NZTA Road Surface Noise Research Programme 2018/2019

Preliminary Chipseal Study

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Contents

List of Figures

List of Tables

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Executive Summary

Background and Scope

About 90% of NZ's 11,000 km state highway network is surfaced with chipseal. As part of an on-going effort to manage the road noise emissions of the network, the NZTA want to better understand what levels of tyre/road noise are generated from existing chipseal surfaces, and ultimately to optimise chipseal specifications and procedures to reduce noise.

NZTA have a Close Proximity (CPX) trailer, which has primarily been used for investigation of asphalt road surfaces to date. WSP's previous study validated CPX measurements on OGPA trial surfaces with wayside noise measurements, finding a good correlation. It also confirmed previous experience that different sections of OGPA surface can have large variability in noise emission even though they are of the same specification.

The current study extends on that work by establishing the CPX trailer's capability for measurement of chipseal through paired CPX and wayside measurements. CPX data was collected along a long distance of state highway, with the objective of capturing the noise emission of a range of chipseal types, ages, and conditions, as they appear 'in the wild'.

This study was planned as a first step towards understanding noise from chipseal. It is intended to provide a proof-of-concept that the CPX trailer can be used to study noise emission from a range of surfaces, particularly chipseal, and as a precursor to further work.

Methodology

A total 700 km of state highway were surveyed by the CPX trailer, using the standard passenger car tyre (P1), the standard heavy tyre (H1), and a tyre typical of passenger cars in NZ (SC). Those data were combined with road surface and traffic data from the RAMM database to produce a dataset containing over 250 km of unique 20 m long road segments on SH73 and SH1 in North Canterbury. Additionally, wayside noise levels were measured at five sites using the Statistical Pass-by (SPB) methodology.

Key Findings

CPX measurement repeatability

Three repeated trips along SH73 from Yaldhurst to Springfield and back with the CPX trailer using the P1 tyre allowed a value to be placed on the typical repeatability of the CPX measurement system in the context of chipseal measurement (section 3.1.1). The typical random variation about the mean at the 95% level of confidence for CPX chipseal measurements is of the order of ± 0.5 dB for a single run, which can be further reduced to ± 0.3 dB by averaging levels over three repeated runs.

The P1 ranks surfaces equivalently to a 'typical' NZ car tyre

Although the P1 tyre is atypical of NZ car tyres in its dimensions, a comparison of CPX results between the P1 and a 'typical' Supercat tyre[4] on chipseal has verified that the P1 responds to the differences between common chipseal and asphalt surfaces in a similar way as the 'typical' Supercat (section 3.1.2). It is recommended that the P1 specification tyre be retained as the NZTA's primary tyre for passenger car CPX measurements.

CPX levels of chipseal 'in the wild'

CPX data from the 250 km of North Canterbury state highway covered during the survey represent the first significant measurements of NZ chipseals 'in the wild'. The data were grouped by surface type, and the average noise emission of each surface type determined (section 3.2.2). Grade 3 chipseal averaged 101 dB $L_{CPX:P1,80}$, while grade 4 and grade 5 were 1 dB and 1.5 dB quieter, respectively. All three two-chip surfaces that were based on a grade 3 chip exhibited the same noise level as the grade 3 chip on its own, with the two-chip surfaces based on a grade 2 chip just slightly louder than those based on a grade-3 chip. The asphalts from quietest to loudest were: PA-10 (at 97.5 dB $L_{CPX:P1,80}$), SMA, and PA-14. The PA-14 was a similar CPX level to grade 5 chipseal.

Variability within a surface specification

The large quantity of CPX surface data collected for this study enabled an analysis of real-world variability within each surface type that has not previously been possible (section 3.2.3). The single-chip seals had a typical variability in the region of ± 1 dB and the two-chip seals in the region of ± 1.5 dB. Data for asphalt surfaces was limited, but SMA and PA-10 were each within ± 1 dB, while PA-14 was a relatively high ± 2 dB (Figure 3-3).

A full picture of variability within a surface type will only be complete once a diverse set of each surface type (across many locations and ages) is available. Until that information is available, it would be reasonable to assume an inherent variability of noise emission of chipseals of about ± 1.5 dB, before taking type, age, traffic or condition into account.

Correlation between noise emission level and surface texture

Mean Profile Depth (MPD, measured in millimetres) is a standardised measurement of surface macrotexture. By combining RAMM texture data with the CPX dataset, it was observed that high MPD is a strong predictor of high CPX levels for a surface type (section 3.2.4). This held across all surface types, including OGPA (with its so-called 'negative texture'), although there were indications that the relationship is weaker for the two-chip surfaces.

Correlation between CPX and the wayside (SPB) noise level

In contrast to the previous study on OGPA, the range of noise levels was highly clustered, leading to higher uncertainties. Overall, the indication is that a linear relationship exists between the $CPXP1_{80}$ level and wayside passenger car levels on chipseal (section 3.3.1), but additional data pairs would be required to quantify the relationship with confidence.

No significant linear relationship could be found between the H1 tyre and wayside heavy vehicle noise (section 3.3.2).

When the chipseal data was combined with the OGPA data from the previous study, and temperature and speed corrections were applied, a strong linear correlation was found, with a slope of $m = 1.3 \pm 0.2$ (section 3.3.3). This deviates significantly from unity, and implies that the CPX trailer may under-represent the actual difference in wayside noise level between different surfaces. The relationship between CPX level and wayside noise level over a wider range of surface types, conditions, and speeds will need to be understood before the CPX trailer is relied upon exclusively to predict changes in wayside noise levels.

Road surface corrections

Corrections in decibels for each surface type are a fundamental part of road-traffic noise assessments, and the CPX trailer may provide the best means of revising the current corrections in the NZTA road surface noise guide, which were based on SPB measurements. Using several approximations, it was possible to show a proof-of-concept set of road surface corrections derived from CPX data (Figure 3-8).

While there was good agreement between the guide's corrections and the CPX corrections for all single-chip surfaces and OGPA PA-10, the CPX corrections for the four two-chip surfaces were consistently lower than the guide's correction by about 2 dB (section 3.4.1). Surface flushing may contribute to some of the discrepancy, but the suggestion from this early data is that the existing corrections for two-chip seals may not be representative of surfaces on at least North Canterbury's state highways, and potentially all of NZ's state highways.

1 Introduction

1.1 Background

Chipseal[1] is ubiquitous on NZ rural roads as well as in urban and suburban settings. It is a hard wearing, flexible, and economical road surface. However, its rough texture means that the tyre/road interaction generates substantial noise, which is received by vehicle occupants as well as the surrounding environment.

About 90% of NZ's 11,000 km state highway network is surfaced with chipseal[2]. As part of an on-going effort to manage the road noise emissions of the network, the NZTA want to better understand what levels of tyre/road noise are generated from existing chipseal surfaces, and ultimately to optimise chipseal specifications and procedures to reduce noise.

1.2 Previous CPX work

NZTA have a Close Proximity (CPX) trailer, which is an instrument capable of measuring road surface noise emission at close proximity to the tyre contact patch and in isolation from other road noise generation mechanisms. The intention is to use the CPX trailer to evaluate the in-situ acoustic performance of NZ road surfaces in a reliable and reproducible manner. The CPX system offers the possibility of efficiently measuring long sections of road – something that would be uneconomical with traditional wayside noise measurement methods.

The NZTA's CPX trailer has primarily been used for investigation of asphalt road surfaces to date[3]. In April 2019, WSP studied[4] passenger car traffic on a type of asphalt called OGPA, Open Graded Porous Asphalt, with paired CPX and wayside noise measurements to validate that the wayside level and the CPX level were highly correlated (r^2=0.95). It also confirmed previous experience that different sections of OGPA surface can have large variability in noise emission even though they are of the same specification.

1.3 Purpose and Scope

The current study extends on the previous work by establishing the CPX trailer's capability for measurement of chipseal through paired CPX and wayside measurements. This study collects CPX data along a long distance of state highway, with the objective of capturing the noise emission of a range of chipseal types, ages, and conditions. This data will contribute to a database of CPX measurements and indicate the range of CPX noise levels likely to be observed on NZ roads.

This study was planned as a first step towards understanding noise from chipseal. It is intended to provide a proof-of-concept that the CPX trailer can be used to inform further investigation, and as a precursor to further work.

[1] "Chipseal" consists of one or more layers of crushed stone ("chip") embedded in bitumen, with the stone being the primary surface in contact with the tyres.

[2] RAMM database query. Road Assessment and Maintenance Management (RAMM) is software used by Road Controlling Authorities (RCAs) to manage their network assets and their condition.

[3] S Chiles & J Bull, *Road surface noise research 2016-2018*, NZTA, April 2018

[4] R Jackett, *NZTA Road Surface Noise Research Programme 2018 – Task A: Close Proximity versus Wayside Measurements*, WSP, April 2019

2 Methodology

The experimental methodology involved making CPX measurements with various tyres along two state highways in North Canterbury.

Five wayside survey sites were chosen adjacent to the surfaces measured by CPX, to investigate the relationship between CPX and wayside noise levels. These sites were selected to cover a range of chipseal surface types (plus one other 'textured' surface type), as well as considering other experimental, practical, and safety factors (e.g. access, even ground, absence of reflecting surfaces, free-flowing traffic, clear sight-lines). Wayside levels were determined from measurements of approximately 100 fleet vehicles at each site.

The noise measurement data was supplemented by road surface information from the RAMM database. Post-processing and analysis of the CPX and wayside data was performed using spreadsheet, database, GIS, and statistical tools.

2.1 Data Collection

CPX routes were chosen as representing a range of chipseal surfaces, generally flat, and free of bumps, as defined and identified in the RAMM database. The study objectives could be efficiently met using two CPX routes:

- SH73 from Yaldhurst to Springfield (56 km) is flat, straight, and relatively bump-free; and has plenty of road side locations that would be suitable for SPB measurement. For use in validation of correlation between CPX measurements and wayside measurements, three circuits were completed on the route using the CPX trailer with the P1 tyre (the standard test tyre used to represent passenger car tyres), one circuit was completed with the H1 tyre (the standard test tyre used to represent heavy vehicle tyres), and one circuit completed with a new condition Supercat tyre (used to represent a typical NZ passenger car tyre)[4].
- SH1 from Tram Road to Amberley (31 km) and from Templeton to Rakaia Bridge (41 km) provides a variety of surfaces and surface ages, it is mostly level and bump-free. To expand the CPX database, one circuit was completed on this route using the CPX trailer with the P1 tyre.

A set of potential wayside measurement sites on SH73 were identified from maps, street view imagery, and RAMM surface data. These were modified in the field to accommodate factors such as site access, safety, visibility, freshly laid or damaged surfaces, road works, and low traffic volume.

Further information on the CPX route selection and survey structure is given in Appendix A and Appendix B.

2.2 Close Proximity (CPX) Measurement

The NZTA's CPX trailer has been developed with the aim of achieving compliance with the international standard ISO 11819-2[5], and although some certification testing is yet to be finalised, it is understood to be broadly compliant with the standard. Detailed information on the specification and operation of the CPX trailer, and processing of its measurement data, can be found in the draft report *Road Surface Noise Research 2016-2018* [3].

The CPX survey took place from 4th to 7th March 2019, during a period of stable dry weather. It had been more than 48 hours since the last rain event and all road surfaces were visibly dry with no spray. Ambient air temperature during the survey was in the range 21-35 °C. CPX noise levels and spectra were measured in the left-hand wheel path with an interval of 20 m.

[5] ISO 11819-2:2017 *Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 2: The close-proximity method*

2.3 Wayside Noise Measurement

Wayside noise levels have been determined using the Statistical Pass-By (SPB) method. This involves measuring the sound generated by a selection of the passing vehicle fleet. For this project, the SPB measurements are intended to give an indication of the relative acoustic performance between selected sections of road at the road side.

Whereas CPX measurements are made at a controlled speed (80 km/h in open road situations), SPB is an observational technique, and therefore incorporates a wide range of speeds and potentially different average speeds between sites. The SPB sound levels can be corrected to some nominal or reference speed to control, to some extent, the effect of speed on the tyre/road noise generation. The choice of the reference speed depends on the application: for a simple comparison of SPB measurements between sites the speed limit or the average speed across the sites might be chosen, while comparing SPB measurements with CPX measurements might involve correction to the CPX trailer speed of 80 km/h.

