NZTA Road Surface Noise Research Programme 2018

Task A: Close Proximity versus Wayside Measurements

Contact Details

Name: Richard Jackett

33 The Esplanade, Petone
PO Box 30 845, Lower Hutt 5040
New Zealand

Telephone: +64 4 587 0600
Mobile: +64 27 548 2451

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Prepared By

Richard Jackett
Principal Acoustic Scientist (WSP-Opus)

Reviewed By

Tiffany Lester
Senior Engineer Science and Research (WSP-Opus)

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Executive Summary

Open Graded Porous Asphalt (OGPA) is a 'low noise road surface' and is often the favoured form of noise mitigation for roading projects involving high traffic volumes and speeds (e.g. expressways and motorways), although it is often also selected for its other functional attributes (good drainage, high skid resistance, good ride quality). The NZ Transport Agency wishes to optimise the specification of porous asphalt, enhancing its acoustic properties in a cost-effective manner, whilst maintaining its other functional attributes. To enable quantification of the acoustic performance of road surfaces the Agency has obtained a Close Proximity (CPX) noise measurement trailer.

The aim of this study is to use wayside measurements and alternate tyres to validate the CPX rankings of the epoxy OGPA test surfaces in Johns Road, Christchurch. The Agency would like to know, qualitatively, that differences in CPX results are related to differences in the wayside levels. If these relationships can be demonstrated, future CPX measurements could be used with some confidence to inform the selection of low-noise epoxy OGPA specifications.

The experimental methodology devised to meet the project objectives involved taking CPX measurements with various tyres along the trial OGPA surfaces on Johns Road. Six wayside survey sites were initially identified, ensuring that the CPX levels in those locations were consistent and representative of those from the trial surface as a whole, as well as considering other experimental and practical limitations (e.g. access, even ground, no nearby reflecting surfaces, traffic not accelerating). Wayside levels were determined from measurements of approximately 150 fleet vehicles at each site. The data were then processed to determine representative CPX and wayside levels for each OGPA trial surface, and measurement uncertainties evaluated.

The key findings from this study are summarised as follows, with reference to the relevant section of the report:

Qualitative ranking of trial sections by CPX and SPB

The CPX and the SPB measurements both ranked the surfaces in the same order from quietest to loudest: EPA7, EPA10, EPA10HV, EPA14. This confirms the hypothesis that motivated this study, that the ranking of the Johns Road epoxy OGPA test sections by the NZTA CPX trailer can be validated by wayside noise level measurements (section 3.3).

Quantitative relationship between CPX and wayside levels

The data also allowed for a deeper quantitative analysis of the relationship between CPX and SPB measurements. A linear least squares regression of CPX(SRTT) versus SPB(cars) results in a strong correlation ($r^2 = 0.95$), and indicates a relationship between the two noise measures that is very close to unity: $SPB_{cars} \approx 0.987 * CPX_{SRTT} - 19.7$, in decibels.

It can be concluded that, in general, if a large difference in noise emission between OGPA sites is identified through SRTT CPX measurements, then a similar magnitude difference (in decibels) would be expected in wayside noise levels from passenger cars at those sites (section 3.3.1).

The relationship between the 'heavy traffic' H1 CPX measurements and SPB(trucks) is not as strong ($SPB_{truck,2b} \approx 0.23 * CPX_{worn} + 62.3$; $r^2 = 0.40$), probably due to wayside truck noise being a combination of several sources (section 3.3.3).

These findings do not necessarily extend to other traffic classifications, surfaces other than OGPA, different traffic speeds, or receiver locations further from the road.

Comparison Between the SRTT and a typical car tyre

A secondary objective of this study was to confirm that the SRTT behaves similar to a 'typical' car tyre when it comes to ranking OGPA surfaces by noise emission. A typical car tyre (the Supercat) was identified and procured in both new and worn conditions (section 2.2.1) for use in CPX measurement. The worn Supercat tyre produced CPX levels that were lower, but consistent with the SRTT across all surfaces. Ranking of the surfaces was the same with the SRTT, new Supercat, and the worn Supercat (section 3.1.1). This effectively disproves the null-hypothesis that the SRTT is too different to typical car tyres to be relied upon to acoustically rank OGPA surfaces.

Comparison between new and worn tyres

Running a single model of the 'typical' tyre in both new and worn condition in the CPX trailer allowed for a small, but well-controlled, investigation into the effect of tyre wear on noise generation. The worn tyre was found to be quieter than the new tyre on OGPA by a small, but statistically significant, margin of 0.3 dB. There are no obvious practical implications from this finding in terms of managing road traffic noise (section 3.1.2).

SPB Measurement Uncertainty

An uncertainty analysis for the SPB methodology has been conducted to support comparison with CPX levels and to enable conclusions on statistical significance of correlations to be drawn (section 3.2.1).

The overall expanded uncertainty at the 95% confidence level for the comparison of passenger car L_{veh} between sites is ± 1 dB. The equivalent uncertainty for L_{veh} of heavy trucks is ± 1.5 dB. For SPBI it is also ± 1.5 dB.

The absolute uncertainty in L_{veh} is at least ± 1.5 dB at the 95% confidence level for cars, and at least ± 1.9 dB for trucks. The absolute uncertainty in SPBI is likely to be greater than ± 2 dB.

Vehicle Sound Level (L_{veh}) and Statistical Pass-By Index (SPBI)

The L_{veh} levels were calculated for each vehicle category and site, and the SPBI computed, following ISO 11819-1 (section 2.3.6). The L_{veh} for cars is far more sensitive to the road surface than either of the heavy categories, with a range of 9 dB from the quietest to the loudest site, compared to a range of just 3 dB for heavy trucks (section 3.2.2). The L_{veh} for cars appears to be a more useful metric than the SPBI for evaluation of the noise contribution from the road surface.

Different SPB levels from identical specification surfaces

SPB measurements of nominally identical surface types were performed at different locations and found statistically significant differences in noise emission levels (section 3.2.3). This is in line with both current and previous experience of CPX measurements on OGPA in NZ, and is a topic of ongoing research by the NZTA.

It should therefore not be assumed that surfaces of nominally the same specification will share noise emission traits. Conversely, SPB or CPX noise measurements on a trial section of a given surface may not represent the broader performance of that surface. The results of this study, as they pertain to the relative performances of different road surface specifications, should be interpreted with those cautions in mind.

1 Introduction

This study conducted close-proximity tyre-road noise measurements and wayside noise measurements to "rank" the noise performance of a set of road surfaces, then compared the ranking from each measurement method.

1.1 Background

Open Graded Porous Asphalt (OGPA) is a 'low noise road surface' and is often the favoured form of noise mitigation for roading projects involving high traffic volumes and speeds (e.g. expressways and motorways). It is often also selected for its other functional attributes (good drainage, high skid resistance, good ride quality). The NZ Transport Agency (the NZTA) wishes to optimise the specification of OGPA, enhancing its acoustic properties in a cost-effective manner, whilst maintaining its other functional attributes.

To this end the NZTA have obtained a Close Proximity Measurement (CPX) trailer, which is an instrument capable of measuring road surface noise emission at close proximity to the road-tyre contact patch and in isolation from other road noise generation mechanisms. The NZTA's intention is to use the CPX trailer to evaluate the in-situ acoustic performance of OGPA-surfaced road sections 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.

To experiment with different specifications of OGPA, the NZTA have set up five trial sections on SH1 Johns Rd in Christchurch. Amongst the road surface performance attributes of interest is the acoustic emission from the road-tyre interaction (colloquially: 'road surface noise').

1.2 Scope

The NZTA's 2018 Road Surface Noise Research Programme aims to address four items of work previously recommended[1] as important steps to realising the long-term goal of optimising OGPA with respect to its acoustic emission:

- Task A - Qualification of initial CPX test results to confirm effects of different tyres and wayside versus close proximity measurement positions;
- Task B - Benchmarking of porous asphalt surfaces laid throughout New Zealand in the last three years to identify the lowest noise surface;
- Task C - Research design, planning and instrumentation development for a trial into causes of variability in CPX levels; and
- Task D - Maintenance and further development of the CPX trailer.

WSP Opus Research have been engaged to deliver Task A of the research programme. This report describes methodology used to collect CPX and wayside noise measurements on the Johns Road trial sections, presents the measurement results alongside analysis, and evaluates the validity of drawing conclusions about OGPA acoustic performance based on CPX measurements.

1.3 Purpose

The aim of this study is to use wayside measurements and alternate tyres to validate the CPX rankings of the trial OGPA sections on Johns Road. The NZTA would like to know that differences

[1] S Chiles & J Bull, *Road surface noise research 2016-2018*, NZTA, April 2018 (pre-publication version)

in CPX results are related to differences in the wayside levels. If these relationships can be demonstrated, future CPX measurements could be used with some confidence to inform the selection of low-noise epoxy OGPA specifications.

2 Methodology

The experimental methodology devised to meet the project objectives involved taking CPX measurements with various tyres along the trial OGPA sections on Johns Road. Six wayside measurement sites were identified, ensuring that the CPX levels in those locations were consistent and representative of those from the trial section as a whole, as well as considering other experimental and practical limitations (e.g. access, even ground, no nearby reflecting surfaces, traffic not accelerating). Wayside levels were determined from measurements of approximately 150 passing vehicles at each site. The data were then processed to determine representative CPX and wayside levels for each OGPA trial surface, and measurement uncertainties evaluated.

2.1 Close Proximity (CPX)

The NZTA's CPX trailer has been developed with the aim of achieving compliance with the international standard ISO 11819-2[2], 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 *Road Surface Noise Research 2016-2018*[1]. The processing produces a noise level for each 20 metre segment of CPX measurement.

