A New Methodology for Deriving Road Surface Noise Corrections for Light Vehicles in New Zealand

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ABSTRACT

A novel methodology for deriving road surface noise corrections has been devised and implemented. It used a large CPX noise survey of the network to accurately classify the performance of different surface types. CPX levels were correlated against wayside single vehicle pass-by levels and a CPX-wayside transfer function derived. A requirement to replace the current 'calibrated reference surface' concept meant that a new reference system was derived, with the new surface corrections being relative to the CRTN noise model's reference condition. The method also recalibrates CRTN for the 2022 NZ light vehicle fleet against this new reference system.

INTRODUCTION

At highway speeds, most road traffic noise is generated at the tyre/road interface. The type, or "specification", of road surface has a very large effect on the level of road traffic noise emission (>12 dB range between noisiest and quietest NZ surfaces), and surface selection is the first consideration when providing noise mitigation for road improvement projects.

Road surface noise corrections ("surface corrections", in dB) are used by noise modellers to quantify the influence of different surface specifications on road traffic noise emission. Besides being necessary for accurate prediction of noise levels, the surface corrections are essential to selecting the appropriate surface specification for a given noise mitigation requirement.

The existing NZ road surface corrections table [1] is based on measurements performed 20-30 years ago [2,3]. Since then NZ's surfaces and vehicle fleet have changed, and the existing asphalt reference surface (AC-10) has become functionally extinct on high-speed roads.

Rather than substitute a different surface type for AC-10, Waka Kotahi NZ Transport Agency required that a new system of reference was developed, eschewing the reference surface[1] concept entirely. As well as deriving a new set of surface corrections in a relative sense, the project would also effectively recalibrate the Calculation of Road Traffic Noise (CRTN) noise model algorithms for NZ in 2022 in absolute terms.

This paper summarises a novel and efficient methodology that is currently being used to derive new surface corrections for NZ surfaces for the 2022 light vehicle fleet. The results of the research will be shared separately, once finalised.

[1] In the existing system, the surface corrections for each surface type are stated relative to AC-10. The noise emission for AC-10 is known in absolute terms.

METHODOLOGY

A schematic overview of the methodology is provided in Figure 1. The methodology may be understood as consisting of several interacting steps:

1. Perform a large close-proximity (CPX) noise survey of NZ state highways.
2. Assign an indicative CPX noise level (in dB $L_{\mathrm{CPX:P1,80}}$) to each different surface type.
3. Find the relationship between $L_{\mathrm{CPX:P1,80}}$ and the effect on the wayside level, using paired measurements of CPX and single-vehicle pass-by L_{AE} levels at many different sites under CRTN reference conditions.
4. Propagate the $L_{\mathrm{CPX:P1,80}}$ for each surface through the relationship to find its equivalent wayside L_{AE} level.
5. Reverse-engineer CRTN to extract its implicit L_{AE} level for a light vehicle under CRTN reference conditions. This forms the new reference for the NZ surface corrections.
6. Compute draft surface corrections relative to CRTN reference conditions: the difference between the derived L_{AE} for a surface and CRTN's implicit light vehicle L_{AE}.
7. Rationalise surface types into a draft surface corrections table.

Each of these numbered steps is described further below.

Large CPX Survey

Waka Kotahi operates a CPX noise measurement trailer [4], which was designed and constructed to comply with ISO 11819-2 [5].

The methodology leveraged the CPX measurement approach to provide an efficient and accurate sampling of tyre/road noise emission of 55,000 road segments across

NZ, representing 1100 lane-km of state highway. The nominal surface specification, taken from the RAMM database [6], was linked to each 20-metre long segment. A visual sanity check was performed using on-road photography [7] and a surface age filter of 6-months to 10-years old was applied. The resulting CPX dataset contained 34,000 measured $L_{CPX:P1,80}$ levels associated with 44 distinct surface specifications.

