At the hourly level, with $q > 50$, the mean error in $L_{Aeq(1h)}$ was +0.5 dB (sd=1.4 dB, n=49).

For context, applying the existing Waka Kotahi CRTN corrections[12], including the -2 dB NZ adjustment, achieved an average error of -1.0 dB (underprediction, sd=0.7 dB) relative to measurement across the same sites. At the hourly level, with $q > 50$, the mean error in $L_{Aeq(1h)}$ was -1.3 dB (sd=1.3 dB, n=49).

The proposed L_{AE}-based corrections therefore performed equivalently to the existing CRTN corrections in this small sample, but with the average error on the side of overprediction rather than underprediction.

2.7 Conclusion

There is sufficient evidence to adopt the L_{AE}-based corrections methodology as it is laid out in the Part 2 report. The risks around comparability of measured and implicit pass-by L_{AE} are now better understood and have been allayed to a moderate extent. New measurements suggest that the potential error is small within the context of other known CRTN implementation errors[11], and will not be a degradation on the existing set of corrections.

- The process of converting pass-by L_{AE} measurements into (absolute) CRTN surface corrections is internally consistent, in that both sides of the equation have been shown to agree across a range of traffic volumes (section 2.4).
- Measured average pass-by L_{AE} appear to sum towards a valid traffic flow $L_{Aeq(1h)}$, verified through measurement (section 2.5).

[9] With both prediction and measurement contributing to the error.

[10] Dravitzki VK, Jackett RJ, Wood CWB (2011) *The variability of road traffic noise and implications for compliance with the noise conditions of roading designations*, Waka Kotahi Research Report 446

[11] Jackett R (2023) *Uncertainty of road-traffic noise prediction in New Zealand*, J. Ac. Soc. NZ, 37(2), p.40-47

- Applying generic L_{AE}-derived surface corrections to a standard CRTN prediction of road-traffic noise aligns well with a limited set of measurements (section 2.6), with an average overprediction +0.7 dB. The existing corrections achieve a similar magnitude of underprediction.
- The possibility of a 2.6 dB overprediction due to the traffic coefficient being closer to 9 than 10 (section 2.2) is not suggested by the measurements. The current evidence tentatively suggests overprediction, but by a smaller margin.
- The conservatively estimated uncertainty component for “validity of CRTN implicit SEL” in Appendix E.4 of the Part 2 report can be reduced from 2.0 dB to 1.0 dB.

The car and truck corrections from the Part 2 and 3 reports have therefore been accepted as the best estimates for surface corrections. These have been consolidated into a single correction for each key surface type in section 3.

3 Consolidation of light and heavy vehicle corrections

3.1 Background

The current surface corrections table[12] has separate components, R_c and R_t, for the car and truck contributions, respectively[13]. The practitioner must combine those via an equation for R (see Eq. 1), representing the specific surface correction in dB for a given section of road, as a function of R_c, R_t, posted speed limit (V), and percentage heavies (p).

$$R = 10\log_{10}\left[\frac{\left(1-\frac{p}{100}\right)\cdot 10^{\frac{R_c}{10}} + \left(\frac{p}{100}+\frac{5p}{V}\right)\cdot 10^{\frac{R_t}{10}}}{1+\frac{5p}{V}}\right] \qquad \text{Equation 1}$$

The Part 3 report[3] proposed heavy vehicle corrections that correlated positively with the light vehicle corrections across the range of surfaces – surfaces that were quiet for cars were also quiet for trucks, etc. The truck corrections had a lower magnitude because their noise emission is not dominated by tyre/road noise as it is for cars.

Given the strong correlation, it has been investigated whether the car and truck corrections could be recombined into a single table entry for each surface type (i.e. the practitioner would adopt the single value from an updated table directly, without needing to use Eq. 1 for R). It is noted that Eq. 1 was created to accommodate the separate corrections for cars and trucks introduced in the 2014 surface guide[12] and is not an inherent part of CRTN. CRTN natively allows for a single surface correction for each surface type across all vehicle types and speeds.

3.2 Investigation

A single correction for each surface type would mean 'permanently' combining R_c and R_t values into a single value R, in the same manner that Eq. 1 currently does for each road segment. The equation scales the contributions to R according to CRTN chart 4's percentage heavy parameter (and therefore also chart 4's vehicle speed parameter) and is applicable to this process.

The parameters for vehicle mix and speed in the equation therefore need to be refixed at an appropriate value.

Note that CRTN's chart 4 still applies outside of the surface correction calculation, so mix and speed remain important inputs to the full noise prediction.

3.2.1 Select appropriate fixed values for percentage heavies and traffic speed

From Eq.1, speed V only has an influence on terms associated with heavy vehicles (p>0) and, over the typical range of values, its effect is secondary to that of p. Therefore, the selection process focused on p, and assumed V=75 km/h, which is both the CRTN reference speed and approximates a midpoint of traffic speeds on NZ highways.

The expected range of values for p on state highways was estimated as lying between a lower bound of 2% and an upper bound of 25% HCV, although exceptions exist at either end.

Assuming a fixed value of p=10 minimised the error across the expected range of %HCV, with error defined as the difference between Eq. 1 calculated based on p=10 and based on the lower and upper bounds.

[12] Waka Kotahi NZTA (2014) *Guide to state highway road surface noise*, version 1.0

[13] The existing corrections show no clear correlation between R_c and R_t terms. Some surfaces that are noisy for cars are quiet for trucks, and vice versa. It is not known whether this is a real effect or an artefact of the sample size. The limited survey of the Part 3 report did not find evidence for this effect.

3.2.2 Effect on uncertainty

The residual error was ±0.6 dB at the bounds, which is on the same scale as the surface correction rounding error (±0.5 dB) and far below CRTN's typical prediction error[11], which is in the region of ± 5 dB. Additional variation in the speed parameter between V=50 and V=100 does not change the estimate of error.

On that basis, combining the R_c and R_t components using fixed values p=10 and V=75 will not lead to any significant degradation in prediction accuracy.

However, the error is not random, so introducing a single value for R will introduce a bias, which is evident when comparing quiet and noisy surfaces. For high %HCV, the single value would slightly underestimate noise from chipseal and overestimate noise from porous asphalt, meaning the gap between those surfaces would appear up to 1 dB narrower compared to the full calculation. For low %HCV the opposite occurs and the gap would be up to 1 dB wider.

In practice, an error of ±1 dB is unlikely to influence surface selection because that process generally seeks to maximise acoustic benefit rather than identify the minimum compliant surface.

A new component for "consolidation of R_c and R_t" should be included in the uncertainty budget for the absolute value of the surface corrections in Appendix E.4 of the Part 2 report, taking the value 0.6 dB and divisor √3. Also incorporating the change described in section 2.7, an additional uncertainty for the truck corrections, and other minor refinements, the combined standard uncertainty for the surface corrections covering both cars and trucks is estimated at 1.2 dB (k=1).