The main survey with the CPX trailer took place on 18 July 2018, during a period of stable dry weather. It had been more than 48 hours since the last rain event and the road surface was visibly dry with no spray. Ambient air temperature during the survey was in the range 15-17 °C. During this survey the standard 'passenger car' tyre and two 'typical' road tyres were run.

A second survey took place on 17 December 2018 using the "heavy vehicle" tyre (H1) in the CPX trailer[3]. This also occurred during a dry spell, with ambient air temperature in the range 18-21 °C.

For each of the four test tyres used (see section 2.2 below), three runs over the left hand (slow) lanes of each of the five trial sites were completed. The measurement data was subsequently processed using the procedure described in the road surface noise report[1].

2.2 CPX measurement with a 'typical' tyre

The CPX trailer is generally run fitted with a special Standard Reference Test Tyre[4] ("SRTT" or "P1" tyre) to represent light/passenger vehicles. Using a tyre labelled the "H1" to represent heavy vehicles is also part of ISO 11819-2.[2,5]

The SRTT has dimensions 225/60R16, making it considerably larger than tyres fitted to the vast majority of the NZ passenger car fleet, both in terms of outside diameter and tread width. To test the hypothesis that the SRTT tyre 'ranks' OGPA surfaces consistently with ranking by a New Zealand-typical passenger car tyre, this study also used a more typical road tyre in the CPX trailer.

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

[3] Around this time a bug in the averaging routines of the CPX system was discovered, causing sound levels to be determined by a single reading for each road segment. Re-analysis of a sample of data from the first survey with and without averaging revealed negligible impact on results. The data analysed for this report are those prior to the bug fix.

[4] ASTM F2493-14, Uniroyal Tigerpaw 225/60 R16

[5] Avon Supervan AV4 195-R14C

2.2.1 'Typical' passenger car tyre selection and fitting

There are many possibilities for how a 'typical' passenger car tyre might be defined, but authoritative data to support any given definition is sparse. The two definitions for which supporting data could be obtained were:

1. The tyre fitted to the most common model of passenger car on NZ roads. The Toyota Corolla is currently the most common passenger car[6,7], and new examples of this model are fitted with either a 195/60R15 or a 195/55R16 tyre. Note that this specification has changed over time and will not be true of all Corollas.
2. The most common single tyre size and design on NZ roads, however no authoritative data on this is available. A UK tyre supplier has produced a list based on their own sales figures[8], which indicated that their most common 'factory' tyres (as opposed to aftermarket performance tyres) were in sizes 195/65R15, 215/55R16, 175/65R14, 185/65R15, & 195/60R15. NZ's Consumer Magazine[9] has published a comparison of 121 car tyres, of which the sizes 175/65R14, 195/60R15, & 215/60R16 were the most numerous.

The practicalities of fitting a tyre and rim to the CPX trailer provide additional constraints on identifying a tyre suitable as both 'typical' and compatible with the CPX trailer. Zero-millimetre offset rims that would fit the CPX trailer were available in sizes 13, 14, and 15 (diameter in inches) only, accepting a range of tread widths from 165 mm to 195 mm.

The size 195/60R15 satisfies both definitions of 'typical' and will fit the available rims. The purpose of this experiment also required that the tyre was: an 'economy' model, of symmetrical design, and produced by a well-known international tyre brand.

Finally, it was preferred that the same model of tyre was available in both new and well-worn (2nd hand) condition, to facilitate a small investigation into the effect of tyre wear on tyre-road noise (section 3.1.2). This additional study could be completed very efficiently, because the worn typical tyre fits the same custom rims as the new typical tyre, and, other than a tyre change, the CPX trailer needs no adjustment between runs with the different typical tyres.

Two brand new Bridgestone Supercat 195/60R15 tyres were purchased (average tread depth 7.8 mm, Shore A hardness 65), along with two well-worn but road-legal examples of the same model (average tread depth 4.5 mm, Shore A hardness 72). The tread patterns and level of wear on both tyres are shown in Figure 2-1. All 'typical' tyres were fitted to 15-inch rims and balanced.

Figure 2-1: The 'typical' tyre, Bridgestone Supercat 195/60R15, in new (left) and worn (right) condition

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[6] Motor Industry Association, *Registrations by Make 1984 to 2016*, https://www.mia.org.nz/Documents, accessed 22/6/18

[7] Motor Industry Association, *Used Car Fleet by Age and Make Dec 2016*, https://www.mia.org.nz/Documents, accessed 22/6/18

[8] AVA Tyre, *The most popular UK tyre sizes*, https://avatyre.co.uk/blog/most-popular-uk-tyre-sizes, accessed 22/6/18

[9] Consumer NZ, *Car Tyres*, https://www.consumer.org.nz/products/car-tyres, accessed 22/6/18

The CPX trailer was adjusted so its measurement geometry with the 'typical' tyres matched, as far as practicable, the geometry with the standard tyres. Shims were applied to the trailer body to adjust its running height and the microphones were relocated to accommodate the different tyre size.

Once the CPX trailer was fitted with the typical tyres and its geometry adjusted, it was operated in the same manner as for the SRTT and H1.

2.3 Wayside Noise Levels

Wayside noise levels were determined using the Statistical Pass-By (SPB) method. This involved selectively measuring the sound generated by the passing vehicle fleet. For this project, the SPB measurements are intended to give an indication of the relative acoustic performance of each OGPA trial section at the roadside.

2.3.1 Statistical Pass-By

Although there are a variety of different methods available for obtaining estimates of the wayside noise level, the advantages of SPB are primarily that it can separate out the contribution to noise from light and heavy vehicles, and to some extent, correct for variations in vehicle speed between sites. The disadvantages are that it can be a time-consuming process and is completely dependent on the traffic available on site (e.g. congestion, frequency of passing vehicles of the appropriate type, speeds, and so on).

A methodology for SPB measurement is described in ISO 11819-1 [10], and has been adopted for this study. The only significant deviation from that methodology related to the number of truck pass-bys measured, which is discussed later in this section (2.3.5).

2.3.2 Instrumentation

SPB measurements occurred on the two days following the main survey of CPX measurements with the passenger car tyres (section 2.1), on 19 and 20 July 2018, in dry and calm weather conditions. The instrumentation used was a calibrated Class 1 Rion NL-32 sound level meter (SN: 851394) with Norsonic Nor1256 field calibrator (SN: 125626168) and a Bushnell Speedster III speed radar gun.

2.3.3 Measurement Position

A wayside measurement position was selected adjacent each of the five OGPA trial sections where a previous CPX measurement in March 2018[1] showed consistent and typical noise levels over several 20 m long segments (i.e. avoiding outliers). Another wayside measurement position was selected adjacent to a set of EPA7 segments which the CPX measurements indicated as the lowest noise emission of all the OGPA trial sections. Site 5 was the lowest noise emission EPA7 measurement position and site 6 was the 'typical' EPA7 measurement.

For each wayside measurement position, the sound level meter (SLM) was located on the road shoulder at 7.5 m from the centre of the nearside (slow) lane of Johns Road northbound, at 1.2 m ± 0.1 m height above the plane of the road. The surface between the lane and microphone consisted of a variable width of OGPA-surfaced road shoulder (approximately 2 m) with the remainder being grass-covered earth, with only the (acoustically transparent) wire rope barrier between the SLM and passing vehicles. Sites were chosen to minimise the effect of reflecting surfaces on either the near or far side of the road, and re-evaluated on-site, which lead to one site (Site 6 – 'typical' EPA7) being moved further south, away from the very large noise walls on the opposite side of the carriageway. Only traffic on the nearside (slow) lane was measured because

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

there was no safe (or ISO 11819-1 compliant) SPB measurement geometry possible for the far (fast) lane.

2.3.4 Vehicle Selection

SPB requires that the L_{Amax} of individual vehicle pass-bys is measured, which requires that vehicle passes are isolated from other noise sources, particularly from the preceding and following vehicles, coincident traffic in the fast lane, and traffic in the opposing lanes. ISO 11819-1 requires that the contribution from non-target vehicles is at least 6 dB below the level from the targeted vehicle's pass-by sound pressure level. In practice, pollution from other noise sources was minimised by ensuring the target vehicle was well-separated from vehicles travelling in the same direction, and avoiding measurements when there were noisy vehicles, such as trucks, in the opposite lanes. Checks using the SLM confirmed that this approach comfortably achieved the 6 dB requirement.

Vehicles that could be audibly or visually identified as outliers were excluded from the sample at each site. For example, vehicles that exhibited abnormally loud engine or exhaust noise, were fitted with off-road tyres, were accelerating or decelerating, or were travelling much faster or slower than the majority of traffic were excluded. Similarly, any measurements that included cats-eye strikes, poor lane keeping, or car horn blasts were omitted from analysis.

2.3.5 Vehicle Categories

ISO 11819-1 requires that each measured passing vehicle is categorised by type, and it provides a minimum number of measurements for each category (Table 2-1).

Table 2-1: Vehicle categories with minimum number of measurements from ISO 11819-1

Category	Vehicle Description	Minimum number of vehicles to be measured
1	Passenger cars	100
2a	Dual-axle heavy vehicles[11]	30
2b	Multi-axle heavy vehicles	30

Additionally, ISO 11819-1 requires that categories 2a and 2b combined total at least 80 measurements.

Note that these categories contain only a subset of the vehicle types present on New Zealand roads, and exclude many common vehicles such as vans, utes, and small trucks. This means that, combined with the vehicle selection restrictions (section 2.3.4), only a small fraction of the passing traffic is viable for measurement. Unless otherwise stated, the terms 'trucks' and 'heavies' will be used in this report to refer to the combination of vehicle categories 2a and 2b.

With limited time available to perform the wayside measurements, it was decided that the focus should be on achieving the requisite number of passenger car passes at each site, at the expense of the full complement of heavy vehicle passes. There were several reasons why this strategy was considered the most appropriate for achieving the project objectives:

1. It was anticipated that the noise generated by passenger car passes would demonstrate greater influence from the road surface than heavy vehicle passes.

