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Road Surface Noise Corrections

Part 3: Heavy Vehicles

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This report ('Report') has been prepared by WSP exclusively for Waka Kotahi NZ Transport Agency ('Client') in relation to refreshing the heavy vehicle surface corrections data in the *NZ Road Surface Adjustments Table* ('Purpose') and in accordance with the Acoustics and Environmental Professional Services Contract Number 6026 dated 14 February 2022 and variation dated 13 May 2022. The findings in this Report are based on and are subject to the assumptions specified in "WSP road surface noise research FY22H2 proposal 20220126" provided by email on 26 January 2022 and the subsequent discussions and emails with Waka Kotahi, including after commencement of the work. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

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Contents

Abbreviations and Definitions

AC	Asphaltic Concrete
A-weighting	Frequency weighting of noise that mimics human sensitivity to frequency
Chipseal	Road surface whose running surface is stones (chip) embedded in binder
Corr.	Correction
CPB	Controlled Pass-by, a pass-by noise measurement of a test vehicle
CPX	Close-proximity Measurement (of noise level)
CPXP_{80}	CPX level, using the P1 (car) tyre carried out at a nominal speed of 80 km/h
CRTN	Calculation of Road Traffic Noise (a noise model)
HCV	Heavy Commercial Vehicle, with subclasses HCV I and HCV II
Heavy Vehicles	Includes trucks and buses (MCV, HCV I and HCV II classes)
%HCV	the percentage of heavy vehicles within a given traffic flow/volume.
k	Statistical coverage factor for a desired level of confidence, e.g. k=2 is 95%
L_{A10}	The A-weighted sound level exceeded for 10% of the measurement time
$L_{\mathrm{Aeq(t)}}$	A-weighted energy equivalent sound pressure level over time period, *t*
L_{AE}	A-weighted sound exposure level (the suffix notation for SEL)
L_{Amax}	A-weighted maximum sound pressure level
$L_{\mathrm{CPX:P1,80}}$	CPX level, equivalent to CPXP_{80}. Alternative notation used as a suffix to dB.
L_{veh}	Vehicle sound level from a Statistical Pass-by survey [ISO 11819-1:1997]
Light Vehicles	Includes cars, light vans, and utes (PC and LCV classes).
LCV	Light Commercial Vehicle
Mobile Road	Web-based portal to selected RAMM data (https://mobileroad.org/)
MCV	Medium Commercial Vehicle
NZ	New Zealand
NZ Adjustment	An adjustment to localise CRTN to NZ reference conditions (surface, fleet)
OGPA	Open-grade Porous Asphalt, a low noise NZ road surface
Pass-by noise	The noise at the roadside as a single vehicle drives by (see SPB & CPB)
PC	Passenger Car
RAMM	Road Assessment and Maintenance Management (software and database)
*R*c, *R*t	Surface adjustment values in dB for cars and trucks respectively [NZTA, 2014]
sd	Standard deviation
SEL	Sound Exposure Level (in dB L_{AE}) includes all sound energy of an event
SLM	Sound Level Meter
SH	NZ State Highway
SMA	Stone Mastic Asphalt (appearance like OGPA without pores)
SPB	Statistical Pass-by, noise measurements of many (individual) fleet vehicles
Surface Correction	An addition to CRTN noise level to account for surface characteristics
Surface Specification	The nominal materials, processes, and chip sizes for a surface (see below)
TMS	Traffic Monitoring System, managed by Waka Kotahi
tyre/road noise	The noise generated by the interaction of a tyre with the road surface
vkt	Vehicle Kilometres Travelled
Waka Kotahi	NZ Transport Agency (formerly NZTA)

Surface Specification

Each named road surface type in NZ has a published NZTA specification that dictates what materials, properties, and other construction parameters it can have. However, references to a “surface specification” in this report indicate a particular and distinct set of surface material, chip/aggregate size(s), construction process, and in some cases surface thickness. Generally, this is a subset of the published NZTA specification (each of which cover a range of aggregate sizes). The *surf_material*, *chip_size*, and *chip_2nd_size* parameters are readily available from Mobile Road for existing roads, and from project engineering teams for proposed roads, so are appropriate and accessible parameters for defining a road surface specification as it relates to noise. There is evidence that variation in void content and surface thickness [Bull et al, 2021] are relevant to the performance of porous asphalts, but RAMM does not hold void data and it includes thickness data inconsistently (and not via Mobile Road). In this report, when a porous asphalt specification also considers its thickness, that will be explicitly stated (in mm). If no thickness is stated then that specification is defined without consideration of thickness.

1 Introduction

1.1 Background

Road traffic noise is an inevitable by-product of traffic on NZ's state highway network. Heavy vehicles (which include buses and trucks but not utes and vans), contribute noise primarily from the engine, exhaust, and the tyre/road interaction. The level of tyre/road noise depends on the surface type (e.g. chipseal or asphalt). Overall, the noise emission from heavy vehicles is far less sensitive to the surface characteristics than for light vehicles [Jackett et al, 2020], but it is still a significant factor.

The road surface noise corrections (or just "surface corrections") are a set of noise level corrections (in dB) that facilitate accurate prediction of the noise emitted by roads with specific surfaces [NZTA, 2014]. The surface corrections were last derived in the 1990s and early 2000s [Barnes & Ensor, 1994; Dravitzki & Kvatch, 2007], and since then both tyre technology and NZ's surface specifications have evolved.

Currently light and heavy vehicles have separate surface corrections. Reports for Part 1 and 2 of this research proposed corrections for light vehicles [Jackett, 2021; Jackett et al, 2022]. This Part 3 report proposes corrections for heavy vehicles.

1.2 Purpose, Scope, and Objectives

Waka Kotahi NZ Transport Agency requires that the noise corrections for road surfaces in table 2.1 of the *Guide to state highway road surface noise* [NZTA, 2014] are updated to reflect the surfaces currently laid on the state highway network [NZTA NV5, 2020]. The corrections were previously specified in relation to a reference surface, asphalt AC-10, but Waka Kotahi required that a new reference was found, in part because AC-10 is being phased-out on state highways. The Part 2 report presents and implements a new process for using measured statistical pass-by (SPB) sound exposure levels (SEL) as a reference back to implicit CRTN vehicle parameters [Jackett et al, 2022], entirely removing the requirement for a reference surface. A similar process was required for heavy vehicles in the absence of a reference surface.

A key difference is that, whereas light vehicle noise is characterised almost entirely by the tyre/road noise emission, heavy vehicles require both the tyre/road and engine/exhaust contribution to be captured.

