Road surface noise research 2016-2018

Stephen Chiles and John Bull

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CPX trailer development and initial measurement results

The NZ Transport Agency has taken delivery of a CPX trailer from the University of Canterbury and has undertaken extensive further work to develop it into an operational road surface noise measurement system. The trailer is now based at the CAPTIF Road Research facility in Christchurch and has been used for measurements on trial sections of epoxy modified porous asphalt, and existing sections of standard porous asphalt and chipseal. Opportunities have been identified to reduce noise from porous asphalt.

NZ TRANSPORT AGENCY
WAKA KOTAHI

New Zealand Government

More information

If you have further queries, call our contact centre on 0800 699 000 or write to us:

NZ Transport Agency
Private Bag 6995
Wellington 6141

REVISION HISTORY

Date	Changes Made	Changes made by
June 2017	Initial version	John Bull/Stephen Chiles
January 2018	New trailer modifications. Details of environmental equipment store. Recent measurement results.	John Bull/Stephen Chiles
April 2018	Certification procedures and results. Shipping container and mudguard details. Recent measurement results.	John Bull/Stephen Chiles

CONTENTS

1. INTRODUCTION

1.1 Report purpose

The purpose of this report is to document work the Transport Agency has undertaken from 2016 to April 2018 in relation to road surface noise research. This has been an active period in which work that developed over many previous years has come to fruition. To give context to the current work this report also summarises the previous road surface noise research in New Zealand.

A central part of the work presented in this report is the development of the CPX ("close proximity") road surface noise measurement trailer. Improvements have been made to that system and it has been successfully used for measurements in live-traffic environments. Potential future enhancements to the system are detailed in the report.

Initial measurements using the CPX trailer have confirmed there are significant opportunities for reducing noise from porous asphalt surfaces. Those initial measurements are presented in this report and recommendations are made for further work to realise the apparent noise reduction benefits.

This report is written primarily for readers who are already familiar with road surface noise, acoustics fundamentals and instrumentation concepts. Other documents such as the Transport Agency *Guide to state highway road surface noise* should be referenced if a more general understanding or layman's explanation of the topic is required.

1.2 Research objectives

As in most other developed countries, thousands of people in New Zealand are exposed to road-traffic noise from state highways at levels above desirable thresholds. This noise exposure can lead to annoyance, disturbance and adverse health effects. In accordance with obligations under the Resource Management Act and Land Transport Management Act, the Transport Agency continually undertakes a range of activities to address state highway noise exposure. Reducing road surface noise where practicable is one of these activities.

For the 2016 to early 2018 period the Transport Agency has worked towards two main objectives with respect to road surface noise:

1. *Make a CPX measurement system operational*
2. *Reduce the noise from porous asphalt*

The reason for the first objective is that an efficient tool is needed to quantify road surface noise, to allow the development and implementation of quieter surfaces. Internationally, the CPX system is the most commonly used road surface noise measurement system, and is appropriate for New Zealand; however, there has not previously been a CPX system readily available for local use.

As set out in this report, the Transport Agency worked with the University of Canterbury to develop a CPX system in New Zealand. The University of Canterbury system required further effort to make it operational, and this work was achieved by the Transport Agency during the 2016 to 2018 period.

While the first objective provides an essential tool, the fundamental reason for work relates to the second objective, which is to investigate porous asphalt surfaces with a view to optimise the noise reduction. Successful trials have been conducted with different mix designs of porous asphalt surfaces, which have confirmed there is significant scope for noise reductions. Further work is required to confirm the causes of variations in road surface noise and realise the potential benefits.

1.3 Project team

This work has been sponsored by Rob Hannaby, Technical Services Manager, and managed by Greg Haldane, Principal Environmental Specialist. Work has been conducted by Stephen Chiles and John Bull, who are both independent consultants contracted directly by the Transport Agency. Stephen's role has been research design and management, while John has undertaken the majority of the work.

The Transport Agency's preferred approach is for external providers to hold the capability to measure and analyse road surface noise, including using the CPX method. Ideally the Transport Agency would not take responsibility for developing, owning or directly operating a CPX trailer. However, in the case of CPX measurements, the preferred model is strained by the large investment that would be required by external providers, and uncertainty around the extent of future CPX measurement work streams to recoup that investment.

To overcome these issues the Transport Agency set out to work in partnership with the University of Canterbury to develop a CPX trailer. The intention was that third-parties would then be able to operate that trailer, with the eventual goal of having the trailer maintained and operated by an external provider potentially under a long-term contract.

The trailer was originally due to be delivered by the University in early 2015, but it was delayed. The Transport Agency initially assigned a graduate engineer (Yan Zhou) to progress development of the CPX trailer with the University in 2016; however, Yan left the Transport Agency in mid-2016. In November 2016, the Transport Agency contracted John Bull to complete the trailer and undertake initial CPX measurements, as set out in this report.

The CPX trailer is now kept at the Transport Agency CAPTIF Road Research facility in Christchurch. Rob Craw at CAPTIF has worked with John Bull on trailer modifications and measurements. Rob has also overseen construction of the environmental equipment store for the CPX trailer at CAPTIF.

1.4 Reference group

All work conducted has been done in close and regular liaison with the Transport Agency pavements team, including David Alabaster, Frank Greenslade and Rob Craw, and their Technical Services Manager, Janice Brass.

As part of one of the sector research projects discussed in the next section of this report, a road surface noise industry reference group was convened, and a further two meetings of that group were held at CAPTIF in February and October 2017 in relation to the low noise road surface work.

In addition to Transport Agency staff named above, the industry reference group currently includes:

- Janet Jackson, Downer
- Jeff Waters, Fulton Hogan
- Robert Patience, Higgins
- John Pearse, University of Canterbury
- Richard Jackett, Opus
- Tiffany Lester, Opus

Inputs from this group have guided the work set out in this report.

2. PREVIOUS WORK

2.1 New Zealand research

The Transport Agency has previously commissioned several projects to understand New Zealand road surface noise characteristics. That work is set out in the following reports (all are available at http://nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/noise-and-vibration/research-and-information/):

- NZ Transport Agency, 1994, Research Report 28 - Traffic noise from uninterrupted traffic flows
- NZ Transport Agency, 2006, Research Report 292 - Road traffic noise: Determining the influence of New Zealand road surfaces on noise levels and community annoyance
- NZ Transport Agency, 2007, Research Report 326 - Road surface effects on traffic noise: stage 3 selected bituminous mixes
- Opus, 2014, Low-noise road surface performance monitoring

The work presented in these reports is based on pass-by sound level measurements at a relatively limited number of locations, which affects the reliability of the data. The pass-by measurements detailed in these reports include investigation into surfaces such as the twin layer porous asphalt product developed by Fulton Hogan from around 2001, and trials cleaning porous asphalt surfaces.

Some pertinent issues identified in these reports include:

- New Zealand chipseal surfaces are relatively noisy, but there is significant variation between chipseal types, which has not been precisely quantified.
- New Zealand porous asphalt surfaces are not significantly quieter than reference asphaltic concrete surfaces. This may be partly as the reference asphaltic concrete surface uses a relatively small 10mm chip size and partly as the standard porous asphalt only has modest void content.
- Twin layer porous asphalt performs well initially but the performance degrades relatively quickly.
- Porous asphalt surfaces with high voids provide a slight noise reduction that is sustained over the life of the surface.

Based largely on the above reports, the Transport Agency published its *Guide to state highway road surface noise* in 2014.

The Transport Agency formed a stakeholder group with the University of Canterbury and Opus to confirm knowledge gaps and direct road noise research in 2012-2013. However, as participants would be prevented from tendering for related sector research projects the group was suspended. The same participants are now part of the current industry reference group.

The original stakeholder group identified that an improved measurement tool, compared to pass-by measurements, was important for further research. The Transport Agency commissioned Opus to conduct a sector research project to include evaluation of potential measurement systems. That project concluded that the CPX system was an appropriate method. Opus then used a vehicle based close proximity system to investigate noise performance of different age asphalt surfaces.

The Transport Agency looked to facilitate use of the then proposed University of Canterbury CPX trailer for the Opus measurements; however, it was not available in time for the work. The vehicle based system developed by Opus broadly complies with the CPX measurement standard, but has exposed microphones resulting in a higher noise floor, as shown later in this report. The findings from the sector research project are presented in the report:

- NZ Transport Agency, 2017, Research Report 626 – The long-term acoustic performance of New Zealand standard porous asphalt

The Transport Agency also commissioned Opus to conduct another sector research project (TAR 14/01) to develop a specification for the acoustics performance of road surfaces. The project was ultimately abandoned, but during that work the current industry reference group was formed and it was agreed the Transport Agency would work with industry to determine causes of variations in acoustics performance. Once those causes have been established then an appropriate specification requirement can be determined. This has resulted in the trials reported in this report for Sawyers to Groynes, Western Belfast Bypass, Mackays to Peka Peka, and Waikato Expressway (Cambridge), working with Downer, Fulton Hogan and Higgins.

2.2 International research

There is a large body of international research on road surface noise including extensive use of CPX systems. This report does not provide a review or summary of that work as the individual New Zealand research reports discussed above have included detailed reviews of international literature and those research projects were guided by the overseas findings. The Transport Agency and New Zealand researchers are actively engaged with international colleagues. Of note is that currently there is a PIARC workstream related to this topic, and the Transport Agency is involved in that work.

While more intense and detailed research has been conducted overseas than in New Zealand, overseas findings need further development for use on New Zealand roads, to account for differing climatic conditions, aggregate characteristics, underlying pavement strengths, and to be cost effective.

While CPX testing has been used for many years internationally, it has only recently been standardised in a series of ISO standards that define the test method and equipment. The Transport Agency CPX trailer was designed to conform to these standards (which were previously available as drafts).

2.3 University of Canterbury

In 2012 the University of Canterbury initiated a final year project to design and build a CPX trailer. The Transport Agency actively participated in that project. A CPX trailer proved too complex to build as a final year project, but the investigation usefully evaluated key design parameters.

In 2013 the University of Canterbury continued to investigate building a CPX trailer, but could not justify the investment. Subsequently, the Transport Agency entered into a research agreement with the University of Canterbury in 2014 to realise a CPX trailer. The Transport Agency provided partial funding for the University to build, calibrate and document a trailer by early 2015. Once completed the Transport Agency would own the trailer, which would remain available for the University (and other parties) to use.

The University made initial progress building the trailer, but reached a hiatus, partly due to the demolition of the mechanical engineering laboratories for earthquake rebuilding in this period and the departure of key post-graduate students from the University.

The Transport Agency took over finalisation of the CPX trailer as detailed in this report. The main design and choice of parameters for the CPX trailer by the University are not documented in this report.

3. CPX TRAILER DEVELOPMENT

3.1 Operating guide

As part of this current work, a guide has been prepared for operation of the CPX trailer, as included in Appendix A. The guide sets out the procedures for health and safety, storage and maintenance, and preparation and operation of the CPX trailer. Appendices to the guide include a hire agreement, traffic management plan (TMP), use of the analysis system and certification. The guide addresses:

Health and safety

Safe trailer handling procedures are listed and cover: jacking tasks, wheel changes and work inside the wheel enclosure. Trailer operating procedures are also given. Operation of the trailer during a measurement session must be conducted with two people present, one of whom is Level 1 Basic Traffic Controller qualified. All measurements must be conducted in accordance with an approved traffic management plan (TMP) and occur outside of peak traffic hours. Where a project-wide TMP exists, it can be used while operating the CPX trailer. In all cases, a site-specific measurement plan must be prepared that identifies the test section start, end and safe turning locations.

Storage and maintenance

The trailer, tools and shipping container are kept at CAPTIF. The operating guide includes an equipment list, outlines the procedures for storage and run-in of the measurement tyres, and identifies maintenance and certification intervals. Certification procedures are detailed in an Appendix. The measurement instrumentation is dedicated to the trailer but is controlled by a separate laptop provided by operators. Operators also need to provide a towing vehicle.

Preparation and operation of the trailer

The guide outlines preparation tasks that need to occur prior to a measurement being conducted. These include administration tasks, preparations at CAPTIF and base, and preparations on site. Measurement tasks and requirements are detailed in the operation section of the guide. These include the permitted measurement speeds, required number of runs and a detailed list of steps needed to perform a measurement.

Analysis system

Details of the analysis system are included as an appendix to the guide. The appendix provides a description of the software needed to run the analysis system the steps needed to process the raw CPX data files output by the measurement system. Examples are included of the plots and drawings that can be generated by the analysis system.

3.2 Hardware

Following delivery of the CPX trailer and the first measurement session by John Bull and Rob Craw, several modifications were identified as high priority from both a health and safety, and ease of use perspective. The Christchurch Fulton Hogan workshop was engaged to make the modifications that required specialist tools and skills. Other modifications were made by John and Rob at CAPTIF.

These required modifications included:

- Adding an adjustable height tow bar to allow the CPX trailer to be towed behind a range of vehicles (Fulton Hogan).
- Adding a central jacking point to allow quicker and safer changes between measurement mode and transport mode (Fulton Hogan).
- Repositioning the ‘Road Inspection’ sign to reduce aerodynamic noise (Fulton Hogan).
- Adding heavy-duty latches and locking pins to the top halves of the wheel enclosures to prevent failure of the hinges.
- Repositioning the instrumentation and battery enclosures at the rear of the trailer, and shortening/securing the signal cables.
- Re-routing electrical cables inside the trailer frame and adding LED lights in improved locations.

- Replacing the microphone and temperature sensor mounts with low-profile designs attached to the wheel enclosures.
- Hot-dip galvanising the chassis and painting the wheel enclosures.
- Replacing the mudguards with a more user-friendly design and lower profile mounting to reduce reflections.
- Modifications to the left wheel enclosure to meet the certification requirements.

The following sections show the modifications in more detail and explain the design decisions.