[11] ISO 11819-1 uses non-standard and ambiguous terminology to describe the axle layout of its heavy vehicle classifications. For this study "dual-axle" (with 'more than 4 wheels' according to Annex A of the standard) was taken as what is commonly known as "tandem-axle" (two axles at the rear). Alternatively, it could be interpreted as trucks with a single rear axle fitted with 4 wheels, which would have resulted in somewhat lighter trucks being included in the survey selection.

2. ISO 11819-1 does not distinguish between categories 2a and 2b for medium speed roads (such as Johns Road), which somewhat reduces the impact of a small sample size of each.
3. An initial survey indicated that there would be more passenger car passes than truck passes, and therefore more data could be gathered in the same period of time.
4. Committing to full compliance with ISO 11819-1 from the outset would have risked running out of time to complete wayside measurements on all the OGPA trial surfaces.

As will be detailed in section 3.2, the full complement of 100 passenger car passes was obtained at all sites, as well as 25% - 50% of the heavy vehicle quota of 80 passes.

2.3.6 Data Analysis

To determine indicative 'average' noise emission for each site and vehicle category, a regression of the set of Lmax measurements against the decadic logarithm of speed is performed. A Vehicle Sound Level (L_{veh}) is then calculated as the ordinate value of the regression for the reference speed (or technically the logarithm of speed). The ISO 11819-1 reference speeds for these sections of Johns Road are 80 km/h for cars and 70 km/h for trucks.

ISO 11819-1 recommends that sound levels are corrected for temperature, but provides no method. Recent research[12] indicates that the influence of ambient temperature on SPB noise from porous asphalt surfaces is in the region of -0.04 dB/°C. However, the thermometer used to measure ambient air temperature during this survey (Nor1256 SN:125626168) was found to be unreliable, and therefore it would be unwise to use this data to correct for temperature effects, and potentially introduce an error. Data from the nearby Christchurch Airport weather station[13] indicates that the ambient air temperature remained between 6 °C and 13 °C during the SPB survey, which would produce a maximum temperature influence of 0.3 dB according to the correction identified above, which is negligible compared to the overall uncertainty of the SPB method (section 3.2.1). Therefore, as it is neither mandatory nor justified, no temperature correction has been applied, and a component has instead been included in the measurement uncertainty.

The Statistical Pass-By Index (SPBI) is an overall indicator of the wayside level at a site, in decibels, calculated from a weighted sum of the L_{veh} for each vehicle type. It is not an equivalent sound level (L_{eq}), but provides a way of comparing different sites with slightly different speeds and traffic mix. Consisting of L_{Amax} measurements from 80 km/h traffic, it is likely to be dominated by tyre/road noise, but ISO 11819-1's contention that SPBI isolates the influence of the road surface is plainly false. SPBI is calculated as follows,

$$SPBI = 10\log_{10}\left[W_1 10^{L_1/10} + W_{2a}\frac{v_1}{v_{2a}}10^{2a/10} + W_{2b}\frac{v_1}{v_{2b}}10^{L_{2b}/10}\right] \qquad \text{Eq. 2.1}$$

where W_i are the proportions of total traffic, v_i are the reference speeds, and L_i are the vehicle sound levels of each vehicle category, *i* : 1, 2a, & 2b.

3 Results and Analysis

3.1 Close Proximity

Three runs were completed over the OGPA trial sections using the SRTT fitted to the CPX trailer (Figure 3-1).

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

[13] Christchurch Airport Weather Station, hosted online at https://www.timeanddate.com/weather/new-zealand/christchurch

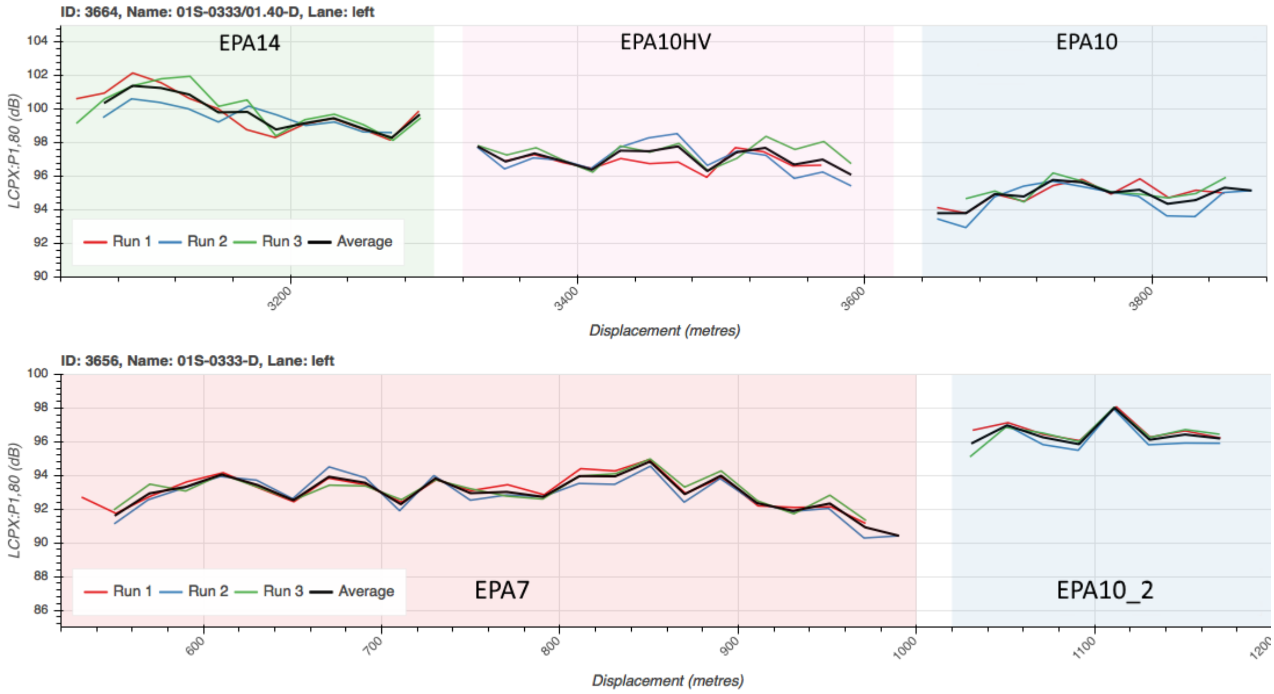

Figure 3-1: Three CPX trailer SRTT passes over the OGPA trial sections (average in black)

Three runs were completed using the H1 'heavy vehicle' tyre fitted to the CPX trailer (Figure 3-2).

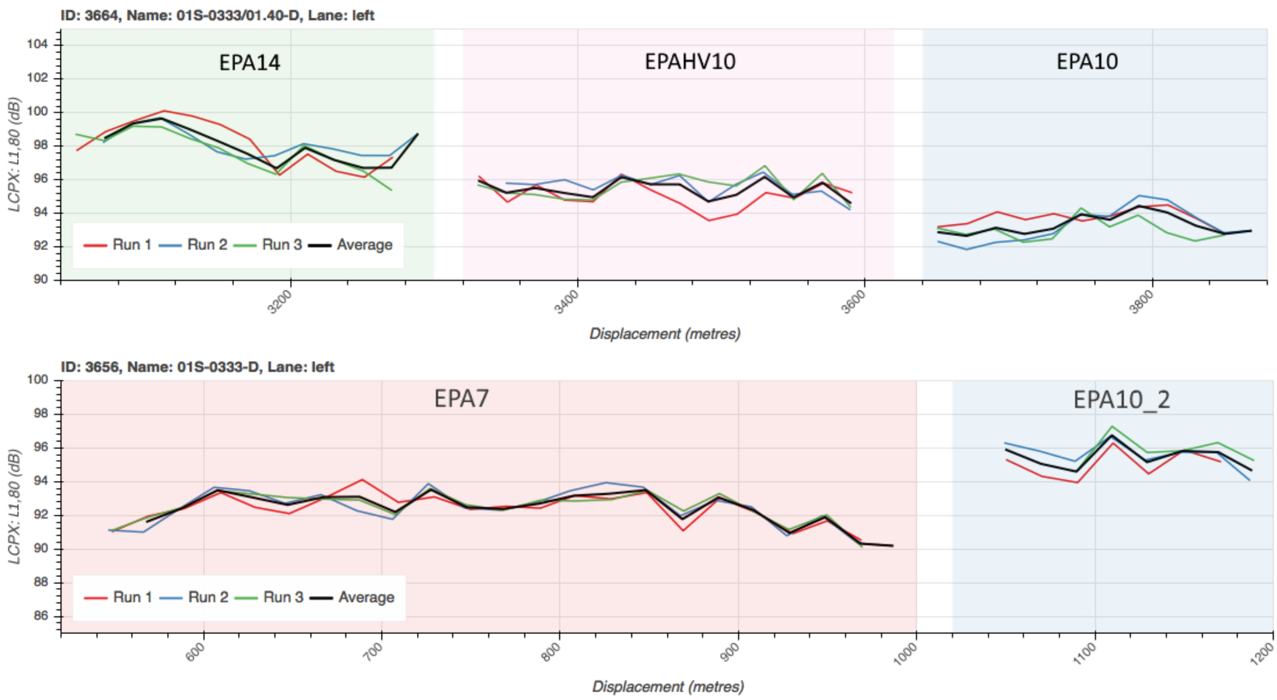

Figure 3-2: Three CPX trailer H1 passes over the OGPA trial sections (average in black)

CPX levels measured from the 40 m of road nearest to each SPB measurement position have been combined to produce the equivalent CPX level. Where the SPB measurement position was at or very close to the junction of two 20 metre CPX measurement segments the arithmetic average of the two segments has been used. Where the SPB measurement position was at or near the midpoint of a CPX segment, quarter-half-quarter linear averaging has been used to derive the equivalent CPX level. Table 3-1 presents the equivalent CPX level for each SPB measurement site, averaged across four runs, for each of the four tyres: the SRTT, new condition Supercat (New SC) as the 'typical' passenger car tyre, the worn Supercat (Old SC), and the H1.

