ALTISSIMO
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ROAD SURFACE NOISE

Comparison of Microphone Position for CPX Measurements

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Contents

Glossary

CPX	Close proximity
CAPTIF	Canterbury Accelerated Pavement Testing Indoor Facility
EPA	Epoxy-modified porous asphalt
ENRAC	Enrichment Seal Over Asphalt
L_{CPX}	Close proximity sound pressure level, typically used to refer to $L_{CPX:P1,80}$
$L_{CPX:P1,80}$	Close proximity sound pressure level measured at a target speed of 80 km/hr using the standard reference test tyre. By default, this is measured using microphone positions 1 and 2
$L_{CPX:P1,80,mic:(1,2)}$	Close proximity sound pressure level using energy average of microphones 1 and 2. Same value as $L_{CPX:P1,80}$ but with microphones explicitly stated.
$L_{CPX:P1,80,mic(4,5)}$	Close proximity sound pressure level using energy average of microphones 3 and 4.
$L_{CPX:P1,80,mic:(\underline{n})}$	Close proximity sound pressure level using singular n^{th} microphone.
PA	Porous asphalt
RAMM	Road Assessment and Maintenance Management
SMA	Stone mastic asphalt
SEL	Sound Exposure Level measured in dB LAE
Top surfaces table	Tables maintained by RAMM and CAPTIF that record information about top surface of pavements in New Zealand.
P1	Standard reference test tyre (passenger tyre)

CPX notation

The notation for the close-proximity sound pressure level has been altered to include the clarify the microphone positions. ISO 11819-2 does allow for microphone position to be included in the standard notation but this notation becomes unclear for multiple microphone positions. An example of the notation is:

$$L_{CPX:P1,80,mic:(1,2)}$$

Where:

- "P1": The type of tyre used during the measurements (P1 tyre).
- "80": The nominal reference speed for the measurement (80 km/hr).
- "mic(1,2)": The microphone positions included in the calculation (1 and 2).

1 Introduction

This study is a continuation of research into tyre/road noise led by Waka Kotahi (Noise and Vibration Research | Waka Kotahi NZ Transport Agency). Previous research by WSP (Jackett et al., 2022) identified a piecewise variation in the relationship between L_{CPX} and pass-by SEL levels of porous and non-porous surfaces, exemplified in Figure 1. Additionally, across all surfaces a slope of ~1.9 was calculated when applying a linear regression between pass-by SEL and L_{CPX} . It was hypothesised that the CPX measurements were not fully capturing how different surfaces influence tyre/road noise, especially the sound absorption properties of porous surfaces.

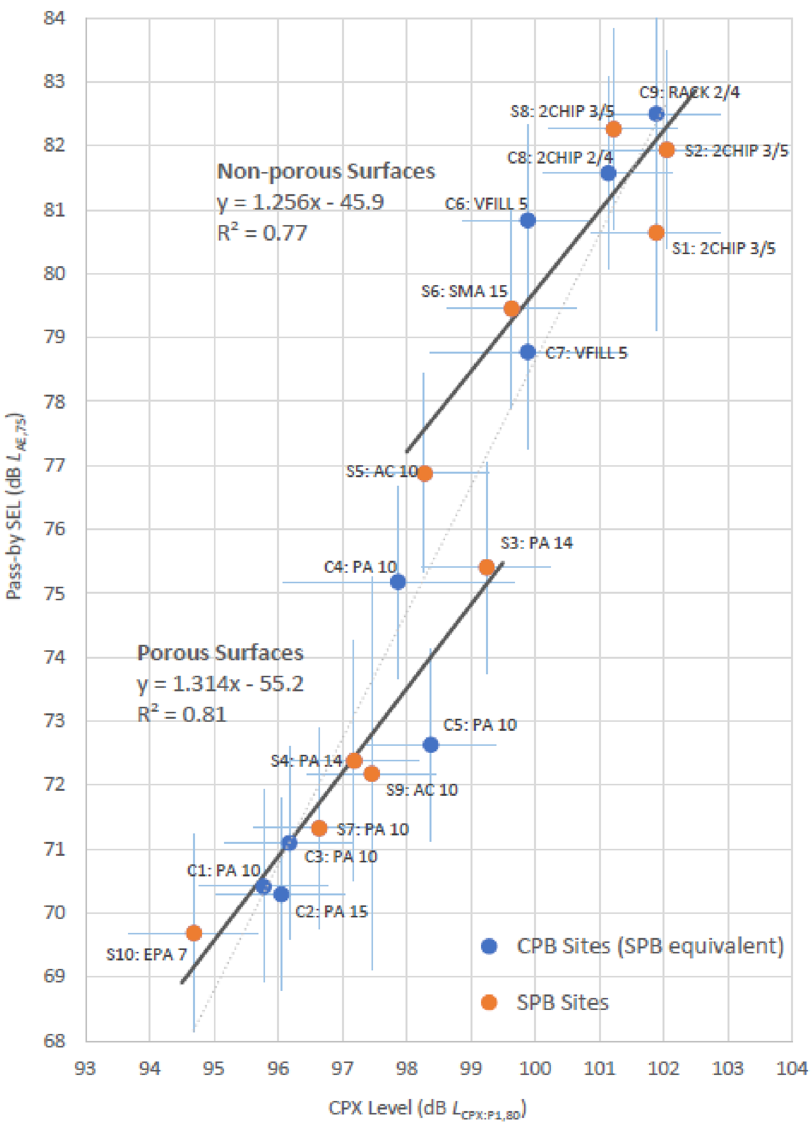

Figure 1: Weighted linear regression of Pass-by SEL on CPXP80 for 19 pass-by sites (Reproduced from Figure 3-1 of (Jackett et al., 2022))

The aim of this work was to test if the use of additional microphone positions within the Waka Kotahi CPX trailer provides additional data that explains the piecewise behaviour shown in Figure 1. The primary hypothesis explored in this analysis is that the additional microphone positions would capture noise generation and propagation mechanisms differently and in turn better characterise the behaviour of porous surfaces.