Adjustable height tow bar

The CPX trailer has low skirts and needs to sit level with the ground when in measurement mode. The tow bar height of the CPX trailer was originally designed for it to be towed behind a specific Nissan Navara owned by the University of Canterbury (Figure 1), or to be used with hitch-mount tow ball attachments customised for each alternative towing vehicle. For current research work with measurements in different regions the CPX trailer needs to be towed with a range of different vehicles, and the use of customised tow ball attachments would not be practicable. Instead, with the new adjustable height tow bar (Figure 2) the CPX trailer can now be towed behind any vehicle with a standard 1 7/8" tow ball, regardless of the vehicle's tow ball height relative to the road surface.

The adjustable height tow bar design implemented has the following features:

- *No fasteners* – No fasteners need to be removed when adjusting the tow bar height. This eliminates the risk of incorrectly reattaching the tow bar to the trailer chassis following height adjustments.
- *Continuous height adjustment* – The mechanism makes use of a swing arm and turnbuckle, allowing a continuous rather than incremental choice of tow bar heights.
- *Adjustments on vehicle* – Height adjustments can be made while the trailer is hitched to the tow vehicle, allowing the correct tow bar height to be set with a single adjustment.

Figure 1 Original fixed height tow bar

Figure 2 New adjustable height tow bar

Formal certification of the trailer under the ISO measurement standard will relate to the trailer used in conjunction with a specific towing vehicle. In future, if the trailer is used to verify compliance with specifications it will need to be certified for each towing vehicle used. For the current research work, formal certification with each different towing vehicle should not affect the outcomes as modern tow vehicles are being used. These vehicles should have minimal influence on the sound recorded adjacent to the test tyre. The certification results with a specific Toyota Hilux tow vehicle are included in this report.

Central jacking point

The CPX trailer has two modes of operation. Measurement mode places the wheel enclosures and microphones close to the road surface, while transport mode raises the wheel enclosures and microphones to reduce the risk of damage while travelling between test sites.

To change between the transport and measurement modes two pins are removed and the trailer is lowered using a jack. The original procedure required the trailer to be jacked off the ground at its rear, which resulted in the trailer being raised or lowered through a significant height range to unload the suspension. A central jacking point allows the chassis to be jacked off the suspension itself, reducing the required jacking height range and improving operator safety by eliminating the need to lift the entire trailer off the ground. A compact 2t bottle jack is now sufficient for the task.

Figure 3 and Figure 4 show the central jacking point with the trailer at transport height and measurement height, respectively. The jack is shown in position, but is removed immediately after making the change between the two modes.

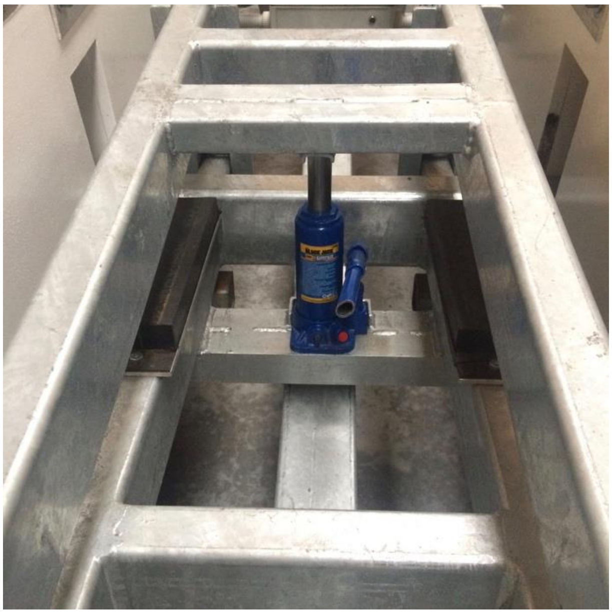


Figure 3 Central height jacking point – Transport height

Figure 4 Central height jacking point – Measurement height

Reposition 'Road Inspection' sign

The 'Road Inspection' sign was originally placed at an elevated position, resulting in significate aerodynamic forces and potential aerodynamic noise while operating the trailer (Figure 5). The sign was trimmed and moved to a lower position at the rear of the trailer (Figure 6).

Figure 5 'Road Inspection' sign – original position

Figure 6 'Road Inspection' sign – new position

Wheel enclosure latches and pins

The wheel enclosures are hinged at their upper edge (Figure 7), allowing the top halves to be lifted when changing the wheels and installing the microphones. The original design resulted in large loads being transferred through the hinges. Pins were installed at the bottom edges of the enclosures to take the weight off the hinges, and the original rubber fasteners were replaced with heavy duty latches to provide a larger clamping force (Figure 8).

Figure 7 Wheel enclosure hinge originally under significant loads

Figure 8 New pins and heavy-duty latches

Repositioning the instrumentation and battery enclosures

The instrumentation enclosure was originally located in an exposed position on the trailer tow bar, and the adjustable height tow bar modification resulted in the signal cables needing to traverse the hinged tow bar joint. Once on the trailer itself the cables followed a convoluted path before reaching the microphones.

In order to place the instrumentation in a more secure location and shorten the signal cable routes, the instrumentation enclosure was moved to the rear of the trailer and the battery (originally housed in the instrumentation enclosure) was installed in a separate enclosure. This now accommodates two larger capacity batteries and simplifies removal of the battery enclosure for overnight charging.

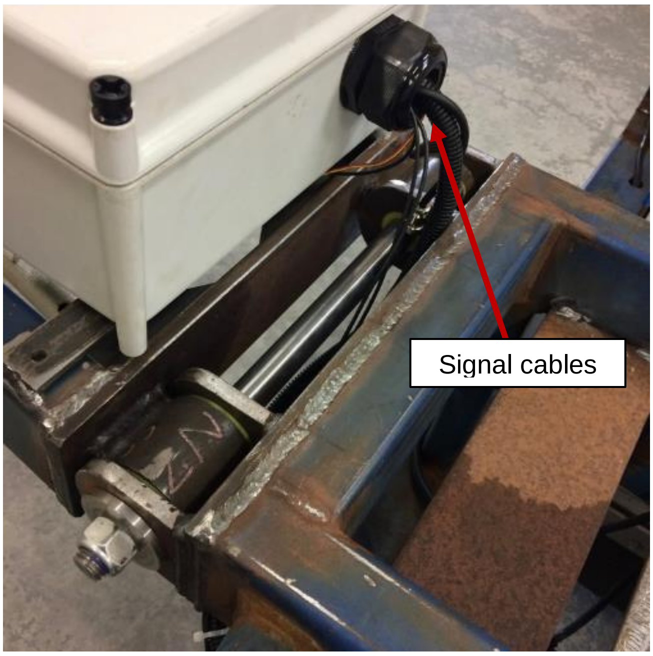


Figure 9 Original instrumentation enclosure with signal cables traversing the hinged tow bar joint

Figure 10 New instrumentation enclosure located behind number plate at rear of trailer

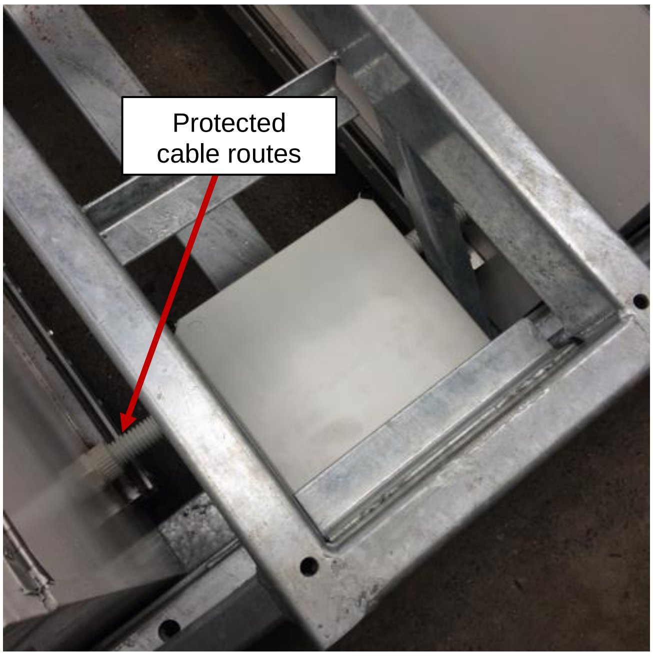


Figure 11 New instrumentation enclosure with protected cables running to the wheel enclosures

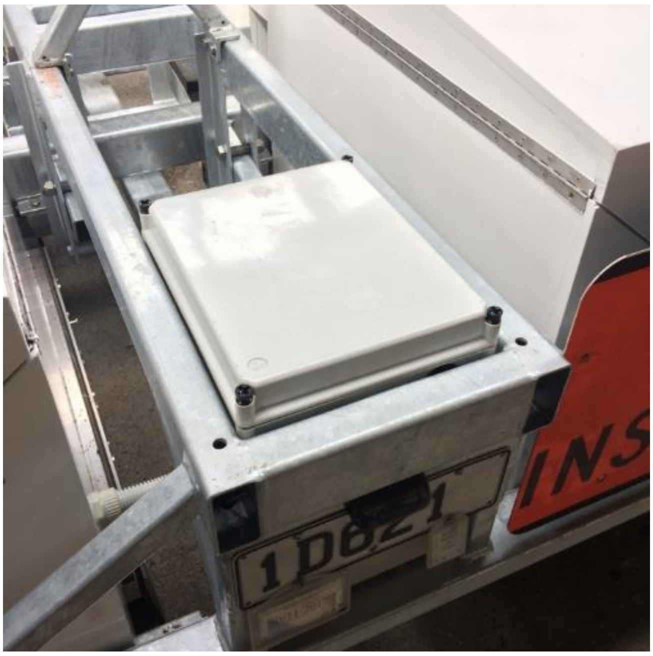


Figure 12 Separate battery enclosure can be removed for overnight charging

Trailer lighting and electrical cables

The original trailer lights were mounted on brackets rather than directly onto the trailer frame. This complicated the wiring routes back to the tow vehicle and made the lights more vulnerable to accidental damage. The rear lights were replaced with slim LED units and mounted directly to the trailer frame. Holes were drilled in the steel members for internal cable routing. The rear electrical junction box was removed and the cables were spliced together with joints then located inside the steel frame.

Figure 13 Original lights attached to brackets

Figure 14 New LED lights attached directly to the frame, with internal cable routing

Replace microphone and infrared temperature sensor mounts

The microphone mounts were originally attached to the trailer such that they remained close to the road surface when the trailer was raised to transport height, requiring the mounts to be removed each time the trailer was raised. New microphone mounting points have been installed that attached to the wheel enclosures and are fully retracted when the trailer is at transport height. The new mounts can remain permanently attached to the trailer and have a low-profile design to reduce sound reflections.

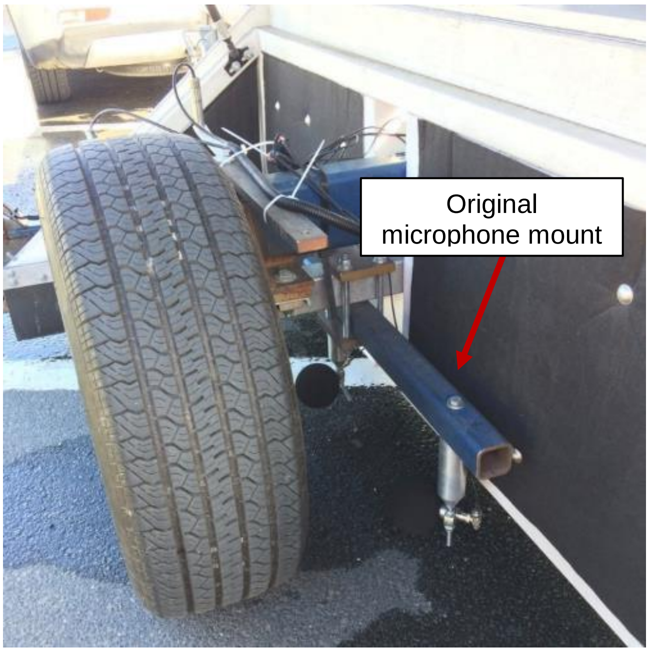


Figure 15 Original microphone mounts

Figure 16 New microphone mounts attached directly to the wheel enclosure

The infrared (IR) temperature sensors were originally mounted to the steel beam that attached to the height adjustment swing arm. The mounting arrangement obstructed access when changing between transport and measurement wheels, and introduced further sound reflecting surfaces near the microphones. The sensors were repositioned on the wheel enclosure lid to swing out of the way during wheel changes.

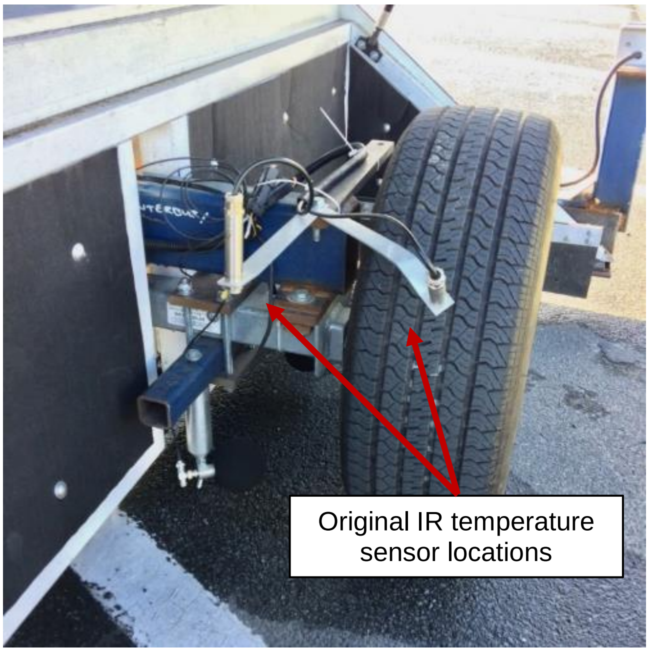


Figure 17 Original IR temperature sensors

Figure 18 New IR temperature sensor located on wheel enclosure lid

Chassis and wheel enclosure coatings

Both the chassis and wheel enclosures were in need of new protective coatings. The trailer chassis was disassembled and hot-dig galvanised at a facility in Christchurch. While removed from the chassis the wheel enclosures were sanded back and painted with three coats of super-gloss enamel paint to provide a hard-wearing surface.