3.3 Conclusion

The key benefits of combining R_c and R_t components into a single published surface correction are

a. A simplification to the noise modelling process
b. Improved transparency (currently the computed R value is often not included in reports)
c. Less reliance on practitioner understanding and correctly computing Eq. 1 for R
d. Consistency with the original formulation of CRTN
e. Avoids incorrect inferences of the accuracy of individual R_c and R_t values ("false precision")
f. The clear change away from using R_c and R_t helps distinguish the old corrections regime from the new

The key costs are,

g. Potentially reintroduces a small systematic error for predictions of very high or very low %HCV
h. Reintroduces a small systematic error into the surface selection process, under high or low %HCV

In the context of the uncertainty of CRTN road-traffic noise prediction as a whole, the additional error (g) is negligible, and in practice the error (h) is unlikely to affect surface selection. The benefits of further simplifying the noise modelling process (a,c) and improving transparency (b) make those trade-offs worthwhile.

With respect to prediction of noise for high %HCV conditions, the error contributed by the surface correction is minor compared to the error from variation in the MCV / HCV mix[14].

[14] Barnes J, Ensor M (1994) *Traffic noise from uninterrupted traffic flows*, Transit New Zealand Research Report No. 28

4 Candidate surface corrections

4.1 Reference level

On the basis of findings from section 2, the reference pass-by SELs are as derived in the Part 2 report (Table 1). Adjustments applied in deriving the reference SELs are summarised in Annex B, Table 13.

Table 1: Reference sound exposure levels (SELs)

Light vehicle reference dB $L_{AE,car}$	**Heavy vehicle reference** dB $L_{AE,truck}$
75.3	84.2

4.2 Surface corrections

The Part 2 report calculated a set of surface corrections for cars and trucks relative to the reference pass-by SELs. Section 3 sets out the rationale and methodology to consolidate the separate car and truck corrections into a single correction per surface type. Table 2 presents the unrounded consolidated *R* (for information only), and the candidate surface correction for use in CRTN noise prediction, rounded to the nearest decibel.

Adjustments applied during derivation of the surface SELs and the surface corrections have been summarised in Annex B, Table 14. The surface corrections use the 75th percentile level for each surface type (Part 2 §4.1.3) rather than the mean, contributing approximately 1 dB towards overprediction on average. The limited data from section 2.6 suggested the recalibration method itself may also overpredict by about 1 dB. The mean overprediction error is therefore expected to be in the region of 2 dB. This estimate has been further refined through the validation study (section 5) and should be reviewed following routine application.

The table requires additional guidance for application to surfaces not explicitly identified, as discussed in section 4.3.2 of the Part 2 report. The porous asphalt surface classifications also require adjustment to reflect additional research optimising mix designs to reduce noise.

Table 2: Candidate noise surface corrections applying to various surface classifications

Surface Classification	***R*** dB	**Surface Correction** dB
Grade 2 or 3	5.7	+6
Grade 4	4.6	+5
Grade 5 or 6	3.9	+4
SMA-14	1.6	+2
SMA-10	0.3	0
Reference SEL	-0.2	0
PA-10 30 mm	-0.8	-1
PA-10 50 mm	-3.0	-3
PA-7 40 mm	-4.1	-4

4.3 Formulae for deriving indicative corrections from $CPXP_{80}$

Incorporating the corrections and intermediate steps from the Part 2 report (and summarised below in Annex B), a mean measured $CPXP_{80}$ level in dB $L_{CPX:P1,80}$ may be converted to an indicative surface correction in dB, via one of the following equations depending on the nominal surface type.

For porous asphalts: $$\text{Correction} = 1.0905 \cdot CPXP_{80} - 107.1 \text{ dB} \tag{4.1}$$

For chipseal: $$\text{Correction} = 1.0667 \cdot CPXP_{80} - 102.4 \text{ dB} \tag{4.2}$$

Unclassified (used for SMA): $$\text{Correction} = 1.6217 \cdot CPXP_{80} - 158.3 \text{ dB} \tag{4.3}$$

These equations are provided for research purposes only. They should not be used to determine surface corrections for projects. Equation 4.3 for unclassified surfaces is an overall ‘best fit’ but should generally be avoided in favour of equations 4.1 or 4.2 where applicable. It is currently used for SMA due to having insufficient available data to generate a dedicated wayside-on-CPX regression within SMA surfaces only.

5 Validation process

An independent validation process has been followed to confirm the validity of candidate surface corrections for road-traffic noise prediction in NZ.

5.1 Survey

Acoustic Engineering Services Ltd was engaged by Waka Kotahi to perform noise monitoring and baseline CRTN noise level prediction for 18 sites across the Auckland, Wellington, and Christchurch regions during February and March 2023. For each site approximately 6 full days of noise measurements were made, and where possible nearby live traffic data was sourced. The detail of the surveys is described in the monitoring report[15].

Whereas the calibration itself[2] took place under essentially CRTN reference conditions[16], these measurements introduce additional variables, notably:

- Distance from road (but all within 30 metres of the road)
- Traffic speed
- Some road curvature
- Road gradient (minor)
- More complex roadside geometry
- Angle of view other than 180 degrees
- Potential for extraneous sources of noise (but assumed negligible compared to traffic noise)

Consequently, they are expected to introduce,

a. Greater variability, reflected by a broad random distribution of errors (on the order of ± 5 dB [11]).
b. Previously uninvolved aspects of CRTN that contribute systematic error.

The latter is likely to be indistinguishable from errors in the calibration of the reference.

5.2 Data

The 18 survey sites are summarised in Table 4. They are high-speed urban and rural sites covering a broad range of surfaces, traffic volumes, and light/heavy vehicle mix.

Average predicted and measured noise levels in dB $L_{\mathrm{Aeq(24h)}}$ are presented in Table 5. The existing and proposed surface corrections used in those predictions are also provided.

The baseline noise level predictions used the posted speed limit and, where available, actual traffic counts and traffic mix. Where actual local counts were not available they were extrapolated[15].

The $L_{\mathrm{Aeq(1min)}}$ measurements were filtered for an acceptable meteorological window according to Table 3.

Table 3: Acceptable meteorological conditions

Quantity	Acceptable range	Comment
Windspeed (mean + 1 sd)	≤ 10 m/s	Typically measured 10 m above ground
Wind direction	Any	No filtering necessary
Rainfall	≤ 0.2 mm/h	Based on observation of noise data
Time since last rain event	> 2 hours	Based on observation of noise data

Only days with greater than 70% valid measurements were included in the analysis. 33 partial days were excluded because monitoring commenced or finished that day, and 6 days were excluded due to weather, leaving 111 valid days of measurements.

[15] Acoustic Engineering Services (2023) *Road surface noise correction validation measurements*, AC22401-06-R1

[16] Essentially the CRTN chart 2 curve without any further correction: 75 km/h, no heavies, no gradient, no ground absorption, no reflections, at 10 m from the edgeline of a long straight 2-lane road.