2 Measurement Details

The Waka Kotahi CPX trailer is equipped with up to 5 mounting locations for microphones. These 5 microphone positions are specified in ISO 11819-2 (ISO, 2017) and are shown in Figure 2. The Waka Kotahi CPX trailer does not have position 6 due to the dimensions of the enclosure. The microphones highlighted in red (positions 1 and 2) are required for all measurements, whereas the other positions are described as optional in the ISO standard. All historical CPX measurements using the Waka Kotahi CPX trailer only used microphones 1 and 2. During the 2023-2024 annual CPX survey, microphones were added at the positions highlighted in purple (positions 4 and 5) and the sound at these locations was recorded.

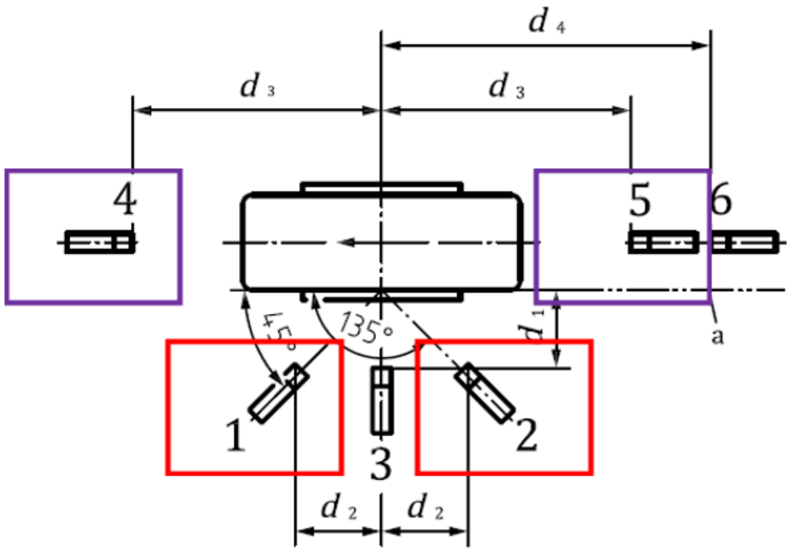

Figure 2: Microphone positions for CPX trailer (Reproduced from Figure 1 of ISO 11819-2)

The distances from the microphones to the road surface ant tyre are presented in Table 1.

Table 1: CPX measurement details.

Microphone pair	Height above road	Distance from tyre wall	Distance from axle
1,2	100 mm	200 mm	-
4,5	200 mm	-	650 mm

CPX measurements in the 2023-2024 survey that are utilised in this report are listed in Table 2.

Table 2: CPX measurement details.

Location	State Highway	Date tested
Christchurch Northern Corridor	SH74	2024/01/12
Christchurch Southern Motorway	SH76/SH1	2024/01/12
Western Belfast Bypass	SH1	2024/01/12
Kirwee chipseal trial site and epoxy chipseal trial site	SH73	2023/12/05
SH2 between Petone to Kaitoki	SH2	2024/03/01
Waikato Expressway (Hampton Downs to southern extent of Cambridge Bypass)	SH1	2024/05/07

The sound pressure level at each microphone is measured simultaneously and is post processed into 20 m longitudinal segments. For standard CPX measurements, the 20 m L_{CPX} uses the average of microphone positions 1 and 2. For this analysis, levels were calculated for each of the 4 microphones, averaged over each 20 m segment. The relevant temperature, tyre hardness, and enclosure corrections were applied to each pair of microphones as described in ISO 11819-2.

Two average CPX levels were also calculated:

- $L_{CPX:P1,80,mic:(1,2)}$: The energy average of the two side microphones, located at positions 1 and 2
- $L_{CPX:P1,80,mic:(4,5)}$: The energy average of the two inline microphones, located at positions 4 and 5

The energy average of all four microphones ($L_{CPX:P1,80,mic:(1,2,4,5)}$) was not used as the absolute levels are influenced by the distance between the microphones and the tyre/road contact area.

3 Results and Discussion

3.1 Comparison with pass-by measurements

The pass-by noise levels captured by WSP were compared to the various CPX levels measured in 2023/2024. The pass-by noise levels measured by WSP are presented in Table 3.

Table 3: Pass-by noise levels and surface type (reproduced from Table 3-1 in (Jackett et al., 2022)).

Site ID	Surface type	RS/RP and location	Measurement date	Pass-by Level (L_{AE})
S1	2CHIP 3/5	EASTERN HUTT RD/5.690 SB	8/4/2021	80.6
S2	2CHIP 3/5	EASTERN HUTT RD/5.690 NB	30/4/2021	81.9
S3	PA 14	002-0962-D/11.212 NB left	7/5/2021	75.4
S4	PA 14	002-0962-I/11.139 SB left	7/5/2021	72.4
S5	AC 10	FERGUSSON DR EAST/0.689 WB	13/5/2021	76.9
S6	SMA 15	002-0962-D/5.909 NB left	14/5/2021	79.5
S7	PA 10	01N-1035-B/0.612 SB	19/5/2021	71.3
S8	2CHIP 3/5	002-0931-B/13.276 NB	25/5/2021	82.3
S9	AC 10	FERGUSSON DR/0.526 EB	26/5/2021	72.2
S10	40mm EPA 7	01S-0333-D/0.840 NB left	23/5/2021	69.7
C1	PA 10	002-0962-D/5.229 NB left	13/5/2022	70.4
C2	PA 15	002-0946-B/6.641 NB	6/5/2022	70.3
C3	PA 10	002-0946-B/5.358 NB	6/5/2022	71.1
C4	PA 10	002-0946-B/7.556 NB	5/5/2022	75.2
C5	PA 10	002-0962-D/2.790 NB left	6/5/2022	72.6
C6	VFILL 5	002-0946-B/1.400 NB	12/5/2022	80.8
C7	VFILL 5	002-0946-B/1.400 SB *	12/5/2022	78.8
C8	2CHIP 2/4	002-0931-B/6.814 NB	5/5/2022	81.6
C9	RACK 2/4	002-0931-B/8.509 NB	12/5/2022	82.5

For each pass-by location the ten nearest 20 m segments had a weighted average applied following the methodology described in Appendix C.6.4 of Jackett et al., 2022.