Figure 19 Wheel enclosures after first coat of paint

Figure 20 Galvanised chassis

Replacement mudguards

The original mudguards were prone to rubbing on the tyres. These were replaced with a safer and more user-friendly design. The mounting system was also redesigned to limit sound reflections.

The new mudguard assembly and can be installed by one person. The two steel mudguard tubes are slotted into brackets attached to the inner wall of the wheel enclosure. The mudguard tubes are secured by four grub screws, which are tightened using a 8mm allen key.

Figure 21 Steel mudguard tubes inserted into brackets

Figure 22 Mudguards fitted to trailer

Left wheel enclosure modifications

The left wheel enclosure had to be modified as part for the April 2018 certification tests after it was found the enclosure did not meet the requirements of ISO 11819-2 A.2. The following modifications were made:

- Remove a section of the inner rubber skirt (Figure 23),
- Add a felt-polyester layer to the lower inner timber members (Figure 23 and Figure 24), and
- Angle the front and rear rubber skirts (Figure 25 and Figure 26).

It is expected that right wheel enclosure will require the same modifications; however, this will need to be checked by performing a certification test.

Figure 23 Section of inner rubber skirt removed

Figure 24 Felt-polyester layer added to lower timber member

Figure 25 Front and rear rubber skirts angled

Figure 26 Enclosure configuration following modifications

3.3 Instrumentation

The measurement instrumentation is based around a National Instruments acquisition unit with an integrated microprocessor running bespoke LabView code.

Following early measurements as part of the current work, several issues with the instrumentation were identified. Some changes were essential to address faults in the system that could invalidate measurements. Other changes were made to improve the usability of the system. A summary of the initial instrumentation issues is given in Table 1 and descriptions of changes made to address each issue are then set out in the paragraphs below.

Table 1 Summary of instrumentation modifications

TYPE	ISSUE/IMPROVEMENT	DESCRIPTION OF INITIAL SYSTEM
System fault	Wheel encoder fault	Wheel encoder reads incorrect speeds, giving incorrect speed corrections that are subsequently applied to the CPX levels. The wheel encoder signal is also used to measure distance travelled, resulting in incorrect location readings and road segment lengths.
	GPS errors	GPS data drops when SBAS satellites are in view.
	Low system voltage	The original battery has insufficient capacity to power the system for a full day of measurements.
Usability improvement	Separate measurement settings file	No ability to repopulate the user interface with measurement settings from a previous measurement session.
	Unable to enter measurement details	The header table, containing measurement details, cannot be changed while moving.
	Limited wireless	WiFi adapter settings limits wireless connections to

TYPE	ISSUE/IMPROVEMENT	DESCRIPTION OF INITIAL SYSTEM
	connectivity	Windows 7 machines. Other machines require an Ethernet cable to connect to the system.
	Graphical user interface extends beyond the screen limits of a small laptop	Graphical user interface designed to fit a desktop monitor or large laptop screen, requiring the operator to scroll around the interface when using a small laptop screen.
	Start point triggering	Add ability for the system to automatically trigger recording once past a set start point (longitude/latitude), so that multiple runs can be spatially synchronised.
System Improvement	Research mode	Raw measurement data is discarded during a normal measurement session. There is no ability to reprocess the data over different road segment lengths, or add a positioning offset to improve alignment with other longitudinal roading data.

Wheel encoder fault

Early CPX results showed cases of unrealistically high speed readings in some 20 metre road segments. This directly affected the accuracy of the CPX levels for those segments, as a speed correction is automatically applied to the measured sound levels. The problem was attributed to the wheel encoder, which is responsible for measuring speed. Since the wheel encoder signal is also used to measure the length of each road segment and the trailer position relative to the start point, there was a risk of further errors being introduced by a wheel encoder fault. The root cause of the spurious wheel encoder readings has not been identified.

A GPS receiver was already being used by the system to provide secondary positional data for each road segment. Other linear measurement systems such as the SCRIM truck rely entirely on GPS positioning, albeit an enhanced sophisticated GPS unit in that instance. Use of a GPS rather than a wheel encoder can simplify operation of the system, removing operator errors and avoiding the potential for whole measurement runs to be affected by momentary errors. Regardless of the issue that arose with the wheel encoder, use of GPS as a primary reference is current best practice.

The University of Canterbury fitted the trailer with a professional grade Trimble GPS unit, which is capable of providing accuracy substantially better than the ISO required minimum of ±5m. However, the LabView acquisition software was still using the wheel encoder as the primary reference. As part of the current work the decision was made to convert the system to solely use the GPS for spatial positioning and speed. This bypasses the wheel encoder fault and provides a more stable and reliable system. The LabView code responsible for recording speed and road segment length was modified to use the GPS data and the wheel encoder code was removed from the LabView program. The wheel encoder hardware was also removed from the trailer.

GPS errors

An issue with the serial communication between the GPS receiver and the CPX measurement system was identified, whereby the measurement system would fail to read the GPS serial message in certain situations. This resulted in complete loss of GPS data during those periods. The issue only arose when a newer type of satellite was in view, which resulted in the GPS receiver sending a different serial message to the CPX measurement system. The problem was due to an outdated piece of LabView code responsible for decoding GPS serial messages. The LabView code was modified to deal with the different serial messages occurring when the new satellites were present.

Low system voltage

The original battery supplied with the trailer had insufficient capacity to power the measurement system for a full day of measurements. The original battery was replaced by two larger batteries (each having 26Ah capacity) to allow extended system operation. A larger charger was also purchased to allow the new batteries to be fully recharged overnight.

Separate measurement settings files

The CPX measurement system was originally designed such that testing on one road section (involving multiple runs) would be completed before moving on to another road section. In practice, it is common to perform a run on several road sections before returning to the first road section to start the next set of runs. For example, taking measurements in both directions of a dual carriageway road would proceed as follows:

- Run 1, northbound;
- Run 1, southbound;
- Run 2, northbound;
- Run 2, southbound.

The original system had no facility for repopulating measurement settings from a previous road section, requiring the operator to manually re-enter the measurement details when returning to complete an additional run.

The LabView code was modified to store a separate measurement settings file for each road section. When returning to a road section to perform an additional run the LabView code simply loads the appropriate measurement settings file.

Unable to enter measurement details

An issue with the LabView code prevented changes being made to the measurement details table while moving. The issue causes problems when the operator needs to enter details for a new road section, but it would be inefficient to pull off the road between measurement runs. For example, when changing from a northbound road section to a southbound road section using a roundabout. The LabView code was modified to fix the issue.

Limited wireless connectivity

The measurement system is operated by setting up a remote desktop connection between the CPX instrumentation and the operator’s laptop or tablet. A WiFi adapter is connected to the National Instruments system to remove the need for an Ethernet cable running between the trailer and the tow vehicle.

The original WiFi adapter settings limited wireless connections to Windows 7 machines. The adapter settings were modified to allow wireless connections from a wider range of machines.

Graphical user interface extents

The layout of the graphical user interface was originally set up for a desktop monitor or large laptop screen, requiring the operator to scroll around the interface when using a smaller laptop screen. The graphical user interface layout was modified to fit on a 13” laptop screen to eliminate the need for scrolling.

Run synchronisation and start point triggering

The original measurement system gave the operator no control over the precise start point of a measurement, making it impossible to synchronise the road segments of consecutive runs. The LabView program was modified to force the system to record at the precise moment the ‘record’ button is pressed by the operator, rather than at the start of the next 20 metre road segment (the system continuously scans 20 metre segments even prior to ‘starting’).

A further modification allows the operator to set the coordinates of a start point. The measurement system will then automatically trigger recording once the CPX trailer passes the set start point. This is used when multiple runs are made. Testing along a 6.5 km section of road has shown that the 20 metre road segments of consecutive runs started at the same point remain synchronised within 2 metres for the entire road section.

Research mode

The raw measurement data was previously discarded, eliminating the possibility to reprocess the data over different road segment lengths, or add a positioning offset to improve alignment with other longitudinal roading data (e.g. mean profile depth and roughness).

The main CPX program was modified to allow the following:

- Store the raw time signals from each microphone as a multichannel wav file.
- Store additional calibration data to allow absolute levels to be determined from the raw time signal data.
- Store GPS data, along with the audio sample number that each GPS point corresponds to, in a text file to allow the raw time signal data to be aligned spatially during post-processing.

Research mode is activated by toggling the “Research mode” switch in the setup tab.

While using the research mode significantly increases the amount of disk space used during a measurement session, it allows future querying and reprocessing of the raw data without the need to repeat the physical measurement.

A 32Gb USB flash drive has been fitted to the system to provide the additional disk space required during research mode measurements.

3.4 Analysis software

As part of the current work, new analysis software has been developed using the programming language “Python” to process the data output from the main LabView program. Generally, the data from the CPX trailer is downloaded from the National Instruments computer at the end of a measurement session and then processed on a standard computer with the Python scripts.

The software takes the form of a set of Python scripts, which can be run on any computer with a Python 2.7 interpreter and the required Python packages installed. All of the required software is open source and available for download through the Python website[1] or a package manager like Anaconda[2] or pip[3].

The Python scripts provide the following capabilities:

- Retrieve Rs/Rp codes for each 20 metre road segment, allowing CPX data to be plotted against RAMM data.
- Average the CPX levels from several runs. Standard and rolling averaging options available.
- Generate plots showing the average CPX level along with the CPX level of individual runs.
- Generate plots with CPX levels and RAMM or other data overlays.
- Export shapefiles for use in generating GIS drawings.
- Add the data to a SQLite database.

QGIS is an open source GIS package that is used to generate GIS drawings from the CPX data. It can be downloaded from the QGIS website[4].

The Python analysis scripts are stored in InfoHub[5]. Details of how to use the analysis software are included as an appendix to the operating guide.

SQL Database

During the work described in this report the need arose for a database to collate CPX data and calculate overall averages across lanes and carriageways. A SQLite database was implemented as a Python script within the analysis software to provide a short-term solution during the early research activities. It is expected that this early database will evolve as the project progresses, and eventually provide a basis for a RAMM table or other Transport Agency database to house CPX data. The SQLite database is currently stored in InfoHub and updated after each new measurement.

[1] http://www.python.org
[2] https://www.continuum.io/anaconda-overview
[3] https://pip.pypa.io/en/stable/
[4] http://www.qgis.org
[5] https://infohub.nzta.govt.nz/otcs/cs.dll/properties/9768139

The SQL database currently includes results for each 20 metre road segment tested. Columns include Rs/Rp location, lane, direction, run number and $L_{CPX:P1,80}$. The following additional columns should be considered when deciding on the final database schema:

- GPS location (latitude and longitude)
- Measurement tyre details (type and ID)
- Reference speed
- Wheel track

3.5 Storage

The design and construction of an environmental equipment store at CAPTIF was completed in early 2018. The store now houses the CPX trailer and other environmental equipment owned by the Transport Agency.

The store is lit with a section of clear roofing sheet and two high powered LED bar lights. The plan below details the locations of benches, shelving and services. The total floor area is 60m^2 (6 metres x 10 metres).

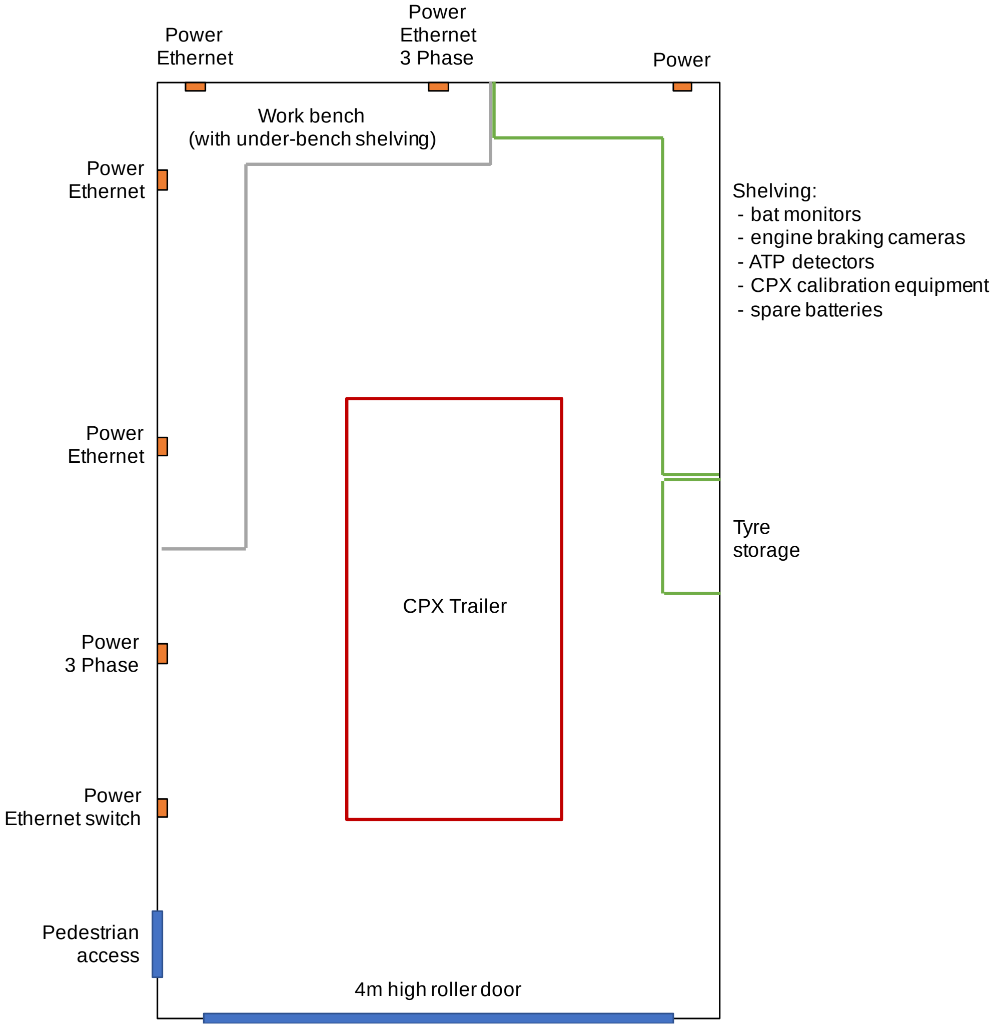
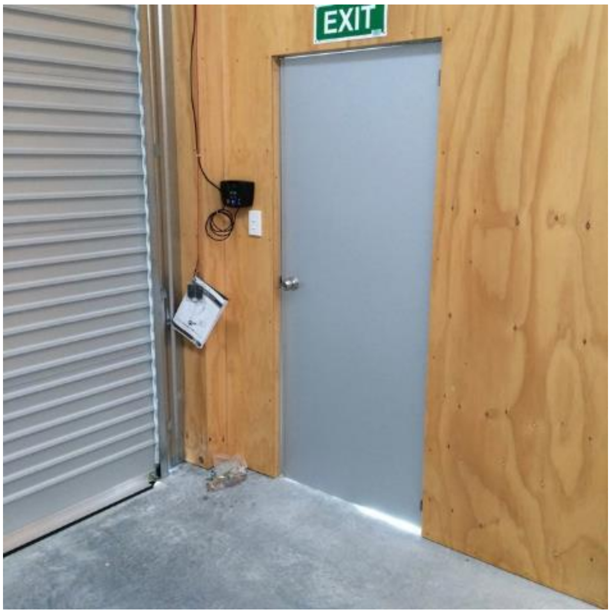