Table 3-1: Equivalent CPX levels adjacent to the SPB survey sites

SPB Site		1	2	3	4	5	6
Surface		EPA10	EPA10HV	EPA14	EPA10	EPA7*	EPA7
Chainage (metres re: RS 1S-0333/Groynes Road)		3700	3418	3110	1060	970	760
SRTT	dB, 40 m Average	94.9	97.0	101.2	96.6	91.3	93.0
	Uncertainty (k=2)	1.1	1.0	1.4	1.0	1.2	1.1
New SC	dB, 40 m Average	93.4	96.6	99.9	95.8	89.9	91.7
	Uncertainty (k=2)	1.2	1.0	1.3	1.1	1.1	1.4
Old SC	dB, 40 m Average	93.5	95.9	99.7	95.2	90.0	91.4
	Uncertainty (k=2)	1.4	1.1	1.3	1.0	1.1	1.0
H1	dB, 40 m Average	93.0	95.6	99.4	95.5	90.3	92.4
	Uncertainty (k=2)	1.4	1.1	1.1	1.2	1.0	1.0
SRTT	dB, March 2018	96.5	98.5	101.0	97.5	92.0	94.0

* Site 5 is the additional 'lowest noise emission' measurement site, Site 6 is the 'typical' EPA7 site.

An uncertainty budget specifically for the NZTA CPX trailer is not available, but ISO 11819-2 (in table K.2) has typical values for the expanded uncertainty, which have been accepted at face value. These have been converted to k=1 coverage, combined in quadrature with the standard error of the 3 repeated measurements, and an expanded uncertainty (k=2) at the 95% level determined for CPX level in decibels at each measurement position, as shown in Table 3-1 and illustrated in Figure 3-3.

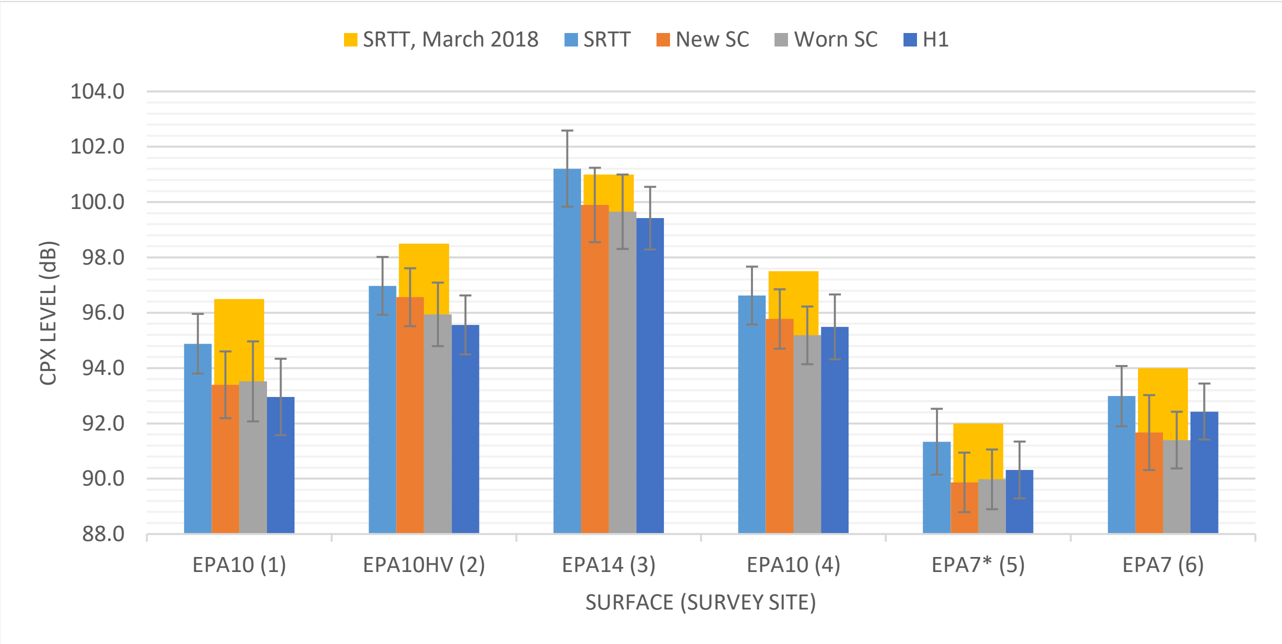

Figure 3-3: CPX sound levels adjacent to the SPB survey locations

This study's CPX measurements with the SRTT follow the same pattern as those extracted from a March 2018 CPX survey (the data used to identify the SPB survey sites), giving an approximate ranking from quietest to noisiest surface of: EPA7, EPA10, EPA10HV, EPA14.

This study's SRTT results are typically 1.0 dB to 1.5 dB lower than those from the March 2018 survey (made four months prior). The cause for the shift is not known. It is unlikely to be a real effect given how consistent it is across sites (with the exception of the EPA14 site, although the recent measurements there showed the highest variability, see Figure 3-1). Temperatures may have been different between the surveys, though the magnitude of the CPX temperature correction for porous asphalt at 80 km/h (-0.05 dB/°C) indicates that would account for only a fraction of a decibel.

3.1.1 Comparison Between SRTT and Typical Car Tyres

A secondary objective of this study is to confirm that the SRTT relates to a 'typical' car tyre when it comes to ranking OGPA surfaces by noise emission. It is generally accepted that the the SRTT is atypical of passenger car tyres in New Zealand in terms of its dimensions, but this is the tyre identified by ISO 11819-2 to fulfil that role (based on performance over time, sensitivity to acoustic properties of the road surface, and ongoing availability)[14] and the SRTT must be used for compliance with that standard and comparison with overseas CPX results. If the SRTT ranks the OGPA trial surfaces similarly to a more typical NZ passenger car tyre, then this will provide some additional confidence that the standardised CPX method is an appropriate means of quantifying the acoustic performance of OGPA surfaces in New Zealand.

Figure 3-4 presents the average CPX levels (n=3) measured along the five OGPA trial sites with the SRTT, the two 'typical' Supercat tyres identified in section 2.2.1, and the H1 tyre.

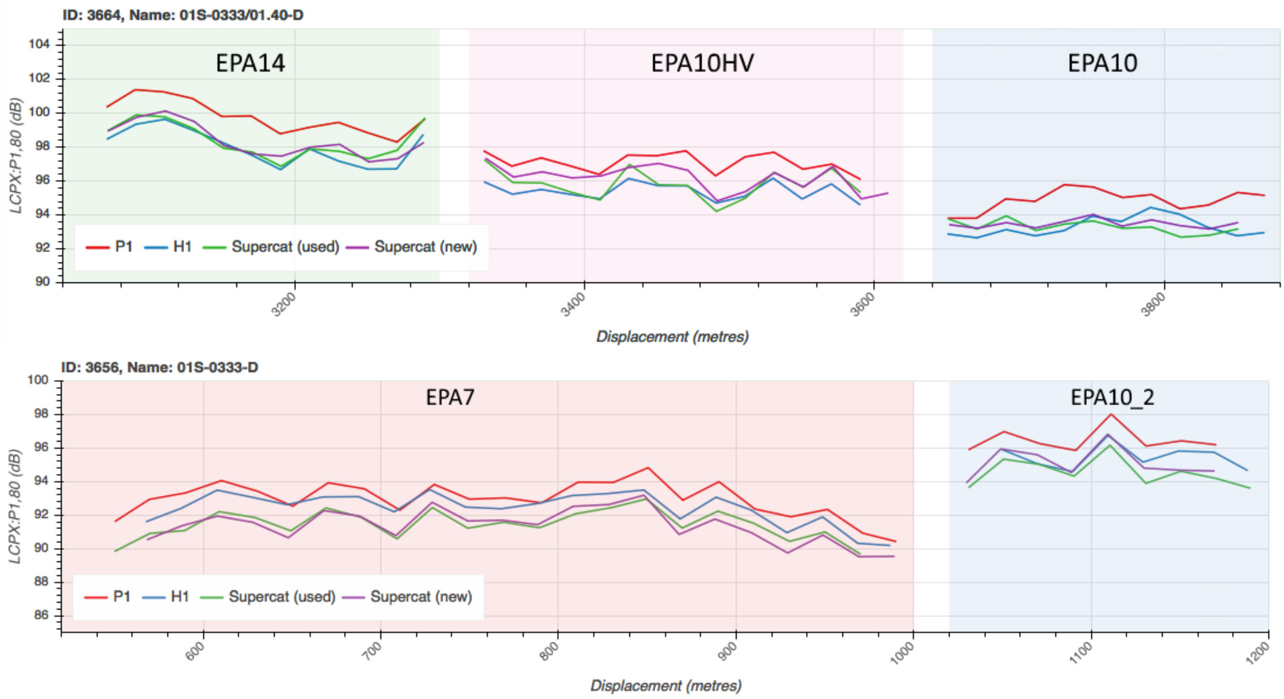

Figure 3-4: CPX sound levels for the new and worn typical tyre, the SRTT, and the H1.

The dataset for this analysis consists of paired CPX measurements at 86 20-metre long segments where three valid CPX measurements exist for each of the tyres. The difference in the CPX measurements between the SRTT and the worn Supercat, $L_{SRTT} - L_{Worn}$, has been plotted for each of the five OGPA trial surfaces in Figure 3-5. In this 'paired difference' experiment, many sources of systematic error have been eliminated through subtraction (e.g. microphone sensitivity). However, some error will also have been introduced in the change in wheel bay geometry that was required to fit the Supercat tyre. An indicative uncertainty for this comparison is taken from the repeatability component of the measurement, but it may be slightly larger if all systematic errors were included.