Several sites have been resurfaced between the pass-by measurements and the 2023-2024 CPX survey and a number were missed in the 2023/2024 CPX survey. Locations with no CPX data (7 sites highlighted in grey in Table 3) or that have been resurfaced (3 sites highlighted in orange in Table 3) were excluded from further analysis. Several surfaces have had an enrichment seal (ENRAC) applied to the underlying PA after the pass-by measurements, this has been assumed to have a negligible effect on the surface noise level and these sites have been included in the analysis.

Table 4: CPX levels for measurement sites and surfacing details.

Site ID	Surface type (RAMM)	CPX level from Jackett et al., 2022 ($L_{CPX\ P1,80,mic(:1,2)}$ dB)	2024 CPX level Mic 1,2 ($L_{CPXP1,80,mic:(1,2)}$dB)	2024 CPX level Mic 4,5 ($L_{CPX\ P1,80,mic:(4,5)}$dB)
S3	PA 14	99.24	99.8	97.5
S4	PA 14	97.18	98.1	94.8
S8	2CHIP 3/5	101.22	100.5	97.8
S10	40mm EPA 7	94.69	93.7	90.4
C2	PA 10	96.05	95.7	91.5
C3	PA 10	96.17	96.9	93.1
C6	VFILL 5	99.88	100.0	98.7
C7	VFILL 5	99.88	99.9	98.1
C9	RACK 2/4	101.88	102.0	99.3

L_{CPX} for the two microphone arrangements are compared to the pass-by SEL noise levels in Figure 3 and Figure 4. Linear regressions have been included for comparison with Figure 1.

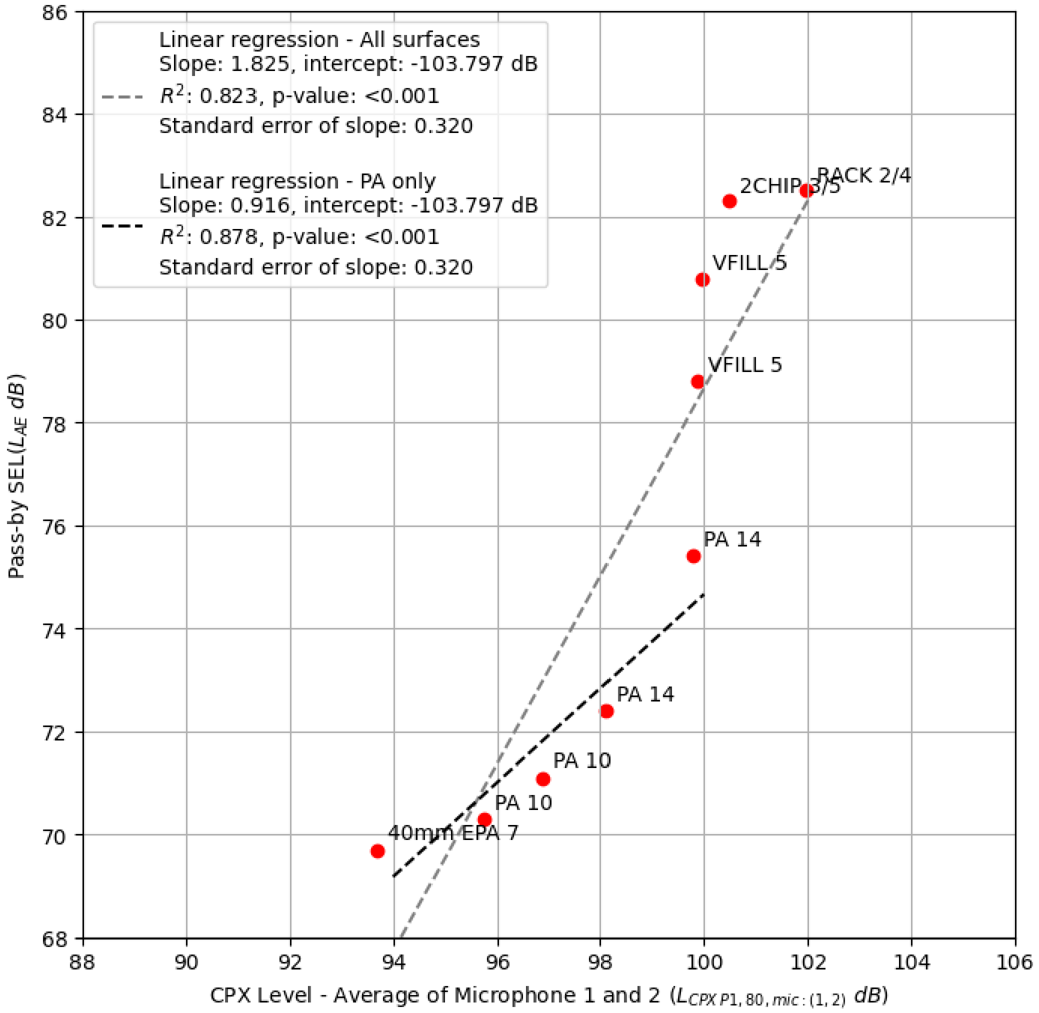

Figure 3: Comparison between pass-by SEL level and CPX level for microphones 1 and 2.