Figure 27 Layout of environmental equipment store

A dedicate refrigeration unit for storing the measurement tyres is recommended by ISO/TS 11819-3; however, the requirements of a refrigeration unit were deemed uneconomic, compared to the costs of replacing measurement tyres, which require regular renewal regardless. The measurement tyres are therefore stored on a shelf in the equipment store.


EXIT


OFF
ON

3.6 Transport

When not in use the CPX trailer is fitted with a set of standard road tyres. These tyres are used in place of the measurement tyres when transporting the trailer locally. When the CPX trailer needs to be transported to locations further afield, the preferred method is to use a 20-foot shipping container. This avoids wear and tear on the trailer, including on the absorbent linings of the wheel enclosures.

The original design of the trailer optimised the wheel track width to perform the required measurements, but also to result in an overall trailer width that fits inside a standard shipping container.

Cost estimates for indicative shipping legs are given in Table 2 below. These are based on quotes from Main Freight in May 2017.

Table 2 Shipping cost estimates for possible shipping legs

SHIPPING COST ESTIMATES	
Christchurch to Paraparaumu	$2,000 + GST
Paraparaumu to Christchurch	$2,600 + GST
Paraparaumu to Cambridge	$1,700 + GST
Cambridge to Christchurch	$1,800 + GST

3.7 Shipping container

A dedicated 20-foot shipping container having doors at both ends was purchased for transport and to serve as a secure weatherproof shelter for the trailer while away from CAPTIF (Figure 28). The shipping container has been fitted out with mounting points for the trailer and ancillary equipment to provide a complete measurement system that can be shipped between sites. The container is stored at CAPTIF.

Figure 28 Dedicated shipping container

Container fit-out design decisions

The ability to entry the shipping container at both ends allowed two potential options for loading and unloading of the trailer:

1. *Drive-through* – the trailer is connected to a tow vehicle and driven forward into the container. The tow vehicle will exit forward through the second set of doors.
2. *Winch* – the trailer is positioned at the bottom of the wheel ramps with a vehicle, then winched inside using a dedicated winch within the container.

The following table lists the pros and cons for the two options.

Table 3 Shipping container loading options

OPTION	PRO	CON
Drive-through	• Faster trailer loading and unloading. • Accessible from both ends. • No manual handling of the trailer.	• Needs a long straight approach area at both ends (~20 metres each side). • Risk of misaligning on entry and damaging the trailer. • Any storage needs to be mounted high enough to allow drive through. Requires an assumption of the maximum tow vehicle height. • Container delivered in the wrong direction: Users may be tempted to manually push trailer out without safe constraint.
Winch	• Minimal approach area needed (~10 metres, front only). • Can have semi-permanent storage and wheel stops at one end, which can be accessed from the rear door. • Less user training/skill required. • Only requires one set of ramps.	• Slower trailer loading and unloading. • Requires a winch, with clearance for the handle. • Requires manual handling. • Container delivered in the wrong direction: Will need to disassemble/move the wheel stops, shelf and winch in order to exit through the rear door. Winch can be reversed to allow safe removal.

Based on the above points the winch option was chosen. Further design details are listed below and shown in Figure 29.

- All fittings are either of a low profile design such that the trailer can roll over the top of them without being damaged, or can be removed and replaced quickly. This is necessary to allow the trailer to exit from both ends of the shipping container in case it is delivered the wrong way round.
- The winch is placed on top of a wooden plinth at waist height to provide clearance for the winch handle and improve the ergonomics.
- The trailer is lowered onto four wooden blocks in the container during transport. The wooden blocks are semi-permanently fixed to the shipping container floor.
- Wooden guide rails are screwed to the floor of the shipping container to limit the transverse location of the trailer and prevent it from running into the container walls during loading and unloading.
- Two wooden ramps are included.
- There is space for two sets of measurement wheels at the rear of the shipping container. These are secured by vertical rods that run through the centre of the wheel hubs.
- A wooden storage unit is included at the rear of the shipping container. The unit secures a plastic bin that is used to store tools, battery chargers and other small pieces of ancillary equipment. The box can be easily removed and placed inside the tow vehicle during testing. The storage unit doubles as a temporary work surface.

Figure 29 Shipping container features

Trailer loading and unloading method

The ramps are installed and the trailer is positioned at the entrance to the container. The winch rope is attached to the trailer and the trailer is slowly winched inside until it reaches wooden limit blocks. The height adjustment bolts are removed and the trailer is lowered down onto the wooden blocks located at each corner, so that weight is taken off the wheels. Supporting the trailer on wooden blocks rather than on its suspension helps to limit movement inside the container. The rear of the trailer is then strapped down using a single 1500kg tie-down strap. The winch rope is left attached to the trailer and secures the front of the trailer.

Figure 30 shows the trailer being loaded into the container using the winch.

Figure 30 CPX trailer being loaded into the dedicated 20-foot shipping container

3.8 Future work

Modifications to the CPX trailer have brought the trailer to a standard that allows reliable and repeatable measurements to be made. Further modifications to the hardware and instrumentation could enhance the system. These tasks are set out in Table 4.

Table 4 Summary of future work recommended

ISSUE/IMPROVEMENT	RECOMMENDED ACTION
Certification test A.5 has not been made	Undertake test A.5 and adjust data exclusion as required.
A structured database is needed for all CPX data.	Establish a custom data table in RAMM and transfer all existing CPX data to RAMM.
Python scripts use A-weighted data, but frequency content may be important.	Enhance Python scripts to quickly show and compare third octave data for selected locations.
Effects of alternative test tyres may be material to initial results.	Purchase H1 tyres and manufacture suitable rims. Purchase other “NZ tyres” for use with the trailer.
Only the left-hand wheel is currently used for measurements.	Fit absorbent linings and microphones to the right-hand wheel bay. Adjust skirts and add felt as required to pass certification tests.
Correlations with surface texture would be more reliable if measured together.	Investigate and fit profile depth laser transducer and video camera.

4. TRAILER CERTIFICATION

4.1 General

Regular certification of the CPX trailer is a requirement of ISO 11819-2 and is described in Annex A to the standard. These tests determine the extent to which the CPX trailer, tow vehicle and external vehicles affect the road surface measurements taken under normal trailer operation. The certification process must be repeated biennially and any deficiencies in the system must be corrected.

The certification tests are explained in detail in ISO 11819-2. Specific details of the Transport Agency methodology are provided in Appendix G of the trailer operating guide. Two of these tests were performed in March and April 2018 as part of the initial CPX trailer certification. The initial certification process involved the development of the in-house equipment and methodology, the details of which are included in the sections that follow.

The road-side test could not be performed in time for inclusion in this report; however, the tools and methodology have been developed and are documented here.

Table 5 Certification tests

REF	DESCRIPTION	DETAILS	TYPE
A.2.	Sound reflections against an enclosure and objects close to the microphones.	Sound pressure level measurements are taken with an artificial sound source placed inside the wheel enclosure. These are compared to measurements without the enclosure present, and used to calculate a set of one-third octave band corrections.	Maximum range: ±3dB. Corrections applied to future measurements.
A.3	Background noise from the test vehicle itself or its operation.	The test tyres are removed from the CPX trailer and replaced with external supporting wheels. Sound pressure level measurements are taken to determine the influence of unwanted noise from the CPX trailer.	Pass/Fail – effectively defines the quietest measurable surface for the trailer (only relevant for the tow vehicle used during the certification test). Reference spectra are used to check the validity of each road segment during a normal measurement run.
		The bearing noise is determined by running the bearing assembly with a smooth tyre over a smooth steel drum.*	
A.4.	Background noise from tow vehicle	The influence of the towing vehicle is included in the A.3.	Same as A.3 above.
A.5.	Background noise from external vehicles	The CPX trailer is positioned on the side of a road (chipseal surface) under normal traffic flow conditions. The sound pressure levels at the two microphones are recorded for passing vehicles and compared to CPX measurements taken on the same type of surface.	Defines the degree of data exclusion required during normal measurements.
A.6.	Alignment of test tyres	Set toe-in to 0 degrees by ensuring suspension assembly is parallel to swing arm. Set camber to 0 degrees by placing the trailer on a flat level surface and measuring with a digital level across the face of the tyre.	Adjust as required.

* The NZ Transport Agency does not currently have facilities to objectively assess the bearing noise. The current approach involves a manual review of audio recordings from the two microphones.

4.2 Test A.2 – Sound reflections

An artificial sound source was built by the University of Canterbury during construction of the CPX trailer. The artificial sound source was based on the design described in ISO 11819-2 A.2.3.

A mounting plate was built as part of the current work program to hold the artificial sound source and microphones, and fix their relative positions during measurements (Figure 31 and Figure 32).

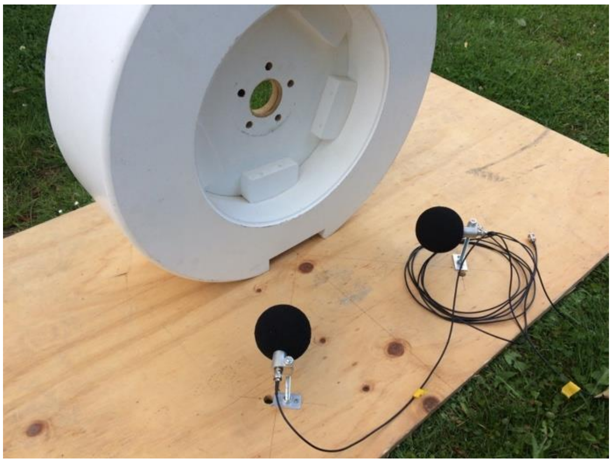


Figure 31 Mounting plate for A.2 certification test

Figure 32 Mounting plate in position during an enclosure test

A LabView program was developed to streamline the test A.2 measurement process (Figure 33), using the main CPX test equipment. The program includes the following features:

- Stores test data for a given test session in a predefined folder structure. This includes the operator name, date, left/right enclosure, sound pressure levels for individual measurements and the device dependent corrections in a format that can be read by the main CPX LabView program.
- Tracks whether a measurement run is a background, free-field or enclosure measurement.
- Displays the microphone pressure signal immediately following a measurement run so the operator can check for contaminating noise events (e.g. wind gusts).
- Automatically calculates the one-third octave band A-weighted sound pressure levels for each measurement run and displays the results on the screen for the operator to review.
- Calculates the device dependent correction from a selected set of free-field and enclosure measurements.

The Labview program does not currently have the ability to generate the white noise signal required for the test. A standalone white noise signal generator is needed that plugs directly into the amplifier.

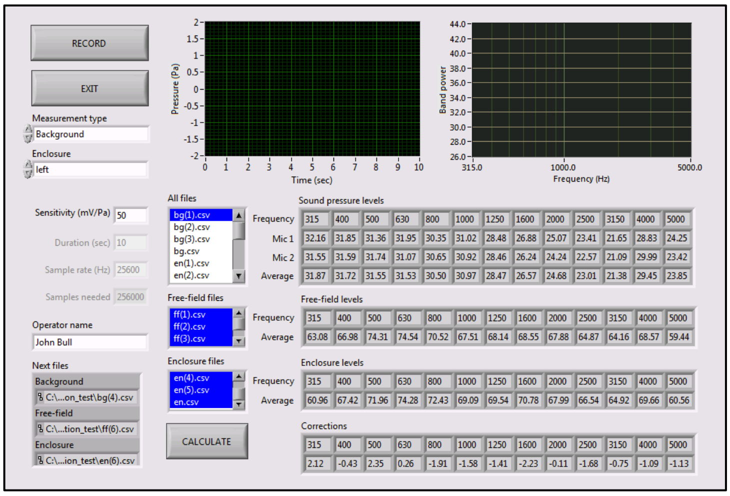


Figure 33 Wheel enclosure certification LabView program

A test methodology was developed as part of this work and is detailed in Appendix G of the trailer operating guide.