[14] Lester, Dravitzki, Carpenter, McIver, Jackett, *The long-term acoustic performance of New Zealand standard porous asphalt*, NZTA Research Report 626, Sept 2017

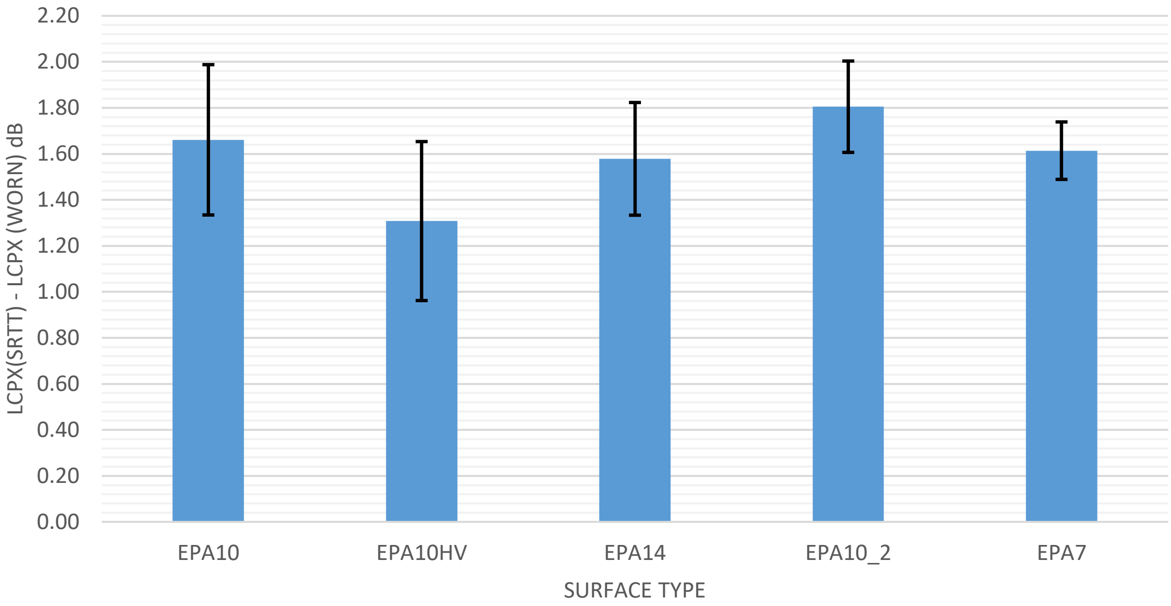

Figure 3-5: The difference in CPX sound levels on each surface between the SRTT and the worn 'typical' Supercat tyre (i.e. L_{SRTT} - L_{Worn}).

Although there is some variation in the average CPX level difference between the two tyres across surface types, the noise emission from the SRTT generally remains about 1.6 dB higher than from the worn Supercat.

This comparison of the SRTT (which is mandatory for the standardised CPX method) and the worn Supercat tyre (which is considered more typical of actual NZ car tyres) indicates that there is not a substantial conflict between how each would rank the noise emission of a given set of OGPA road surfaces, at least down to a level of precision approaching ± 0.3 dB or so, which is well below the absolute uncertainty of the CPX method.

3.1.2 New vs. Worn Tyre

It was identified prior to tyre procurement that running a single model of 'typical' tyre in both new and worn condition would allow for a small investigation into the effect of tyre wear on noise generation. Whereas the comparison between different models and sizes of tyre using the CPX trailer can be influenced by factors other than the tyre-road interaction (i.e. the reconfiguration of the CPX trailer leads to different internal dimensions and/or microphone positions within the trailer), this straight swap of new-condition to worn-condition tyre has few confounding variables, making it a fairly clean experiment. Because most sources of systematic error have been eliminated or reduced to negligible levels, an indicative uncertainty for this comparison is taken from the repeatability component of the measurement alone.

The dataset for this analysis consists of measurements at 86 20-metre long segments where three valid CPX measurements exist for each of the two tyres (plotted in Figure 3-4). The repeated CPX runs with the worn tyre on some segments displayed poor internal repeatability, so the worst 15% of sections were removed, achieved by excluding any segment with a standard deviation of greater than 1 dB in either new or worn tyre runs. The difference in the CPX measurements between the worn and new tyre, $L_{CPX\text{-}worn} - L_{CPX\text{-}new}$, was found from the resulting 73 road sections to be -0.27 dB ± 0.11 dB. Therefore, the worn tyre is quieter than the new tyre, statistically significant at the $p < 0.05$ level. However, the level difference of just 0.3 dB on OGPA appears to offer no practical implications in terms of managing road traffic noise.

With reference to Table 3-1 and Figure 3-3, there was no significant difference between the CPX levels from the two 'typical' tyres' at any of the SPB survey sites.

3.2 Statistical Pass-By

SPB measurements were completed at six survey sites, located within five OGPA trial sections, and representing four different surface types, as discussed in section 2.3.3,. Table 3-2 provides information about the time and location of each survey, as well as the number of valid passes captured for each of the three vehicle categories.

Table 3-2: Statistical Pass-By survey information

Site	**1**	**2**	**3**	**4**	**5**	**6**
Surface	EPA10	EPA10HV	EPA14	EPA10	EPA7*	EPA7
Chainage (metres re: RS 1S-0333/Groynes Rd)	3700	3418	3110	1060	970	760
Date	19-Jul	19-Jul	19-Jul	20-Jul	20-Jul	20-Jul
Start Time	10:50	13:44	16:51	9:45	10:48	11:54
Approx. Air Temperature (°C)	9	13	8	6	8	10
Cat 1 Pass-bys : Cars (n)	106	101	110	124	121	104
Cat 2a Pass-bys: Light Trucks[11] (n)	14	13	7	9	5	7
Cat 2b Pass-bys: Heavy Trucks (n)	25	21	20	14	31	24

* Site 5 is the additional 'lowest noise emission' measurement site, Site 6 is the 'typical' EPA7 site.

The number of pass-bys of trucks during the survey was limited, particularly those meeting the category 2a criteria (see Table 2-1 and footnote 11). The analysis of truck pass-by noise has been performed on category 2b vehicles only. The number of pass-bys of passenger cars captured exceeded expectations, with the full 100 passes captured at each of the six sites. As explained in section 2.3.5, this analysis of pass-by data will focus mainly on passenger car L_{veh}.

3.2.1 Measurement Uncertainty

A thorough uncertainty analysis of the SPB measurements has been performed, following the general methodology of ISO/IEC Guide 98-3 (GUM)[15]. As the project objective is to compare different sites, the uncertainty calculated is the relative uncertainty between sites, rather than the absolute uncertainty of measurement, which would be slightly larger. For example, the absolute calibration uncertainty of the SLM has been excluded from the uncertainty budget, with only the variation in SLM sensitivity that could occur between the measurement sites over the two days of the survey included. The uncertainty budget for the vehicle sound level (L_{veh}) for passenger cars only is presented in Table 3-3. Detail on the purpose and derivation of each component listed in the budget is discussed further below the table.

[15] ISO/IEC 2008. GUIDE 98-3. Uncertainty of measurement —. Part 3: Guide to the expression of uncertainty in measurement. (GUM:1995)

Table 3-3 : Uncertainty budget for L_{veh} for cars (for comparison between sites rather than absolute level)

Uncertainty Component	Semi-range (dB)	Distribution	Divisor	Source
Instrument stability	0.50	Rectangular	√3	Repeated measurements with single SLM
Temperature effect	0.28	Rectangular	√3	Maximum temperature error of ± 7 °C
Fleet variation (cars)	0.15	Std Error	1	Different set of cars passing by each site
Speed variation	0.05	Std Error	1	Slightly different speeds for each site
Position of SLM	0.24	Rectangular	√3	Mic position and position of traffic within lane
Background noise	0.10	Rectangular	√3	Predominantly the influence of other traffic
Reflections	0.21	Rectangular	√3	The possible influence of reflecting surfaces
Repeatability	0.50	Gaussian	2	Random variation between repeats at same site
Combined Uncertainty	0.48			
Expanded Uncertainty (k=2)	1.0			

Instrument stability (relative) – For measurements in similar environmental conditions using the same instrument. Absolute uncertainty of calibration is not relevant to this study, but should it be subsequently required, ISO 11819-1 suggests that it be increased to 1 dB.

Temperature effect – The proposed temperature correction for OGPA[12] is -0.04 dB/°C, and the range of temperatures during the SPB measurements was 7 °C. Therefore the maximum semi-range of the error is the product, 0.3 dB, and the distribution is rectangular.

Fleet variation (cars) – Individual passing cars during the survey varied in L_{max} with a typical standard deviation of 1.5 dB at each site, before speed correction, which was fairly consistent across survey sites. For 100 passes this corresponds to a standard error of the mean of 0.15 dB.

Fleet variation (trucks) – Individual passing category 2b trucks during the survey varied in L_{max} with a standard deviation, varying by site, of up to 2.5 dB, before speed correction. The maximum standard error of the mean at any site was 0.53 dB.

Speed variation – Speed differences between sites is somewhat accounted for by the L_{veh} calculation method. The residual standard error of the mean is estimated from the variation of speeds at each site and the slope of the noise emission with vehicle speed for 100 car passes (truck noise emission was effectively independent of speed).

Position of SLM – An estimated ± 0.4 m lateral and ±0.15 m vertical uncertainty in SLM location relative to the left hand wheel path. This estimate includes both measurement error relative to the edgeline, and the observed variation of the average vehicle position in lane relative to the edgeline between sites.