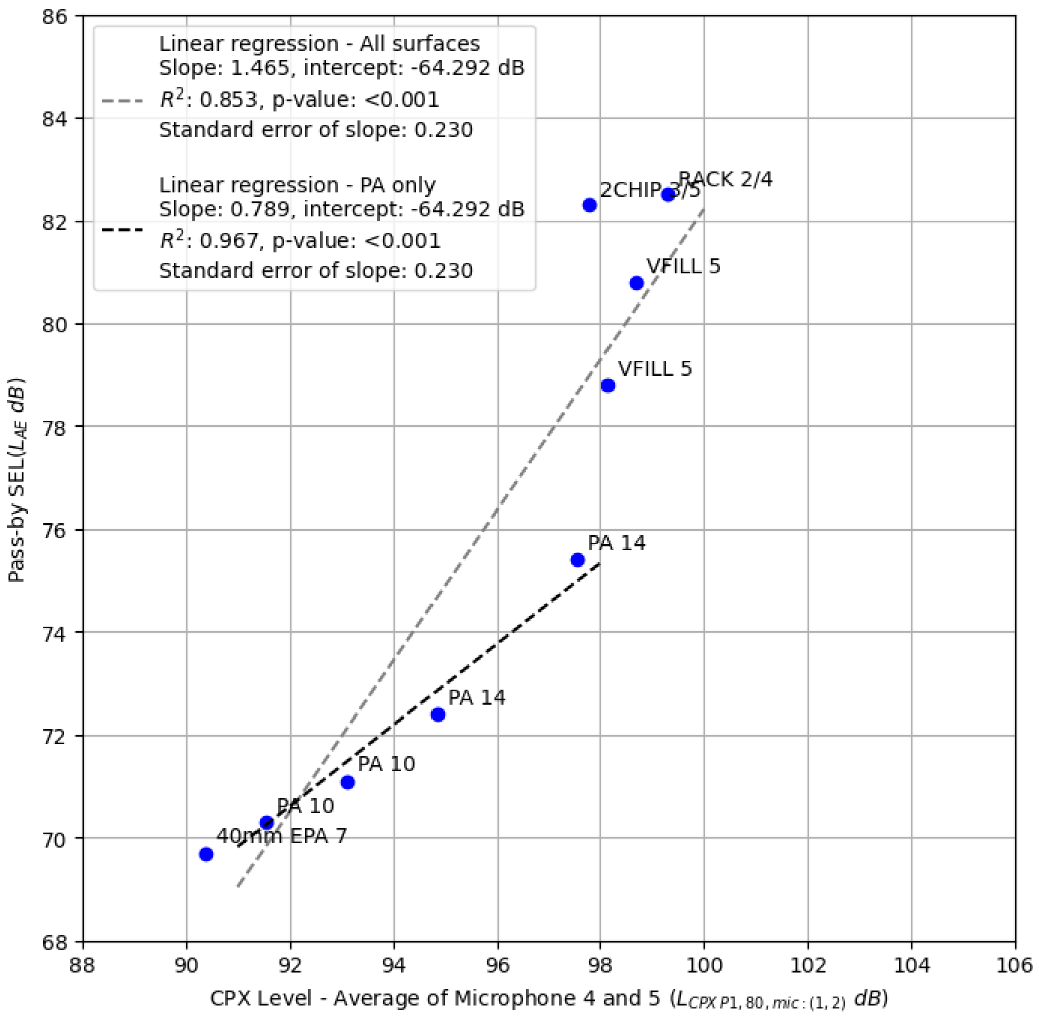

Figure 4: Comparison between pass-by level and CPX level for microphones 4 and 5.

The slope of a linear regression between $L_{CPX,P1,80,mic:(1,2)}$ and the pass-by SEL level was 0.25 dB/dB greater than the same regression using $L_{CPX,P1,80,mic:(4,5)}$. It is hypothesised that this change is caused by microphones 4 and 5 capturing tyre/road noise behaviours differently than microphones 1 and 2.

The slope of a linear regression between the CPX levels and the pass-by SEL for only PA surfaces was 0.92 dB/dB for $L_{CPX,P1,80,mic:(1,2)}$ and 0.79 dB/dB for microphones $L_{CPX,P1,80,mic:(4,5)}$. Both these slopes are lower than the slope of 1.31 dB/dB shown in Figure 1.

The rank order of the surfaces for both microphone arrangements and the pass-by measurements are presented in Table 5 in ascending order of noise level based on the pass-by level. Some changes in this ranking occurred when using the different microphone pairs across these nine sites.

Table 5: Ascending ranking of surfaces

Site ID	Surface type and date (RAMM)	Rank based on $L_{CPX:P1,80,mic:(1,2)}$	Rank based on $L_{CPX:P1,80,mic:(4,5)}$	Rank based on pass-by level
S10	40mm EPA 7	1	1	1
C2	PA 10	2	2	2
C3	PA 10	3	3	3
S4	PA 14	4	4	4
S3	PA 14	5	5	5
C7	VFILL 5	6	7	6
C6	VFILL 5	7	8	7
S8	2CHIP 3/5	8	6	8
C9	RACK 2/4	9	9	9

3.2 Comparison between porous and non-porous surfaces

The energy average of the two microphones located to the side of the tyre $L_{CPX\ P1,80,mic:(1,2)}$ were compared to the average of the two microphones located in-line with the tyre $L_{CPX\ P1,80,mic:(4,5)}$ using the data collected during the 2023-2024 annual CPX survey (measurement details are provided in Section 2).