A methodology for SPB measurement is described in ISO 11819-1 [6], and has been adopted for this study (and the previous work[4]). The only significant deviation from the ISO 11819-1 methodology relates to the number of vehicle pass-bys measured, which were generally reduced slightly from the guidance values in order to allow for a broader survey of sites within the time available. SPB of passenger car passes achieved 80-100% of the suggested statistical power. SPB of truck passes were collected only incidentally as they were available during the survey of passenger car passes. Previous work demonstrated that truck SPB is time consuming and provides comparatively low value data on road surface performance[4].

2.3.1 Statistical Pass-By Survey

Five SPB surveys took place across the 6th and 7th of March 2019, in dry weather conditions, with ambient temperatures in the range 19˚C – 31˚C. There were light north easterly winds, varying from <1 m/s to 5 m/s depending on site. The instrumentation used was a calibrated Class 1 Brüel & Kjær 2250 sound level meter (SN: 3027649) with Norsonic Nor1256 field calibrator (SN: 125626168) and a Bushnell Speedster III speed radar gun.

Following a recommendation of the previous report[4], a modified definition of ISO 11819-1 vehicle class 2a (‘dual-axle with more than 4 wheels’) was adopted, shifting from tandem-axle trucks to instead capture trucks with a single rear axle fitted with 2 wheels each side. This definition includes smaller trucks with tyres that are more like the Avon AV4 Supervan tyre used as the H1 CPX test tyre.

Table 2-1 gives information of the SPB survey sites and vehicle passes.

[6] ISO 11819-1:1997 Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By method

Table 2-1: Statistical Pass-By Survey Information

Site ID	1	2	3	4	5
Surface; Date surfaced; Condition	Grade 3; Feb 2010; Good	2-coat 3/5; Mar 2009; Good	Grade 5; Nov 2014; Good	2-coat 2/4; Feb 2017; Flushed	Grooved AC14; 2009; Good
Route Position	073-0015/ 02.064	073-0034/ 04.153	073-0015/ 03.950	073-0005/ 08.625	073-0005/ 07.276
Direction	D (East)	D (East)	D (East)	D (East)	I (West)
Survey Date	6-Mar	6-Mar	6-Mar	7-Mar	7-Mar
Survey Start Time	10:25	14:00	15:45	9:15	10:55
Approx. Air Temperature (°C)	22	29	31	19	24
Cat 1 Pass-bys (n): Passenger Cars	98	87	73	104	68
Cat 2a Pass-bys (n): Light Trucks	5	7	5	5	3
Cat 2b Pass-bys (n): Heavy Trucks	13	13	2	9	11
Average car speed (km/h)	91.9	94.9	89.1	91.7	86.6

SPB survey sites for the targeted road surface types were limited primarily by the presence of a safe place from which to conduct the measurements. The number of vehicle pass-bys captured depended on the rate at which suitable measurement opportunities arose (related to the total traffic volume, truck traffic volume, and time of day) and the time available to conduct the survey. Survey duration at each site was managed to achieve an adequate number of passenger car passes across all five SPB sites, rather than achieving high pass-by counts in all the vehicle categories and potentially compromising the number of passenger car passes at one or more SPB sites.

2.3.2 Speed and temperature corrections

The previous study paired L_{CPX} measurements at 80 km/h with wayside SPB measurements where the speed of the passing vehicle fleet was close to 80 km/h, so the comparison of CPX and SPB measurements required no speed correction. In the current study the CPX trailer was again run at 80 km/h (as required by the CPX standard[5]) but the SPB sites had 100 km/h speed limits and greater variability of passing vehicle fleet speeds.

The SPB standard methodology[6] features some correction for the effect of traffic speed, but it has decreasing accuracy as the average measured speed gets further from the target speed to which noise levels will be corrected. The standard also specifies road speed categories that do not relate to the NZ situation (they correct to 110 km/h at the high end). Therefore, for a general analysis of how CPX at 80 km/h relates to the SPB level under a 100 km/h speed limit, individual vehicle speeds were corrected to the average speeds measured during the SPB survey: passenger car speeds were corrected to 90 km/h and truck speeds were corrected to 85 km/h.

Where the chipseal SPB survey results are compared with OGPA SPB survey results (from the previous study), passenger car noise levels were corrected to 80 km/h, and trucks to 70 km/h.

All SPB measurements have been corrected to a reference temperature of 20˚C using Bühlmann's[7] suggested chipseal coefficient of 0.08 dB/˚C, or OGPA coefficient of 0.04 dB/˚C, as appropriate.[8]

2.3.3 Measurement uncertainty

An uncertainty budget for SPB measurements was developed as part of the previous study on OGPA trial sites[4]. For this study there are several factors that lead to a small increase in the expanded measurement uncertainty at the 95% level for L_{veh} of passenger cars from ±1.0 dB to ±1.1 dB:

- more variability in individual vehicle noise emission (± 0.16 dB from ± 0.15 dB) and from vehicle speeds within a site (± 0.11 dB from ± 0.05 dB);
- more variability in lane-keeping by vehicles affecting the distance between the microphone and the traffic (± 0.30 dB from ± 0.24 dB);
- fewer passenger car pass-bys at some sites (uncertainty assumes the worst case);
- assumed contribution from temperature effects is slightly lower because a correction is now being applied (25% of the correction is taken as error of the correction itself: ± 0.24 dB from ± 0.28 dB);
- an additional component to cover the correction for vehicle speed between sites is required: the difference between target speed and average measured speed at a site contributes a standard error of approximately 0.025 dB per km/h difference (± 0.38 dB)

[7] E Bühlmann, U Sandberg, P Mioduszewski, Speed dependency of temperature effects on road traffic noise, Internoise, San Francisco, 9-12 August 2015, Table 6

[8] Previous work compared SPB measurements across only a small temperature range and correction for temperature effects was determined ineffectual. With the inclusion of the chipseal SPB sites the temperature range is 25˚C, and the temperature correction provides valuable adjustment.

3 Results and Analysis

3.1 Focused CPX Survey (SH73)

The survey to investigate CPX repeatability and effect of CPX tyre types took place on SH73, and consisted of three CPX runs with the P1 tyre and one CPX run with each of the new SuperCat and the H1 tyre.

3.1.1 Repeatability of CPX_{P1} measurements

A calculation of the repeatability achieved by the CPX trailer (P1 tyre) required three return trips along SH73. For each 20 m section of road surveyed, the arithmetic mean of the three readings was taken as an estimate of the CPX noise emission.

The standard error of the mean is influenced by the random variation in measured level between runs (described by the standard deviation, SD) and by the number of repeated measurements (n). The standard error should be calculated for each survey undertaken to help determine a confidence interval about the mean, but it can also be considered as an inherent property of the measurement system in its current state.

The standard error computed from the three repeated CPX runs in each direction on SH73 might be taken as representative of the current repeatability of the NZTA's CPX measurement system in the context of chipseal measurement. These standard errors are shown in Table 3-1, for SH73 Westbound and SH73 Eastbound.

Table 3-1 also shows the root mean square standard error of the mean (RMSE) computed from repeated CPX runs on OGPA, made using the CPX trailer in previous work.

Table 3-1: Repeatability of CPX_{P1} measurements

CPX Route	Date	Surface	$RMSD_{n-1}$ (dB)	Number of 20 m road segments	RMSE of 3 runs (dB)
SH73 Westbound	5/3/19	Various chipseals	0.25	1997	0.14
SH73 Eastbound	5/3/19	Various chipseals	0.25	2125	0.14
Johns Road S2G	18/7/18[9]	Various OGPA	0.56	40	0.33
Johns Road WBB	18/7/18[9]	Various OGPA	0.28	31	0.16

Two times the RMSE value is the half-width of the 95% confidence interval about the mean of three runs, excluding any systematic errors. The values for RMSE in the table indicate that the typical random variation about the mean of three CPX measurements is ± 0.3 dB. However, the Johns Road S2G measurements indicate that this level of repeatability may not always be possible. It has been established that OGPA CPX noise emission is variable in the longitudinal direction[10], and it may be that small deviations in lane position between runs have exposed a similar variability in the lateral direction. The relative variability of chipseal and OGPA surfaces will be explored further in section 3.2.3.

3.1.2 Difference between P1 and Supercat tyres

The P1 is atypical of passenger car tyres in NZ in terms of its dimensions, but for NZ CPX measurements to be comparable to those made overseas, this is the tyre that must be used. To provide some assurance that the P1 ranks road surfaces similarly to a 'typical' NZ passenger car tyre

[9] A bug in the averaging routines of the CPX system affected the original survey, but these data have been reprocessed from the original wav recordings, and can be compared on a like-for-like basis with the chipseal data.
[10] Lester, Dravitzki, Carpenter, McIver, Jackett, *The long-term acoustic performance of New Zealand standard porous asphalt*, NZTA Research Report 626, Sept 2017

(selected[4] as the Bridgestone Supercat 195/60R15), a single circuit of SH73 was undertaken using the CPX trailer with the Supercat (SC) and compared with the mean of the P1 runs.

The previous study found that the P1 was generally about 1.6 dB louder than the SC tyre, which was fairly consistent across all OGPA specifications in the trial. A similar comparison is now made for chipseal. Figure 3-1 presents the average difference $L_{CPX:P1,80}$ - $L_{CPX:SC,80}$ for each of nine road surface types.

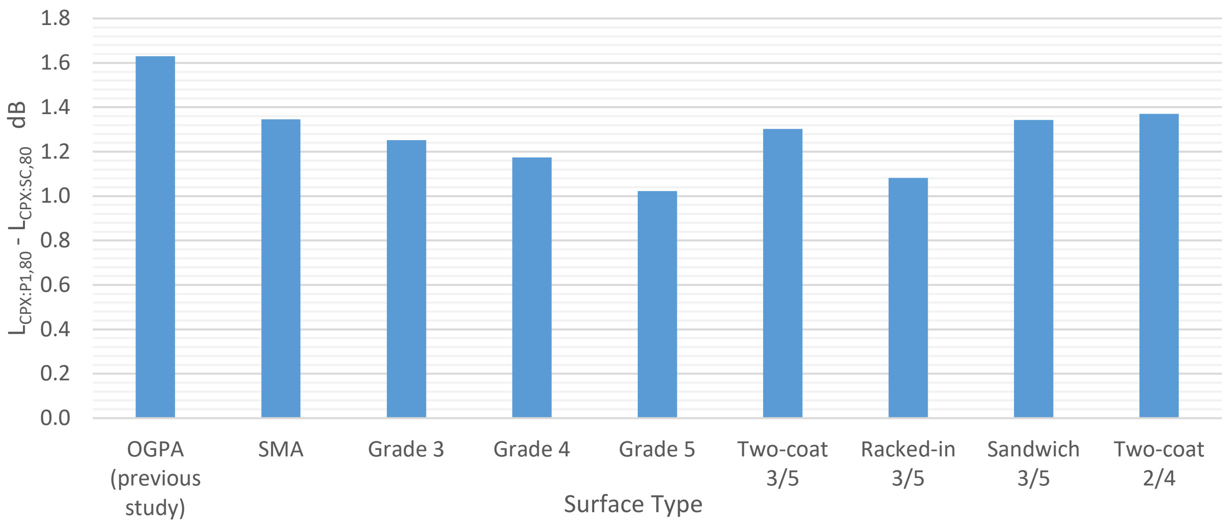

Figure 3-1: Average difference in L_{CPX} between the P1 and SC tyre across different surfaces

The P1 is 1.0 dB to 1.6 dB noisier than the SC on the surface types experienced on SH73 and Johns Road. On average, the P1 is noisier than the SC by 1.2 dB on chipseals, and by 1.3 dB on SMA. The minor differences between how the different tyres respond to chipseals and asphalts provide confidence that, despite its unusual dimensions, the P1 tyre responds to NZ road surfaces in a similar way to a typical passenger tyre from the NZ fleet. Given the other benefits that the P1 tyre provides (particularly ongoing availability and international comparability), it is therefore recommended that the P1 specification tyre be adopted permanently as the NZTA's primary passenger car CPX tyre.