The objectives for this report are therefore:

1. Define a new system of reference back to CRTN that is achievable and consistent with the system used for light vehicles.
2. Determine a method of quantifying the overall noise emission of heavy vehicles (including the engine, exhaust, and tyre/road noise).
3. Sample and characterise the noise emission of the 2022 NZ heavy vehicle fleet, and use this to scale the absolute heavy vehicle level of the CRTN noise prediction model. This is equivalent to a re-calibration of CRTN for modern NZ conditions, last performed by Barnes & Ensor in 1994 (i.e. the "NZ Adjustment") using a different methodology.
4. Determine the relative performance of NZ road surfaces types (the surface corrections) for heavy vehicle noise, including the unaffected contribution from engine and exhaust. This is equivalent to updating the existing table of surface corrections.
5. Integrate these heavy vehicle corrections with those found for light vehicles in Part 2 of the research project.

Waka Kotahi has recognised that with the new corrections urgently required, and the budget and timeline constrained, an increased level of uncertainty and risk is expected. We have therefore devised a novel methodology that is highly efficient and does not rely upon the traditional reference surface concept used up until now. However, it is an unproven methodology and the results will require review and validation.

The final set of surface corrections will be published separately by Waka Kotahi, following a review and ratification process.

1.3 Project Structure

The project consists of three main parts, which have been reported on separately over the last year:

Part 1 determined the light vehicle tyre/road noise differences between 39 NZ road surface specifications using CPX noise data collected on state highways across 5 regions of NZ. The report for Part 1 [Jackett, 2021], was completed in September 2021.

Part 2 related the CPX levels found in Part 1 back to the CRTN noise model. It detailed the replacement of the reference surface and recalibration of CRTN for the 2021 light vehicle fleet. The core output of that work was a table of draft surface corrections direct to CRTN for cars. The draft report for Part 2 [Jackett et al, 2022] was completed in November 2021, and updated with additional CPB data in June 2022.

Part 3 adapts the part 2 methodology to apply to heavy vehicles. Its core output is a table of draft surface corrections direct to CRTN for heavy vehicles.

This report covers Part 3 of the project only. Within it, regular reference will be made to results in the Part 1 and Part 2 reports, and to an earlier desktop study of heavy vehicle noise [Jackett et al, 2020].

Collectively these reports describe WSP's research findings and recommendations. The research outputs should not be interpreted as guidance for practitioners or applied to projects in advance of review and ratification by Waka Kotahi. If Waka Kotahi elects to update the surface corrections that will be communicated separately.

2 Methodology

2.1 Overview

The methodology for heavy vehicles differs somewhat from the methodology for light vehicles in Part 2, primarily because the CPX trailer is not able to approximate the heavy vehicle noise emission as it does for light vehicles[1]. Instead, it relies entirely on heavy vehicle pass-by noise measurements made at the wayside, which are sensitive to engine, exhaust, and tyre/road noise.

The pass-by measurements of Sound Exposure Level (SEL) include both:

- Statistical Pass-by (SPB) of many 'random' fleet vehicles passing by a measurement site to characterise the NZ heavy vehicle fleet; and,
- Controlled Pass-by (CPB) of a test truck to efficiently quantify different sites and surfaces.

Some additional modelling has been used to extrapolate surface performance for different sized trucks based on the single test truck, an MCV as it was not possible to run an HCV test truck.

A single SEL value for the 'standard' heavy vehicle was derived by a weighted combination of MCV, HCV I, and HCV II vehicle classes, based on their respective vkt on NZ state highways.

In common with the Part 2 methodology, the pass-by noise measurements (of SEL) are related to CRTN without the use of an intermediate reference surface. This was achieved by extracting the implicit per-vehicle SEL that CRTN uses when it calculates noise levels from a stream of traffic under its reference conditions (75 km/h, 10 m from the edgeline, flat and straight road, etc). The difference in SEL between heavy vehicles and light vehicles was determined and related to CRTN via the known (measured) light vehicle SEL from Part 2.

A more detailed explanation of the CRTN analysis and pass-by measurement methodology are available in the Part 2 report [Jackett et al, 2022]. This chapter will focus on the elements specific to determining the heavy vehicle surface corrections.

2.2 Changes to original methodology

The methodology for this project has evolved significantly in response to early findings. In practice, the originally planned SPB measurements proved to be very time consuming (in terms of both survey and processing time) and problematic with regards to the health and safety framework. In an attempt to achieve the desired project outcomes within the project budget and timeframe, with the agreement of Waka Kotahi the methodology changed to:

1. Use CPB measurements wherever possible, which take a fraction of the time per site and can be performed without needing to approach the live lane on foot.
2. Find the difference in SPB level between heavy vehicles and light vehicles on the old CRTN reference surface, AC, and use that to relate back to CRTN, rather than a direct method, which would require heavy vehicle SPB to be determined at multiple sites.

These changes allowed the general methodology to remain viable but had a moderate negative impact on the uncertainty of the heavy vehicle surface corrections. Mostly that relates to having to rely on the delta between heavy and light vehicles at one SPB site to set the absolute level of heavy vehicle noise.

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[1] It is not known whether the CPX H1 tyre is representative of truck tyre/road noise emission in NZ [Jackett, 2019a], nor is truck noise emission dominated by tyre/road noise at highway speeds (in contrast to car noise).

The more CPB-centric method was beneficial for quantifying the relative difference between surfaces for the MCV class. Ideally an HCV test vehicle would also have been used but this was not possible due to practical limitations.

Overall, the results from this study are likely to approximate the heavy vehicle contribution but should be validated before being applied.

2.3 Statistical Pass-By Measurement

2.3.1 Vehicle SEL and speed measurement

At each site a tripod-mounted sound level meter was placed 10-metres from the lane nearside edge, and 1.2-metres above the road surface.

Vehicle pass-bys were measured using a calibrated SLM [B&K 2250 SN:3027649]. A series of 100-millisecond A-weighted equivalent continuous sound pressure levels, $L_{\mathrm{Aeq(100\ ms)}}$ were captured from which the pass-by SEL was computed in post-processing (see section 2.5). The average duration of a heavy vehicle pass-by measurement was about 6 seconds, after isolating the event.

The acoustic measurements were supplemented by video footage at 1080p and 60fps from a GoPro Hero 5. For each pass-by, the vehicle's class, approximate length, axle count, axle configuration, and a still image in profile were recorded. The vehicle's average speed was determined by manually timing the vehicle's transit time (to the nearest video frame) between two pre-determined points 20-metres apart, after accounting for lens distortion.

2.3.2 SPB site

Because CRTN combines %HCV and speed corrections into one equation, it is necessary to introduce these "chart 4 corrections" for heavy vehicles (whereas it was intentionally avoided in the light vehicle methodology). With chart 4 now required anyway, measurement speeds other than the reference speed of 75 km/h are viable. This removes a big practical constraint on SPB site selection.

SPB site requirements:

- Flat geometry, safe access, and calm environmental conditions, as described in Appendix C.1 of the Part 2 report.
- A high %HCV to maximise the rate of sample capture / minimise time on site.
- The specific road surface being representative of its type and free from significant damage and discontinuities, by visual inspection.
- At any posted speed limit between 50 km/h and 100 km/h, but without acceleration/deceleration.