The surface type for each 20 m segment was assigned by combining the CAPTIF and RAMM top surfaces tables. A 40m buffer was applied around locations where surface type changed and data within these buffers was excluded. Each 20 m segment was grouped into three overarching categories: SMA, PA, and chipseal.

The distribution of the differences[1] between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ in each 20 m segment is presented in Figure 5. A two-sample t-test was performed between the differences for each pair of surfaces and the results are presented in Table 6. The results of the t-test indicate that there is a statistically significant variation in the difference between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ for each surface type. A difference of 0 dB was not expected between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ due to the different distances between the microphones and tyre/road contact patch.

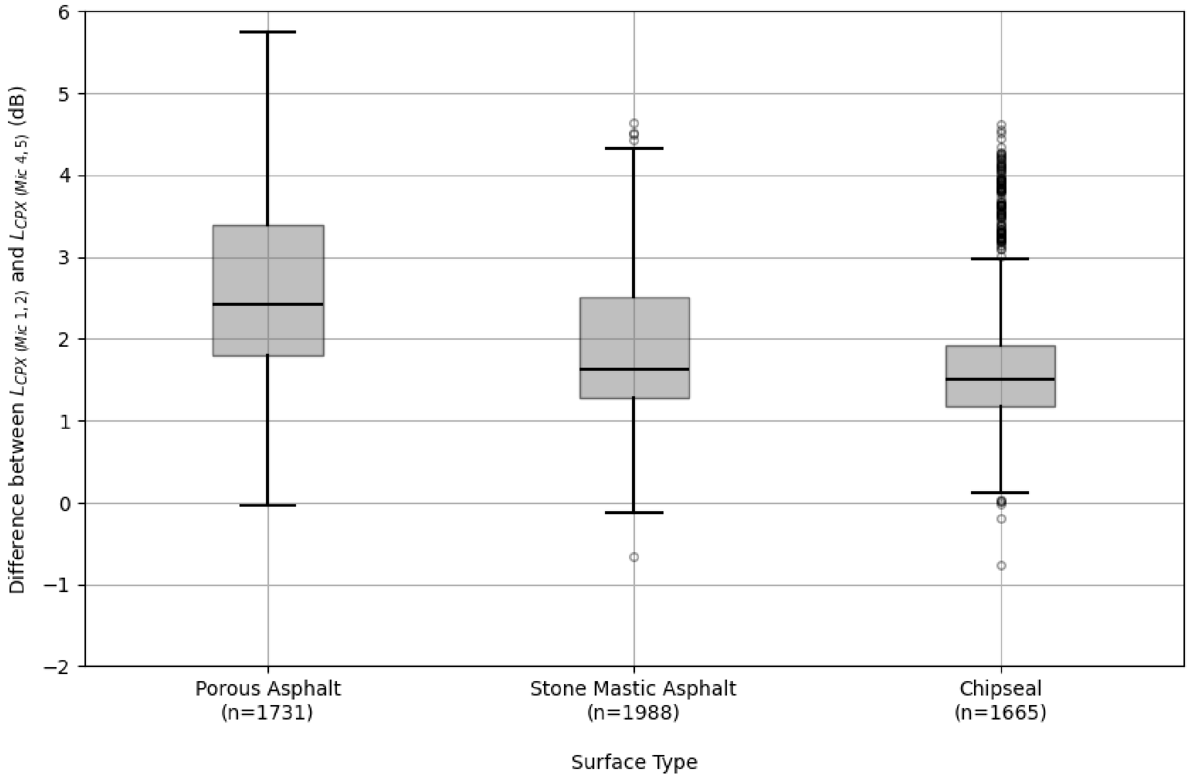

Figure 5: Distribution of differences between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ within each 20 m segment surveyed

[1] $L_{CPX\ P1,80,mic:(1,2)}$ - $L_{CPX\ P1,80,mic:(4,5)}$

Table 6: Results of two-sample t-test on differences between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ within each 20 m segment for each surface type

Surfaces	Difference in means	t-statistic	p-value
Porous asphalt and stone mastic asphalt	0.7 dB	21.0	<0.01
Porous asphalt and chipseal	1.0 dB	29.1	<0.01
Stone mastic asphalt and chipseal	0.3 dB	9.9	<0.01

There were a small number of outlying segments that are likely to be due to errors in the acquired data. Segments with $L_{CPX:P1,80,mic:(1,2)}$ or $L_{CPX:P1,80,mic:(4,5)}$ outside of the 99th percentile range have been excluded. After this exclusion 5,459 20 m long segments remained. Figure 6 presents $L_{CPX,P1,80,mic:(1,2)}$ against $L_{CPX,P1,80,mic:(4,5)}$ for the three overarching surface categories.