3.2 Wide Area Survey (SH73 and SH1)

The combination of the averaged SH73 CPX repeat-runs using the P1 tyre with the SH1 CPX using the P1 tyre produces a CPX P1 dataset covering over 250 km of state highway network, and many different surface types. This was combined with RAMM surface and traffic data to form the dataset from which the results in this section have been drawn.

3.2.1 Surfaces Covered

The data were grouped by surface type, but excluding surface types with only very short sampled lengths or where the surface classification could not be relied upon (e.g. the nature of a void-fill can vary enormously between applications). For the purpose of investigating noise effects, the resulting list of surface types can be divided into two chipseal categories, 'single-chip' and 'two-chip', and an asphalt category.

The single-chip category includes surfaces where only one size of chip is in contact with the tyre (e.g. single coat seal). The two-chip category includes surfaces where two different sizes of chip may be in contact with the tyre. There are several examples of surface types within this category, all of which apply the smaller chip size last (e.g. two-coat, racked-in, sandwich seal, void fill). Figure 3-2 provides examples to illustrate the differences between single-chip and two-chip categories.

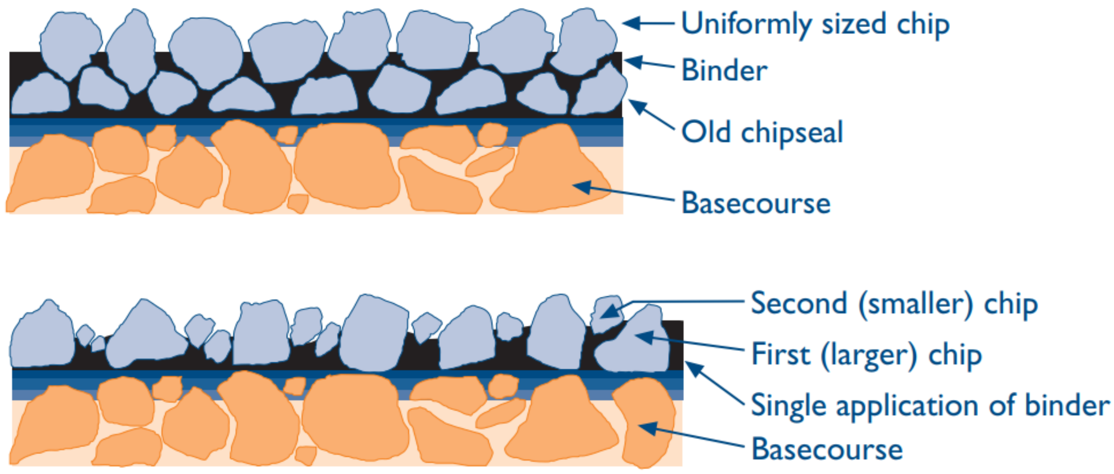

Figure 3-2: A single-chip "single coat" seal (top) and a two-chip "racked-in" seal (bottom)
image credit: Chipsealing in NZ[11]

Table 3-2 presents P1 tyre CPX noise levels, $L_{CPX:P1,80}$, averaged across all 20 m road segments within each surface type. Also included for each surface type are the noise level variability, length of the sample, average surface age, and an estimate of the average number of truck passes during the surface's lifetime.

Table 3-2: CPX results from SH1 and SH73 using P1 tyre

Surface Type	Category	$L_{CPX:P1,80}$ dB	$L_{CPX:P1,80}$ variation: 95% range dB	Total length of surface sampled km	Average age of surface years	Approx. lifetime heavy traffic million passes
Grade 3	Single-Chip	101.0	± 1.2	37.9	9	4
Grade 4	Single-Chip	100.1	± 0.8	9.9	6	2
Grade 5	Single-Chip	99.5	± 1.4	23.9	8	2
Two-coat 3/5	Two-Chip	101.2	± 1.4	57.2	9	5
Racked-in 3/5	Two-Chip	101.0	± 2.0	15.8	9	5
Sandwich 3/5	Two-Chip	101.3	± 1.3	11.7	8	4
Two-coat 2/4	Two-Chip	101.5	± 1.7	5.9	3	1
Sandwich 2/5	Two-Chip	102.1	± 1.0	7.3	12	7
SMA 10/14/15	Asphalt	98.6	± 1.0	1.6	8	3
OGPA PA-10 [12]	Asphalt	97.7	± 0.9	1.1	7	Unknown
OGPA PA-14 [12]	Asphalt	99.4	± 1.7	2.0	9	5

[11] Transit New Zealand, Road Controlling Authorities & Roading New Zealand (2005), Chipsealing in New Zealand, https://www.nzta.govt.nz/resources/chipsealing-new-zealand-manual/chipsealing-in-new-zealand.html

[12] This OGPA data is from surfaces on SH1 near Kaiapoi measured in this study, not from the Johns Road trial measured in the previous work.

The number of CPX samples collected within each category differed markedly, with the most common chipseals represented by tens of kilometres of CPX data, whereas the total across all asphalt surfaces is less than 5 km. Comparing between the different sample sizes therefore requires caution.

The average age in years of the surfaces in the survey is generally similar between the different types, which will help to reduce bias, although the average two-coat 2/4 encountered was significantly younger and the average sandwich 2/5 somewhat older. Age is only one determinant of how much wear a surface has been subjected to, so it is useful to also consider the average lifetime heavy traffic for each surface type (the right-hand column of Table 3-2). This shows considerable variation between sites. In the following analysis, CPX levels have not been corrected for either age or lifetime heavy traffic, as these effects have not been quantified for all surface types.

3.2.2 Noise emission level by surface type

Figure 3-3 presents the Table 3-2 CPX level data in a graph format, with error bars representing the 95% range of level measured within each surface type.

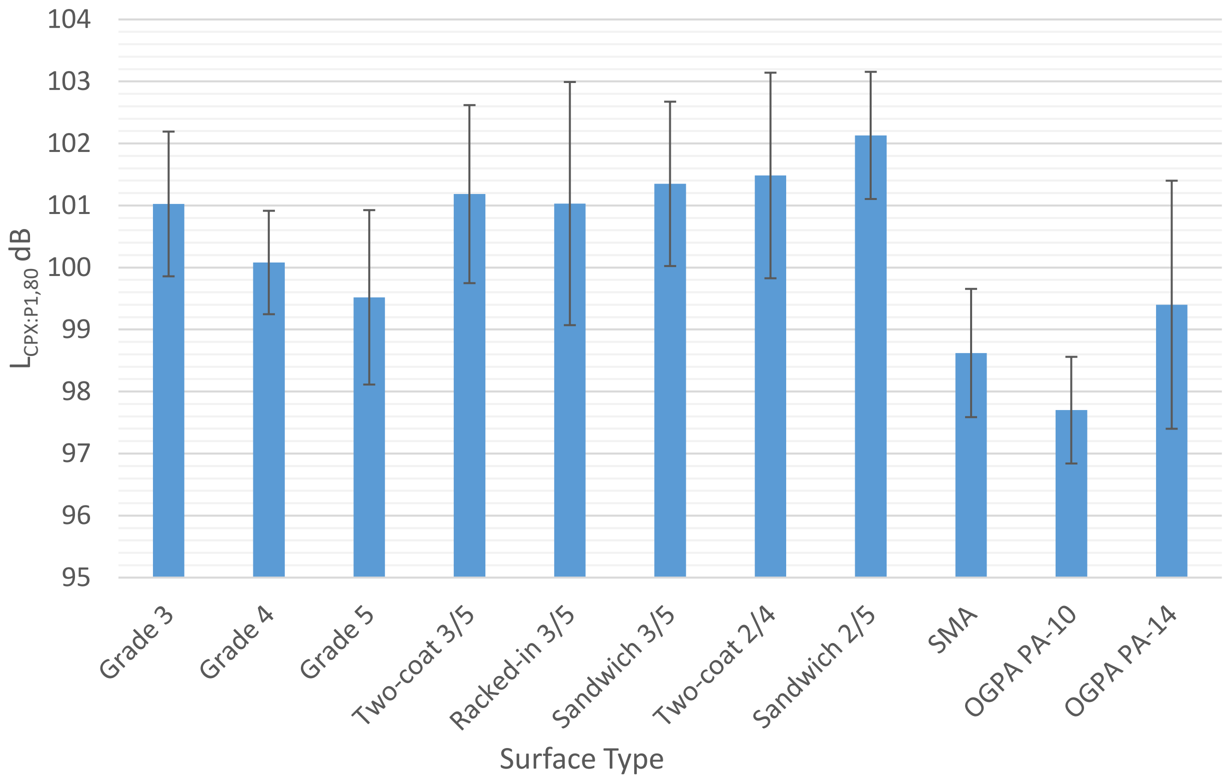

Figure 3-3: CPXP1$_{80}$ level and variability, grouped by surface type (SH1 and SH73)

Within the single-chip category, there is a clear downward stepping in noise emission with decreasing chip size (chip size decreases as the grade number increases, so a grade 1 chip is the largest and grade 6 is the smallest chip size typically used in NZ chipseals). This is consistent with the existing understanding of tyre/road noise generation from single chip surfaces, with the smaller chip size expected to produce a smoother surface (texture is examined in section 3.2.4), and lower tyre/road noise level.

The two-chip surfaces are similar in noise emission level – the means of all five types are covered by 1 dB. The three types of 3/5 surface produced very similar levels, covered by less than 0.3 dB, despite the different surfacing procedures. They are equivalent in level to the single-chip grade 3 surfaces on average. It is noted that of the five surfaces in the two-chip category, those based on the larger grade 2 chip produced the higher noise levels.

The tentative conclusions from the chipseal results are that:

1 single-chip surfaces are behaving acoustically as expected;

2 for two-chip surfaces the noise level appears to be independent of the method by which the second (smaller) chip was applied to the surface;

3 the three 3/5 two-chip noise levels are essentially the same as the grade 3 single-chip noise level.

Two hypotheses therefore arise, which would need to be tested on a broader dataset:

a) on average, the noise emission of the two-chip surfaces is dominated by the larger chip size; and more broadly,

b) the noise emission of any chipseal surface (single- or two-chip) is dictated by the largest chip size present.

No substantial lengths of grade 2 single-chip surfaces were available for CPX measurement in North Canterbury, and the only two-chip grade 2/4 surfaces encountered were newer than the other two-chip surfaces in the survey. Future CPX research should aim to fill those data gaps, and test the above hypotheses.

Only a short length of asphalt was covered by this project's survey (5 km in total), which limits confidence in how representative it may be of asphalt on the wider network. The single PA-10 site provided the lowest noise emission of the survey, as expected, with the combined SMA sites close behind. The PA-14 site was unexpectedly noisy, equivalent to the grade 5 chipseal surfaces of similar age (Table 3-2). It is not yet clear whether this surface is representative of other older PA-14 surfaces on the network or if it is an outlier.

3.2.3 Variability within a surface specification

The large volume of CPX surface data collected in this survey enables an analysis of real-world variability distinct from the analyses of the previous work which measured short-length trials of freshly laid surfaces.

The error bars in Figure 3-3 form a 95% confidence interval around the mean CPX level for each surface type (realised as $\pm 2\sigma$). This provides a meaningful metric of the amount of variability in noise emission within each surface type, as they appear in the survey. Henceforth all statements of variability will be provided at the 95% confidence level.

The single-chip seals have a typical variability in the region of ± 1 dB, and the two-chip seals showed a little more variability, in the region ± 1.5 dB on average. The most variation of the chipseals was found in the racked-in 3/5 seal, with ± 2 dB.

Within the 1.6 km of SMA-surfaced road in the survey there was representation from three SMA specifications: SMA10, SMA14, and SMA15. Despite the different specifications being combined in the analysis (to obtain a better sample size) the variability was only ± 1 dB.

The two OGPA specifications encountered had different mean noise levels (section 3.2.2) and also showed very different variability. PA-10 is made with a nominal chip size of 10 mm and PA-14 is made with a nominal chip size of 14 mm. The quieter PA-10 achieved ± 1 dB, in line with the SMA10/14/15 and the best chipseals. Variability within a single 2 km stretch of PA-14 was ± 2 dB, so while some sections of this surface were amongst the quietest in the survey, others were more typical of the loudest chipseal.