Due to time restrictions and the change from a mainly SPB-based methodology to a mainly CPB-based methodology, only two SPB sites were visited, and only one produced usable data: the Esplanade in Lower Hutt (see Table 2-1). However, that site was of good quality: a flat straight 50 km/h section of divided carriageway with a wide berm and AC-20 surface. This surface type proved helpful to the project because it is very similar to CRTN's dense graded asphalt reference surface. In practice, heavy vehicles generally travelled in the 50-60 km/h speed range at this site: the average speed was 55 km/h.

2.3.3 SPB Vehicles

Qualifying vehicle classes were MCV, HCV I, or HCV II. Heavy vehicle passes were generally much louder than the ambient traffic noise and could be captured with acceptable accuracy without needing night-time measurements. In some circumstances where a passing light vehicle also contributed to the measured SEL, its contribution was removed by subtracting a nominal light vehicle SEL (based on an average from the same site). This allowed a much higher rate of heavy vehicle passes to be captured, without significantly impacting accuracy.

2.4 Controlled Pass-By Measurement

2.4.1 Vehicle SEL and speed measurement

The noise measurement and calculation of SEL was identical to the process used for the SPB measurements. The average duration of a heavy vehicle CPB measurement was about 20 seconds, after isolating the event.

The test vehicle was an unladen MCV-class 6.5 t Isuzu box truck (Figure 2-1).

The test vehicle was additionally fitted with a measurement microphone 100 mm ahead of the left rear outer tyre at axle height. This system logged $L_{Aeq(1s)}$ for the duration of the survey, which were subsequently synchronised with site pass-by times to provide an additional 'quasi-CPX' level at each site for informational purposes.

The target speed of the MCV test vehicle past each measurement site was determined by GPS speedometer and managed by the driver (no cruise control was available).

Where the posted speed limit allowed, a constant speed of 75 km/h was maintained past each survey site, and at 50 km/h past the Esplanade SPB site. Three passes were completed at each site, and once invalid measurements had been removed (interference from other traffic, etc), an arithmetic average of the SELs was corrected for temperature and ground absorption, and taken as the representative test vehicle SEL for that site.

Figure 2-1: MCV test vehicle (6.5t Isuzu box truck)

2.4.2 CPB sites

Because there is full control over the test vehicle speed, and no requirement to capture vehicles from within the traffic stream, site requirements for CPB are less onerous than those for SPB.

CPB site requirements:

- Flat geometry, safe access, and calm environmental conditions, as described in Appendix C.1 of the Part 2 report.

- The specific road surface being representative of its type and free from significant damage and discontinuities, by visual inspection.
- At any posted speed limit between 50 km/h and 100 km/h, but 80 km/h or higher preferred, to allow pass-by at 75 km/h.
- Sites chosen to include the surfaces AC, OGPA, SMA, a coarse chipseal (e.g. grade 2 or 3), a fine chipseal (e.g. grade 4 or 5).

Eleven sites were surveyed, covering all of the target surface types (Table 2-1). Visual inspection of the voidfill (VFILL 5) surfaces indicated similarity to a fine single coat chipseal (e.g. 1CHIP 5), which is consistent with general findings from the Part 1 report. The 2CHIP and RACK surfaces in the table are coarse chipseals. Four OGPA surfaces were surveyed (PA), and one each of SMA and AC.

Table 2-1: Controlled Pass-by sites

Site Name	Surface	Surface Date	Survey RP	Lane	n (valid)
SH2 NB Grounsel SMA	SMA 15	2017	002-0962-D/5.901	NB, left	1
SH2 NB Grounsel OGPA	PA 10	2015	002-0962-D/5.229	NB, left	3
SH2 NB Whakatikei	PA 10	2017	002-0946-B/7.556	NB	3
SH2 NB Maidstone	PA 15	2017	002-0946-B/6.641	NB	3
SH2 NB Totara Park	PA 10	2014	002-0946-B/5.358	NB	3
SH2 Te Marua NB	2CHIP 3/5	2009	002-0931-B/13.278	NB	2
SH2 Kaitoke NB 1	2CHIP 2/4	2016	002-0931-B/6.814	NB	3
SH2 Kaitoke Farm NB	RACK 2/4	2018	002-0931-B/8.509	NB	3
SH2 Birchville NB	VFILL 5	2017	002-0946-B/1.400	NB	3
SH2 Birchville SB	VFILL 5	2017	002-0946-B/1.400	SB	1
Esplanade WB *50 km/h*	AC 20	2011	The Esplanade Sth/2.150	WB	4

2.5 Post-Processing

2.5.1 Calculation of SEL

The SLM measurement data was extracted and post-processed using MATLAB software.

For each pass-by, the time series was plotted and the pass-by event was manually selected. Included $L_{Aeq(100\text{ ms})}$ levels were first converted to units of sound pressure, then combined into an SEL for the event using,

$$SEL = 10\log_{10}\left[\int_0^T \frac{p^2(t)}{p_0^2}\,dt\right] \qquad (2.1)$$

where:
T = the pass-by duration,
p = the measured sound pressures in Pascals, and
p_0 = the reference sound pressure level, 20e-6 Pa.

Equation (2.1) follows from the general definition of SEL, with the requirement that $p(t) \rightarrow minimum$ as $t \rightarrow 0$ and $t \rightarrow \infty$, which is to say that the measurement period captured almost all of the sound energy of the pass-by. In practice this occurs at a level about -15 dB below the pass-by peak level.

CRTN's speed correction algorithm in chart 4 was then used to calculate a correction back to the reference speed of 75 km/h, and this was applied to each SPB event SEL. The CPB event SEL was directly measured at 75 km/h and did not require correction.

The average SEL for each site and vehicle class was calculated using logarithmic average for SPB (c.f. a traffic flow consisting of dissimilar vehicles) and an arithmetic average for CPB (c.f. repeated measurements of the same quantity). The site averages were corrected for ambient temperature back to a reference of 15°C using a coefficient of -0.05 dB/°C. Note that CRTN has no reference temperature, so 15°C was chosen for this data as it did not cause a large magnitude of correction from most of the survey temperatures and is reasonable as an 'average' year-round temperature for NZ. CRTN's chart 8 was used to correct the average SELs for the effect of ground absorption on site, to the reference condition of no ground absorption.

2.5.2 Translation between CPB and SPB

To find the relationship between the CPB and SPB measurements, five CPB measurements of the test vehicle were made at the SPB site. The CPB measurements were made under reasonably similar conditions to those during the SPB survey, such as the presence of other nearby light vehicle traffic, and a relatively short event duration of 6 seconds on average. The test vehicle SEL was compared to the average MCV class SEL from the SPB survey (n=15), both adjusted to 75 km/h using CRTN chart 4 and corrected for ambient temperature, which resulted in a translation factor of +2.25 dB. That is, the average fleet MCV (in a logarithmic sense) has an SEL that is 2.25 dB higher than the test vehicle under the same conditions.