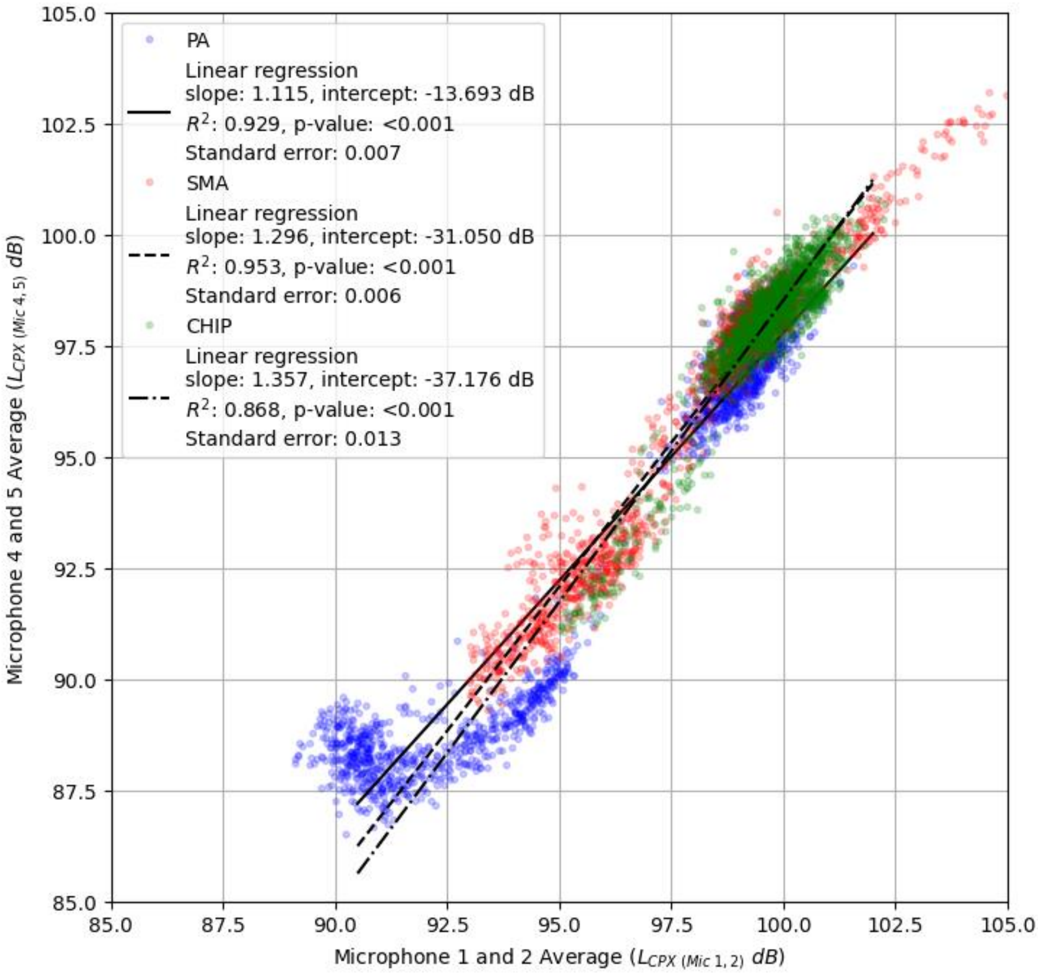

Figure 6: Comparison between chipseal, PA, and SMA surfaces for different microphone pairs

The surface for each 20 m segment was defined as porous and non-porous using the following mapping:

- **Non-porous**: SMA, AC, Chipseal
- **Porous**: PA, EPA

The distribution of the differences between $L_{CPX\ P1,80,mic:(4,5)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ in each 20 m segment for the porous and non-porous surfaces are presented in Figure 7 and the results of a two-sample t-test Table 7. The results of the t-test indicate that there is a statistically large variation in the difference between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ for each surface type. The mean of the differences is higher for porous surfaces.

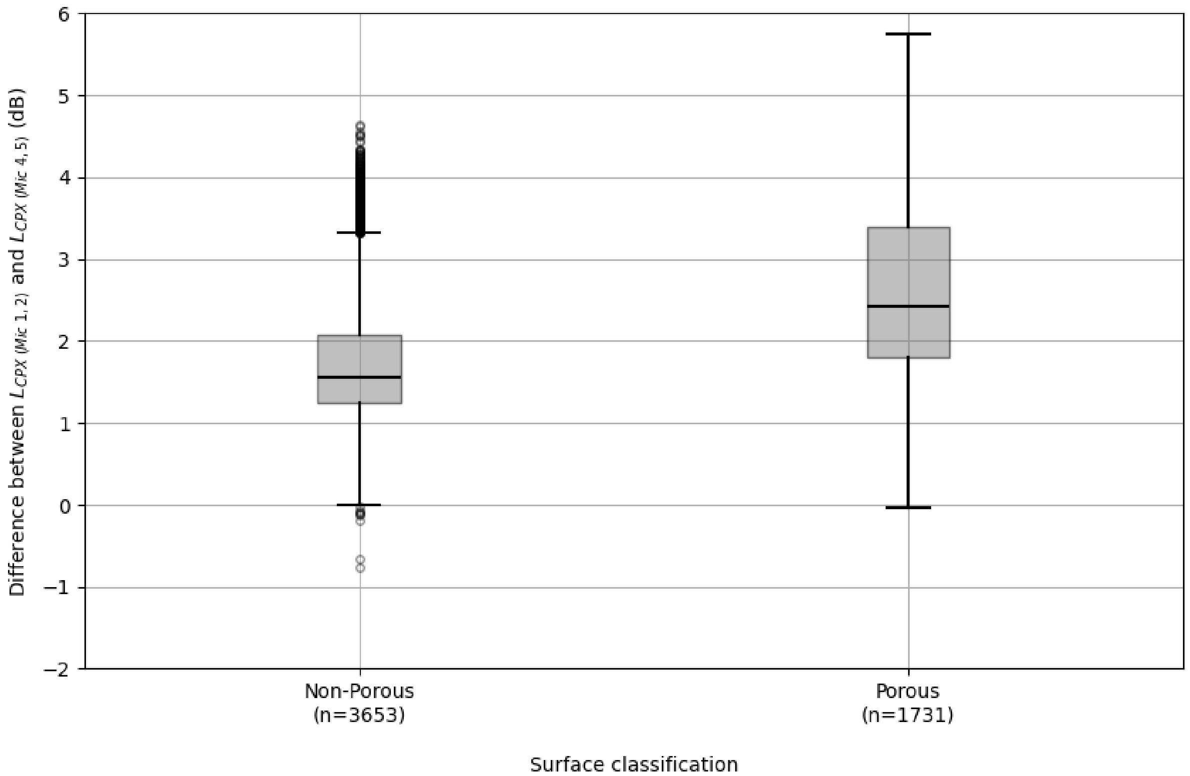

Figure 7: Distribution of differences between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ within each 20 m segment surveyed for porous and non-porous surfaces