Table 4: Survey site information

Site	Location	Distance from lane metres	Lanes	Speed limit km/h	RAMM surface material	Surface year	AADT	%HCV	Full days of data
CHCA	Wigram	13.0	4	100	OGPA 14	2014	40452	5.6	5
CHCB	Dunsandel	6.0	4	100	2CHIP 3/5	2023	13666	13.3	6
CHCC	Northwood	7.5	4	100	EPA 7	2018	21431	10.2	6
CHCD	Springfield	9.3	2	100	1CHIP 5	2011	2028	14.4	4
CHCE	Waipara	9.9	2	100	2CHIP 2/4	2018	9039	18.3	5
CHCF	Little River	10.0	2	80	2CHIP 2/4	2017	2555	5.9	6
WLGA	Trentham	26.0	2	100	OGPA 10	2021	27604	3.2	7
WLGB	Upper Hutt	4.2	3	100	OGPA 10	2014	19248	3.2	7
WLGC	Peka Peka	28.2	4	100	OGPA 10	2018	24681	6.5	6
WLGD	Plimmerton	10.6	4	100	2CHIP 3/5	2022	11070	5.6	6
WLGE	Manakau	16.0	2	100	1CHIP 2	2012	18242	9.8	6
WLGF	Kuku	19.3	2	100	2CHIP 2/4	2019	18242	9.8	6
AKLA	Huntly	13.0	4	110	SMA 10	2020	34162	21.1	7
AKLB	Silverdale	26.3	4	100	OGPA 10	2018	31232	6.5	6
AKLC	Rosehill	12.0	4	100	OGPA 10	2013	68588	9.7	7
AKLD	Paerata	9.0	2	80	SMA 14	2008	14175	3.9	7
AKLE	Karaka	12.0	2	80	SMA 10	2021	19017	5.8	7
AKLF	Pokeno	6.8	2	90	2CHIP 2/4	2014	13572	12.3	7

Table 5: Survey data

Site	RAMM surface material	New surface classification	Existing surface correction dB	Proposed surface correction dB	CRTN Existing $L_{Aeq(24h)}$ dB	CRTN Proposed $L_{Aeq(24h)}$ dB	Measured $L_{Aeq(24h)}$ dB
CHCA	OGPA 14	PA-10 30 mm	-2.3	-1	67.7	68.9	73.7
CHCB	2CHIP 3/5	Grade 2 or 3	3.4	6	74.2	77.1	75.1
CHCC	EPA 7	PA-7 40 mm	-2.5	-4	69.4	67.8	67.6
CHCD	1CHIP 5	Grade 5 or 6	0.5	4	62.6	66.4	65.8
CHCE	2CHIP 2/4	Grade 2 or 3	2.4	6	71.4	75.5	72.9
CHCF	2CHIP 2/4	Grade 2 or 3	3.7	6	65.1	67.4	66.1
WLGA	OGPA 10	PA-10 30 mm	-2.2	-1	62.5	63.7	61.4
WLGB	OGPA 10	PA-10 30 mm	-2.2	-1	71.6	72.7	70.4
WLGC	OGPA 10	PA-10 30 mm	-2.4	-1	64.6	65.9	62.7
WLGD	2CHIP 3/5	Grade 2 or 3	3.6	6	69.8	72.2	72.1
WLGE	1CHIP 2	Grade 2 or 3	2.9	6	71.1	74.0	75.0
WLGF	2CHIP 2/4	Grade 2 or 3	2.9	6	71.6	74.6	67.9
AKLA	SMA 10	SMA-10	-1.6	0	73.4	74.9	73.7
AKLB	OGPA 10	PA-10 30 mm	-2.2	-1	65.2	66.6	62.3
AKLC	OGPA 10	PA-10 30 mm	-2.6	-1	73.7	75.2	76.8
AKLD	SMA 14	SMA-14	-0.8	2	68.8	71.6	70.5
AKLE	SMA 10	SMA-10	-1.0	0	68.4	69.3	68.2
AKLF	2CHIP 2/4	Grade 2 or 3	2.8	6	73.6	76.8	75.8

5.3 Analysis

Weighted linear regression, ANOVA, and paired differences have been used to evaluate the quality of CRTN noise predictions based on the existing and the proposed surface corrections. In these analyses, noise measurements were used as a proxy for the 'true' noise level, but themselves carry significant uncertainty. The ANOVA was focused on the independent site averages (n=18) rather than daily averages (n=111), which were not fully independent.

5.3.1 Site Weights

Confidence in the noise and traffic monitoring data differed between sites. The analysis accommodated this by weighting the data in the linear regression. Table 6 provides the weightings used for each site, along with the reason. The weighting values were based on judgement, considering the impact a deficiency could have on the measured or predicted level.

Table 6: Site weightings in regression analysis

Description	Weighting	Sites
Acceptable traffic and measurement data	100%	CHCB, CHCC, CHCD, CHCE, CHCF, AKLD, AKLE, AKLF
Minor traffic extrapolation	90%	WLGA, WLGB, WLGD, AKLB historic mix WLGC distant traffic counter
Major traffic extrapolation	70%	WLGE, WLGF, AKLC historic counts AKLA very distant traffic counter
Impaired measurement	--	None. All site averages were based on 4+ days of data, after filtering for weather, etc
Known major issue with input data	0%	CHCA had a PA-14 surface condition unrepresentative of the classification

The CHCA site was identified as having a surface condition that was unrepresentative of its porous asphalt classification. The $CPXP_{80}$ level was in the range usually occupied by a grade 2 or 3 chipseal (101-102 dB). Because this is primarily an outlying surface issue that rather than a surface correction issue, this site was removed from the regression analysis via a zero weighting.

5.3.2 Linearity

Linear least squares regression of the survey data was performed using the weights in Table 6. The regression of measured levels, L_{meas}, on predicted levels, L_{pred}, should ideally achieve a coefficient (slope) of m = 1. The regression is sensitive to the overall performance of the CRTN noise model, not just the corrections, and is also sensitive to error in the measured level.

CRTN using the proposed corrections achieved $L_{meas} = 1.04\ L_{pred} - 4.8$ dB (p<0.05, R^2=0.87, n=18). At the 95% level of confidence the coefficient was $m = 1.04 \pm 0.22$.

CRTN using the existing corrections achieved $L_{meas} = 1.11\ L_{pred} - 7.4$ dB (p<0.05, R^2=0.81, n=18). At the 95% level of confidence the coefficient was $m = 1.11 \pm 0.29$.

Both sets of corrections include the ideal value of 1.00 within their 95% confidence intervals. In terms of minimising bias, the proposed corrections performed slightly better across the range of the validation data (approximately 60 dB to 80 dB). The coefficient of determination for the proposed corrections, R^2 = 0.87, represents good predictive ability, at least within the set of validation data.

Analysis of the residuals found no correlation with traffic volume, traffic speed, or setback distance.

Figure 1 presents the regression of site L_{meas} on site L_{pred} for both sets of surface corrections (bold dots), along with coordinates for each valid day (pale dots). The regression lines shown are based on the site averages, described above. Points above the m=1 line were underpredicted, and points below it were overpredicted. The general overprediction of the proposed corrections is covered in section 5.4.1.