2.6 Reframe CRTN in Terms of Vehicle SEL

The Sound Exposure Level (SEL) of a vehicle pass-by is a measure of its total sound energy emission (expressed as a sound pressure level in dB L_{AE}). The derivation in Appendix A of the Part 2 report demonstrates that CRTN's noise calculation for a traffic flow can be expressed as a function of light vehicle and heavy vehicle SELs. We refer to these as *CRTN's implicit SELs*. "Implicit" because the CRTN model was originally developed from full traffic flows [Delany et al, 1976] rather than individual pass-by measurements.

The analytically derived CRTN implicit SELs for light vehicles and heavy vehicles are:

$$L_{\mathrm{AE,car}} = 75.3\ \mathrm{dB} \tag{2.2}$$

$$L_{\mathrm{AE,truck}} = 84.2\ \mathrm{dB} \tag{2.3}$$

The SELs above form the baseline for CRTN predictions under reference conditions, to be scaled by traffic volume.

CRTN's implicit delta between light and heavy vehicles SEL under reference conditions is therefore:

$$\Delta L_{\mathrm{AE,CRTN}} = 84.2\ \mathrm{dB} - 75.3\ \mathrm{dB} = 8.9\ \mathrm{dB} \tag{2.4}$$

This delta can be measured in the field, and the link between CRTN and heavy vehicle levels can be completed using the $L_{\mathrm{AE,car}}$ values determined in Part 2.

3 NZ Heavy Vehicle Fleet

The CRTN surface correction, and the majority of NZ traffic volume projections, group all heavy vehicle classifications together and express this as a percentage, %HCV, of the total traffic volume, AADT.

However, contained within the %HCV metric are vehicles ranging from 2-axle 3.5 tonne trucks to 9-axle 60 tonne trucks, having vastly different noise emissions.

To ensure that the appropriate balance between classes is achieved, average SELs for each class have been determined separately and combined by weighted average (section 3.2), following the characteristics of the NZ heavy vehicle fleet.

3.1 Class Distribution

3.1.1 Traffic Volume

The percentage of vehicle-kilometres travelled (vkt) by each vehicle class on NZ state highways has been approximated using recent Waka Kotahi vkt breakdowns[2,3] and TMS data[4]. The NZ light/heavy vkt split[2] on state highways was enhanced for light vehicle[3] and heavy vehicle[4] sub-classifications to achieve the required level of granularity.

Table 3-1: Vehicle classifications by their contribution to total NZ SH vkt

EEM Code	EEM Class	TNZ 1999 Class	Approximate percentage of total NZ SH vkt
PC	Passenger Car	1	71.7%
LCV	Light Commercial Vehicle	1	18.3%
MCV	Medium Commercial Vehicle	3	5.1%
HCV I	Heavy Commercial Vehicle I	4,5,6,7	1.8%
HCV II	Heavy Commercial Vehicle II	8,9,10,11,12,13,14	3.1%

Buses are included in the MCV or HCV I classifications, depending on the number of axles.

The MCV class makes up about half of the heavy traffic volume, with HCV II taking three tenths and HCV I two tenths. These proportions will be used to weight the averaging of truck SELs.

3.1.2 Speed

The different classes also travel at different average speeds. Jackett et al [2020] used TMS data to find average vehicle speed on straight sections of NZ state highway by vehicle class and posted speed limit (Table 3-2).

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[2] https://www.nzta.govt.nz/assets/userfiles/transport-data/VKT.xls

[3] https://www.transport.govt.nz/statistics-and-insights/road-transport/sheet/vehicle-kms-travelled-vkt

[4] https://www.nzta.govt.nz/assets/resources/traffic-monitoring-state-hways/docs/traffic-monitoring-state-highways.pdf

Table 3-2: Average speed by vehicle class on straight sections of NZ state highway

Alignment	Speed Limit (km/h)	Average vehicle speed (km/h)		
		PC&LCV	MCV	HCV
Straight	100	91.9	90.2	84.6
Straight	50	47.7	47.5	46.6

Interpolating from Table 3-2 for the CRTN reference speed of 75 km/h, the MCV class travels at 93% of the posted speed limit on average, and the combined HCV I and HCV II classes at 89% of the posted speed limit.

3.2 Weightings

The noise measurements of the individual classes must be weighted and combined such that their effect on noise is accurately described by CRTN's single %HCV metric and the posted speed limit.

The relative volume and speed of each heavy vehicle class have been used in the determination of weightings, in dB, between the different classes (Table 3-3). The typical difference between vehicle speed and the posted speed limit (section 3.1.2) was first accounted for by applying CRTN chart 4 correction at the reference speed of 75 km/h to each class's SEL. The necessary single estimate of the 'average' heavy vehicle SEL was found by a vkt-weighted logarithmic average of the individual class SELs (following section 3.1.1).

Table 3-3: Individual class weights used for %HCV aggregation

EEM Code	EEM Class	Fraction of %HCV by vkt	Typical fraction of speed limit	CRTN speed effect at 75 km/h dB
MCV	Medium Commercial Vehicle	0.51	0.93	-0.36
HCV I	Heavy Commercial Vehicle I	0.18	0.89	-0.51
HCV II	Heavy Commercial Vehicle II	0.31	0.89	-0.51

4 Measurement Survey Results

4.1 Statistical Pass-By Survey

The SPB survey captured the pass-by sound pressure levels of 63 individual heavy vehicles of different classes. Vehicle SELs have been corrected to reference speed, reference temperature, and for zero ground absorption, as described in section 2.5.1. The SELs of each class have been weighted to represent their respective traffic volumes and speeds within the NZ heavy vehicle fleet (see section 3.2) resulting in an 'average' heavy vehicle SEL for the Esplanade SPB site (Table 4-1 below). This will be related to the Esplanade light vehicle SEL (below), and from there back to CRTN in chapter 5.

Table 4-1: Results of heavy vehicle SPB survey at the Esplanade site

Vehicle Class	Average Vehicle SEL under CRTN Reference Conditions dB $L_{AE,75}$	Standard Deviation (n-1) dB	Sample Size, n
PC&LCV	70.6 *	1.3	33
MCV	77.2	1.7	16
HCV I	80.6	1.7	20
HCV II	83.2	1.8	27
Average Heavy Vehicle	80.0 *	--	63

* a logarithmic average of other classes, weighted by NZ traffic mix and typical NZ vehicle speed

The absolute level of the average heavy vehicle (corrected to reference conditions using CRTN's own formulae) is 80.0 dB L_{AE}, which is significantly lower than CRTN's implicit heavy vehicle level under reference conditions of 84.2 dB L_{AE} (equation 2.3). However, in this project a direct comparison is not intended, because the uncertainty in the absolute level is very high, given there is only one SPB site (which is 50 km/h and has significant ground absorption).