A full picture of variability within a surface type will only be complete once a diverse set of each surface (across many locations and ages) is available. Until that information is available, it would be reasonable to assume an inherent variability of noise emission of chipseals of about ± 1.5 dB, before taking type, age, traffic or condition into account. Asphalts were not the focus of this survey, but these results were consistent with previous findings that SMA has relatively low variability and OGPA potentially very high variability.

3.2.4 Correlation between noise and surface texture

Mean Profile Depth (MPD, measured in millimetres) is a standardised measurement of surface macrotexture[13], and is collected over the entire state highway network once a year by the NZTA's SCRIM truck[14]. This process uses vehicle-mounted laser profilometers aimed at the road surface – including the left wheel path, where this study's CPX measurements are made – and post-processing to determine the MPD, which represents something of an average between the highest and lowest points of the surface at the macrotexture scale (0.5 mm to a few mm).

Surface texture is a driver of tyre-road noise via several mechanisms[15], and considered the primary reason why chipseal, with its typically high MPD, is generally a noisy road surface.

MPD has been determined for each 20 m road segment of the survey from the left wheel path MPD field of the RAMM hsd_texture table. The average MPD for each surface type has been plotted against the average CPX level in Figure 3-4.

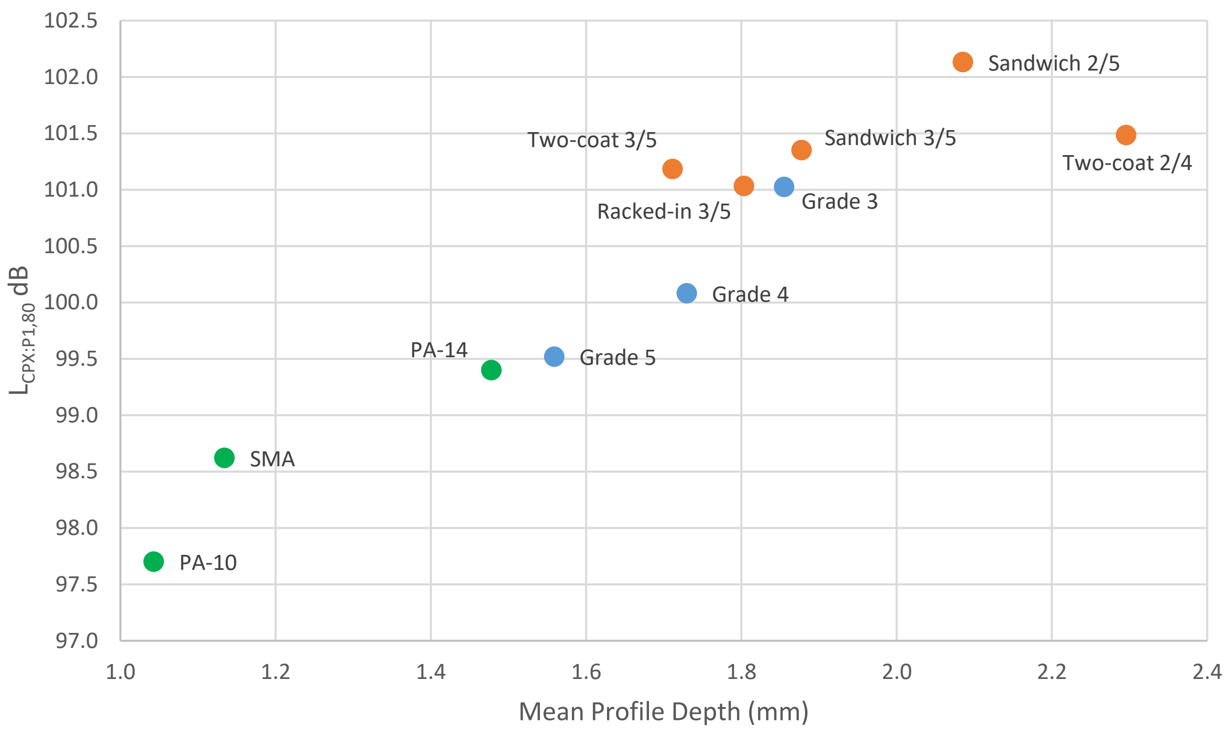

Figure 3-4: Relationship between CPXP1$_{80}$ level and average MPD, coloured by surface type

Overall, a strong, apparently linear, relationship exists between average MPD of a surface type and the average passenger car CPX level on that surface type ($L_{CPX:P1,80} \approx 3.42*MPD + 94.5$ in dB; r^2=0.87). The implication is that the texture of a surface is the dominant factor in determining its CPX noise emission level, accounting for most of the variation in levels between surface types.

The three single-chip surfaces have progressively higher MPD with increasing chip size, as expected. The steps between grades in both MPD (in mm) and $L_{CPX:P1,80}$ in dB are very even.

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[13] ISO 13473-1:2019, Characterization of pavement texture by use of surface profiles - Part 1: Determination of mean profile depth

[14] https://www.nzta.govt.nz/roads-and-rail/road-composition/pavement-condition-surveys/

[15] Sandberg & Ejsmont (2002), Tyre/Road Noise Reference Book, Informex, Sweden, pp.95

The linear relationship appears to hold even for the OGPA surfaces. MPD measurement on negative-texture surfaces such as OGPA is usually treated with caution because the geometry of the measurement process is such that the laser does not necessary reach the bottom of the troughs. However, it appears that from a noise-generation perspective, the existing SCRIM truck profilometer produces useful texture measurements on OGPA.

The positive-sloped relationship appears to break down when considering only the two-chip surfaces. Despite a large difference in average MPD, there is only a small range in average CPX level.

Within each surface type, the correlation between MPD and $L_{CPX:P1,80}$ across the 20-metre-long road segments is generally weak, with MPD typically accounting for 0% to 30% of the variation. Therefore, despite the strong correlation at the surface type level that proves a relationship exists, it would not be appropriate to use the SCRIM truck texture data alone to estimate noise emission levels for any given section of road – the CPX trailer will be required to do that.

3.3 CPX vs Wayside SPB

Five sites were surveyed by CPX paired with measurements at the wayside (Table 2-1), using the statistical pass-by (SPB) methodology outlined in section 2.3.

3.3.1 P1 tyre

The previous study found that the CPX ranking of six OGPA road segments was the same as the SPB ranking, and furthermore, that there was a strong linear relationship between the two measurands. The same process has been undertaken for chipseal, this time using a weighted average to determine an equivalent CPX level for the 20 m long segment of road adjacent to each SPB survey site. Figure 3-5 presents $CPXP1_{80}$ level on the horizontal axis and the SPB L_{veh}(cars) on the vertical axis, for each of the five survey sites. The error bars represent the uncertainty of measurement at 95% coverage.

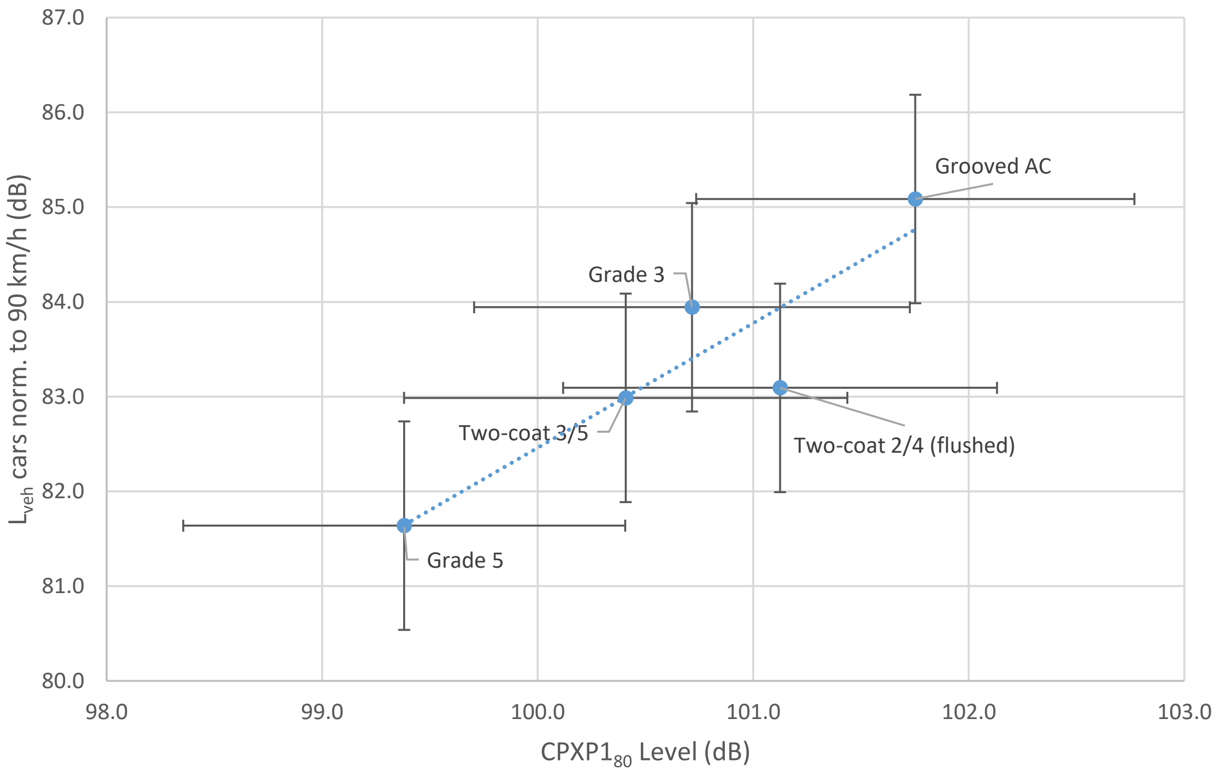

Figure 3-5: Relationship between $CPXP1_{80}$ and wayside passenger car noise levels (at 90 km/h)

A linear least-squares regression across the coordinates representing the five sites provides a reasonable correlation between the two measurement techniques ($SPB_{cars,\ 90\ km/h} \approx 1.31^{*} L_{CPX:P1,80}$ - 49.0; $r^2 = 0.82$; $p < 0.05$). The coefficients of the line equation also depend on the choice of target vehicle speed for the SPB speed correction (section 2.3.2), in this case 90 km/h, the average measured car speed across all sites.

The previous work with OGPA trial sites found a slope closer to unity but it is noted that the measurement uncertainties are slightly higher in this study (section 2.3.3) and the data are far more clustered (a CPX level range of just 2 dB compared to 10 dB for the OGPA study) which leads to a large uncertainty in the slope: m = 1.3 ± 0.7 at the 95% level. This indicative regression has been based on the means of the CPX and SPB levels, but once more data pairs are available, the regression should also take the uncertainty distribution of each pair into account.

The two-coat 2/4 coordinate is probably biased, because it was noted during the SPB survey that lane-keeping at this site was more variable than at other sites (it was on the inside of a slight curve) and the surface was badly flushed within the left hand wheel path, and less flushed to either side. The CPX trailer was driven to maintain a neutral road position between the centre- and edge-lines, and is likely to have measured a less flushed portion of the road than traversed by most of the car pass-bys, which typically hugged the edgeline where the flushing was stronger. This would have the effect of shifting the coordinate down and/or to the right from where it might otherwise have been.

The noisiest site on SH73 for both CPX and SPB was a short stretch of transverse-grooved asphaltic concrete (site 5 in Table 2-1). The transverse grooves were not observed by the CPX trailer operators and were only apparent once the operators were stopped and looking directly across the road. The presence of the grooves is not indicated in the RAMM data or identifiable from Argonault RoadRunner[16] photos, so caution will always be required when interpreting CPX results on nominally AC surfaces.

Overall, the indication is that a linear relationship exists between the $CPXP1_{80}$ level and the wayside $L_{veh(cars)}$ level on chipseal, but additional data pairs would be required to quantify the relationship with confidence.

3.3.2 H1 tyre

CPX with the H1 tyre is intended to provide an indication of the performance of a surface under heavy vehicle traffic, according to ISO 11819-2. Figure 3-6 presents $CPXH1_{80}$ level on the horizontal axis and SPB L_{veh}(trucks) level (category 2a and 2b combined) on the vertical axis, for each of the five survey sites. The error bars represent the uncertainty of measurement at 95% coverage.