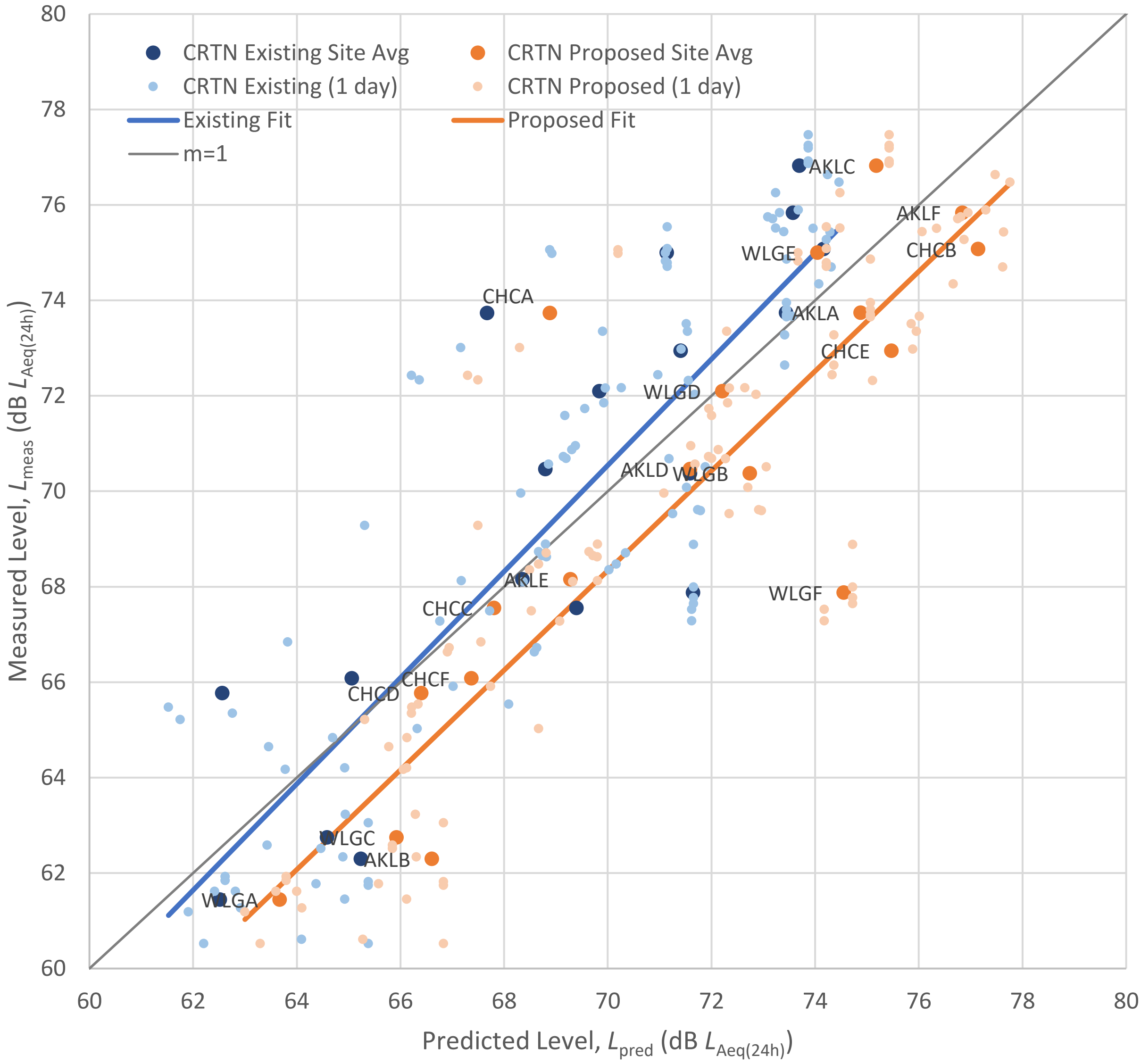


Figure 1: Daily measured and predicted $L_{Aeq(24h)}$ noise levels at 18 sites

For completeness, the regression statistics for the daily data are also provided, but it is noted that the assumption of independence is not met by this dataset.

CRTN using the proposed corrections achieved L_{meas} = 1.07 L_{pred} – 6.5 dB (p<0.05, R^2=0.85, n=111).

CRTN using the existing corrections achieved L_{meas} = 1.16 L_{pred} – 10.7 dB (p<0.05, R^2=0.81, n=111).

5.3.3 Mean error

Before commencing the validation study there was an expectation for overprediction in the region of +2 dB on average for the proposed corrections, most of which was intentional (see 5.4.1).

For the proposed corrections, the mean error of the predicted $L_{Aeq(24h)}$ level was +1.6 dB (overprediction, n=18 weighted) with a 95% confidence interval of [+0.6, +2.6] dB.

For the existing corrections, the mean error of the predicted $L_{Aeq(24h)}$ level was -0.4 dB (underprediction, *n*=18 weighted) with a 95% confidence interval of [-1.6, +0.7] dB.

5.3.4 Residual and random error

The proposed corrections produced a weighted RMS residual of 1.7 dB about the regression line defined in section 5.3.2 (*n*=18). The weighted RMS error (from the paired differences with measurements) was 2.5 dB.

The existing corrections produced a weighted RMS residual of 2.0 dB about the regression line defined in section 5.3.2 (*n*=18). The weighted RMS error was 2.2 dB.

Note that measurement error also contributes to these values.

5.4 Findings

The results of the analysis are summarised in Table 7 for CRTN predictions, using either the proposed corrections or the existing corrections, against measurements.

Table 7: Summary of statistics comparing CRTN predictions with measurements at 18 sites

Quantity	**Proposed Corrections**	**Existing Corrections**
Slope of regression (close to 1.0 is preferred)	1.04 ± 0.22	1.11 ± 0.29
Coefficient of determination, R^2	0.87	0.81
Mean error, dB (positive is overprediction)	+1.6 ± 1.0	-0.4 ± 1.2
RMS Residual, dB	1.7	2.0
RMS Error, dB	2.5	2.2

In general, the proposed corrections modestly out-perform the existing corrections for the validation dataset.

Based on the slope of the regression line and the mean error, the existing corrections may be biased towards underprediction at higher noise levels (not shown to be statistically significant). The proposed corrections do not suggest a strong bias with noise level, at least within the limited validation sample.

The lower residual error of the proposed corrections compared with the existing corrections (and equivalently the higher R^2) suggests a modest improvement in attributing acoustic properties to each surface, despite the simplifications employed (see section 3).

5.4.1 Overprediction

Within the validation dataset, the proposed corrections overpredicted the noise level by +1.6 ± 1.0 dB on average, consistent across the range of predicted levels (see 5.3.2).

Some overprediction was intentional and has been independently quantified. The recommendation in the Part 2 report to characterise each surface's performance by its 75th percentile CPX level should contribute approximately +1 dB (+0.6 dB for chipseal and SMA and +1.4 dB for porous asphalt) compared to predicting their mean values.

If the 75th percentile levels are temporarily replaced with the mean level for each surface type for this validation analysis, the linear regression equation for the proposed corrections becomes $L_{\text{meas}} = 1.00\ L_{\text{pred}} - 1.1$ dB (p<0.05, R^2=0.86, n=18). The mean error becomes +0.8 dB (overprediction, n=18 weighted) with a 95% confidence interval of [-0.2, +1.8] dB. This remaining magnitude of error is within the 95% uncertainty limits [-2.4,+2.4] dB calculated for the calibration methodology (section 3.2.2). Up to +0.5 dB of this may be attributed to the calibration's use of CRTN's $L_{10(1h)}$ chart 2 equation rather than its $L_{10(18h)}$ chart 3, which are not internally consistent (see Part 2 report, appendix A, note 3).