The relative difference between light and heavy vehicles can be determined with much lower uncertainty. From Table 4-1, the measured delta between an average light vehicle (PC&LCV) and the average heavy vehicle on the AC surface of the SPB site was,

$$\Delta L_{\mathrm{AE,SPB}} = 80.0\ \mathrm{dB} - 70.6\ \mathrm{dB} = 9.4\ \mathrm{dB} \cong 9\ \mathrm{dB} \qquad (4.1)$$

The noise emission of NZ heavy vehicles can therefore be related to the absolute noise emission level of the NZ light vehicle fleet, which has been measured with greater accuracy (due to the much larger sample size: more than 500 vehicles across 11 sites) in the Part 2 report.

4.2 Controlled Pass-By Survey

CPB measurements with the MCV test vehicle were undertaken so that road surface corrections could be derived for heavy vehicles across the five key surface types (section 2.4.2). The noise emission of the test vehicle has been related to that of the NZ MCV fleet by comparison at the SPB site (section 2.5.2). The noise emission of the larger HCV I and HCV II classes over the different surface types was not measured but has been extrapolated from overseas heavy vehicle data in section 5.3.

In Table 4-2 the *CPX:MCV,75* column provides a quasi-CPX level in dB $L_{Aeq(3s)}$ measured 100 mm ahead of the test vehicle's left rear outer radial tyre (in brand new condition). The *Measured* column is the measured SEL of the test vehicle without corrections. The *MCV SPB* column is an estimate of the NZ fleet MCV pass-by SEL, derived from the test vehicle SEL based on its relationship to the MCV fleet (section 2.5.2), and corrected for ground absorption and survey ambient temperature. *MCV SPB* levels have not been corrected for typical fleet vehicle speed in this table (see section 3.2).

Table 4-2: Controlled Pass-By results with MCV test vehicle

Site Name	Surface	Temp. °C	Ground Abs. I	CPX:MCV,75 dB $L_{Aeq(3s)}$	Measured dB $L_{AE,75}$	MCV SPB* dB $L_{AE,75}$
SH2 NB Grounsel SMA	SMA 15	7	0.25	99.9	79.9	82.5
SH2 NB Grounsel OGPA	PA 10	7	0.75	97.5	74.6	78.7
SH2 NB Whakatikei	PA 10	8	0.50	98.7	76.8	80.2
SH2 NB Maidstone	PA 15	8	0.00	97.2	75.2	77.1
SH2 NB Totara Park	PA 10	8	0.00	98.3	76.1	78.0
SH2 Te Marua NB	2CHIP 3/5	7	0.00	102.8	82.4	84.2
SH2 Kaitoke NB 1	2CHIP 2/4	8	0.25	102.5	81.9	84.5
SH2 Kaitoke Farm NB	RACK 2/4	7	0.25	102.7	81.5	84.1
SH2 Birchville NB	VFILL 5	7	0.00	102.4	82.0	83.9
SH2 Birchville SB	VFILL 5	7	0.00	101.8	81.0	82.8
Esplanade WB †	AC 20	8	1.00	95.0 †	71.1 †	--

* Estimated SPB: extrapolated from CPB using the known relationship between NZ MCV fleet and test vehicle

† Esplanade pass-bys made at 50 km/h and results shown for 50 km/h. All other pass-bys at 75 km/h.

5 CRTN Surface Corrections

5.1 Absolute Calibration of 2022 NZ Heavy Vehicle Fleet

Within the constraints of the project, the most accurate means of 'calibrating' the absolute noise emission of the 2022 NZ heavy vehicle fleet is by relating it to the average light vehicle noise emission. This also reduces the chances of the light and heavy classes getting out of step with each other due to measurement uncertainty.

The measured delta between those two classes at the Esplanade SPB site was found in section 4.1 as $\Delta L_{\mathrm{AE,SPB}} = 9.4$ dB (equation 4.1).

CRTN's implicit delta is $\Delta L_{\mathrm{AE,CRTN}} = 8.9$ dB (equation 2.4 from section 2.6).

Because measurements were made on the CRTN reference surface[5] and corrected to CRTN reference conditions using CRTN's own formulae the two values are directly comparable.

The 2022 measurements of the delta match the 1988 noise model delta closely, and thus for some reference condition, nominally an AC surface, the *R*c and *R*t values[6] will be the same (as they are in CRTN natively). The remaining step is to define this reference condition, noting that AC is no longer the reference surface in NZ (see Appendix B of the Part 2 report). We have chosen to use a light vehicle wayside SEL of 75 dB as the anchor point for defining the heavy vehicle noise emission. This SEL corresponds approximately to the expected mean light vehicle SEL for AC (from the Part 1 and 2 reports). It sits towards the middle of the expected *R*c and *R*t range.

$$L_{\mathrm{AE,HV,ref}} = 75\ \mathrm{dB} + 9\ \mathrm{dB} = 84\ \mathrm{dB} \qquad (5.1)$$

CRTN's implicit heavy vehicle SEL under reference conditions is $L_{\mathrm{AE,truck}} = 84.2$ dB (equation 2.3). Therefore, this project's recalibration for heavy vehicles on the AC surface specification has effectively measured the same level, albeit the reference surface concept is now abandoned.

5.2 Interim MCV Surface Corrections

The definition of the MCV surface corrections for other surfaces relies mostly on CPB survey results.

Consistent with the methodology of the previous section, we have chosen to define interim[7] surface corrections for the MCV class that are related back to the corrections for light vehicles derived in the Part 2 report. The MCV CPB survey captured just 1 to 3 examples of each of 8 different specifications and therefore has very large uncertainty in the actual emission of any given surface type. Conversely, the Part 2 report uses a total of 700 km of CPX:P1,80 data to comprehensively characterise each surface type, before relating that to a light vehicle wayside pass-by SEL. It was therefore advantageous to leverage that confidence in surface characteristics also in the case of the MCV pass-by SEL.

At 12 sites, both light vehicle and MCV surveys were conducted, and a strong linear relationship in pass-by SEL exists between the two classes (equation 5.2, $p<0.01$, $R^2=0.96$, $n=12$) as shown in Figure 5-1 (mostly CPB data, adjusted to fleet SPB levels for both classes).

$$L_{\mathrm{AE,MCV}} = 0.59\ L_{\mathrm{AE,PC\&LCV}} + 35.5\ \mathrm{dB} \qquad (5.2)$$

---

[5] Dense graded asphaltic concrete, abbreviated "DGA" by DoT, U.K. [1988] and usually as "AC" in NZ.

[6] *R*c is the surface correction value in dB for cars (light vehicles) and *R*t the value for trucks (heavy vehicles).

[7] "Interim" because the MCV and HCV corrections are not the final output and will later be weighted and combined into a single heavy vehicle correction representing the nominal CRTN Heavy Vehicle.