Certification results

Tests were performed by John Bull in March 2018 according to the methodology detailed in the trailer operating guide. The tests had to be performed at a residential location with low background noise because the noise environment at CAPTIF was too loud.

Only the left wheel enclosure was tested as the right wheel bay is yet to be fitted out. Significant modifications to the left wheel enclosure were required to meet the performance requirements. The following discusses the sequence of the measurements taken, subsequent investigations and the enclosure modifications required.

Initial tests showed that the left wheel enclosure did not meet the performance requirement, having level differences of more than 3 dB in multiple one-third octave bands, as shown in the table below.

Table 6 Sound reflection test results

	1/3-OCTAVE BAND CENTRE FREQUENCY												
	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Free-field levels (dB)	62.3	65.9	73.9	75.1	70.2	67.4	67.9	67.7	66.7	65.1	62.2	68.6	60.7
Enclosure levels (dB)	60.5	65.8	69.0	75.5	72.3	69.6	70.5	69.2	70.5	68.7	65.8	71.1	62.8
Correction, C_d (dB)	1.8	0.1	**4.9**	-0.4	-2.1	-2.2	-2.6	-1.5	**-3.7**	**-3.5**	**-3.6**	-2.5	-2.2

Of particular concern was the result in the 500Hz band where the enclosure had the effect of reducing the sound pressure level compared to the free-field situation. The decrease in level of 4.9 dB indicated a strong reflection of the 500Hz sound, resulting in destructive interference between the direct and reflected waves. Further investigation showed that the reflection was associated with the inner rubber skirt and lower timber members. The section of rubber skirt in the vicinity of the microphones was removed and a felt-polyester fibre layer was added to the lower timber members.

The reflection tests were repeated and showed that the enclosure still had an unacceptable effect on the measured sound pressure levels in the 2,000Hz one-third octave band. Investigation showed that reflections off the front and rear rubber skirts were likely to be the cause, and the front and rear skirts were placed on an angle to alter the direction of reflected sound away from the microphones.

The results from the three scenarios are shown graphically below, with scenario C being used as the final device dependent corrections. The final enclosure configuration is detailed in Section 3.2 above.

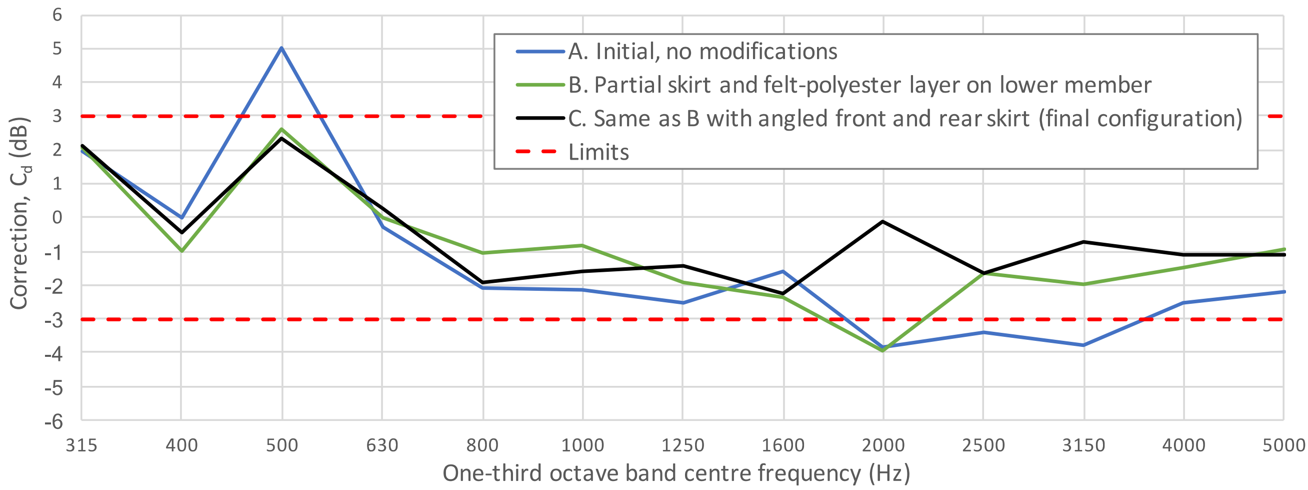


Figure 34 Device dependent corrections for the various enclosure configurations

The final test details and results are included in Appendix B.

4.3 Tests A.3 and A.4 – System noise

These tests require the CPX trailer to be run at measurement speed without the usual noise generated by the tyre/road interaction. To meet this requirement a set of externally mounted wheels were built that can be fixed to the rear of the trailer. It was intended that the test be performed on a closed test track, so the external wheels did not need to be road legal; however, safety remained a primary concern.

The following points were considered while designing the external wheels:

- The external wheels need to be positioned as far from the microphones as practical to avoid contamination of the certification measurements by noise from the external wheels.
- For a single set of external wheels they need to be positioned as far forward as practical to limit the vertical load placed on the tow ball of the towing vehicle.
- Any extension arms need to be rigid enough to sustain cornering loads without excessive deflection.
- Any extension arms need to be short enough to safely negotiate obstacles when entering/exiting the test track and safely negotiate corners at a moderate speed.
- The assembly should not be overly heavy and should be easily transportable to the test track.

The chosen design consists of a single 4.5 metre long steel beam running across the rear of the trailer (Figure 35). The arms extend out 1.1 metres either side of the trailer to increase the distance between the microphones and external wheels. A diagonal support member provides additional rigidity to the beam to limit deflection. The entire assembly is attached to the CPX trailer by eight bolts, and can be transported to the test track strapped to the top of the trailer.

One drawback of this external wheel design is that it requires a tow vehicle rated for a vertical tow ball load of 250 kg. This exceeds the tow ball load limits of most cars and compact SUVs, meaning that in some cases it will not be possible to have a system fully certified to ISO 11819-2.

Figure 35 External wheel assembly

The main LabView program is used as per a normal CPX measurement. The LabView program outputs the raw unweighted one-third octave band levels (for each microphone position) over 20 metre long road segments on the test track. This data is then A-weighted and averaged by the operator (over the microphone positions and road segments).

The current test methodology is detailed in Appendix G of the trailer operating guide.

Certification results

Tests were performed by John Bull and Robin Wareing in April 2018 according to the methodology detailed in the trailer operating guide. Only the left wheel enclosure was tested as the right wheel bay is yet to be fitted out.

The tests were performed at Ruapuna Raceway, Christchurch. Three test runs were performed at 80km/h and three more runs at 50km/h. A final test run was performed starting at 80km/h and coasting to 50km/h with the vehicle engine in an unloaded condition.

The one-third octave band A-weighted sound pressure levels for the two measurement speeds are included in the table below. These levels represent the background noise of the trailer and tow vehicle that would be recorded as part of a normal CPX measurement; however, usually masked by the much higher road-tyre noise generated by the measurement tyres.

These background levels are specific to the Toyota Hilux (KNE926) used during the certification tests. Therefore, a separate certification test is required for each new tow vehicle.

Table 7 System generated background noise

	BACKGROUND NOISE DUE TO THE TRAILER AND TOW VEHICLE												
	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
LAeq (dB), 80km/h	68.9	68.8	70.0	72.6	73.6	74.7	76.3	72.9	72.3	70.2	67.5	63.2	59.7
LAeq (dB), 50km/h	63.8	64.9	65.0	66.5	68.0	68.3	69.5	66.3	64.8	62.9	60.7	56.8	53.4

The background noise levels can be used to determine a spectrum that represents the lowest valid measurement levels that would still conform to ISO 11819-2 for a the certified tow vehicle. This is based on the ISO 11819-2 performance requirement, which states that the trailer and tow vehicle must not influence the results by more than 1.0dB in the 500Hz to 5kHz bands and 2.0dB in the 315Hz and 400Hz bands.

The lowest valid measurement spectra are presented in the table below. The 80km/h spectrum is compared to two surface measurements (the quietest EPA10 and EPA7 surfaces tested to date) in Figure 36.

Table 8 Lowest valid measurement spectra

	LOWEST VALID MEASUREMENT LEVELS												
	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
LAeq (dB), 80km/h	73.3	73.1	76.9	79.4	80.5	81.6	83.1	79.8	79.2	77.1	74.4	70.1	66.6
LAeq (dB), 50km/h	68.1	69.3	71.9	73.3	74.8	75.1	76.4	73.2	71.7	69.7	67.6	63.6	60.3

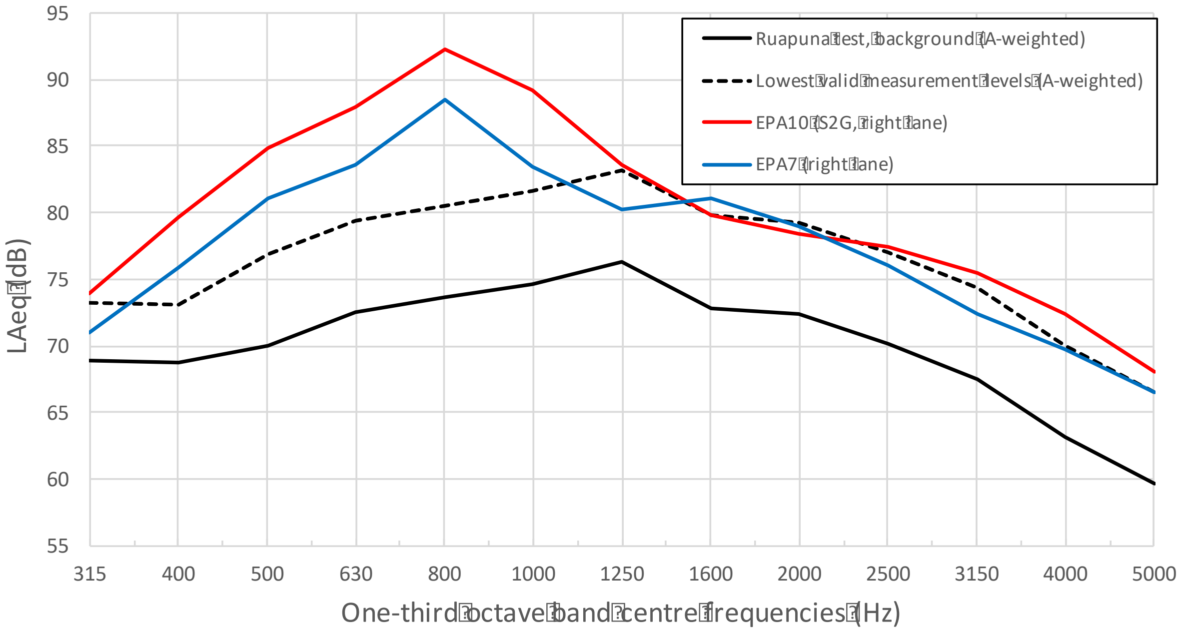


Figure 36 Lowest valid measurement spectrum and comparison with reference surfaces for 80km/h reference speed

From the figure above it is clear that measurements taken on some of the quietest surfaces may be contaminated by background noise from the trailer and tow vehicle. However, this generally affects only the low (315Hz) and high (1250Hz and above) frequency bands.

The A-weighting filter results in a reduction in the effect that these frequency bands have on the overall noise level, and the none conformance only has a limited effect on the overall A-weighted levels. This is demonstrated in Table 9.

Table 9 Comparison between the measured LAeq and the calculated effective level after the background noise has been accounted for.

	LAeq (measured)	LAeq with effect of background noise removed	Error
EPA10 (S2G, right lane)	96.1 dB	95.9 dB	0.2 dB
EPA7 (right lane)	92.3 dB	91.8 dB	0.5 dB

The certification test details and results are included in Appendix B.

4.4 Test A.5 – Passing vehicles

This test has not yet been conducted, although the current operating procedures discussed below mean that it has no effect on measurements.

The results of the future test will inform the trailer operator of the extent to which passing vehicles must be excluded during a normal CPX measurement run. The data exclusion approach currently used requires the operator to exclude all passing vehicles by flagging any affected 20 metre segments using the appropriate button on the LabView program user interface. The failure to conduct test A.5 does not affect the validity of past and future measurements, however, it is intended that this test be performed as part of the biennial trailer certification.

The test requires the CPX trailer to be positioned on the side of a road with a posted speed limit of 80 km/h. Noise levels associated with discrete vehicle pass-by events are taken and adjusted for the actual vehicle speed using the same method applied in a during CPX measurement.

ISO 11819-2 A.5 requires the road surface to be a DAC or SMA surface; however, the noisiest surfaces in New Zealand are typically chipseal surfaces so the procedures have been developed to refer to measurements on a Grade 2/4 chipseal surface.

A LabView program has been partially developed to streamline the test A.5 measurement process (Figure 37). The program includes the following features, however, will require further refinement following the initial certification test.

- Stores all test data for a given test session in a predefined folder structure based on the enclosure and lane being assessed. The test data includes the operator name, date, left/right enclosure, left/right assessment lane, vehicle speed and type, pass-by sound pressure level, speed corrections and the final corrected level.
- Displays the microphone pressure signal immediately following a measurement run so the operator can check for contaminating noise events (e.g. wind gusts).
- For each vehicle pass-by, automatically calculates the one-third octave band noise levels, speed corrections and final corrected level.