Background noise – ISO 11819-1 requires that background noise sources are at least 6 dB below the measured pass-by level, which corresponds to an error on the measured level of 1 dB (always increasing the level). The distribution of this error is not expected to vary between sites, and therefore is reduced according to the number of samples made. It is noted that measurements made during the survey generally had far lower influence from background noise than required.

Reflections – Variation in the presence of nearby reflecting surfaces between sites has been conservatively estimated by assuming there may be up to 5% influence of (horizontal) reflections on the measured L_{max} levels (by this definition, 100% influence would be an acoustically 'hard' surface immediately behind the microphone, providing + 3 dB).

Repeatability – This component quantifies the random error inherent in repeated measurements of the same quantity, once all sources of systematic errors have been removed or accounted for. In this case it represents the distribution of L_{veh} or SPBI that would be obtained if the same site was re-measured in identical conditions. It is usually determined through a great number of repeated measurements of the quantity, which is clearly not feasible. However, in this study the unknown portion of the random error has been minimised by determining the 'fleet variation' and 'speed variation' components, and thus a value of 0.5 dB may be conservatively assumed (c.f. ISO 11819-1 references ISO 5725-1 to suggest that the entire random error is better than 1 dB).

Uncertainty budgets for L_{veh} for heavy trucks, and for SPBI have also been prepared, but differ only in the 'fleet variation' component from the example provided for L_{veh} of passenger cars. For heavy trucks this is explained in the component description above. For SPBI the standard error is propagated through equation 2.1 and an allowance for the uncertainty in traffic mix and speed included.

From this analysis into the relative uncertainty, the overall expanded uncertainty at the 95% confidence level for a comparison of passenger car L_{veh} between sites is ± 1 dB. The equivalent uncertainty for L_{veh} of heavy trucks is ± 1.5 dB. For SPBI it is also ± 1.5 dB.

When the analysis is repeated for absolute uncertainty in L_{veh} it would increase to at least ± 1.5 dB at the 95% confidence level for cars, and at least ± 1.9 dB for trucks. This is due to an increase in the components for instrumentation, temperature, background noise, and potentially reflections. The absolute uncertainty for SPBI includes an important additional component: the accuracy of the traffic mix. For a single pass, the heavy truck noise emission dominates the passenger car noise emission by approximately 10 dB, so the result of the SPBI calculation will be sensitive to errors in that mix. An expanded uncertainty of ± 2 dB or more should be expected (based on ± 2 % heavy vehicles in the traffic mix). The absolute uncertainty is useful for comparing between sites that are geographically different or separated, have different traffic mixes, are measured at different times, or making predictions about hypothetical or unmeasured roads. However, in this study the lower uncertainties of the 'relative' approach are always applicable and will be used in the remainder of the report.

3.2.2 Vehicle Sound Level and Statistical Pass-By Index

The L_{veh} levels were calculated for each vehicle category and site as described in section 2.3.6.

The SPBI was calculated from the survey data for each site by equation 2.1, modified to remove category 2a. The definition of a medium speed road given in ISO 11819-1 is appropriate for Johns Road and the following parameters have been assumed:

- Reference speeds of 80 km/h and 70 km/h for cars and heavy trucks respectively.
- Traffic mix proportions of 85% passenger cars and 15% heavy trucks - broadly in line with the most recent (2017) traffic data[16], although note that ISO 11819-1's traffic mix parameter is not directly equivalent to the familiar %HGV value generally used in NZ traffic data.

Table 3-4 presents the vehicle sound level (L_{veh}) for each vehicle category at each site, and the resulting statistical pass-by index (SPBI) for each site calculated on the 'medium speed road' parameters as discussed above. An additional row, representing the L_{veh} for utility vehicles ('utes'), has been included for several sites where the sample size of this vehicle classification was greater

[16] https://mobileroad.org

than 5 passes. The ute data is not an input to the SPBI calculation and is included for information only.

Table 3-4: Vehicle sound levels (L_{veh}) and SPBI for the six survey sites

Site	1	2	3	4	5	6
Surface	EPA10	EPA10HV	EPA14	EPA10	EPA7*	EPA7
Cat 1: Cars (L_{veh} dB)	72.6	76.3	80.1	76.2	71.2	71.5
Cat 2a: Light Trucks (L_{veh} dB)	81.1	83.8	84.2	83.3	79.1	82.5
Cat 2b: Heavy Trucks (L_{veh} dB)	83.8	86.3	85.8	84.4	83.5	85.8
SPBI (dB)	77.6	80.4	81.8	79.2	76.9	78.9
Utes (L_{veh} dB)		78.7	80.4	77.4	74.2	

* Site 5 is the additional 'lowest noise emission' measurement site, Site 6 is the 'typical' EPA7 site.

As predicted, the L_{veh} for cars appears to be more sensitive to the road surface than either of the heavy categories, with a range of 9 dB from the quietest to the loudest site, compared to a range of just 3 dB for heavy trucks.

If the overall wayside level is assumed to be best represented by the SPBI then data indicate that the surfaces are ranked from quietest to loudest approximately as follows: EPA7, EPA10, EPA10HV, EPA14.

3.2.3 Significance Test on Identical Specification Surfaces

Where measurements of nominally identical surface types were performed at different locations the results differ. For EPA10 the difference in SPBI has a magnitude of 1.6 dB between sites 1 and 4. For EPA7 the difference in SPBI has a magnitude of 2.0 dB between sites 5 and 6. If a normal distribution of means with a standard deviation of 0.75 dB (c.f. the k=1 "combined uncertainty" in Table 3-3, but for SPBI) are assumed, then both differences are significant at the $p < 0.05$ level. Therefore, despite being nominally the same, the two EPA10 surfaces do not belong to the same population with respect to pass-by noise. The same applies to the two sections of the EPA7 surface.

The core conclusions from this test are:

1. It should not be assumed that surfaces of nominally the same specification will share noise emission traits.
2. Conversely, SPB noise measurements adjacent to a section of a given surface may not represent the broader performance of that surface.

3.3 Comparison of CPX and SPB

The primary purpose of this part of the 2018 road surface noise research programme is to qualitatively validate the CPX rankings of epoxy OGPA using wayside noise measurements. In section 3.1 the surface ranking was determined by CPX measurements, and in section 3.2.2 it was determined SPB measurements. The two methods are in agreement that the surfaces are ranked from lower to higher noise emission as follows: EPA7, EPA10, EPA10HV, EPA14.

3.3.1 Regression against the SRTT

The data also allow for a deeper quantitative analysis of the relationship between CPX and SPB measurements. In this section a simple linear regression has been used for each pairing of levels. If more paired sites are added in future then this data could re-analysed, taking the probability distributions of each ordinate pair into account, if necessary.

Figure 3-6 plots the SPB levels for passenger cars against the SRTT CPX measurements at each site, which reveals the expected linear relationship between the two measurands.

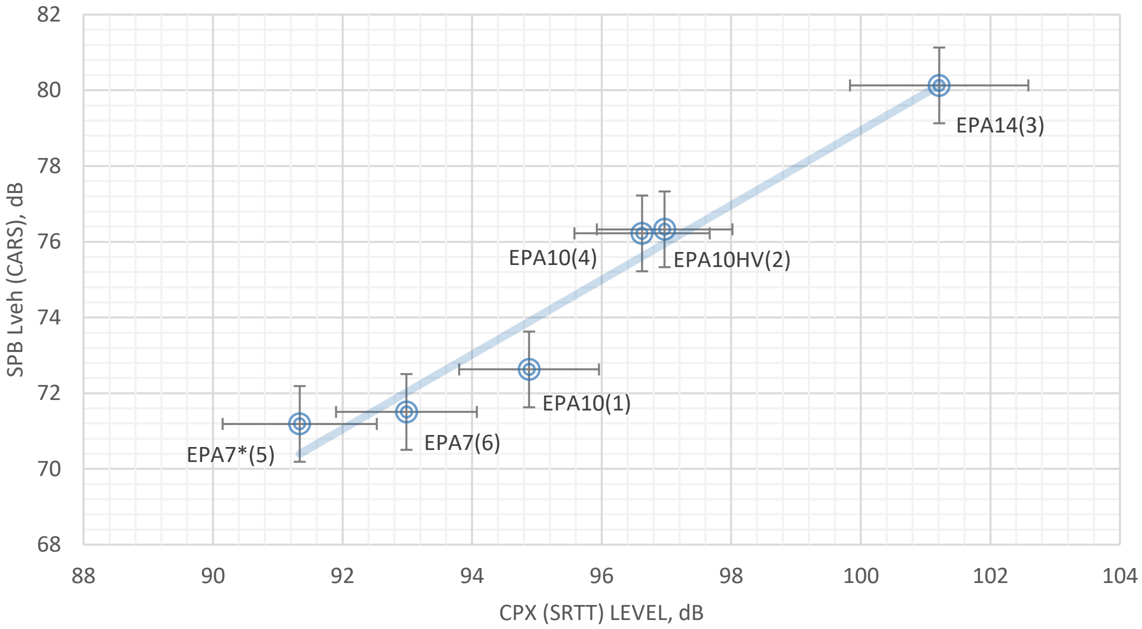

Figure 3-6: The relationship between CPX(SRTT) and SPB level of passenger cars at the six survey sites

A linear least squares regression of CPX(SRTT) versus SPB(cars) results in a strong correlation (r^2 = 0.95), and the relationship between the two noise measures is very close to unity: $SPB_{cars} \approx 0.987 * CPX_{SRTT} - 19.7$, where all terms are in A-weighted decibels. This confirms the hypothesis that the CPX is highly correlated with the wayside noise level from passenger cars.