Therefore, the finding of +1.6 ± 1.0 dB overprediction from the validation study is within the range expected from the 75th percentile surface contribution plus the allowance for calibration uncertainty.

5.4.2 SMA

Due to insufficient wayside measurement data, the Part 2 report could not be definitive about placing SMA within either the nominally "porous" or "non-porous" grouping, so instead estimated SMA 10 and SMA 14 corrections using a general L_{CPX}-to-L_{AE} conversion and recommended further investigation.

The validation survey has included 3 SMA sites (AKLA, AKLD, AKLE) which all fall within 0.5 dB from the regression equation. With no suggestion of a significant systematic error, the proposed SMA surface corrections have not been revisited.

5.4.3 Limitations

All validation measurements were performed close to the road on a variety of surface types, which was appropriate for testing the recalibration of CRTN in the absence of the previous reference surface. The broader accuracy of the CRTN prediction was outside of scope and has not been tested, but is the subject of separate research[11].

The surface types in the validation survey did not cover all the proposed corrections, and the proportions of each surface type in the survey did not reflect their proportion of the full SH network.

No evidence has been obtained for the validity of the corrections on low-speed roads.

Factors that are not expected to contribute to the validation measurements, but might contribute to application of the corrections include,

- The proposed corrections assume actual vehicle speed is approximately 92% of the posted speed limit (with the posted speed limit used in CRTN predictions). In the validation survey it was sampled at 91% on average, and the speed ratio was not correlated with the residuals.
- The validation modelling originally used 24-hour AADT traffic volume and mix data to populate CRTN's 18-hour (0600-2400) parameters, which contributed +0.3 dB to the $L_{\text{Aeq(24h)}}$ level on average, so this bias was subsequently removed for the sake of evaluating the calibration. However, inputting 24-hour traffic data directly into CRTN is preferred practice in NZ, so it is likely that in application there will be an additional +0.3 dB mean error.
- In application, error in traffic volume and mix projections affect CRTN predictions, but for the validation study these quantities were measured where possible and would not contribute significantly to mean error.
- The conversion from $L_{10(18h)}$ to $L_{\text{Aeq(24h)}}$ via a constant may also contribute systematic error for both proposed and existing corrections[17].

[17] Abbot PG, Nelson PM (2002) *Converting the UK traffic noise index $L_{A10,18h}$ to EU noise indices for noise mapping*, TRL report PR/SE/451/02

6 Final Surface Corrections

6.1 Low Noise Surfaces

For practical implementation and to reflect research findings for porous asphalt surfaces, modifications have been made to the surface classifications in the corrections table.

Two generic high-performance low-noise (LN) surface classifications have been introduced, denoted LN3 and LN5, representing surface corrections of -3 dB and -5 dB respectively.

This performance-based approach to specifying surfaces is new, and will assist in providing certainty of acoustic performance in designation conditions, whilst maintaining some flexibility in surface design. For now, only the following proven mix designs drawn from NZTA P11[18] are classified as LN3 or LN5 surfaces:

LN3: EPA7 with minimum thickness 40 mm
PA7 with minimum thickness 40 mm

LN5: EPA7 with minimum thickness 50 mm

With reference to Table 2, 40 mm PA7 and EPA7 have been conservatively classified as a LN3 surface.

The LN5 classification of 50 mm EPA7 is based on $CPXP_{80}$ data collected in Christchurch[19,20] and Hamilton in 2021-22. The data indicate that 94.0 dB $L_{CPX,P1,80}$ is indicative of a 75^{th} percentile performance for 50 mm EPA7, provided appropriate quality controls are implemented during surface construction. That corresponds to a surface correction of -5.8 dB, which is conservatively taken as -5 dB.

The LN3 and LN5 classifications are only given to new surfaces constructed with the appropriate controls for achieving the minimum surface thickness[18,21].

6.2 Final Surface Corrections

Following the successful validation process, the final surface corrections are presented in Table 8. They derive from those given in Table 2, but with the addition of the high-performance low-noise LN generic surface classifications (section 6.1). The surface classification names in the table represent convenient labels for each set of surface types rather than implying a particular surface specification. The membership of each classification is described in the “Applies to” column.

[18] Waka Kotahi NZ Transport Agency *P11 – Specification for open graded porous asphalt*
[19] Wareing R (2022) *Christchurch Northern Corridor - Trial Site Preliminary Investigations*, 21-104/R02/C
[20] Wareing R (2021) *Road surface noise – Summary of CPX measurements 2021*, 20-118/R01/B
[21] Waka Kotahi (2023) *Guide to assessing road-traffic noise*

Table 8: Final road surface noise corrections

Surface Category	Surface Classification	Applies to	Surface Correction dB
Chipseal	Grade 2 or 3	Any chipseal that includes grade 2 or 3 chip, including single coat, two-coat, racked-in, etc. Any other unlisted surface type.	+6
	Grade 4	Single coat grade 4 chipseal. Two-coat grade 4/6 chipseal.	+5
	Grade 5 or 6	Single coat grade 5 or 6 chipseal.	+4
Asphalt (non-porous)	SMA14	SMA14 and any other unlisted SMA. Slurry seal.	+2
	SMA10	SMA7 and SMA10 Any AC and DG (ungrooved).	0
Porous Asphalt	PA	Any porous asphalt other than LN types. Includes PA & EPA, and HV & HS variants.	-1
	LN3	High-performance low-noise surface using an approved mix design and thickness controls.	-3
	LN5	High-performance low-noise surface using an approved mix design and thickness controls.	-5

6.3 Guidance

The new surface corrections in Table 8 embody a recalibration of CRTN for the 2023 traffic fleet (in absolute terms) as well as quantifying the difference in acoustic performance between surface types (in relative terms).

6.3.1 Noise modelling

With this recalibration, the reference surface concept has been discarded[2]. The corrections now relate directly to CRTN's L_{A10} output. The -2 dB previously applied for the former NZ AC10 reference surface, and by extension all CRTN predictions, should no longer be applied.

The new corrections account for both light and heavy vehicles with a single correction value. The previous corrections required combining R_c and R_t correction values along with %HCV and speed, but this is no longer required.

The conversion from $L_{A10(18h)}$ to $L_{Aeq(24h)}$ is still required.

Users of noise modelling packages that implement CRTN (for example, SoundPLAN) would enter the applicable Table 8 values (and potentially $L_{A10(18h)}$ to $L_{Aeq(24h)}$ conversion) as appropriate for their software and modelling process.

The surface corrections include some allowance for surface variability and are based on each surface's 75th percentile noise level rather than its mean level. Therefore, on average, CRTN predictions made using the corrections should be 1-2 dB higher than the true mean level. This will need to be taken into account when comparing predictions to validation measurements. This conservative allowance does not represent a full accounting of prediction uncertainty.