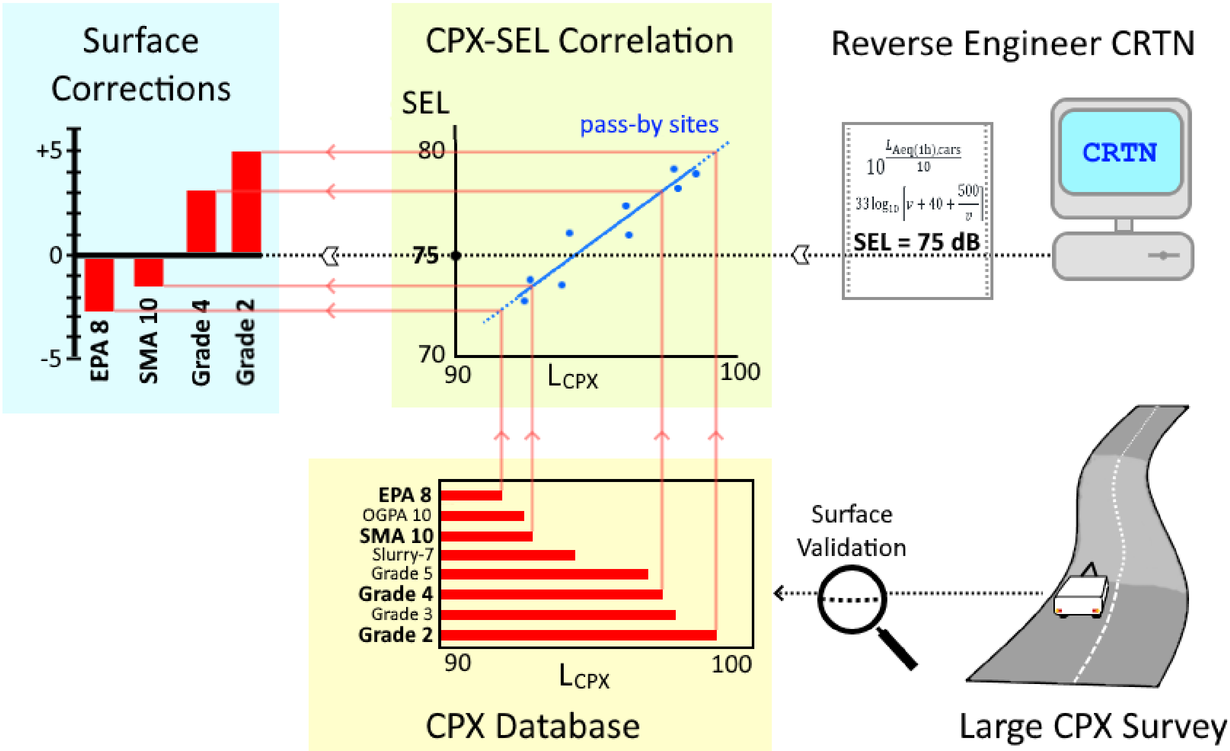

Figure 1. Schematic visualisation of methodology, read from right to left (numbers are examples for sake of illustration only)

Indicative $L_{CPX:P1,80}$ noise levels for surfaces

Within each distinct surface specification there was a distribution of $L_{CPX:P1,80}$ levels, resulting mostly from the intrinsic variation in materials, construction, traffic, age, climate, and other factors that occur between different road segments of nomially the same specification. Generally, chipseals and SMA had the least spread (sd ≤ 0.8 dB) and porous asphalts the most (sd ≥ 1.6 dB).

Surface thickness is known to affect the acoustic performance of porous asphalt [8] but is not reliably recorded within RAMM so its contribution to the observed variability could not be quantified. Where an aging effect was statistically significant for a specification, its noise levels were normalised to a standard age of 4 years.

It was determined that the unequal variances between surface specifications meant the arithmetic mean was not a conservative estimate of surface performance in relative terms, so the 75th percentile CPX level in dB LCPX:P1,80 for each specification was taken as indicative.

Relationship between $L_{CPX:P1,80}$ and wayside L_{AE}

Sound exposure level (SEL) measurements were made at the wayside during pass-by of more than 500 individual vehicles from the NZ light vehicle fleet across 19 different sites. Effort was made to match as close as possible to CRTN reference conditions: 10 metres from the edgeline, 1.2 metres high, 75 km/h vehicle speed, a long straight and flat road, no nearby reflecting surfaces, no ground absorption, no surface anomalies, and in dry calm weather. The 19 sites were as equivalent as practicable in all respects other than the road surface, with residual differences being corrected using CRTNs own corrections where possible (e.g. speed, temperature, ground absorption). Controlled pass-by of a test vehicle was used at 9 sites instead of fleet measurements, after characterising it against the fleet average at 6 other sites.

Single vehicle SEL measurements were required by the methodology (see step 6 above) but acoustically isolating individual vehicle pass-bys from other vehicles and background noise proved impossible during the daytime, so all SEL measurements were undertaken late at night or early morning. The effects of vehicle mix (cars, utes, vans) and outliers were accounted for, and an average pass-by level in dB L_{AE} was computed for each site.

Measurements of $L_{CPX:P1,80}$ were also made adjacent each pass-by site, using the Waka Kotahi CPX trailer. The CPX measurements were weighted according to their proximity to the pass-by measurement site (i.e. by the contribution each 20-metre segment of road made to the pass-by level).

A weighted least-squares linear regression of SEL on CPX was performed, provisionally resulting in separate linear relationships for porous and non-porous surface types (not indicated by Figure 1).