It can be concluded that, in general, if a large difference in noise emission between OGPA sites is identified through SRTT CPX measurements, then a similar magnitude difference (in decibels) would be expected in wayside noise levels from passenger cars at those sites. In absolute terms, this survey found that the SPB L_{veh} for passenger cars was approximately 20 dB below the average CPX(SRTT) level of the adjacent 40 m section of road.

These findings do not necessarily extend to CPX measurements with other tyre types, SPB measurements of other vehicle types, measurements with surfaces other than OGPA, or different traffic speeds. It also does not define the geographical extent, either in terms of the length of road or distance from the road, that measured CPX levels would continue to indicate (or influence) the noise level at wayside receiver/measurement locations.

3.3.2 Regression against the worn Supercat

This analysis has been repeated for the CPX trailer fitted with the worn Supercat tyre with nearly identical results: a strong fit (r^2 = 0.95), and a relationship very close to unity: $SPB_{cars} \approx 0.989 * CPX_{worn} - 18.5$, where all terms are in A-weighted decibels (Figure 3-7).

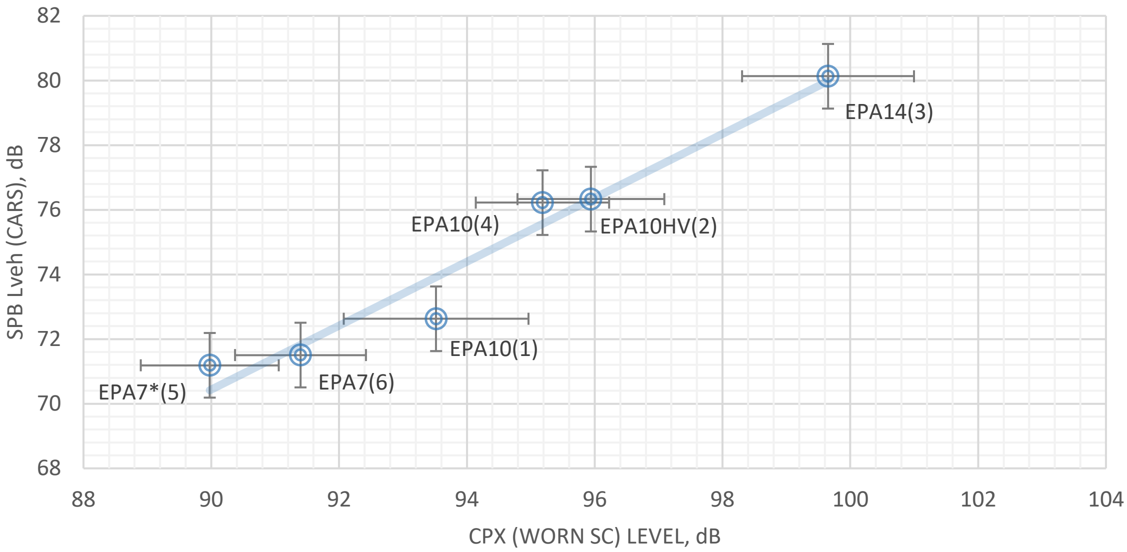

Figure 3-7: The relationship between CPX(worn Supercat) and SPB level of cars at the survey sites

3.3.3 Regression against the H1 "heavy" tyre

Regressing the SPB level for heavy trucks (classification 2b) against the CPX trailer fitted with the H1 tyre (Figure 3-8) reveals a relatively poor prediction for wayside noise level from trucks ($r^2 = 0.40$). The coefficient in the relationship $SPB_{truck,2b} \approx 0.23^*CPX_{worn} + 62.3$ (in A-weighted decibels) indicates that the wayside level from trucks is considerably less sensitive to changes in the road surface than CPX measurements with the H1 tyre. This is consistent with the on-site observation that truck engine and aerodynamic noise were significant at 80 km/h, whereas the CPX method measures only the tyre-road contribution.

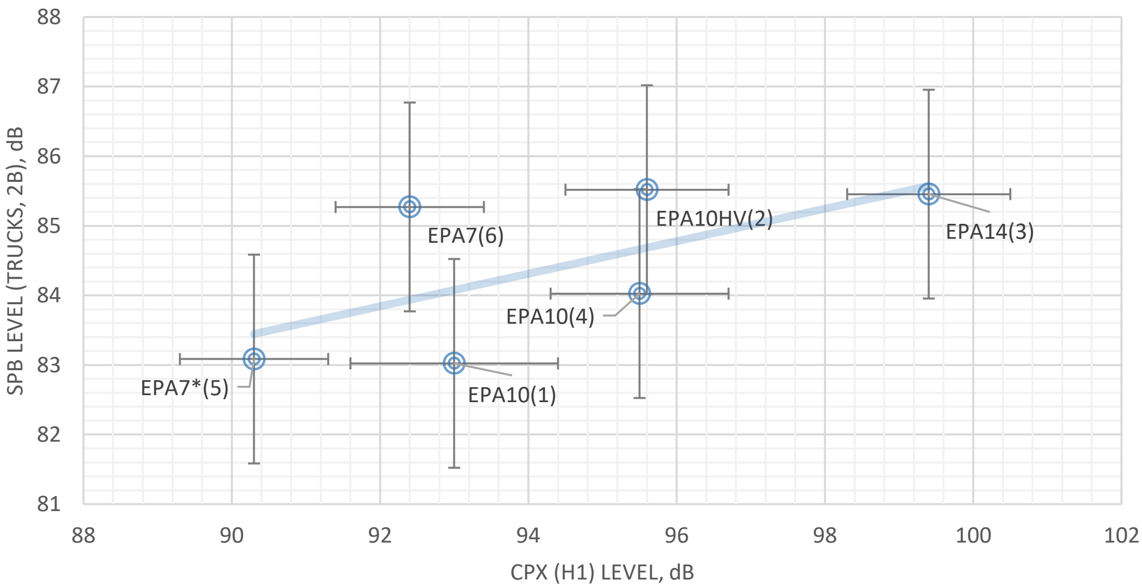

Figure 3-8: The relationship between CPX(H1) and SPB level of trucks (2b) at the survey sites

It is notable that the H1 tyre is a van tyre, and arguably closer to a typical NZ passenger car tyre than a large truck tyre in most respects. While the data does not necessarily indicate that the H1 tyre is unrepresentative of truck tyre noise – that cannot be determined due to the presence of the other noise sources – it offers only the most minor benefit over the SRTT and Super Cat for predicting truck wayside levels (both $r^2 = 0.32$). Conversely, CPX(H1) does strongly correlate to SPB(cars) ($r^2 = 0.96$) at the six EMOGPA sites.

3.3.4 Regression for SPBI

The equivalent CPX metric to the SPBI (section 3.2.2) is the CPX Index (CPXI), which is composed of a weighted average of the CPX level for passenger cars and the CPX level for heavy vehicles, and is intended to represent the overall acoustic properties of the tested road section[2]. Unlike the SPBI, the weightings for the CPXI cannot be varied to represent the actual traffic mix on any given road or even road classification, and are fixed at equal weighting (ISO 11819-2 considers this to be equivalent to a 20% heavy mix on 80 km/h roads):

CPXI = 0.5 * CPX(SRTT) + 0.5 * CPX(H1)

A linear least squares regression of SPBI against CPXI results in a good correlation (r^2 = 0.84), and the relationship between the two noise measures across the six test sites is *SPBI* ≈ 0.50**CPXI + 31.5*, where all terms are in A-weighted decibels (Figure 3-9).

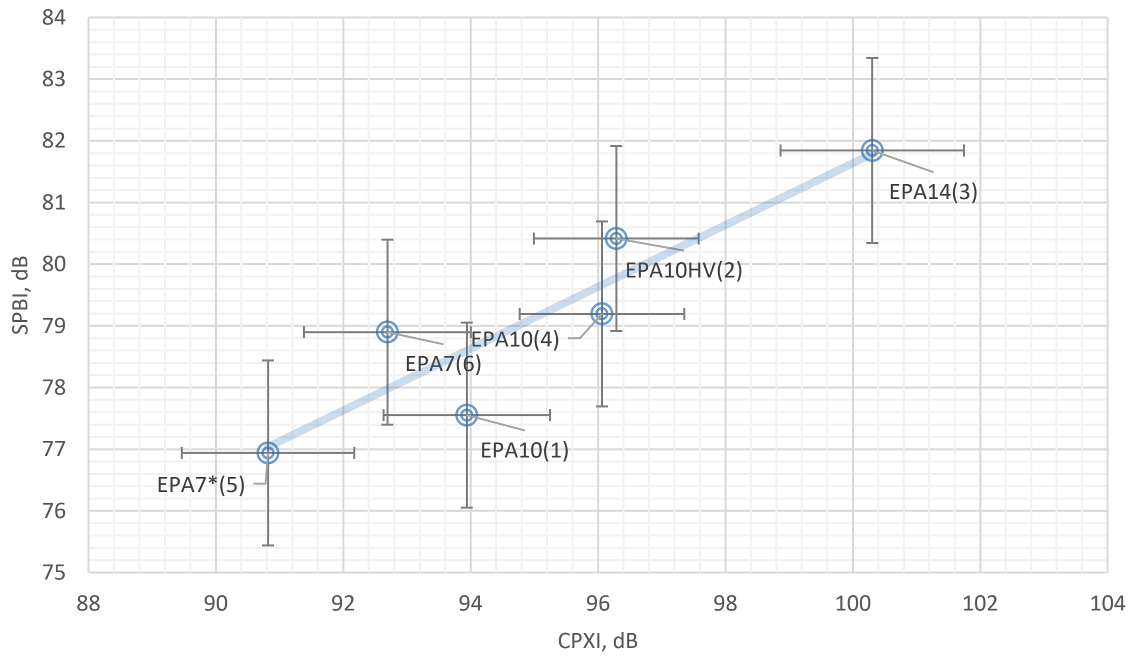

Figure 3-9: The relationship between CPXI and SPBI at the six survey sites

While the SPBI is not itself an L_{eq} level, it has a similar purpose of providing an overall road traffic noise level at the wayside to allow some comparison between sites and different traffic mixes. These results show that CPXI provides a useful estimate of the SPBI on OGPA at 80 km/h with the traffic mix encountered. Despite this, the value of the CPXI metric in the comparison of road surfaces is limited because of its reliance on the H1 tyre, whose equivalence to heavy vehicle tyre-road noise emission is yet to be established.