6.3.2 Surface classifications

No distinction is made between single-coat and multi-coat chipseals in the new corrections. The lowest grade (i.e. largest chip size) present in the chipseal shall be used to determine its correction. For example, a *two-coat 3/5* surface requires the grade 3 correction of +6 dB, not the grade 5 correction.

The SMA10 classification includes all stone mastic asphalt (SMA) mixes with maximum aggregate size 11 mm and smaller, as well as any mix of ungrooved dense graded asphalt (DG) or asphaltic concrete (AC).

SMA14 includes all SMA mixes with maximum aggregate size 12 mm and larger, as well as slurry seal.

Unless explicitly an approved LN3 or LN5 surface, all porous asphalts use the PA correction.

The LN3 and LN5 high-performance low-noise surface classifications are only applicable when a surface has been or will be constructed with specific quality controls in place, as detailed in the appendix to the *Guide to assessing road-traffic noise*[21]. The low-noise properties of porous asphalt are sensitive to surface thickness, which is the focus of the controls.

Annex A: Measurements of $L_{Aeq(1h)}$ at former L_{AE} sites

The Part 2 report identified specific risks with the methodology regarding the equivalence of measured pass-by SEL and the SEL implicit within CRTN's equations (the reference SEL). This annex contains brief reporting of additional measurements performed to evaluate those risks. Refer to section 2 of this report for the background and outcomes of the analysis.

In March 2023, WSP performed noise and traffic monitoring at four sites[22] previously included in the 2022 SPB survey[2] and therefore with known SPB L_{AE} levels. Traffic volume, traffic mix, and $L_{Aeq(1h)}$ noise levels were measured at sites S1, S7, S8 (all 80 km/h speed limit) and The Esplanade (50 km/h speed limit).

Reuse of the same sites allows a direct test of the $L_{Aeq(1h)} = f(L_{AE,car}, L_{AE,truck})$ relationship (equation A.0 from the Part 2 report). Additionally, it is already known where these surfaces sit relative to the nominal correction value, which provides context for L_{Aeq} predictions made using the general surface corrections.

A.1 Survey site information

Summary data for the four sites are presented in Table 9. CPXP80 and pass-by SEL_{car} levels were measured in 2021[2]. The $L_{Aeq(T)}$ and $L_{Aeq(1h)}$ survey took place in 2023. No change in speed limit or resurfacing occurred at these sites between the surveys. The 2023 survey did not replicate all the 2021 locations precisely, but found acoustically-equivalent locations within 50 metres for all but the Te Marua site. The Te Marua sound level meter had to be moved across the road onto grass, requiring an extra correction for ground absorption to be applied.

Table 9: Noise monitoring data for the revisited SPB survey sites

Site name	**Site ID**	**Surface type**	**Speed limit** km/h	**Survey avg. speed** km/h	**Survey length, T** hours	**CPXP80** dB $L_{cpx:P1,80}$	**SEL_{car}** (meas.) dB L_{AE}	**SEL_{truck}** (calc) dB L_{AE}	**Survey level** dB $L_{Aeq(T)}$
Esplanade WB †	S11	AC-20	50	48.5	17	--	68.3†	79.8	64.1
Paekakariki SB	S7	PA-10	80	77.0	14	96.64	71.3	81.7	59.5
Eastern Hutt Road SB	S1	Chip 3/5	80	67.6	16	101.88	80.6	87.8	71.7
Te Marua NB *	S8	Chip 3/5	80	75.0*	11	101.22	82.3*	88.9	69.6

† SEL values for The Esplanade site represent 50 km/h vehicle pass-by speed (all others 75 km/h reference speed).
* SEL measurements on Te Marua were made 10 m east of the NB lane over tarmac, whereas the L_{Aeq} monitoring was performed 10 m west of the NB lane over grass. Speeds at this site were not measured so have been estimated.

A.2 Data

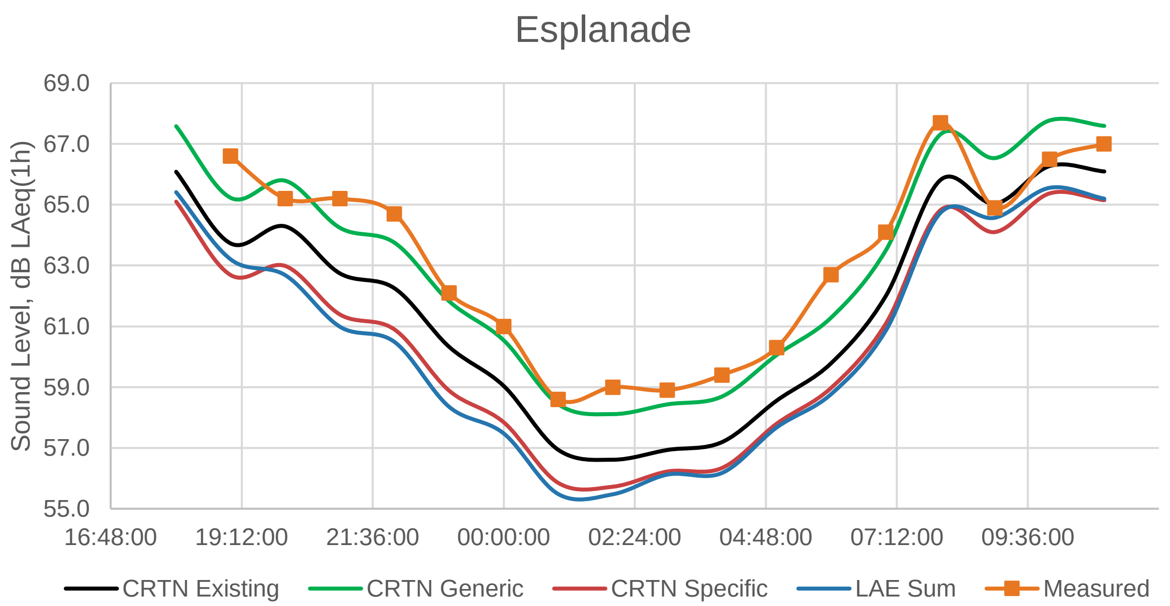
Four noise prediction methods have been employed for comparison with measurements (Table 10). Each method was used to predict $L_{Aeq(1h)}$ and $L_{Aeq(T)}$ for each site. Three of the prediction methods apply CRTN using various surface correction definitions, while the L_{AE} Sum method uses A.0 with site-specific L_{AE}. All predictions are based on the same measured light and heavy vehicle counts, or equivalently, total traffic count and percentage heavies. Where applicable the measured average traffic speed was used.