Table 7: Results of two-sample t-test on differences between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ within each 20 m segment for porous and non-porous surfaces

Surface classification	Difference in means	t-statistic	p-value
Porous and non-porous	0.9 dB	30.0	<0.01

Figure 8 presents $L_{CPX,P1,80,mic:(1,2)}$ against $L_{CPX,P1,80,mic:(4,5)}$ for porous and non-porous surfaces. A linear regression analysis between the CPX levels for the two pairs of microphone positions exhibited a slope of ~1.1 for porous surfaces and ~1.3 for non-porous surfaces.

The porous surfaces exhibit a clustering below 92 dB $L_{CPX,P1,80,mic:(1,2)}$ and 90 dB $L_{CPX,P1,80,mic:(4,5)}$ which does not appear to conform to the linear trend across the higher noise levels. The cause of this clustering is not known.

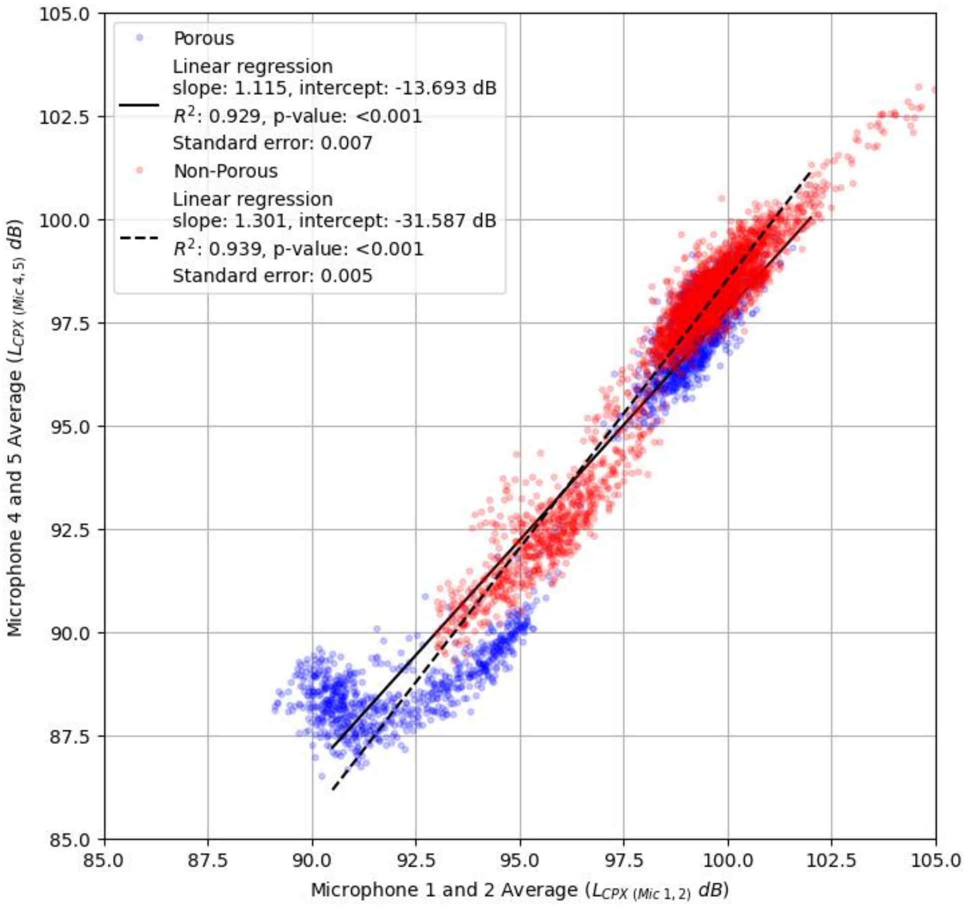

Figure 8: Comparison between porous and non-porous surfaces for different microphone pairs

The mean difference between the $L_{CPX,P1,80,mic:(4,5)}$ for SMA and the $L_{CPX,P1,80,mic:(4,5)}$ for SMA was calculated for 0.5 dB binned $L_{CPX,P1,80,mic:(1,2)}$ levels and is presented in Figure 9. The difference in $L_{CPX,P1,80,mic:(1,2)}$ is ~1.5 dB for $L_{CPX,P1,80,mic:(1,2)}$ below 95.5 dB and ~0.5 dB above 98.0 dB. 2. This shows that for the same $L_{CPX,P1,80,mic:(1,2)}$ level the porous surfaces had a quieter $L_{CPX,P1,80,mic:(4,5)}$ level by ~1.5 dB when $L_{CPX,P1,80,mic:(1,2)} < 95.5$ dB, suggesting that front and rear inline microphones (4,5) are more sensitive to the presence or absence of surface porosity than the standard (1,2) positions.