[16] https://roadrunner.argonautltd.co.nz

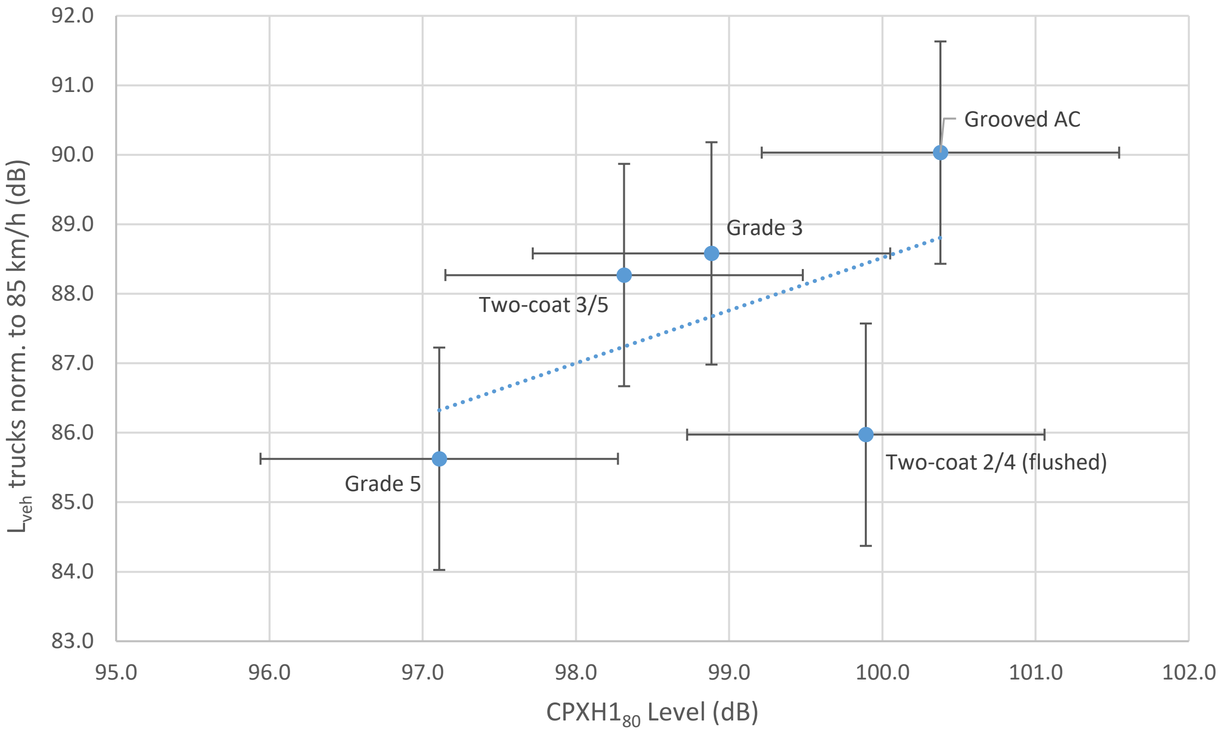

Figure 3-6: Relationship between CPXH1$_{80}$ and wayside truck noise levels (at 85 km/h)

In this case, performing a linear least-squares regression across the five sites does not reveal a statistically significant relationship ($SPB_{trucks, 85 km/h} \approx 0.76^* L_{CPX:H1,80} + 12.6$; $r^2 = 0.28$; not significant at $p < 0.05$). It is likely that a sample larger than five sites and the removal of the potentially biased 'two-coat 2/4' coordinate (see section 3.3.1) would result in statistical significance. However, as discussed for the OGPA study[4], the H1 measurements are of less practical value than the P1 measurements due to the fact that heavy vehicle noise is less influenced by the surface than passenger cars and heavy vehicle passes are generally less frequent.

3.3.3 Combine with previous study

The previous study collected SPB data at six OGPA sites, so the combined dataset now consists of eleven CPX + SPB pairs. As discussed in section 2.3.2, there is a range of ambient temperatures and traffic speeds across the eleven sites. A temperature correction to the SPB data has been employed, and all SPB car levels are corrected for an 80 km/h target speed for a like-for-like comparison with the OGPA data (Figure 3-7).

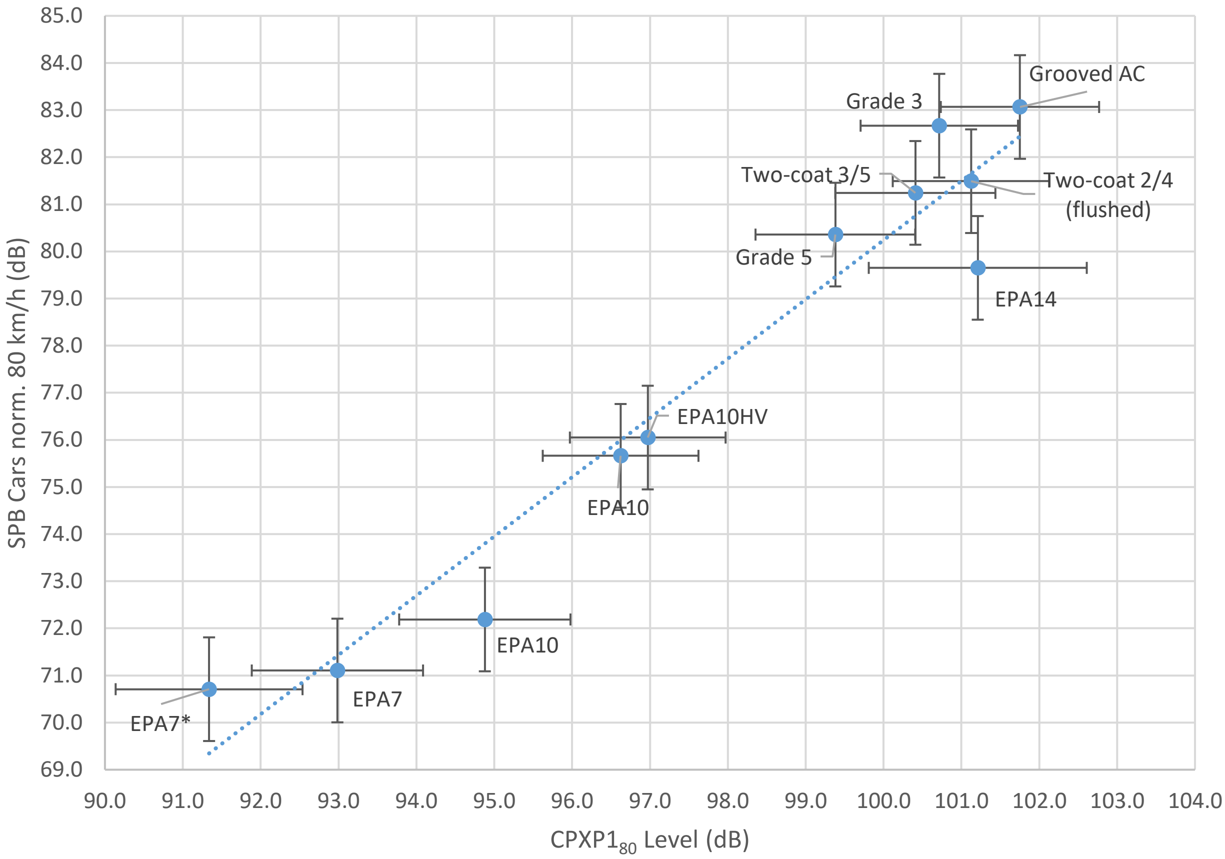

Figure 3-7: Relationship between CPXP1$_{80}$ and SPB(cars) across eleven sites (at 80 km/h)

A linear least-squares regression across the eleven coordinate pairs reveals a strong correlation between the two measurement techniques ($SPB_{cars,\ 80\ km/h} \approx 1.26 {*} L_{CPX:P1,80} - 45.5$; $r^2 = 0.94$; $p < 0.05$). The probability distributions of each pair are not the same size, nor are the CPX levels evenly or randomly distributed along the *x*-axis (they arise from the choice of SPB site), and therefore the line-of-best-fit presented here is only indicative. However, the linear relationship between CPX measurements and the wayside SPB noise level is seen to generally hold across various surface types and surface conditions, with CPX level predicting over 90% of the variation in wayside level within the combined surveys.

The slope of m = 1.3 ± 0.2 deviates significantly from unity, and implies that the CPX trailer may under-represent the actual difference in wayside noise level between different surfaces. Some of the deviation from unity probably relates to the different SPB vehicle speeds between survey sites, and some may result from how the noisiest surfaces were from a different survey at a different time of year (i.e. not all points are subject to the same systematic error). It is possible that there is also a contribution from acoustic absorption by the shoulder on OGPA-sealed roads. The relationship between CPX level and wayside noise level over a wider range of surface types, conditions, and speeds will need to be understood before the CPX trailer is exclusively relied upon to predict changes in wayside noise levels.

Repeating the regression for the combination of the H1 tyre and truck pass-bys does not result in a statistically significant linear relationship between the CPX level and the SPB level.

3.4 Road Surface Types

3.4.1 Road Surface Corrections

In NZ, noise modelling is used to assess the noise impact of new roads and alterations to existing roads. One of the key inputs to the modelling process is the *road surface correction*[17], given in decibels, which accounts for the particular surface type on each modelled road.

Currently the road surface correction is based on a large number of SPB-type surveys[18], but it inevitably suffers from the fact that only a few short examples of each surface type were included in producing an indicative value for all surfaces of that type. As discussed previously[4], the CPX trailer may represent an accurate and efficient means of updating the NZ road surface corrections.

Subject to several provisos, it is possible to use the CPX data from SH73 and SH1 to produce a limited set of road surface corrections as a proof-of-concept (Figure 3-8). The limitations and caveats to this process are significant and are presented upfront:

- The corrections here are not made against the traditional reference surface of AC-10, as no un-grooved AC was available. Rather, they are calculated for each surface relative to CPX-measurements of SMA (which shares many structural similarities to AC), and then the NZTA guide's[17] AC-10 to SMA correction of +1.5 dB is added.
- The CPX level has not yet been established as a reliable indicator of the wayside level on all road surfaces, and it is the wayside level that is modelled and assessed for the impact of new roads and alterations. For example, OGPA appeared to be 1:1 between CPX and SPB[4], whereas Figure 3-5 indicates a 4:3 relationship between CPX and SPB on chipseal. The road surface corrections presented in Figure 3-8 are for CPX level only, with no correction made for the equivalent wayside levels.
- No attempt has been made to account for the age, condition, or trafficking of each of the surfaces, and Table 3-2 demonstrates that the grouping of surveyed road segments by surface type does not result in evenly sized or equivalently aged samples. Many of the two-chip surfaces on SH73 in particular were badly flushed.
- Some effort has been made to remove non-representative sections of surface from the analysis (e.g. bridges), but the dataset is mostly un-curated and some inherited errors from RAMM are inevitable. For large sample sizes the arithmetic average will reduce those errors to negligible levels, but for smaller sample sizes they may be significant.

The proof-of-concept corrections calculated from the CPX data are presented alongside the existing corrections from table 2.1 of the NZTA guide[17] in Figure 3-8.