Because many sources of systematic error cancel out under this experimental design, there is reasonable confidence in the general relationship. However, surfaces that behave differently for truck tyres than for car tyres may not be accurately captured. It is also possible, but in our opinion unlikely, that either test vehicle responds very differently to surfaces compared to the fleet.

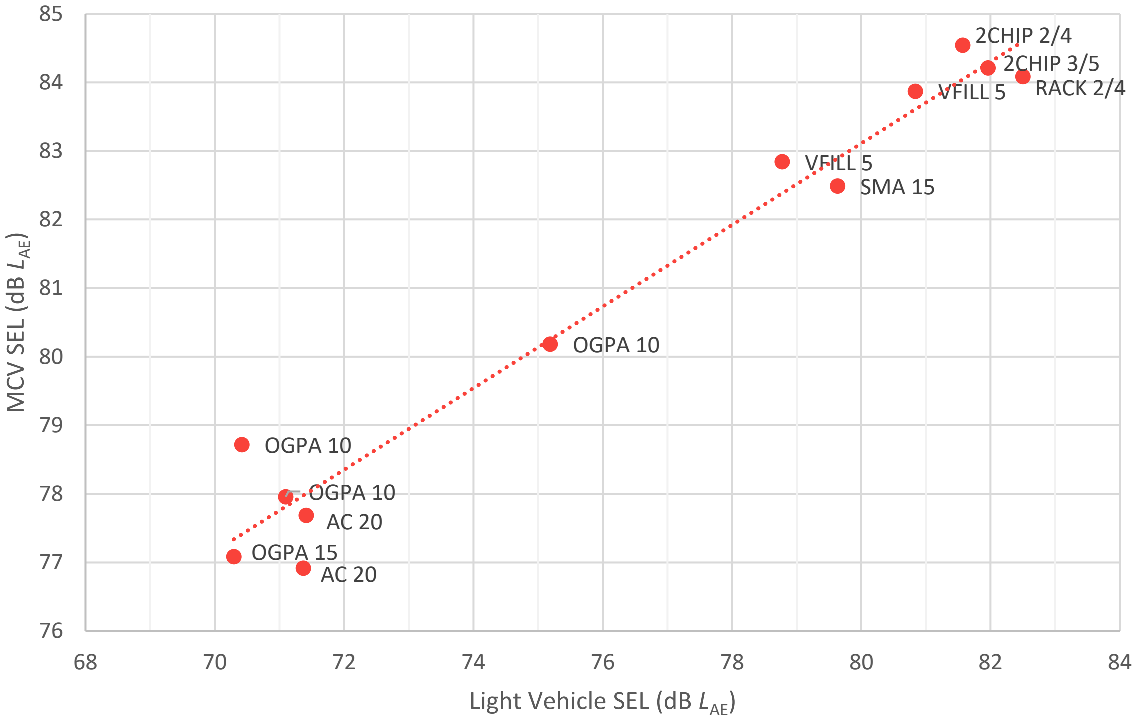

Figure 5-1: Pass-by SEL of MCV and light vehicle classes, corrected to fleet SPB levels.

The slope of 0.59 between $L_{AE,MCV}$ and $L_{AE,PC\&LCV}$ indicates that MCV pass-by noise is less sensitive to the surface characteristics than light vehicle traffic, as expected. We cannot state with confidence the exact reason: it may be due to lower tyre/road sensitivity, higher engine noise, or both. For the MCV corrections it is not particularly important because they are based off wayside measurements, but it becomes important when extrapolating HCV corrections or optimising road surfaces and is examined further in Appendix A.

At the light vehicle SEL of 75 dB L_{AE}, which has been chosen as a reference point (see section 5.1), the MCV fleet level should be approximately 81 dB L_{AE} at 75 km/h to satisfy Table 4-1 after correcting for typical vehicle speed using Table 3-3. The delta between the classes is therefore approximately $\Delta L_{AE,MCV\text{-}PC\&LCV}$ = 6 dB and the relationship becomes:

$$L_{\mathrm{AE,MCV}} = 0.59\ L_{\mathrm{AE,PC\&LCV}} + 36.4\ \mathrm{dB} \tag{5.3}$$

MCV corrections have thus been derived from the Part 2 corrections for light vehicles, propagated through equation 5.3 (see Table 5-1 in section 5.4).

5.3 Interim HCV I and HCV II Surface Corrections

There is no NZ measurement data with which to quantify HCV I & II noise emission between different surfaces, so an indirect route to extrapolate them was required. The uncertainty of the estimated SELs is correspondingly higher than that of the MCV SELs.

Appendix A summarises a pass-by and quasi-CPX measurement analysis performed on MCV data and intended to aid the extrapolation of HCV corrections. It was hoped to better understand the tyre/road influence on truck tyres. Unfortunately, different data and analyses support different conclusions:

- Quasi-CPX data for the MCV test vehicle suggest that the wayside level is mostly tyre/road noise, but that the difference in truck tyre/road emission between surfaces is half what it is for a car tyre. This implies that the tyres themselves are less sensitive to surface type.
- Comparison of measured MCV and PC pass-by levels against the CNOSSOS-EU noise model are almost completely consistent with the MCV wayside level being an even mix of propulsion and rolling noise contributions (crossover is at 75 km/h). If this is true then truck tyres would need to have a similar sensitivity to surface type as car tyres, in terms of tyre/road noise emission.

A dedicated study of truck tyre/road noise emission would be required to determine which, if either, is correct.

We have tentatively adopted the latter conclusion for now and adapted the single vehicle noise emission component of the CNOSSOS-EU noise model [Directive (EU) 2015/996] to estimate HCV corrections.

5.3.1 *Estimate HCV corrections*

Using the same rolling noise adjustments for the PC and HCV classes, CNOSSOS-EU produces an approximately linear relationship with a slope of 0.67 between overall $L_{\mathrm{W,HCV}}$ and $L_{\mathrm{W,PC}}$ vehicle sound power levels at 75 km/h.

At the reference level of 75 dB L_{AE} the delta for the combined HCV classes is approximately $\Delta L_{\mathrm{AE,HCV\text{-}PC\&LCV}}$ = 11 dB, based on a weighted average of those classes.

Therefore, at 75 km/h the HCV pass-by SEL is estimated based on the light vehicle SEL using:

$$L_{\mathrm{AE,HCV}} = 0.67\ L_{\mathrm{AE,PC\&LCV}} + 35.9\ \mathrm{dB} \qquad (5.4)$$

HCV corrections have thus been derived from the Part 2 corrections for light vehicles, propagated through equation 5.4 (see Table 5-1 in section 5.4).