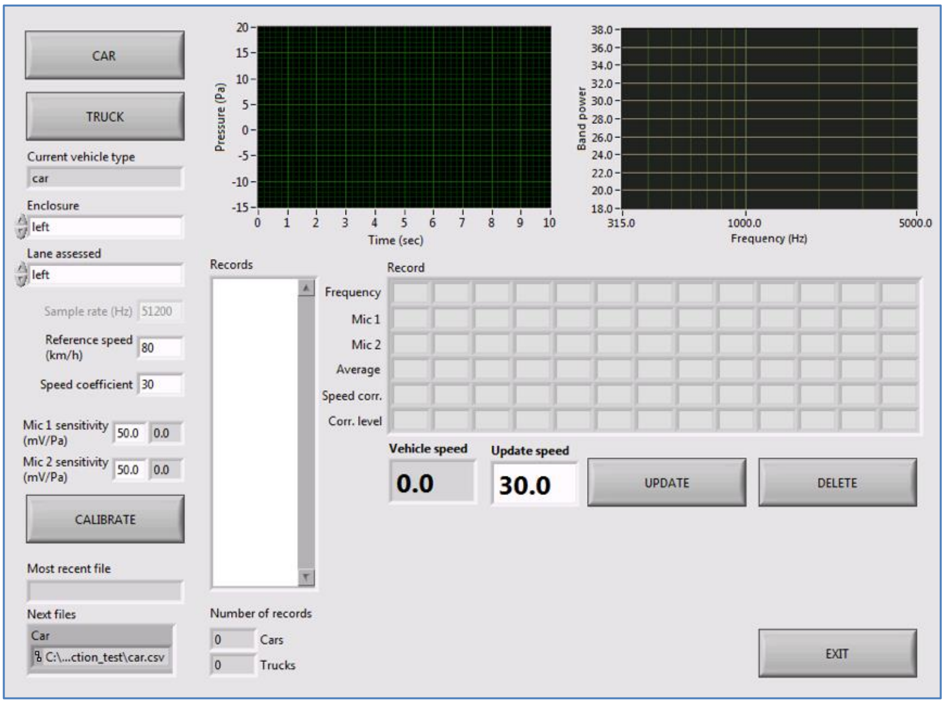


Figure 37 Road-side certification LabView program

5. INITIAL MEASUREMENT RESULTS

5.1 High voids asphalt

Based on previous pass-by measurements showing potential noise reduction, trials have been arranged with high void porous asphalt surfaces. These were laid in 2017 on the northbound carriageway of State Highway 1 between the Sawyers Arms Road roundabout and the Greywacke Road exit in Christchurch. Four mix designs were initially investigated:

- EPA10 – standard epoxy modified porous asphalt, with 10 mm chips
- EPA14 – epoxy modified porous asphalt, with 14 mm chips
- EPA10HV – epoxy modified porous asphalt, with 10 mm chips and increased void content
- EPA14HV – epoxy modified porous asphalt, with 14 mm chips and increased void content

The EPA14HV mix failed its preliminary laydown test and was excluded from the trials.

The high void trial sections were laid on both the right and left lanes on 11 & 12 February 2017. Four measurement sessions were conducted on the following dates:

- 21 February 2017 (10 days old)
- 10 April 2017 (8 weeks old)
- 26 April 2017 (10 weeks old)
- 21 March 2018 (13 months old)

The relative performance of each mix and the differences in $L_{CPX:P1,80}$ between the test dates are shown in Figure 38 and Figure 39 for the right and left lanes. The ranking of each mix is the same for both right and left lanes, with the EPA10 surface exhibiting the lowest $L_{CPX:P1,80}$ values and the EPA14 surface having the highest $L_{CPX:P1,80}$ values.

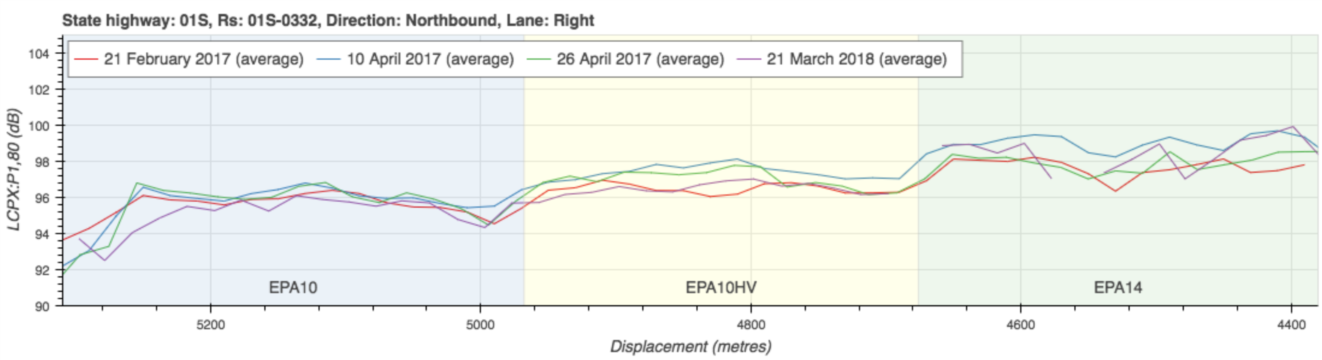


Figure 38 High void trial sections - Right lane

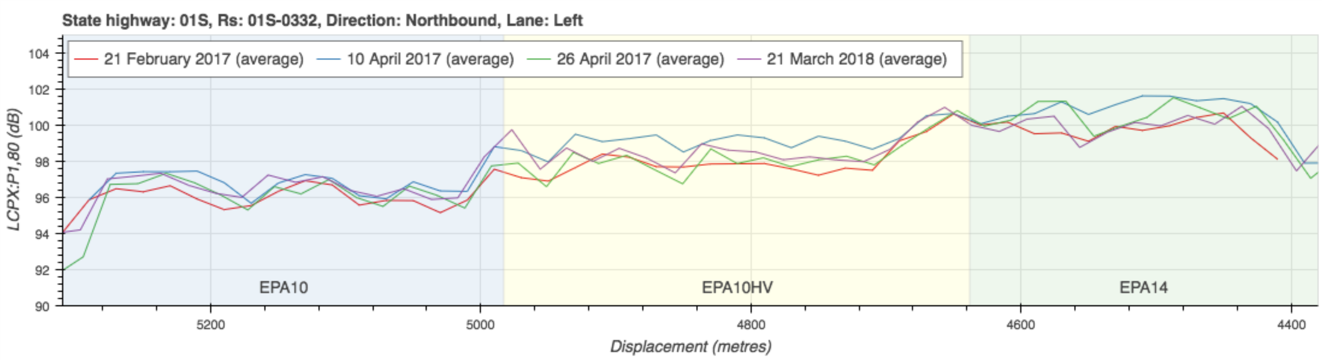


Figure 39 High void trial sections - Left lane

Comparisons between $L_{CPX:P1,80}$ values for the right and left lanes are shown in Figure 40 to Figure 43 for each of the days measurements were conducted. The results from all measurment sessions show consistently higher $L_{CPX:P1,80}$ values for the left lane, despite identical mixes being used, laid one day apart by the same equipment and crew.

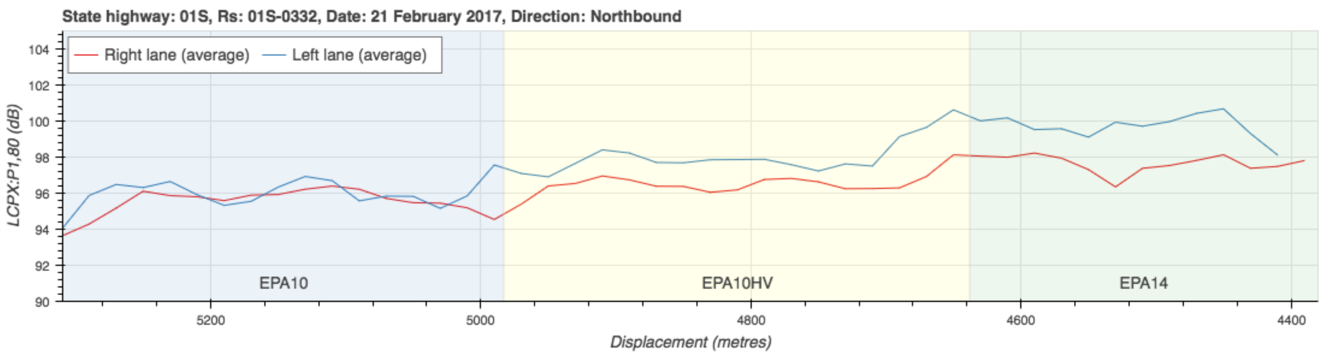


Figure 40 High void trial sections - 21 February 2017

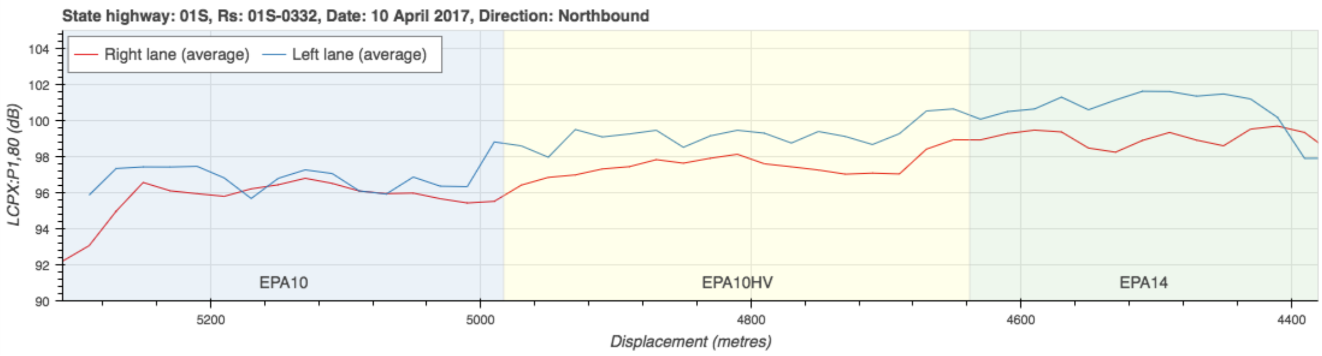


Figure 41 High void trial sections - 10 April 2017

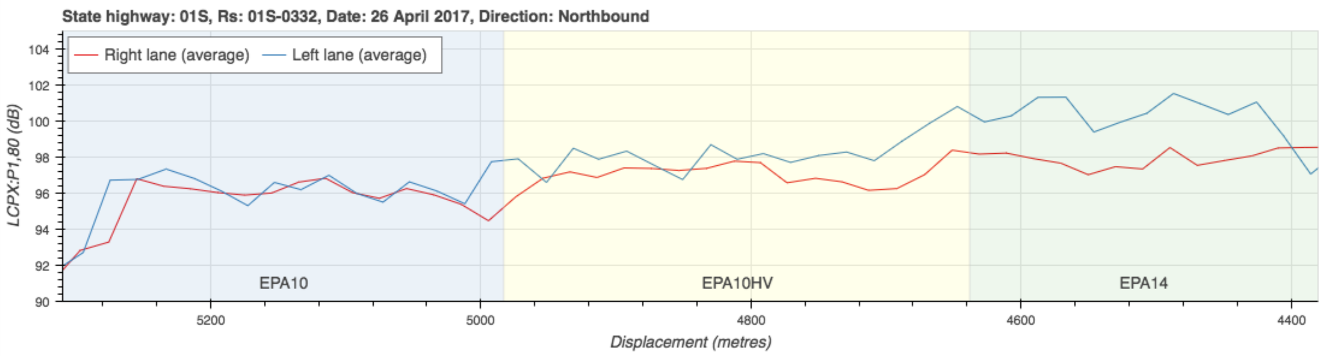


Figure 42 High void trial sections - 26 April 2017

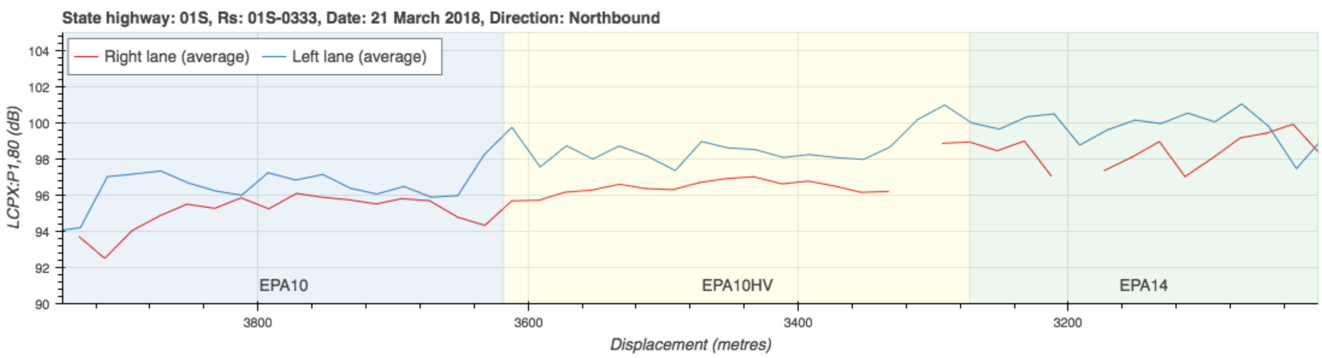


Figure 43 High void trial sections - 21 March 2018

Mean Profile Depth (MPD) measurements were taken by Downer on 13 February 2017 for each lane and are presented in Figure 44 and Figure 45 along with the $L_{CPX:P1,80}$ values from the first measurement session (21 February).

The $L_{CPX:P1,80}$ and MPD values show a close correlation between both the lanes and the different surfaces. Discussions with David Alabaster (Transport Agency) and Janet Jackson (Downer) regarding the differing MPD values between the lanes highlighed the differences in traffic management in the 36 hours following paving and differences in the width of paving. These are summarised as follows:

- Right lane paved Saturday, 11 February. Opened to traffic ~18 hours later with temporary traffic management in place. This resulted in well controlled rolling by traffic within the wheel paths during the 18-36 hours following paving. Fully opened to traffic ~36 hours after paving.
- Left lane paved Sunday, 12 February. Fully opened to traffic ~18 hours after paving (no temporary traffic management). Initial traffic was able to wander within the lane reducing the amount of rolling within the wheel paths compared to the right lane.
- Right lane narrower than left lane, and potentially receives a longer duration of rolling by the 7-ton roller during construction, and had the paver screed extensions largely retracted.
- By the time the MPD measurements were taken on Monday, 13 February, the right lane wheel paths had effectively received a longer duration of rolling than the left lane wheel paths, resulting in a smoother surface.