[17] NZTA, Guide to state highway road surface noise, Table 2.1, p.36

[18] Dravitzki, V., Kvatch, I. 2007. Road surface effects on traffic noise: stage 3 – selected bituminous mixes. Land Transport New Zealand Research Report 326

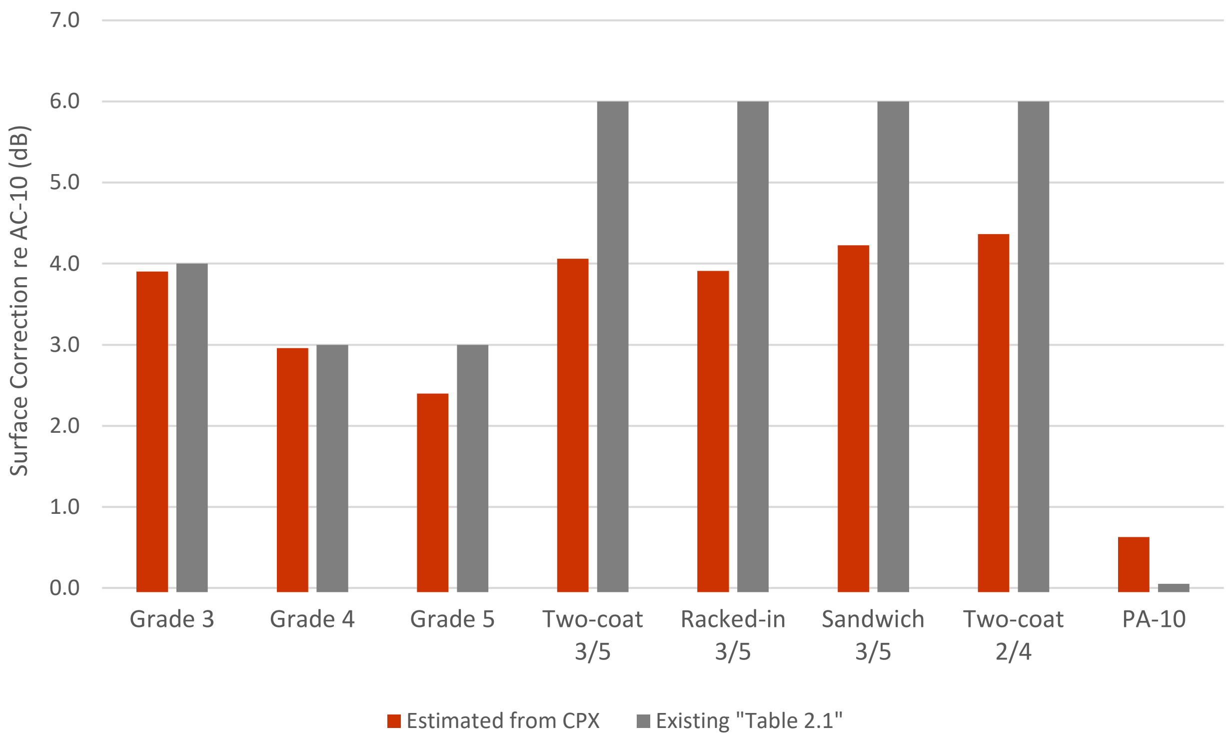

Figure 3-8: Proof-of-concept road surface corrections from CPX data

Keeping the caveats in mind, the comparison between the newly measured and the NZTA guide surface corrections is none-the-less very good for the single-chip surfaces, which all had several kilometres of CPX data to draw from.

The two-chip surface corrections from this study's CPX measurements were all approximately 2 dB below where the NZTA guide corrections table would have placed them. Many of the 3/5 surfaces on SH73 were noted as moderately to heavily flushed along their full lengths during the CPX survey, implying a loss of texture, and possibly diminishing their noise emission (see section 3.2.4) and accounting for some of the reduction in road surface correction. However, most of the SH1 surfaces were not badly flushed, and in particular the 6 km of two-chip 2/4 that was surveyed was not visibly flushed and had an average age of only 3 years, meaning flushing is unlikely. Therefore, these early chipseal data suggest that the NZTA guide corrections may not be representative of two-chip surfaces on at least North Canterbury's state highways, and potentially all of NZ's state highways.

The estimated correction for PA-10 is fairly close to the value provided by the NZTA guide. The guide doesn't provide a correction for PA-14 or for two-coat 2/5, so those surfaces are not represented in the figure, but this highlights another benefit of the CPX methodology: the possibility to define corrections for a broad selection of surfaces is far more feasible using CPX than using SPB.

3.4.2 Spectra

In addition to logging the overall sound level, the CPX trailer also collects 1/3 octave band spectra between 315 Hz and 5000 Hz. Spectra can be useful in describing the "nature" of the road noise emission; beyond just low loud it is.

It is not intended here to perform a comprehensive spectral analysis, just to illustrate the depth of data contained in the CPX database. Figure 3-9 presents the arithmetically averaged spectra over all surveyed examples of five common surface types based on grade 3 and/or grade 5 chip (using P1 tyre data only).

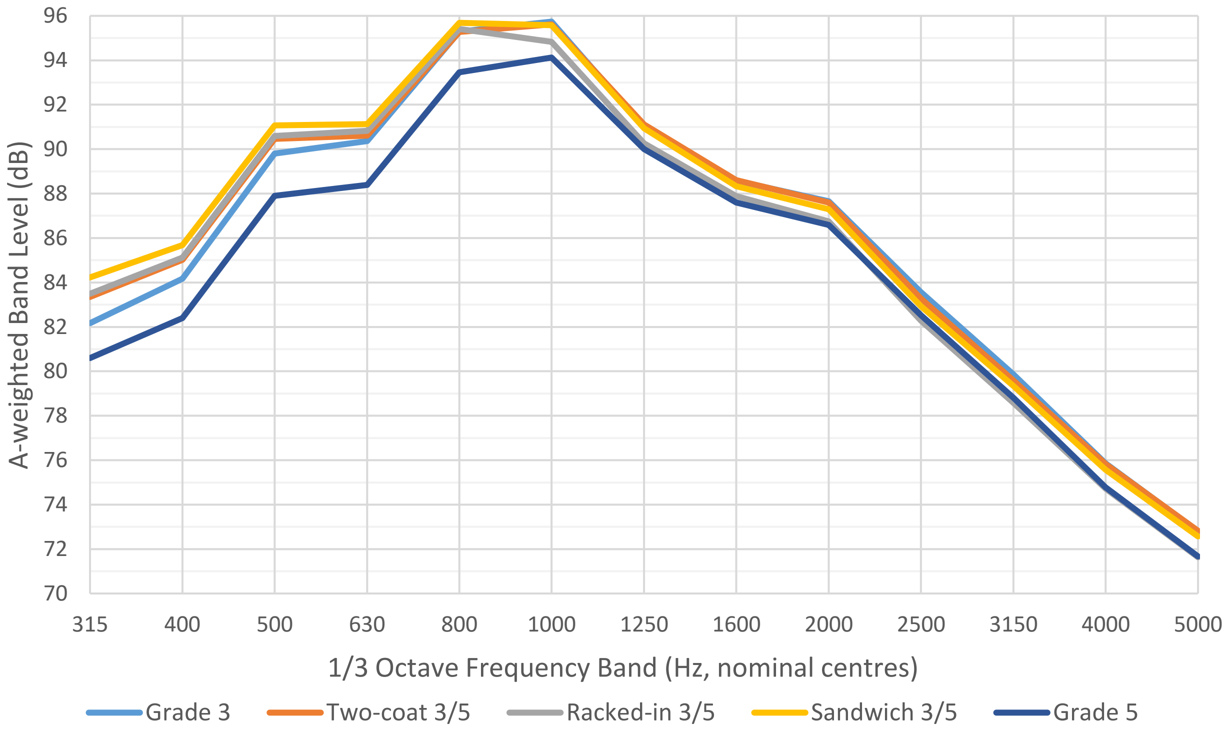

Figure 3-9: Average spectra for five chipseal types (P1 tyre)

The nearly identical spectra of the grade 3 and the two-chip 3/5 surface types is striking, particularly above about 500 Hz. This is further evidence that the acoustic behaviour of the two-chip surfaces is dominated by the larger-sized chip, in this case a grade 3 chip.

The grade 5 spectrum maintains a nearly identical profile to the grade 3 spectrum (dark and light blue, respectively) but appears shifted downwards by 1 – 2 dB.

The racked-in 3/5 (grey) behaves like the other two-chip seals up to 800 Hz, in that it is similar to the single-chip grade 3. Above about 1250 Hz it behaves more like the grade 5 chipseal. The difference is only about 1 dB in any given band, so it is not likely to have any practical implications, but it is interesting that it is the only two-chip surface type to mimic the smaller chip size over any portion of the frequency range.

The CPX survey also included short sections of asphalt, and indicative spectra for those are contrasted with the grade 5 chip spectrum in Figure 3-10.

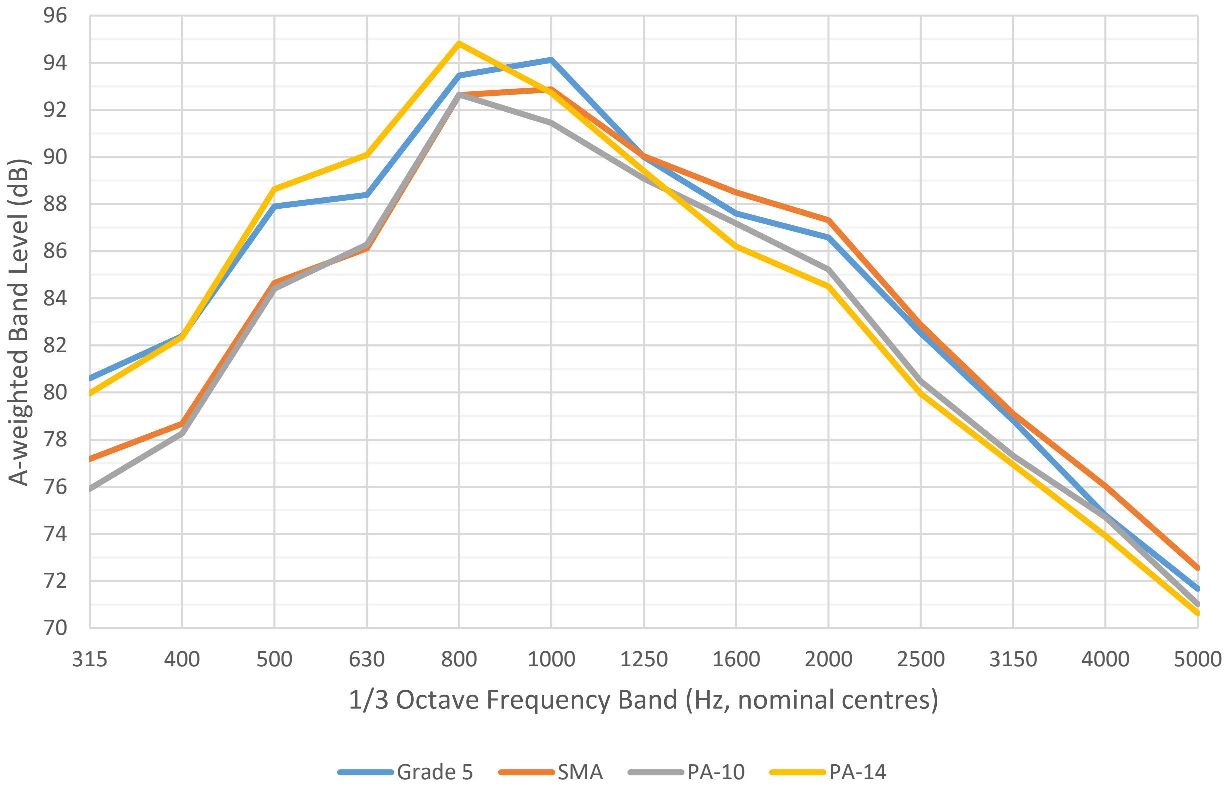

Figure 3-10: Average spectra of asphaltic surfaces (P1 tyre)

While there appears to be a characteristic shape for the chipseals, with a broad peak in emission spanning the 800 Hz and 1000 Hz 1/3rd octave bands (Figure 3-9), both examples of OGPA in Figure 3-10 show a single strong peak at 800 Hz and a steady decline in emission level with increasing frequency. The PA-10 has a lower emission than the quietest chipseal (grade 5) in every band.

The 2 dB difference in the PA-10 and PA-14 $L_{CPX:P1,80}$ noise levels discussed in section 3.2.2 arises almost entirely from the difference in the peak emission at 800 Hz, but it is interesting to note the different shapes of their spectra before and after the peak. The difference is up to 5 dB in the low frequencies, while the two curves are almost identical above 1250 Hz.

SMA spectra averaged across the three specifications very closely mimick PA-10's low emission properties up to 800 Hz, but the SMA has a broad peak similar to the chipseals, and more closely matches the grade 5 chip behaviour in the high frequencies.