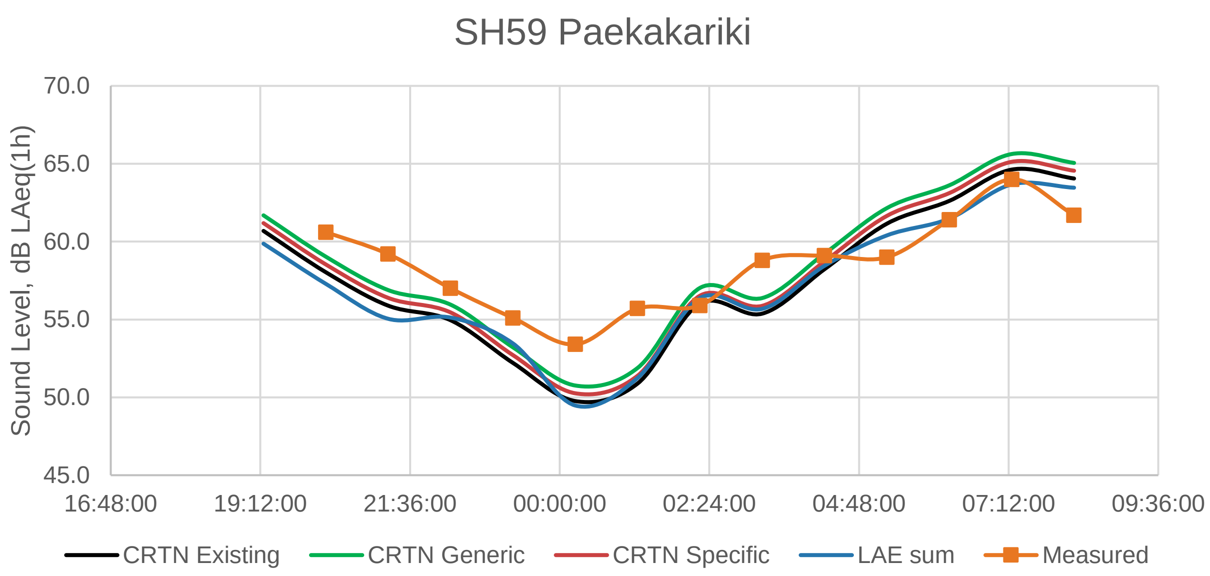
[22] van Hout, G (2023) *Hutt Valley Continuous Flow Traffic and Noise Measurements*, WSP230327-527858-GvH-M1

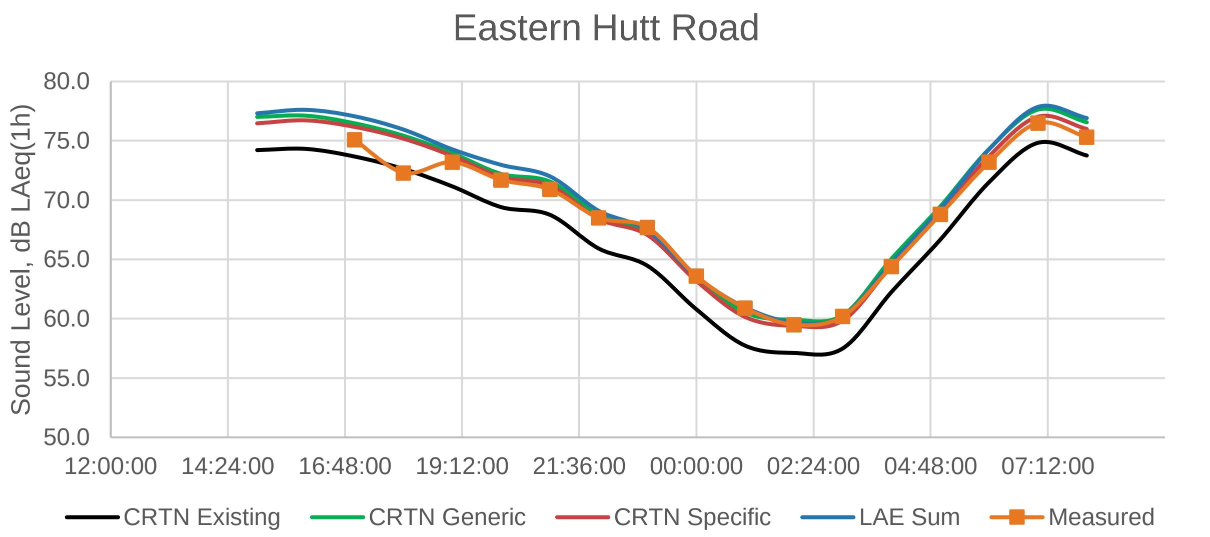
Table 10: Prediction or measurement methods

Label	Basis for prediction	Additional information
CRTN Existing	CRTN using existing corrections	Corrections from table 2.1 of the surface guide[12], including -2 dB NZ adjustment.
CRTN Generic	CRTN using the Part 2 report corrections	Corrections from Table 2 without rounding, with the 75th percentile overprediction removed.
CRTN Specific	CRTN using corrections derived from that site's measured pass-by L_{AE}	Corrections via Eq. 1 with R_c and R_t defined as the average site SEL (without correcting for ground absorption) minus the reference level.
L_{AE} Sum	Predicted from A.0 equation	Corrected for 2 lanes of traffic situated 10 m and 14.5 m away by subtraction of 0.58 dB following Part 2 eq. A.6. Assumes 75 km/h traffic (50 km/h on Esplanade) and cannot correct for deviations from this. Te Marua (only) has been corrected for ground absorption using CRTN's chart 7.
Measurement	Wayside measurement of $L_{Aeq(1h)}$	No corrections made.

The following figures show the hourly measurement data alongside the predicted levels for the four sites.







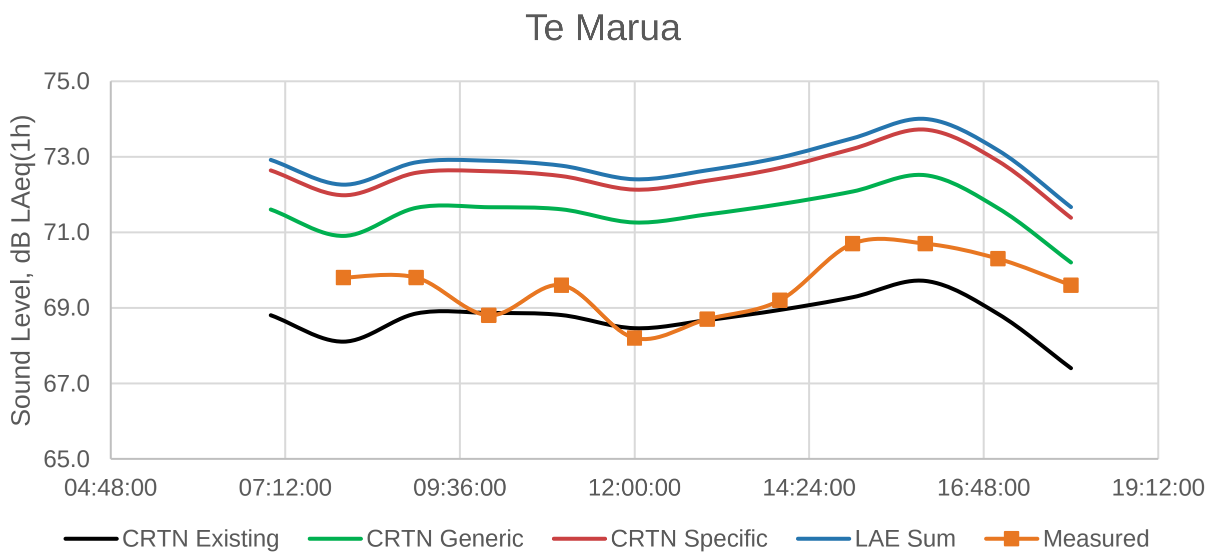


Figure 2: LAeq(1h) noise prediction and measurement at four sites

A.3 Error calculation

The four prediction methods were compared to measurement, and the error computed as *prediction minus measurement* (a positive error represents overprediction). Contributions to the error arise from both prediction and measurement terms. Table 11 provides the error in the average noise level $L_{Aeq(T)}$ over the full survey at each site, and Table 12 provides the error across all $L_{Aeq(1h)}$ predictions.