Find equivalent wayside L_{AE} levels for surfaces

The resulting linear equations were used to transform the indicative CPX levels in dB $L_{CPX:P1,80}$ for each surface specification into indicative wayside SELs in dB L_{AE}, assuming CRTN reference conditions. The porous surfaces indicated a lower wayside level for the same input $L_{CPX:P1,80}$ level compared to the non-porous surfaces. The mechanism behind the propagation difference is hypothesised to be a combination of acoustic absorption and directivity effects, but does not need to be fully understood in order determine the surface corrections themselves.

Extract CRTN's implicit light vehicle SEL

The CRTN noise model [9] was originally developed from full traffic flows [10] rather than individual pass-by measurements, but its equations can be viewed as multiplying implicit per-vehicle SELs by the number of vehicles over time to predict traffic noise levels.

A full derivation will be presented within a future publication [11] but for light vehicles the implicit SEL can be quickly approximated using CRTN's chart 2 equation for traffic noise, in dB $L_{10(1h)}$, from a traffic flow of q vehicles per hour, under reference conditions,

$$L_{\mathrm{A10(1h)}} = 42.2 + 10\log_{10}[q] \tag{1}$$

Applying a small additional approximation to the broadly used $L_{Aeq(24h)} \approx L_{A10(18h)} - 3$ dB for traffic, this becomes

$$L_{\mathrm{Aeq(1h)}} = 39.2 + 10\log_{10}[q] \tag{2}$$

Generally, the equivalent sound level, L_{Aeq}, from n events all having the same sound exposure level, L_{AE}, over a period of time, T, in seconds is given by,

$$L_{\mathrm{Aeq(T)}} = 10\log_{10}\left[n\,10^{\frac{L_{\mathrm{AE}}}{10}}/T\right] \tag{3}$$

For 1 hour, n and q are equivalent (number of events), and T = 3600 s. Equating (2) and (3) gives,

$$10\log_{10}\left[q10^{\frac{L_{\mathrm{AE}}}{10}}/3600\right] = 39.2 + 10\log_{10}[q] \tag{4}$$

Solving for L_{AE} gives the implicit SEL for light vehicles under CRTN reference conditions,

$$L_{AE,car,CRTN} \approx 75\ dB \tag{5}$$

The value in equation (5) underpins the new reference system. Rather than being relative to an intermediary reference surface (AC-10 or otherwise), under this reference system surface corrections would be directly relative to CRTN in its refence condition. The existing "NZ adjustment" of -2 dB between CRTN and AC-10 [1] that works as an absolute calibration would no longer be applied, as the absolute calibration would form part of each surface correction.

There are risks in adopting this approach, particularly in terms of the absolute calibration. As a model with empirical roots, it is not known what other effects (or in this application: errors) have been 'baked-in' to CRTN's implicit SEL under reference conditions in order that the model performs well across all situations and conditions. It is known that many compromises and simplifications were made to the model [10]. Notwithstanding the risk, assuming equivalence between the implicit SEL and measured single vehicle pass-by SELs provides a very efficient means of 'recalibrating' the CRTN noise model for NZ in 2022 compared to relying on long-term measurements of traffic streams over multiple examples of the reference surface, as was necessary previously [3].

Compute and rationalise surface corrections

An initial set of draft surface corrections were computed as the difference between the equivalent wayside L_{AE} levels for each surface and the implicit CRTN L_{AE} given by equation (5).

Findings from the CPX survey [12] were that many materially or structurally similar surface specifications also had similar acoustic performance, particularly within the population of chipseals. With consideration of the overall uncertainty of CRTN prediction, the 44 distinct surface specifications were reduced down to an initial set of 8 broad surface classifications, most of which encompassed multiple specifications. The 8 classifications – 3 chipseals and 5 asphalts – collectively represent 95% of the surfaces on the NZ state highway network by length. Supplementary written guidance would enable practitioners to assign any remaining uncommon surface types to one of the 8 classifications. Further rationalisation of surfaces may yet occur.

A draft table of surface corrections was developed based on the 8 surface classifications, with corrections rounded to the nearest 1 dB.

CONCLUSION

A novel methodology for deriving surface corrections has been devised and implemented using both CPX and wayside noise measurements. As required, it has replaced the 'calibrated reference surface' concept by linking surface corrections directly to CRTN. Therefore, by necessity it also recalibrates CRTN for the 2022 NZ light vehicle fleet (the previous calibration being based on the outgoing AC-10 reference surface).

The new method has proved very efficient, with significantly reduced time and cost to repopulate the surface corrections table and recalibrate CRTN compared to the previous methods used.

The accuracy of the approach has not yet been formally validated. The expectation is that the risk is mainly associated with the absolute level of the corrections (the recalibration aspect), while significant benefits to the relative accuracy between surfaces is expected, because the performance of each surface type now derives from a very large survey of surfaces rather than a handful of examples.

At the time of writing, the main body of research is complete, and detailed research reports have been produced, pending publication [11,12,13]. If validated and ratified, the new surface correction table will be published on the Waka Kotahi website.

ACKNOWLEGMENTS

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