The tonality of different road surface types does not currently factor into road surface decisions, but there is some indication that it plays a part in annoyance[19]. The spectra can also assist in understanding noise mechanisms and should be included in any future CPX study that considers road surface condition or aging effects.

[19] Dravitzki, Walton & Wood, Road traffic noise: determining the influence of NZ road surfaces on noise levels and community annoyance, LTNZ research report 292, 2006

4 Conclusions

4.1 Key Findings

The key findings from this study are summarised below, with reference to the relevant section of the report.

4.1.1 CPX measurement repeatability

Three repeated trips along SH73 from Yaldhurst to Springfield and back with the CPX trailer using the P1 tyre allowed a value to be placed on the typical repeatability of the CPX measurement system in the context of chipseal measurement (section 3.1.1). The typical random variation about the mean at the 95% level of confidence for CPX chipseal measurements is of the order of ± 0.5 dB for a single run, which can be further reduced to ± 0.3 dB by averaging levels over three repeated runs.

4.1.2 The P1 ranks surfaces equivalently to a 'typical' NZ car tyre

Although the P1 tyre is atypical of NZ car tyres in its dimensions, a comparison of CPX results between the P1 and a 'typical' Supercat tyre[4] on chipseal has verified that the P1 responds to the differences between common chipseal and asphalt surfaces in a similar way as the 'typical' Supercat (section 3.1.2). It is recommended that the P1 specification tyre be retained as the NZTA's primary tyre for passenger car CPX measurements.

4.1.3 CPX levels of chipseal 'in the wild'

CPX data from the 250 km of North Canterbury state highway covered during the survey represent the first significant measurements of NZ chipseals 'in the wild'. The data were grouped by surface type, and the average noise emission of each surface type determined (section 3.2.2). Grade 3 chipseal averaged 101 dB $L_{CPX:P1,80}$, while grade 4 and grade 5 were 1 dB and 1.5 dB quieter, respectively. All three two-chip surfaces that were based on a grade 3 chip exhibited the same noise level as the grade 3 chip on its own, with the two-chip surfaces based on a grade 2 chip just slightly louder than those based on a grade-3 chip. The asphalts from quietest to loudest were: PA-10 (at 97.5 dB $L_{CPX:P1,80}$), SMA, and PA-14. The PA-14 was a similar CPX level to grade 5 chipseal.

These early chipseal results suggest a hypothesis: is the noise emission of any chipseal surface (single- or two-chip) dictated by the largest chip size present?

4.1.4 Variability within a surface specification

The large quantity of CPX surface data collected for this study enabled an analysis of real-world variability within each surface type that has not previously been possible (section 3.2.3). The single-chip seals had a typical variability in the region of ± 1 dB and the two-chip seals in the region of ± 1.5 dB. Data for asphalt surfaces was limited, but SMA and PA-10 were each within ± 1 dB, while PA-14 was a relatively high ± 2 dB (Figure 3-3).

A full picture of variability within a surface type will only be complete once a diverse set of each surface type (across many locations and ages) is available. Until that information is available, it would be reasonable to assume an inherent variability of noise emission of chipseals of about ± 1.5 dB, before taking type, age, traffic or condition into account.

4.1.5 Correlation between noise emission level and surface texture

Mean Profile Depth (MPD, measured in millimetres) is a standardised measurement of surface macrotexture. By combining RAMM texture data with the CPX dataset, it was observed that high MPD is a strong predictor of high CPX levels for a surface type (section 3.2.4). This held across all surface types, including OGPA (with its so-called 'negative texture'), although there were indications that the relationship is weaker for the two-chip surfaces. One observation is that MPD was able to correctly place PA-14 as equivalent to a grade 5 surface (in terms of noise emission level), despite these surfaces being in different categories of asphalt and chipseal, and negative and positive texture (Figure 3-4).

4.1.6 Correlation between CPX and the wayside noise level

Statistical pass-by (SPB) surveys were paired with CPX measurements at five sites with the aim of determining whether CPX levels measured along a chipseal road are indicative of the wayside traffic noise levels.

In contrast to the previous study on OGPA, the range of noise levels is highly clustered, leading to higher uncertainties. Overall, the indication is that a linear relationship exists between the $CPXP1_{80}$ level and wayside passenger car levels on chipseal (section 3.3.1), but additional data pairs would be required to quantify the relationship with confidence.

No significant linear relationship could be found between the H1 tyre and wayside heavy vehicle noise (section 3.3.2).

When the chipseal data was combined with the OGPA data from the previous study, and temperature and speed corrections were applied, a strong linear correlation was found, with a slope of m = 1.3 ± 0.2 (section 3.3.3). This deviates significantly from unity, and implies that the CPX trailer may under-represent the actual difference in wayside noise level between different surfaces. The relationship between CPX level and wayside noise level over a wider range of surface types, conditions, and speeds will need to be understood before the CPX trailer is relied upon exclusively to predict changes in wayside noise levels.

4.1.7 Road surface corrections

Corrections in decibels for each surface type are a fundamental part of road-traffic noise assessments, and the CPX trailer may provide the best means of revising the current NZTA road surface noise guide values[17], which were based on SPB measurements. Using several approximations, it was possible to show a proof-of-concept set of road surface corrections derived from CPX data (Figure 3-8).

While there was good agreement between the guide's corrections and the CPX corrections for all single-chip surfaces and OGPA PA-10, the CPX corrections for the four two-chip surfaces were consistently lower than the guide's correction by about 2 dB (section 3.4.1). Surface flushing may contribute to some of the discrepancy, but the suggestion from this early data is that the existing corrections for two-chip seals may not be representative of surfaces on at least North Canterbury's state highways, and potentially all of NZ's state highways[20].

4.1.8 Road surface spectra

The average frequency spectra of eight different road surface types have been examined. The chipseal spectra were easily distinguishable from the OGPA spectrum by shape (section 3.4.2). The grade 3 and two-coat 3/5 spectra were nearly identical, lending credence to the theory that noise emission characteristics can be attributed to the largest chip present in the surface.

4.2 Observations and Lessons

Issues relevant to future work have been identified through undertaking this study and the previous work.

4.2.1 Difficulty in identifying surface treatments

It is very difficult to visually identify surface treatments (such as transverse grooves) whilst travelling at highway speed or from onboard footage. Unfortunately, RAMM is also unreliable when it comes

[20] If a broader study found this conclusion to be true, the implication for road noise assessments of new roads involving two-chip seals is that they would err in the conservative direction, potentially resulting in less community noise exposure than expected.

to surface treatments in particular. Roadside inspection is probably required for surfaces that may commonly undergo surface treatment, such as AC.

4.2.2 Traffic management requirements for wayside measurements

Following the survey work of this report (March 2019), the NZTA introduced upgraded safety requirements for all work activities occurring within the highway corridor, which includes SPB measurements. It will no longer be possible to conduct SPB measurements using the current procedure, as this requires the operator to come within 5 m of the side of the road, which then triggers a temporary speed restriction requirement, which would render the measurement meaningless. It should be possible to place a speed restriction on a site during the equipment set up, and then remove the speed restriction while performing the survey at a distance further from the road, but this is likely to have a significant effect on cost and the number of SPB surveys that could be completed in a day.

4.2.3 Quality and quantity of CPX data

There is far more information in the combined 250 km long CPX – RAMM dataset than analysed within the scope of this project. Similarly, there is more data than can be thoroughly checked for accuracy, particularly the RAMM data with its known weaknesses. This exploratory project acts as a proof-of-concept that the combination of the two data-sources is possible for long lengths of highway (in this case 250 km) and can produce meaningful results.

Achieving accuracy in future studies will also need to find a balance between careful filtering of data and relying on the statistical power of large volumes of data. Care needs to be taken in how much granularity in results can be achieved whilst still maintaining a large and representative sample.

Future project objectives will also need to be quite explicit about what is required from the analysis, and what is not, to avoid scope-creep. This study has indicated that the measurement procedure is efficient but capable of gathering, in a short time, a quantity of data that will take a long time to process, analyse, and report on.

4.3 Recommendations

These recommendations mostly relate to improvements that could be made to the methodology to the benefit of future similar CPX studies.

4.3.1 Introduce a verification surface to the CPX measurement procedure

The previous study revealed evidence of a shift in the sensitivity of the CPX trailer on the order of 1 dB over a year, and potentially even greater going back several years. Microphone sensitivity should be verified before each run using a microphone calibrator, as per the current procedure, but also a method to verify the operation of the whole measurement system should be found and executed regularly. A short section of a stable surface near where the CPX trailer is stored (the CAPTIF facility in Christchurch) should be used as a verification surface before each survey to provide a field-check of the consistency of the entire CPX system. Verification need not be run at 80 km/h, the surface and procedure only need to provide fairly consistent noise generating properties over time.

AC-10 may be a good surface choice because it is a long-life surface, has a very low surface texture (therefore low wear), is very strong, and is already the NZ reference surface for noise. It may be necessary to consult with the local road controlling authority to determine a stretch of AC that is not due to be resealed for a long time, and when eventually resealed, will remain as the same specification of AC. Alternatively, a private surface might be found (e.g. there are several airports and a racetrack within a few minutes of CAPTIF). A concrete surface may also be a good option.

4.3.2 Identify the best and worst performing road sections

Once a larger dataset of surfaces has been assembled, it may be useful to use the CPX data to identify the best and worst examples of each surface type (where there is a big range). A site inspection of these surfaces may provide evidence on the causes, and potentially inform steps to avoid the worst acoustic behaviour in future, or to move the average surface closer to the best-in-category. This may advise improvements to either the specification or the surfacing process.

4.3.3 Age and traffic effects

A cursory investigation of surface age and traffic effects determined that the current dataset was probably too small and too focused on the North Canterbury region to warrant an in-depth analysis. Once a larger dataset has been assembled, featuring data from outside of the region, it might be analysed to extract an indicative relationship between acoustic performance and chipseal age. This information would be invaluable in determining a nominal value to be used in any future revision to the road surface corrections.

4.3.4 Measurements on AC-10

No examples of the current NZ reference noise surface were available in the survey area, and therefore the proof-of-concept road surface corrections in this study were calculated indirectly from SMA. Any future study should endeavour to find at least one 200 m long stretch of AC-10 (DGA-10), but preferably several. This will be complicated by the surface not being used on high speed roads. A private road or significant traffic management may be required to operate the trailer at 80 km/h. Alternatively, a separate trial of several surfaces at 50 km/h could be undertaken to tie all results back to the reference surface, if a suitable AC-10 section with a 50 km/h speed is located.

As all NZ research on road surface noise to date has been conducted using AC-10 as a reference, and the “NZ adjustment” to CRTN is based on this surface, it will be essential to conduct some CPX measurements on this surface and this should be given priority in future work.

4.3.5 Automatic data cleansing at time of capture

As discussed above in section 4.2.3, the quantity of data the CPX is capable of collecting makes ensuring a high level of data quality very time consuming. It would be a net time saving if the measurement system itself was more discerning in what data it captured, or marked as valid, even if this slightly reduced the overall quantity of data collected. One suggestion would be to use a trailer-mounted accelerometer to reject CPX measurements made when acceleration passed some threshold. This could be set to a level that would exclude most bridge joints and bumps in the road that might generate noise on the microphone either through suspension compression or shock to the microphone casing or wiring.

4.4 Further work

The results of this study suggest several areas of future work.

4.4.1 Two-chip surfaces

The early indication from this initial North Canterbury CPX survey is that noise emission from the two-chip surfaces may have been over-estimated in the past. A broader sample of these surfaces should be obtained, including North Island sites, with a view to determining if the corrections in the NZTA road surface guide[17] need to be revised.

4.4.2 Grade 2 chipseal

No substantial grade 2 single-coat surfaces were available in North Canterbury, and the only grade 2/4 surfaces encountered were considerably newer than the other surfaces in the survey. Future CPX research should aim to fill those data gaps, and test the hypothesis that the largest chip size present dominates the noise emission of the surface (for two-chip chipseals).