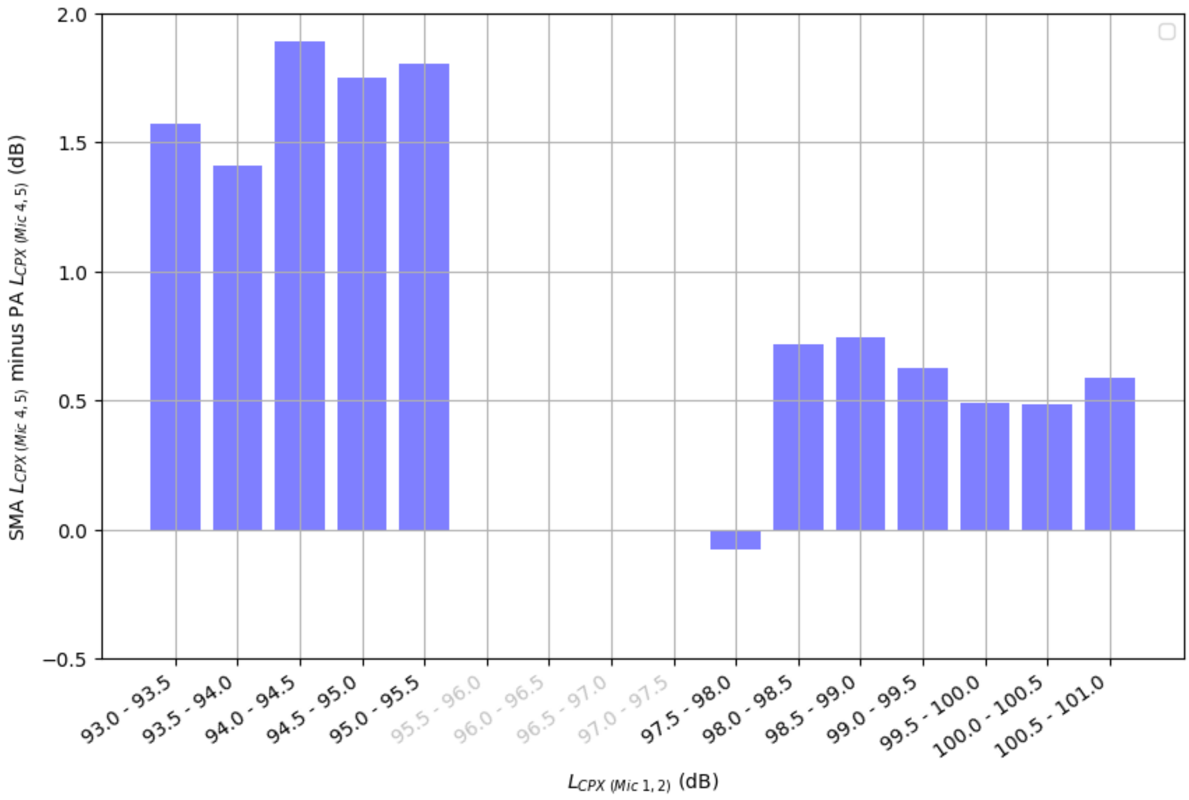

Figure 9: Difference between SMA and PA $L_{CPX\ P1,80,mic:(4,5)}$ levels within 0.5 dB $L_{CPX\ P1,80,mic:(4,5)}$ bins (columns with light grey labels had insufficient samples of both SMA and PA – n_{SMA} *or* n_{PA} *< 10)*

4 Conclusions and recommendations

The use of microphones 4 and 5 provided additional information on the performance of the surfaces. The key differences that were observed between microphones 4 and 5, and microphones 1 and 2 were:

- The slope of a linear regression between the measured CPX level and the noise at the roadside (pass-by) is ~1.8 for microphones 1 and 2 and ~1.4 for microphones 4 and 5.
- The slope of linear regression between the measured CPX level and the noise at the roadside (pass-by) when only PA surfaces were considered is ~0.9 for microphones 1 and 2 and ~0.8 for microphones 4 and 5.
- For all surfaces $L_{CPX\ P1,80,mic:(1,2)}$ was higher than and $L_{CPX\ P1,80,mic:(4,5)}$, due to microphones 1 and 2 being closer to the tyre/road interface.
- The difference between $L_{CPX\ P1,80,mic:(1,2)}$ and $L_{CPX\ P1,80,mic:(4,5)}$ in each 20 m segment was larger for the porous surfaces.
- The difference in $L_{CPX\ P1,80,mic:(4,5)}$ for SMA and PA surfaces is ~1 dB greater at $L_{CPX\ P1,80,mic:(1,2)}$ levels below 95.5 dB. This suggests that at low $L_{CPX\ P1,80,mic:(1,2)}$ microphones 4 & 5 are more sensitive to the surface porosity.
- Minor changes in the rank order of the surfaces present at the nine pass-by sites occurred between $L_{CPX,P1,80,mic:(1,2)}$ and $L_{CPX,P1,80,mic:(4,5)}$. These changes in rank order were only seen in surfaces with higher $L_{CPX,P1,80,mic:(1,2)}$ levels.

The causes of these changes have not been explored further and the mechanisms for some are not fully understood.

It is recommended that microphones 1 and 2 are maintained for all CPX measurements for the following reasons:

- Continuity with the existing dataset of CPX measurements performed in New Zealand.
- Compatibility with the relevant international standards and other CPX systems used globally.
- The different distance from the tyre and contact patch result in different CPX levels when using microphones 4 and 5.

It is recommended that microphones 4 and 5 be used for specific research tasks such as trial sites, especially when the absorption of the surfaces under investigation is expected to have a significant impact on the CPX level. The following should be considered when utilising microphones 4 and 5:

- The absolute levels from microphones 4 and 5 cannot be directly compared to microphones 1 and 2 due to the different distance from both the tyre and contact patch. Care should be taken when reporting the values measured using microphones 4,5 as they can appear to show a reduction in CPX level if misinterpreted.
- In the current (2024) arrangement the trailer is only equipped with four microphones, as such the use of microphones 4 and 5 currently requires the removal microphones 1 and 2 from the right wheel enclosure.
- Further pass-by measurements on a wider range of surfaces where CPX measurements with microphones 4 and 5 have been performed are recommended.

References

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