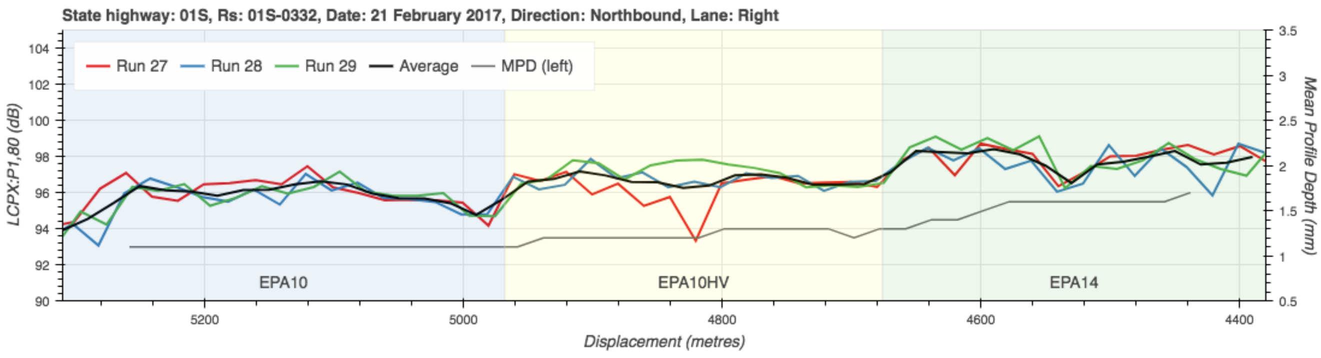


Figure 44 High void trial sections - Right lane, 21 February

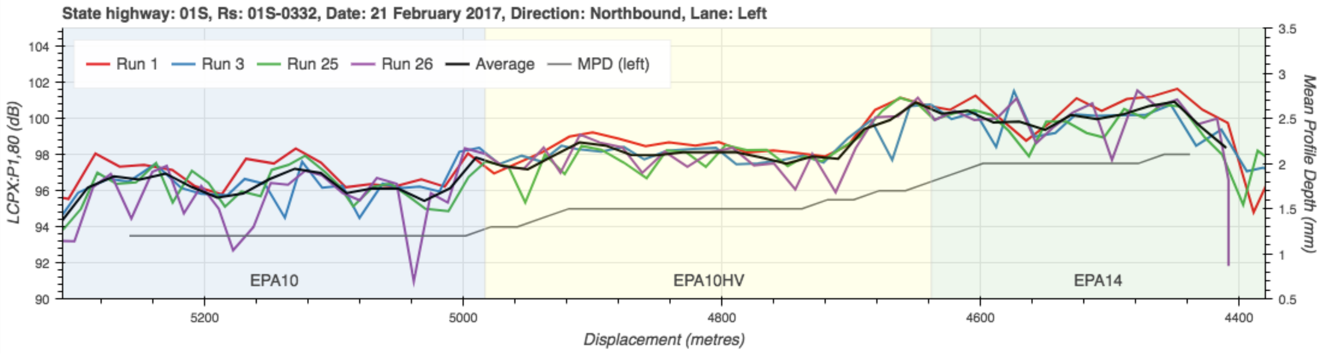


Figure 45 High void trial sections - Left lane, 21 February

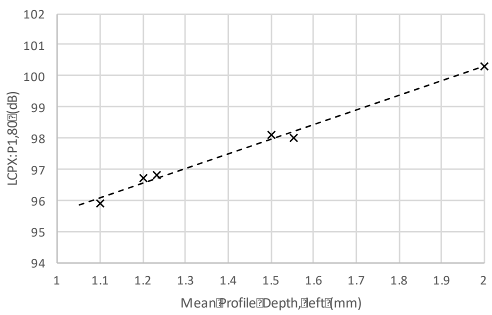


Figure 46 High void trial sections - relationship between Mean Profile Depth and $L_{CPX:P1,80}$

Further examination of the findings at this trial site and testing of the observations made as to potential causes of differences is recommended. With respect to the relative performance between the EPA10 and EPA10HV, investigation is needed of different tyre types and differences between close proximity and wayside locations.

5.2 Reduced chip size

Initial results from the Sawyers to Groynes sections showed that as expected based on international literature, surfaces with higher mean profile depth values (i.e. EPA14 compared to EPA10) produced higher noise levels. It was expected that a reduction in chip size, and hence mean profile depth, would result in a quieter surface.

A section of EPA7 was laid by Fulton Hogan in late 2017 at Western Belfast Bypass to investigate the effect of reduce chip sizes in a porous asphalt surface, and CPX measurements were taken in March 2018. The results for the left and right lanes are presented in Figure 47.

As was the case with the high void test sections, the EPA7 section shows higher noise levels in the left lane compared to the right lane. Unlike the high void test section, the EPA7 surface was laid before the road was opened to the public, so any degradation of the left lane has occurred well after the surface finished curing.

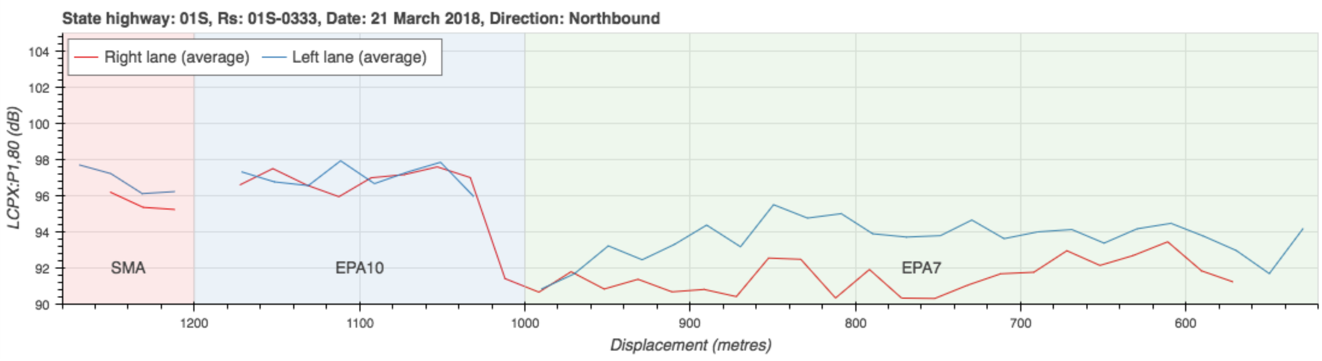


Figure 47 EPA7, Western Belfast Bypass (SH1) – 21 March 2018

Overall, there has been a reduction in noise of 2–4 dB compared to the EPA10 section laid as part of the high void test sections. Further measurements and investigation at this site would assist in:

- Determining whether there is a sustained noise benefit, or whether the noise levels increase over time,
- Determining the rate of degradation and clogging of the EPA7 surface compared to other porous asphalt surfaces and its effect on long term acoustic performance, and
- Determining the source of the left/right lane differences.

A further section of EPA7 was laid by Downer along SH1 at the Memorial Avenue bridge in April 2018. This section has not yet been tested.

5.3 Epoxy modified asphalt

Epoxy dilution trial sections were laid on the left lane of Christchurch Southern Motorway, heading south from the Barrington Street onramp during November 2012. Three different trial sections were laid along with two control sections. These are listed in Table 10, with locations shown in Figure 48.

Table 10 Epoxy dilution trial sections

NAME	BLEND	START	END
100% Epoxy	0% M/1 Bitumen - 100% Chemco Epoxy	5685 m	5893 m
Control	0% Epoxy	5900 m	6100 m
50% Epoxy	50% M/1 Bitumen - 50% Chemco Epoxy	6842 m	7039 m
Control	0% Epoxy	7050 m	7250 m
25% Epoxy	75% M/1 Bitumen - 25% Chemco Epoxy	7261 m	7466 m

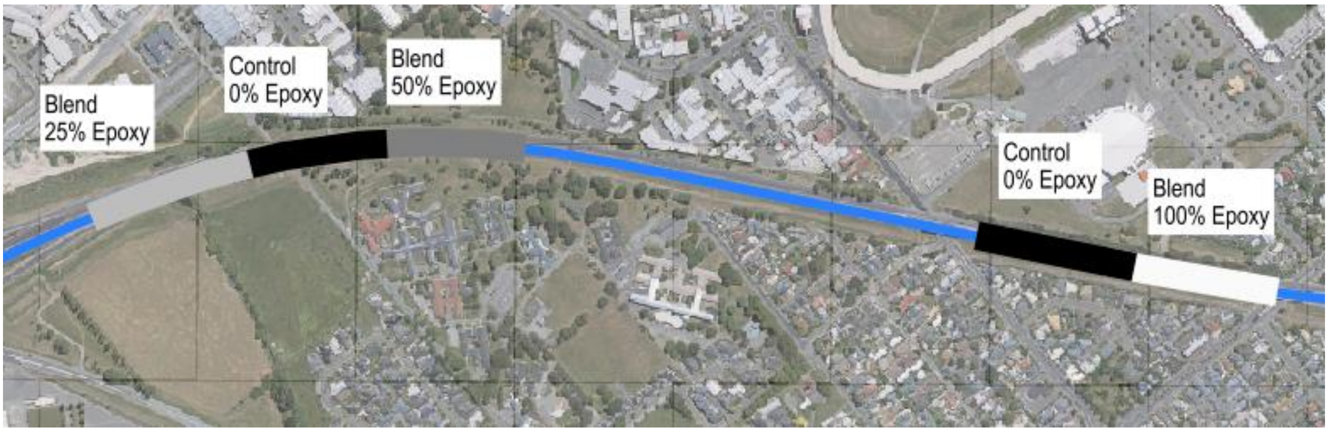


Figure 48 Epoxy dilution trial locations

CPX measurements were made on 26 April 2017 to investigate the influence of the epoxy dilution on the three trial sections. The results of the measurements are shown in Figure 49. Inspection of the plot shows the 25% epoxy blend to have the lowest values of $L_{CPX:P1,80}$, with the 50% epoxy blend having the second lowest values of $L_{CPX:P1,80}$. Both are quieter than the control section with no epoxy. As for the other trials, further investigation is recommended to determine the causes of the differences.

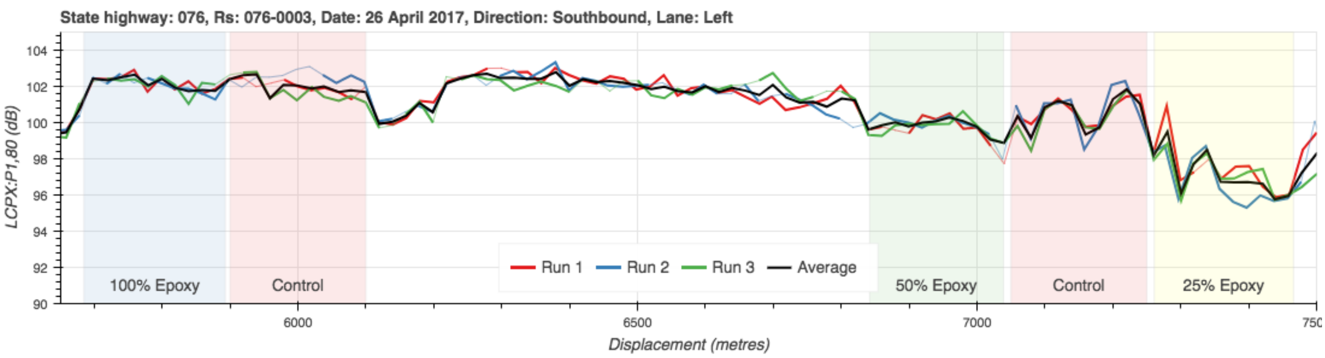


Figure 49 Epoxy dilution trial sections - 26 April 2017

5.4 Comparison of measurement systems

CPX measurements along the Christchurch Southern Motorway have previously been taken by both Opus in September 2014 and the University of Canterbury in May 2016, allowing comparison with the recent Transport Agency measurements, shown in Figure 49 above. The section of road covering the epoxy dilution trial sections from Section 5.3 is used as a sample section of road and the average levels from each measurement session/organisation are shown in Figure 50.

The general trend is consistent between the three measurement systems, with the following observations:

- The Opus results do not exhibit dips in the sound levels where the other measurements do. This is potentially caused by the higher noise floor of the Opus system restricting the dynamic range, due to the absence of microphone/wheel enclosures.
- The Transport Agency measurements have sound levels consistently higher than those measured by the University of Canterbury. While the measurement system is essentially the same for both tests, there are several factors that may differ. These include surface age, surface moisture, tyre hardness, transverse positioning on the road, and location and speed measurement techniques.