5.4 Heavy Vehicle Surface Corrections

5.4.1 *Derivation*

The previous sections derived equations 5.3 and 5.4 for the MCV and HCV pass-by levels, respectively, which are based on their relationships to light vehicle pass-by level. Those equations can be weighted using the data in Table 3-3 to estimate a heavy vehicle SEL at 75 km/h, $L_{\mathrm{AE,Heavy}}$,

$$L_{\mathrm{AE,Heavy}} = 10\log_{10}[10^{0.059\ L_{AE,PC\&LCV}+3.348} + 10^{0.067\ L_{AE,PC\&LCV}+3.270}]\ \mathrm{dB} \qquad (5.5)$$

The correction to CRTN, Rt, is therefore found from the difference between equations 5.5 and 2.3,

$$Rt = L_{\mathrm{AE,Heavy}} - 84.2\ \mathrm{dB} \qquad (5.6)$$

Because $Rc \approx 0$ at $L_{\mathrm{AE,PC\&LCV}}$ = 75 dB and $Rt \approx 0$ at $L_{\mathrm{AE,Heavy}}$ = 84 dB (c.f. equations 2.2 and 5.6), it can be shown[8] that the heavy vehicle correction is closely approximated by,

$$Rt = 0.65\ Rc \qquad (5.7)$$

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[8] Via regression, rather than analytically

5.4.2 Draft Corrections

Based on the light vehicle data and surface selection in the Part 2 report, draft heavy vehicle surface corrections, *R*t, have been calculated using equations 5.5 and 5.6, and are shown in Table 5-1. Average pass-by SELs for MCV, HCV, and Heavy Vehicle classes have been predicted using equations 5.3, 5.4, and 5.5, respectively.

Table 5-1: Draft road surface corrections for heavy vehicles

Surface Classification	Light Vehicle SEL dB L_{AE}	Predict MCV SEL dB L_{AE}	Predict HCV SEL dB L_{AE}	Predict Heavy SEL dB L_{AE}	Raw Correction (re $L_{Aeq(24h)}$) dB	Draft *R*t Correction (re CRTN) dB	Existing *R*t Correction (re CRTN) dB
Grade 2 or 3	81.9	84.7	90.7	88.6	4.4	+4	-1
Grade 4	80.6	84.0	89.8	87.7	3.5	+3	-4
Grade 5 or 6	79.8	83.5	89.3	87.2	3.0	+3	-4
SMA-14	77.2	81.9	87.5	85.5	1.3	+1	-3.5
SMA-10	75.6	81.0	86.5	84.5	0.3	+0	-3.5
*Reference SEL**	*75*	*80.7*	*86.1*	*84.1*	*-0.1*	*+0*	-2
PA-10 30 mm	74.3	80.2	85.6	83.6	-0.6	-1	-4
PA-10 50 mm	71.6	78.6	83.8	81.9	-2.3	-2	-6
PA-7 40 mm	70.3	77.9	82.9	81.0	-3.2	-3	--

* Not a reference surface but a reference Light Vehicle SEL of 75 dB L_{AE}

6 Conclusions

6.1 Findings

1. A system of reference to CRTN has been found that is consistent with the system used for light vehicles (section 2.6).
2. Methods for quantifying the overall noise emission of heavy vehicles have been determined and documented. Both statistical pass-by (section 2.3) and controlled pass-by (section 2.4) measurements were used.
3. The 2022 NZ heavy vehicle fleet has been characterised for noise emission, accounting for the relative volumes and speeds of each class in NZ (section 3.2) and the typical noise emission of each class (section 4.1).
4. A 'recalibration' of the absolute heavy vehicle level has been performed (section 5.1), which found that the delta between light and heavy vehicles of 9 dB in CRTN is still appropriate in NZ in 2022.
5. Heavy vehicle noise at the wayside has been estimated for different NZ surfaces and heavy vehicle classes (chapter 5), but there is a moderate degree of uncertainty with these estimates due to extrapolation.
6. Road surface corrections for heavy vehicles have been drafted, which are related to those found for light vehicles in Part 2 (Table 5-1). There is a moderate degree of uncertainty around the corrections.

6.2 Comparison with Other Evidence

The absolute calibration of the heavy vehicle fleet is consistent with CRTN, excluding the NZ Adjustment. However, the relative heavy vehicle corrections between surfaces differ from the existing corrections.

6.2.1 Existing heavy vehicle corrections

From Table 5-1 it is observed that the 'new' corrections are very different to the 'old' corrections, typically much higher. The chipseals in particular have dramatically different behaviour: a positive *R*t value in the new corrections and a negative *R*t value in the old corrections.

This is somewhat concerning, because to our knowledge the old corrections have not been reported by acoustic practitioners as being inaccurate (admittedly it would be difficult to pin-point to the *R*t value even if they were).

The old heavy vehicle corrections derive from a broader study of surface types [Dravitzki & Kvatch, 2007], and included HCV-class passes on most surfaces, whereas the new corrections rely on extrapolation from a MCV test vehicle, and a European noise model for HCVs. Conversely, the old correction methodology arguably under-represented the MCV class, which makes up half the current NZ heavy vehicle fleet.

6.2.2 Other NZ heavy vehicle measurements

The new *R*t correction values are a large proportion of the *R*c values (65%). Previous NZ measurements haven't suggested heavy vehicle wayside levels were quite that sensitive to the tyre/road interaction [Dravitzki & Kvatch, 2007; Jackett, 2019a).

The average magnitude of *R*t in the old corrections table is about 50% of the average magnitude of *R*c, before including the NZ Adjustment, but there is far less correlation between the two for any given surface type. The survey for the old corrections [Dravitzki & Kvatch, 2007] used SPB in part, and it is not known how variation in the fleet between measurement sites may have influenced the outcome (c.f. the combined HCV class had sd ≈ 2 dB in the current measurements).

A previous study of truck noise on 5 different OGPA surfaces [Jackett, 2019a] implied a relationship closer to *R*c = 0.25 Rt at a similar speed, albeit with a very high uncertainty due to a small sample at each site.

6.2.3 *The Dutch corrections to CNOSSOS-EU*

The Dutch corrections for CNOSSOS-EU, once propagated through that model's frequency- and speed-dependent surface correction algorithm, are often of a similar magnitude between PC, MCV and HCV classes for asphalts, though there are exceptions [Directive (EU) 2015/996]. The MCV and HCV corrections are all identical, although it is possible that is also the result of an extrapolation, as with this study.

6.2.4 *Western Belfast Bypass SPB*

Rob Wareing (Altissimo) conducted a SPB survey adjacent a 40 mm EPA-7 surface on Western Belfast Bypass in Christchurch on 23/5/2022. Only PC&LCV and HCV II classes were captured, but exactly the same delta existed between these two classes as in the Esplanade SPB survey (12.7 dB), implying that *R*c and *R*t values should be very similar to each other for this surface.

The EPA-7 values from this project are *R*c = -5 dB and *R*t = -3 dB. The values for the quietest OGPA in the existing corrections table are *R*c = -4 dB and *R*t = -6 dB.