Higher level analyses of these data are provided in sections 2.4 to 2.7.

Table 11: $L_{Aeq(T)}$ prediction error of four methods, calculated as $L_{Aeq(T)}$ prediction minus $L_{Aeq(T)}$ measurement

Site Name	**Duration, T** Hours	**CRTN Existing** dB	**CRTN Generic** dB	**CRTN Specific** dB	**L_{AE} Sum** dB
Esplanade WB	17	-1.5	-0.2	-2.6	-2.6
Paekakariki SB	14	+0.1	+0.6	+0.6	-0.5
Eastern Hutt Road SB	16	-1.5	+1.1	+0.8	+1.6
Te Marua NB*	11	-0.9	+1.7	+2.9	+3.2
Weighted average	--	-1.0	+0.7	+0.2	+0.2

Table 12: $L_{Aeq(1h)}$ prediction error of four methods, calculated as $L_{Aeq(1h)}$ prediction minus $L_{Aeq(1h)}$ measurement, for q>50

$L_{Aeq(1h)}$ Error	**CRTN Existing** dB	**CRTN Generic** dB	**CRTN Specific** dB	**L_{AE} Sum** dB
Mean error	-1.35	+0.50	-0.09	-0.06
Standard deviation	1.3	1.4	2.5	2.7
Same size, *n*	49	49	49	49

Annex B: Summary of adjustments to SEL

A number of adjustments to the SEL values were applied to ensure the general applicability of the corrections, and to account for known sources of systematic error in the measurements, input data, or introduced by the methodology itself. For clarity, Table 13 lists all the adjustments made to the reference SELs, and Table 14 lists all the adjustments made to the surface SELs and the subsequent surface corrections.

It is noted that noise prediction is made for dry road surfaces only, with the $L_{Aeq(24h)}$ resulting from a CRTN-based prediction representing a typical dry day with "moderate adverse propagation" conditions, and not an annual average day. For a variety of practical reasons, this is the correct definition to maintain, and therefore no adjustment for climate is required.

Table 13: Adjustments made to reference SEL

Component	Details	Reference
Lane spacing	SEL methodology required mathematically combining two notional lanes of traffic to remain consistent with the CRTN definition of a road.	Part 2 Eq. A.6
Delta between light and heavy vehicles	The heavy vehicle reference has been redefined. It is now +9 dB relative to a light vehicle SEL of 75 dB L_{AE}. CRTN's implicit heavy vehicle SEL is 84.2 dB, but no adjustment for the -0.2 dB discrepancy was warranted or included (CRTN already contains rounding error in its chart 4 equation).	Part 3 §5.1
Non-homogeneous vehicle SELs	No modification of derivation, but the definition of L_{AE} in Part 2 Appendix A no longer assumes identical vehicle pass-by levels, it now represents a (measurable) logarithmic-average pass-by.	Section 2.1

Table 14: Adjustments made to measured SELs

Applied	Component	Details	Reference
Per vehicle	Ambient Temperature	CRTN does not consider the effect of temperature. For consistency between surveys, each pass-by SEL was adjusted by -0.05 dB/°C to a common 15 °C 'reference temperature'.	Part 2 §3.1
Per vehicle	Vehicle speed	SPB SELs were adjusted on a per vehicle basis to the CRTN reference speed of 75 km/h using the Chart 4 equation.	Part 2 §3.1.2
Per site	Ground Absorption	Each site SEL was adjusted using CRTN's Chart 7 to represent the reference condition of zero ground absorption.	Part 2 §3.1.5 Part 3 §4.2
Per surface type	Surface aging effect	Only adjusted when average sample age was not 4 ± 2 years old and when aging effect confirmed. SMA had its $L_{CPX:P1,80}$ level increased by 0.5 dB. No other surface required adjustment.	Part 1 §3.3.4
Per surface type	Variation within a surface specification	Variability of surface noise emission is significant and differs between surface types. This was managed by adopting the 75th percentile of each surface's CPX distribution as indicative, then propagating through to each surface's SEL.	Part 2 §4.1.3
Per surface type	Conversion from CPX to SEL	A piecewise-linear relationship was used to propagate $L_{CPX:P1,80}$ to L_{AE}, and by extension, $L_{Aeq(24h)}$.	Part 2 §3.3.4

Applied	Component	Details	Reference
Overall	Fleet composition (cars)	Passenger cars and LCVs (vans and utes) were characterised separately and combined by weighted average for their prevalence in the 2019 NZ fleet.	Part 2 §3.1.4
Overall	Posted speed limit (cars)	The posted speed limit typically overestimates the actual traffic speed by a few percent. SEL_{car} (representing a light vehicle travelling at 75 km/h) was adjusted by -0.62 dB to compensate. This effectively replaces CRTN's §14.2 speed classification.	Part 2 §3.1.3
Overall	Outliers (cars)	Atypically noisy vehicles were excluded from site averages and accounted for by a general adjustment of +0.43 dB.	Part 2 §3.1.5
Overall	Fleet composition (trucks)	MCV, HCVI, and HCVII classes were characterised separately and combined through a weighted average of their prevalence in the NZ fleet.	Part 3 §3.1.1
Overall	Traffic speed (trucks)	The posted speed limit typically overestimates the actual traffic speed by a few percent. SELs for the different heavy classes were adjusted to compensate. This effectively replaces CRTN's §14.2 speed classification.	Part 3 §3.1.2
Overall (excluded)	Outliers (trucks)	Outlying trucks were not defined and never excluded from site average, therefore no adjustment required.	--
Overall (excluded)	24-hour traffic parameters	Typical modelling practice is to use 24-hour traffic volume and mix data to populate CRTN's 18-hour parameters. This contributes about +0.3 dB on average and was not factored into the calibration.	Section 5.4.1
Overall	Consolidation of R_c and R_t	Corrections for light and heavy vehicles combined into single noise correction per surface type.	Section 3
Overall (excluded)	L_{A10} to $L_{Aeq(24h)}$ conversion is **not included**	The L_{AE}-based corrections do not include the conversion to $L_{Aeq(24h)}$, typically -3 dB. Core output of CRTN remains $L_{A10(1h)}$ or $L_{10(18h)}$ and will generally need correction.	--
Overall (excluded)	NZ adjustment is **not required**	Previously an adjustment of -2 dB was applied to all CRTN predictions, as a way to calibrate CRTN for the NZ reference surface. The updated calibration is now built into each surface correction and the -2 dB adjustment must not be applied.	Part 2 §2.2