4 Conclusions

4.1 Key Findings

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

4.1.1 Qualitative ranking of trial sections by CPX and SPB

The CPX(SRTT) and the SPB measurements both ranked the surfaces in the same order from quietest to loudest: EPA7, EPA10, EPA10HV, EPA14. This confirms the hypothesis that motivated this study, that the ranking of the Johns Road OGPA trial sections by the NZTA CPX trailer can be validated by wayside noise level measurements (section 3.3).

4.1.2 Quantitative relationship between CPX and wayside levels

The data also allowed for a deeper quantitative analysis of the relationship between CPX and SPB measurements. A linear least squares regression of CPX(SRTT) versus SPB(cars) results in a strong correlation (r^2 = 0.95), and indicates a relationship between the two noise measures that is very close to unity: $SPB_{cars} \approx 0.987 * CPX_{SRTT} - 19.7$, in decibels.

It can be concluded that, in general, if a large difference in noise emission between OGPA sites is identified through SRTT CPX measurements, then a similar magnitude difference (in decibels) would be expected in wayside noise levels from passenger cars at those sites (section 3.3.1).

The relationship between the 'heavy traffic' H1 CPX measurements and SPB(trucks) is not as strong ($SPB_{truck,2b} \approx 0.23 * CPX_{worn} + 62.3$; r^2 = 0.40), probably due to wayside truck noise being a combination of several sources (section 3.3.3) with road/tyre noise less dominant compared with car noise.

These findings do not necessarily extend to other traffic classifications, surfaces other than OGPA, different traffic speeds, or receiver locations further from the road.

4.1.3 Comparison Between the SRTT and a typical car tyre

A secondary objective of this study was to confirm that the SRTT behaves similar to a 'typical' car tyre when it comes to ranking OGPA surfaces by noise emission. A typical car tyre (the Supercat) was identified and procured in both new and worn conditions (section 2.2.1) for use in CPX measurement. The worn Supercat tyre produced CPX levels that were lower, but consistent with the SRTT across all surfaces. Ranking of the surfaces was the same with the SRTT, new Supercat, and the worn Supercat (section 3.1.1). This effectively disproves the null-hypothesis that the SRTT is too different to typical car tyres to be relied upon to acoustically rank OGPA surfaces.

4.1.4 Comparison between new and worn tyres

Running a single model of the 'typical' tyre in both new and worn condition in the CPX trailer allowed for a small, but well-controlled, investigation into the effect of tyre wear on noise generation. The worn tyre was found to be quieter than the new tyre on OGPA by a small, but statistically significant, margin of 0.3 dB. There are no obvious practical implications from this finding in terms of managing road traffic noise (section 3.1.2).

4.1.5 SPB Measurement Uncertainty

An uncertainty analysis for the SPB methodology has been conducted to support comparison with CPX levels and to enable conclusions on statistical significance of correlations to be drawn (section 3.2.1).

The overall expanded uncertainty at the 95% confidence level for the comparison of passenger car L_{veh} between sites is ± 1 dB. The equivalent uncertainty for L_{veh} of heavy trucks is ± 1.5 dB. For SPBI it is also ± 1.5 dB.

The absolute uncertainty in L_{veh} is at least ± 1.5 dB at the 95% confidence level for cars, and at least ± 1.9 dB for trucks. The absolute uncertainty in SPBI is likely to be greater than ± 2 dB.

4.1.6 Vehicle Sound Level (L_{veh}) and Statistical Pass-By Index (SPBI)

The L_{veh} levels were calculated for each vehicle category and SPB measurement position, and the SPBI computed, following ISO 11819-1 (section 2.3.6). The L_{veh} for cars is far more sensitive to the road surface than either of the heavy categories, with a range of 9 dB from the quietest to the loudest site, compared to a range of just 3 dB for heavy trucks (section 3.2.2). The L_{veh} for cars appears to be a more useful metric than the SPBI for evaluation of the noise contribution from the road surface.

4.1.7 Different SPB levels from identical specification surfaces

SPB measurements of nominally identical surface types were performed at different locations and found statistically significant differences in noise emission levels (section 3.2.3). This is in line with both current and previous experience of CPX measurements on OGPA in NZ, and is a topic of ongoing research by the NZTA.

It should therefore not be assumed that surfaces of nominally the same specification will share noise emission traits. Conversely, SPB or CPX noise measurements on a trial or small section of a given surface may not represent the broader performance of that surface. The results of this study, as they pertain to the relative performances of different road surface specifications, should be interpreted with those cautions in mind.

4.2 Additional Observations, Lessons, and Recommendations

4.2.1 Survey timing

Having several consecutive days of settled weather is important to both CPX and SPB measurements. The accuracy of weather forecasts for more than a few days out is limited, meaning that SPB/CPX work is likely to always have a last-minute go/no-go decision associated with it, and follow-on implications for travel costs and operator availability. It is recommended that surveys longer than 1 or 2 days be scheduled for the summer months, whenever possible.

4.2.2 Statistical Pass-By

The vehicle categories of ISO 11819-1:1997 were developed more than 20 years ago based on assumptions about the European vehicle fleet of the 1990s, and do not represent the modern NZ vehicle fleet (e.g. Sport Utility Vehicles (SUVs) now dominate the NZ 'passenger car' classification[17]).

The heavy vehicle classification of ISO 11819-1 is also ambiguous[11], particularly in terms of which vehicles fall into the "dual-axle" category 2a.

There is no modern NZ equivalent for this standard, but it would be possible to localise it to the NZ situation, and provide a degree of consistency in application and interpretation that is currently missing.

4.2.3 SPB for truck noise

The subjective experience during the SPB survey was that truck pass-by noise was far more influenced by aerodynamic, drivetrain, and engine/exhaust sources compared to cars. The analysis in section 3.3.3 also demonstrates that the influence of the road surface on the overall wayside truck noise is diminished, as expected. The SPB measurements of trucks may be representative of their overall wayside noise level, but this measurement approach gives poor differentiation between different surface types.

The H1 tyre is not a tyre that would be fitted to any truck in category 2a or 2b as they were interpreted for this study. It is a tyre that could be fitted to vans, utes, and light trucks, and we recommend that future studies involving SPB measurements introduce a new category for vehicles running H1-like tyres, or re-interpret category 2a to that end.

4.2.4 CPX for truck noise

Following from section 4.2.3, isolating the influence of the tyre-road interaction on truck noise will require CPX measurements. ISO 11819-2, in J.2, suggests that the H1 tyre, although it fits larger cars, has been found empirically to give a surface influence that is reasonably similar to that of 'heavy traffic'. The implication is that the H1 can represent all heavy traffic, not just the light trucks and vans to which it can be fitted.

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[17] https://www.stuff.co.nz/motoring/news/104973092/why-our-roads-seem-to-be-swarming-with-compact-suvs

If the tyre-road noise of heavy traffic on NZ road surfaces is going to be of enduring interest to the NZTA, then it is recommended to establish whether CPX measurements using the H1 tyre are representative of truck tyre-road noise emissions.

4.2.5 High voids

It has been hypothesised that although the CPX levels for the high voids OGPA (EPA10HV) surface are high, the wayside levels might benefit from additional absorption as the sound propagates across the more porous surface. However, Figure 3-6 demonstrates that the CPX measurement places the high voids OGPA appropriately (relative to the other surfaces) in terms of its wayside noise level. The sample is too small to draw general conclusions about this surface type, but there is no evidence to suggest that the higher void content contributes to a lower wayside level than CPX would otherwise indicate.

4.2.6 General observations from the SPB survey

Inherent variation between trucks was large. Truck measurements were probably also more influenced by operating mode (e.g. power on or off) but it was often not possible to identify this from audio cues alone, contributing to apparent variation in SPB measured levels.

Determining height relative to the road surface is complicated by super-elevation at some survey sites. The average propagation height above the road surface is quite different depending on whether it is a positive or negative slope.

4.2.7 Proposed research utilising the CPX trailer

1. An uncertainty analysis specific to the NZTA CPX trailer should be performed.
2. The extent to which the traffic noise level at any given wayside location, especially at greater distances from the road, is influenced by any particular CPX measurement segment (typically 20 m long) is not known. This is significant because OGPA surfaces are known to have high variation in emission over their length. The wayside measurements in this study were performed very close to the roadside where they could be correlated closely with individual CPX measurement segments (the equivalent of two 20-metre segments was used here). However, it is not clear how far an acoustically ‘bad section’ of road might influence the overall noise level at receivers.
3. Establish the relationship between CPX measurements and wayside noise levels across a wider range of speeds, road surface types, and road surface conditions.
4. Once the relationship between the CPX levels and wayside noise levels is established, the statistical variation within and between surfaces on NZ roads should be determined by survey. This would benefit the NZTA by quantifying the distribution of the expected noise reduction from using low noise surfaces. At the moment, only a nominal mean value is used, which represents a 50% likelihood that the reduction is at least equal to the target value, with knock-on implications for any conformance testing that is undertaken.
5. Longer term, a catalogue of indicative surface emission levels could be assembled to assist in noise modelling and mitigation (i.e. update the ‘New Zealand road surface adjustments, relative to AC-10 for speeds of 40km/h and above’ in the NZTA’s ‘Guide to state highway road surface noise’).

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