6.2.5 *Summary of evidence*

Against the proposed *R*t values:

- The exiting corrections suggest much lower *R*t values, and no clear pattern between *R*t and *R*c across surface types.
- Previous NZ measurements of trucks on OGPA show a smaller surface influence on the wayside noise level.

Supporting the proposed *R*t values:

- The Dutch corrections suggest that the MCV and HCV classes share the same response to different European surfaces (which don't include chipseal), similar to the extrapolation process assumed for the proposed corrections.

Neutral:

- A very recent SPB survey on a very low noise OGPA implied very similar *R*c and *R*t values. The proposed corrections have *R*t = *R*c + 2 dB, whereas the best match from the existing corrections has *R*t = *R*c – 2 dB.

6.2.6 *Sensitivity to Rt*

The CNOSSOS-EU vehicle noise emission model was applied to typical NZ traffic flows in Table 4-1 of Jackett et al (2020). It indicates that a difference in truck tyre/road emission of 3 dB would make approximately a 0.5 dB of difference to road traffic $L_{Aeq(24h)}$ levels.

6.3 Recommendations

High quality pass-by data has been collected for the fleet at two sites, and for a MCV test vehicle at 11 sites. However, there remains significant uncertainty in how heavy vehicle noise emission is affected by the road surface.

Introducing the new corrections as they are drafted in this report would represent a big change to the predicted noise levels for heavy vehicles (up to +7 dB for some chipseals). However, the impact on the predicted overall road traffic $L_{Aeq(24h)}$ noise level is likely to be much lower, on the scale of 1 dB at most locations.

It would be prudent to delay adoption of the new *R*t corrections until there is more validation data available.

6.3.1 Suggested research

During the course of this study, several directions for future research presented themselves but were out of scope:

- While conducting the pass-by surveys for this study, we also piloted an additional "quasi-CPX" measurement to quickly and efficiently collect *relative* tyre/road noise emission levels between different sites. This produced results that were valuable to the interpretation of the wayside levels: the MCV test vehicle indicated that wayside pass-by noise level correlated at near to 1:1 with the CPX level. The MCV tyre/road emission appeared to change at half the rate of the Mazda3 tyre/road emission between different surfaces, implying that the MCV tyre itself is less sensitive to the road surface. A study of MCV and HCV CPX may be able to confirm or otherwise explain these provisional measurements, and would affect how we model and optimise road surface noise in future.

- SPB surveys on chipseal and SMA would be beneficial to defining the heavy vehicle corrections for those surface types, as well as validating the absolute calibration to CRTN. The existing study did not capture the HCV class on chipseal, which is a significant source of uncertainty in the proposed corrections.

- A CPB survey using a HCV I test vehicle would be valuable for defining the correction between sites. For practical and logistical reasons, this would be more difficult than the CPB survey with the MCV test vehicle. Pass-by laps would probably be longer and slower, and a suitable vehicle would need to be available at short notice for night time work. However, the data could be quickly used to update section 5.3 of this report.

- The proposed corrections were generated through a largely pass-by based methodology. These corrections should be validated by measurements of actual traffic flow. This is especially important in regards to the absolute level of the corrections. With the right design, both light and heavy vehicle corrections could be validated using the same set of wayside road traffic noise measurements.

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Appendix A Examine Pass-By and CPX Data

A.1 CNOSSOS-EU vehicle source model

The CNOSSOS-EU [Directive (EU) 2015/996] vehicle noise source model was based on a large number of wayside, on-vehicle, and laboratory measurements of vehicle rolling (tyre/road and aerodynamic) and propulsion (engine and exhaust) noise. It provides sound power levels for PC, MCV, and (combined) HCV classes, each with separate components for rolling and propulsion sources. The CNOSSOS-EU per-vehicle sound power emission levels for rolling, propulsion, and overall noise are included in Appendix B of the truck tyre/road noise report [Jackett et al, 2020].

To test its potential to extrapolate the NZ HCV corrections, we have compared its predictions for MCVs against our measured MCV pass-by data relative to the PC class:

- When its rolling noise component is changed by the same factor for PC and MCV vehicles (i.e. the same value surface correction in dB is applied to both) it produces an approximately linear relationship with a slope of 0.57 between overall $L_{W,MCV}$ and $L_{W,PC}$ vehicle levels at 75 km/h. This compares well with the slope of 0.59 found experimentally in section 5.2.
- At 50 km/h on asphalt, CNOSSOS-EU predicts ΔL_W = 6 dB whereas we measured ΔL_{AE} = 7 dB.
- At 75 km/h on asphalt, CNOSSOS-EU predicts ΔL_W = 4 dB whereas we measured ΔL_{AE} = 5 dB.

The fit for MCVs is reasonably good, and these three findings provide some confidence that the CNOSSOS-EU vehicle model, applied in a relative manner, may also produce reasonable estimates for the HCV class.

The sensitivity of HCV tyre/road emission would also need to approximate that of car tyres for this to hold true.

The Dutch corrections for CNOSSOS-EU, once propagated through the frequency- and speed-dependent surface correction algorithm, are often of a similar magnitude between PC, MCV and HCV classes for asphalts, though there are exceptions [Directive (EU) 2015/996]. The MCV and HCV corrections are all identical, although that may also be the result of an extrapolation.

A.2 Quasi-CPX Data

Both CPB test vehicles were also fitted with a measurement microphone ahead of their left rear tyres, which we have labelled a quasi-CPX measurement. For both vehicles the relationship between the wayside CPB level and the quasi-CPX level was reasonably well-defined and linear, with slopes of both approximating m=1.

$$L_{\mathrm{AE,PC}} = 1.11\, L_{\mathrm{CPX:PC,75}} - 36.5\ \mathrm{dB} \quad (p<0.01,\ R^2=0.86,\ n=18) \tag{5.3}$$

$$L_{\mathrm{AE,MCV}} = 1.18\, L_{\mathrm{CPX:MCV,75}} - 37.3\ \mathrm{dB} \quad (p<0.01,\ R^2=0.93,\ n=10) \tag{5.4}$$

Note that $L_{CPX:PC,75}$ and $L_{CPX:MCV,75}$ levels are not directly comparable. They were measured in different locations relative to their respective tyres, and at different distances. The wayside levels are comparable.

Over the same set of surfaces, the range of $L_{AE,MCV}$ is about half that of $L_{AE,PC}$, and the range of $L_{CPX:MCV,80}$ about half that of $L_{CPX:PC,80}$. Regressing $L_{CPX:MCV,80}$ on $L_{CPX:PC,80}$ gives a slope of 0.54 (R^2=0.91, n=10), implying that the surface correction to the rolling noise component for MCVs would be about half that of the correction for PCs. On the other hand, this result may be specific to the test vehicle.

Whereas the CNOSSOS-EU comparison in A.1 suggested that the lower surface sensitivity of MCVs is a consequence of their higher propulsion noise component, this result is consistent with the pass-by level difference between surfaces being driven mostly by the tyre/road interaction itself.

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