4.4.3 The effect of tonality in road noise annoyance

There is evidence from both NZ and overseas research that the tonality of road noise affects community annoyance[19,21]. In particular, there is a suggestion that the low frequency content of the noise may have a greater effect on perception of loudness than the A-frequency-weighting would indicate. The spectra in Figure 3-10 imply that asphalt has a substantial advantage over chipseal at low frequencies, and that CPX is an effective way of measuring this on real world surfaces. Investigating the effect of tonality on road noise annoyance, specific to NZ surfaces, could provide valuable information on which surface types will minimise community annoyance to noise, beyond just comparing A-weighted noise emission values.

4.4.4 Appropriateness of using CPX to determine road surface noise corrections

This study of chipseal, along with the previous study on OGPA, have indicated that a linear relationship exists between CPX P1 measurements and wayside passenger car noise levels (section 3.3.3). However, the current sample size of 11 sites is insufficient to establish the exact nature of that relationship without a considerable associated uncertainty. There is also some evidence that the slope of the relationship is different on OGPA than it is on chipseal, which might be a P1 tyre effect.

Further work should be done to quantify the relationship to the extent that the CPX P1 data can be used to accurately reflect the wayside noise levels. Once that relationship is established, the benefit of any surface specification change could be demonstrated without SPB surveys.

The key data that are missing are existing in situ examples of SMA, at least one slurry, non-grooved AC (if available), OGPA, and more examples of chipseal. It would be advantageous to find both very quiet and very noisy examples of chipseal to extend the range over which the regression can operate. The CPX-SPB pairs should include sites from outside of North Canterbury. At a rough estimate, an additional 10 or so CPX–SPB pairs would be required to adequately define the relationship(s) for chipseals and asphalts.

4.4.5 Revise road surface noise corrections

In the previous study it was suggested that the CPX trailer may be an effective way to collect data to support a revision of the NZ road surface noise corrections table. The current study reinforces that view, and has shown proof-of-concept corrections for passenger cars in Figure 3-8.

For corrections derived from CPX data to be valid and representative:

1 the relationship to wayside noise would need to be fully quantified (section 4.4.4)

2 the dataset would need to be expanded to include more examples of each surface type from a wider range of regions

3 there would need to be measurements of the AC-10 reference surface (section 4.3.4)

It is likely that the speed correction given in the NZ road surface guide will remain applicable, at least as long as CRTN is in common usage, but some thought should be given to whether it is necessary to collect CPX results at 50 km/h in addition to 80 km/h to validate this (and this may be required to locate an appropriate AC-10 anyway).

4.4.6 Road surface noise contribution from trucks

This study did not find any statistically significant relationship between CPX with the H1 tyre and the wayside level from truck pass-bys, either for the chipseal data on its own or combined with the OGPA data from the previous study. If the H1 tyre does not correlate with wayside truck noise level then it should not be used to evaluate the performance of road surfaces or to populate the heavy traffic portion of the road surface corrections table. It should be investigated whether there are any modifications to the measurement or processing methodology that could recover some value

[21] Sandberg & Ejsmont (2002), Tyre/Road Noise Reference Book, Informex, Sweden, pp.515-521

from the H1 CPX tyre, or whether an alternative way of determining the heavy vehicle contribution needs to be found.

Appendices

Appendix A: Site Selection

To determine the feasibility of using North Canterbury as the survey location for the CPX chipseal measurements, a desk-based scoping study was completed. It was found that the region has a number of attributes that make it an excellent site for both CPX and SPB measurements.

- The climate in March & April is generally favourable for CPX and outdoor noise measurements.
- The CPX trailer and experienced operators are already based in Christchurch.
- The roads have diverse surface types and ages (from RAMM surface data)
- The surfaces used on North Canterbury state highways appear to be representative of those used throughout the rest of the country.
- There are a number of long, straight, flat, and 'low congestion' roads that are suitable for both CPX and wayside noise measurement.
- RAMM data indicates that the amount of bumps on the road, which might damage the trailer, is not excessive.

Avoidance of Bumps

Large bumps in the road could potentially damage the CPX trailer, which sits low to the road surface in its operating mode. Until there is more experience running the trailer on the road network a cautious approach was necessary. A map of bumps was generated based on RAMM's left-wheelpath and right-wheelpath bump parameters (Figure A-1).

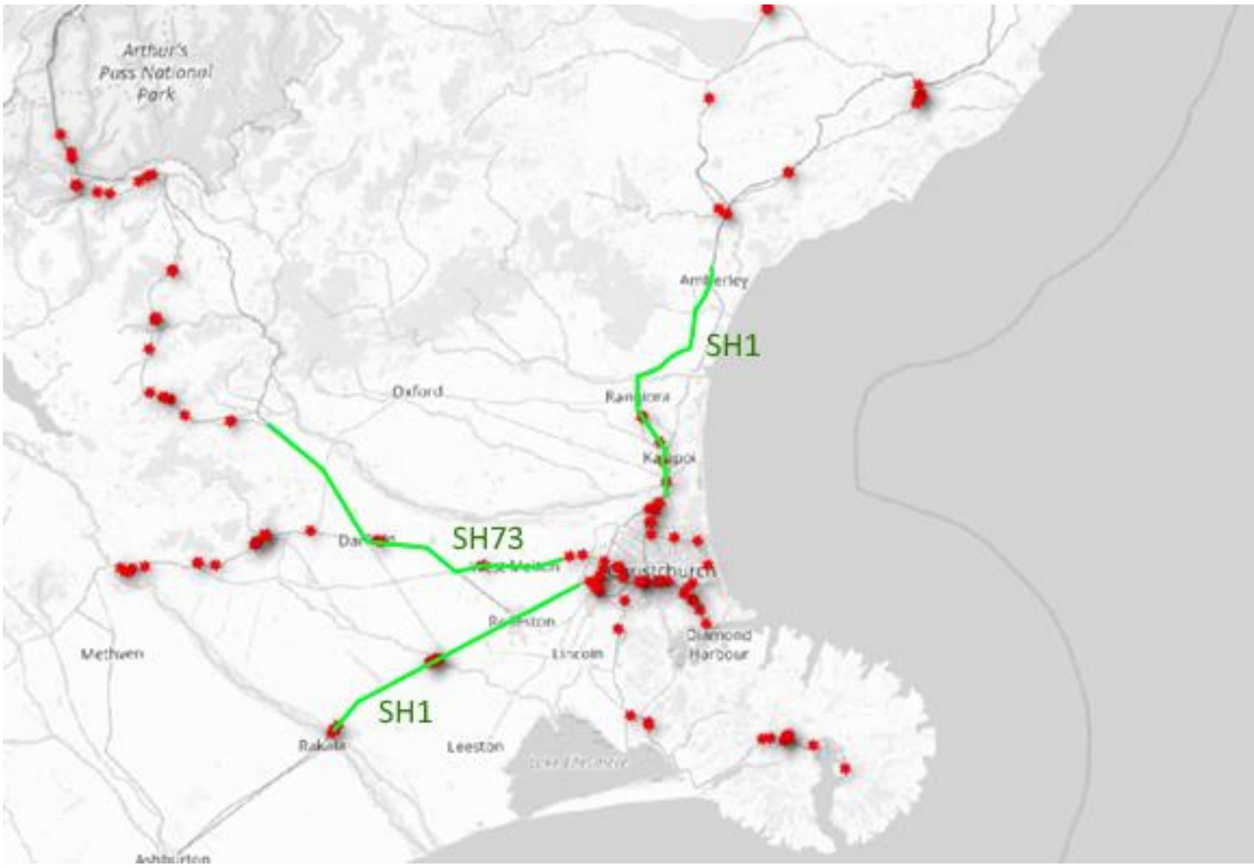

Figure A-1: North Canterbury bump map (red spots) with CPX routes in green

SH1 is generally free of bumps between Rakaia in the south and Waipawa in the north, with the exception of some bridges and through Christchurch City. SH73 is generally good between Yaldhurst and Springfield. This also corresponds to the flattest areas of state highway.

During the survey there were no issues with striking bumps in the highway, and the bump avoidance described here could be relaxed for future surveys.

Surface Types

The research objectives require a sample of several chipseal surface types, so the selection focuses on those types that are most prevalent. The laid length of each of the most common types of road surface in the North Canterbury NOC[2], by lane-kilometre, are given in Table A-1.

Table A-1: Prevalence of surface materials in North Canterbury NOC (Feb 2019)

Rank	Surface Type	Approx. Length (lane km)
1	Two-coat 3/5	341.8
2	Grade 3	173.0
3	Grade 5	146.3
4	Sandwich 3/5	138.4
5	Two-coat 2/4	89.4
6	OGPA	71.0
7	Racked-in 3/5	43.9
8	Sandwich 4/5	42.4
9	Sandwich 2/5	39.7
10=	SMA	33.0
10=	AC	33.0

The priority for route selection was therefore to capture single-chip seals from grade 3 and grade 5 (no single-chip grade 2 surfaces exist in North Canterbury), as well as two-coat 3/5, sandwich 3/5, and two-coat 2/4. If possible, capturing a racked-in 3/5 surface could provide an interesting comparison to the other 3/5 surfaces.

The location of each surface would ideally also allow for wayside measurements to be conducted (section 2.3).

CPX route selection

The CPX routes are shown in green in Figure A-1.

SH73 from Yaldhurst to Springfield (56 km) was an ideal candidate for the high detail route, because it contains all the top 5 surface types; begins very close to CAPTIV (where the CPX trailer is housed); is flat, straight, and relatively bump-free; and has plenty of road side locations that would be suitable for SPB measurement. This was about a 2 hour round trip with the CPX trailer in measurement mode.

SH1 north and south of Christchurch was likewise an obvious choice for expanding the geographical scope of the survey, because of the variety of surfaces and surface ages, and because it is mostly level and bump-free. Runs along SH1 from Tram Rd to Amberley (31 km) and from Templeton to Rakaia Bridge (41 km) were therefore included.

Wayside measurement site selection

A set of potential wayside measurement sites on SH73 were identified from maps, street view imagery, and RAMM surface data. These were modified in the field to accommodate factors such as site access, safety, visibility, freshly laid or damaged surfaces, road works, and low traffic volume.

Appendix B: Survey Structure and Post-Processing

The study requirements pointed towards a schedule that covers one route in high detail over several passes, followed by other routes that can significantly expand the dataset with just a single pass. In finding a balance between repeated measurements over the same route vs. trying to cover as big an area as possible, the following factors were considered:

- One of the research objectives is to establish the repeatability of the CPX measurements on chipseal, so that any variability that is detected in the data can be attributed to the surface rather than the instrumentation.
- Covering a wider area will provide more examples of each type of surface, which could lead to better understanding the variation in emission within each surface type.
- Covering a wider area may provide a range of ages of particular surfaces that could subsequently allow analysis of aging effects.
- RAMM surface data is not considered 100% reliable, so on at least one route the road surface should be visually inspected to determine that the RAMM categorisation is correct. It would be most efficient to maximise the use of that validated route.
- In order to correlate the Supercat (typical road tyre) and Avon tyre to both the CPX and the SPB measurements, it is necessary to run those on the same route as the SRTT and SPB.
- SPB measurements should be conducted on surfaces that have already been covered by the CPX measurement (to help identify the best wayside locations).
- The start of the CPX route and the SPB measurement sites should be as close to Christchurch and/or to each other as feasible, to cut down on travel time and the potential for driver fatigue.
- There should be a purpose to-, and benefit from-, all survey data collected, and we should have a strategy for how it will be analysed and used before we devote resources to collecting it.
- Routes should:
    - be as free from bumps as possible
    - be as level as possible and straight roads are generally preferable over curving roads
    - cover at least the top 5 most prevalent surface types.
- Examples of target surface types should be neither very old nor brand new. It would be ideal to incorporate examples of both young (~5 years) and old (~15 years) chipseal if possible.

Post-processing

Over 700 km of CPX sound recording data was collected over the course of the survey. This was post-processed using scripts developed by John Bull and output into a "CPX database" of sound levels and spectra at 20 m intervals (with consistent positioning between runs).

The database has subsequently been linked to relevant tables from RAMM (carr_way, surface_structure, hsd_texture, hsd_rough, roadnames, ud_scanner_new, traffic_loading, traffic_site) to allow for correlation to road and traffic properties. The tables consist of 2018 data because the 2019 data was not available at the time of analysis.

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