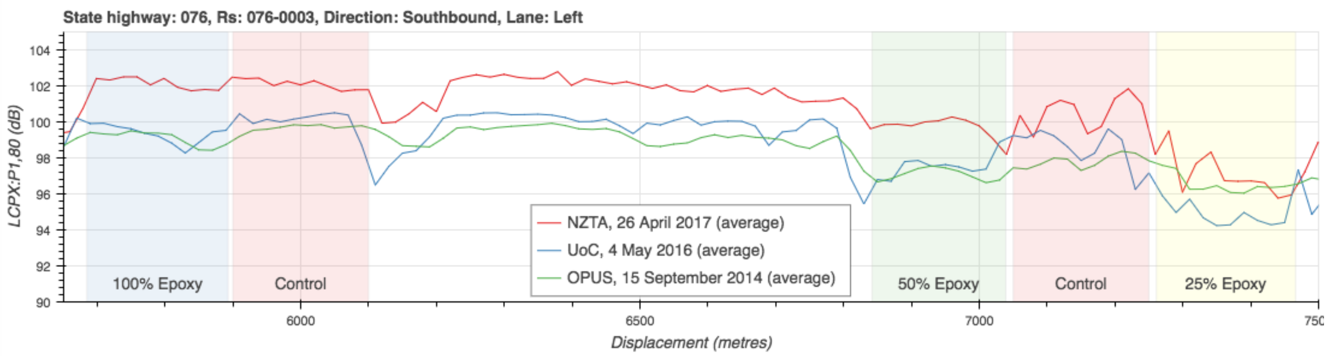


Figure 50 Comparison of measurement systems

5.5 M2PP porous asphalt and chipseal

CPX measurements of the Mackays to Peka Peka Expressway (opened in February 2017) were made in June 2017 together with parts of the old State Highway 1 (now bypassed by the Expressway) to provide a local comparison.

The average $L_{CPX:P1,80}$ for each test section, arranged by surface type, are given in Table 11 and Table 12 below. Graphs of the detailed longitudinal data are presented in Figure 51 to Figure 56.

Table 11 Average $L_{CPX:P1,80}$ for M2PP Expressway

DIRECTION	LANE	$L_{CPX:P1,80}$		ACOUSTIC VARIABILITY, s_r	
		POROUS ASPHALT	CHIPSEAL	POROUS ASPHALT	CHIPSEAL
Northbound	Left	97.0 dB	101.4 dB	2.0 dB	0.4 dB
	Right	96.6 dB	100.6 dB	2.0 dB	0.6 dB
Southbound	Left	97.0 dB	101.3 dB	1.8 dB	0.4 dB
	Right	96.7 dB	100.9 dB	1.9 dB	0.7 dB

Table 12 Average $L_{CPX:P1,80}$ for old State Highway 1

DIRECTION	LANE	$L_{CPX:P1,80}$		ACOUSTIC VARIABILITY, s_r	
		POROUS ASPHALT	CHIPSEAL	POROUS ASPHALT	CHIPSEAL
Northbound	Left	97.0 dB	100.9 dB	1.5 dB	1.1 dB
Southbound		97.5 dB	100.9 dB	1.4 dB	1.1 dB

The following observations were made from the results of the M2PP measurements.

Relative performance

The porous asphalt surfaces, used on the majority of the Expressway, provide CPX levels 4 dB lower than the chipseal sections located on the Expressway. The same difference in CPX level between porous asphalt and chipseal surfaces is observed on the old State Highway 1. CPX levels associated with the porous asphalt surfaces on the Expressway and old State Highway 1 are in line with CPX levels of other porous asphalt surfaces found around New Zealand.

Longitudinal variations

The 20 metre road segments containing porous asphalt exhibit large variations in CPX levels, ranging between 93 dB and 101 dB $L_{CPX:P1,80}$. These large variations in CPX levels along the porous asphalt surfaces are found on other porous asphalt surfaces around New Zealand.

The 20 metre road segments containing chipseal exhibit smaller variations in CPX levels of around 2 dB $L_{CPX:P1,80}$.

Left/right lane variations

CPX levels in the left lanes of the Expressway appear to be slightly higher than those in the right lanes, however, the differences are generally within the acoustic variability shown in Table 11.

Differences in CPX levels between lanes was observed in the high void asphalt trials above. In the previous case, lower CPX levels in the right lane had been attributed to a reduced paving width and increased rolling time during construction (due to a narrower lane width) and a longer period of post-construction traffic management. Neither of these hypotheses explains the differences in CPX levels found on the M2PP Expressway, since surfacing took place several weeks prior to opening.

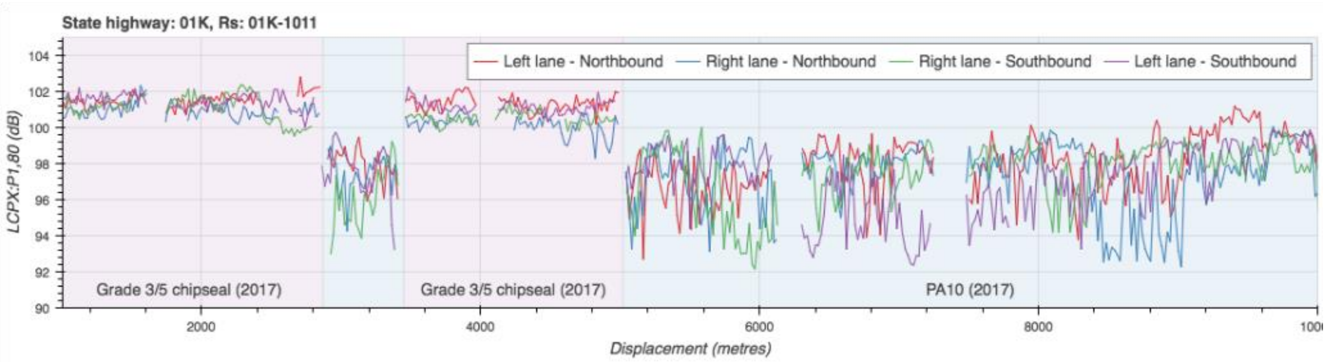


Figure 51 M2PP Expressway – Northern half

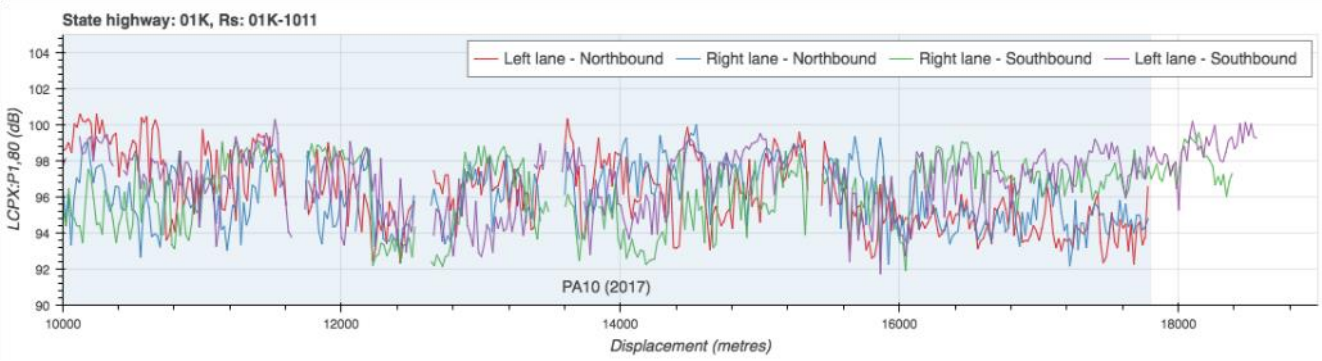


Figure 52 M2PP Expressway – Southern half

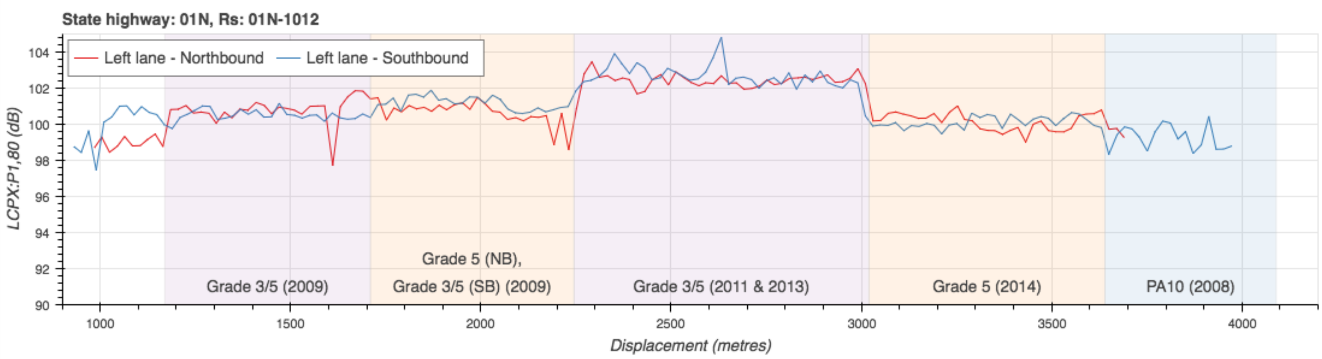


Figure 53 Old State Highway 1 – Peka Peka Interchange to Waikanae

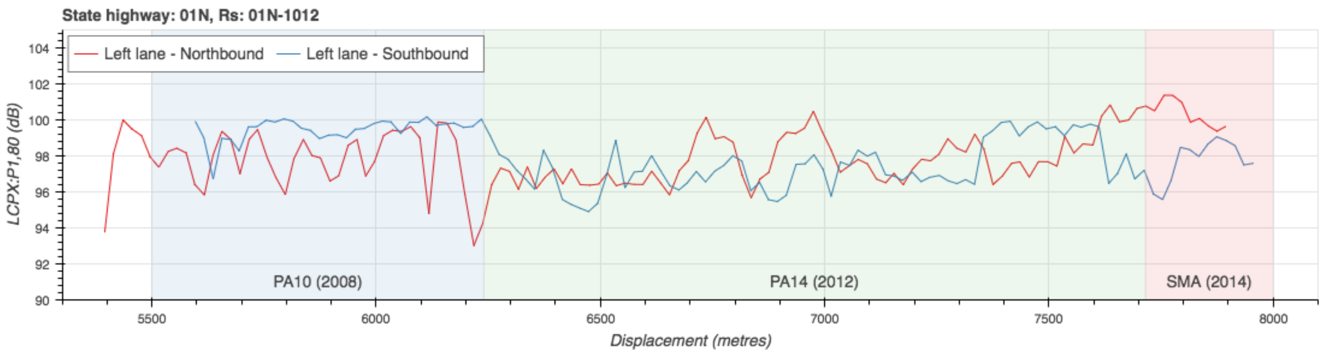


Figure 54 Old State Highway 1 – Waikanae to Otaihanga Rd roundabout

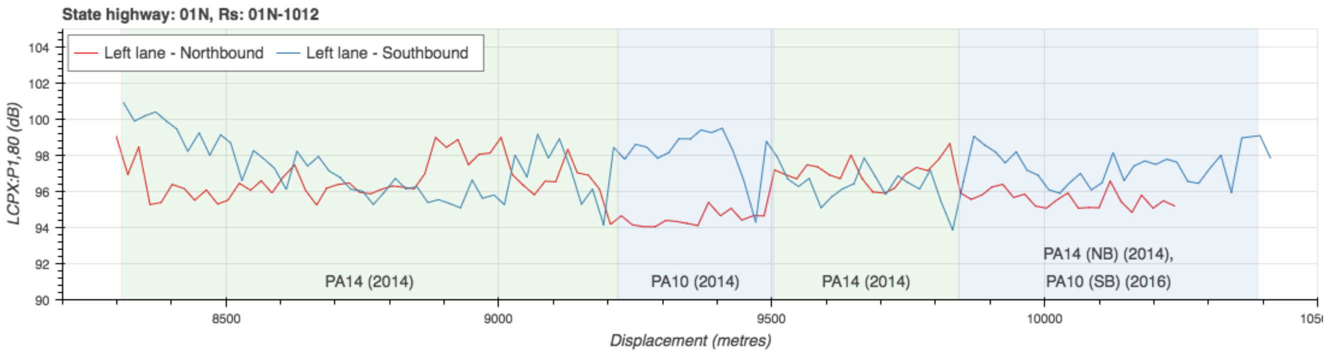


Figure 55 Old State Highway 1 – Otaihanga Rd roundabout to Paraparaumu

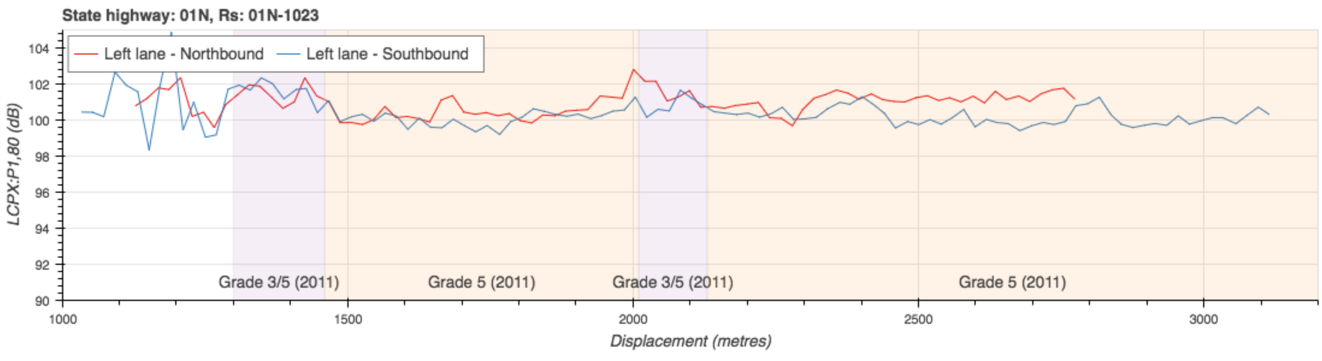


Figure 56 Old State Highway 1 – Paraparaumu to Poplar Ave roundabout

5.6 Waikato Expressway porous asphalt

CPX measurements were made along the Te Rapa (paved 2014), Ngaruawahia (paved 2015) and Cambridge (paved 2017) sections of the Waikato Expressway in August 2017. Measurements were made in all four lanes at a reference speed of 80 km/h.

The overall $L_{CPX,P1:80}$ and acoustic variability are given for each lane in Figure 57 and Figure 58, along with longitudinal plots in Figure 59 to Figure 66 (red shaded areas are not porous asphalts surfaces and have been excluded from the overall averages).

The results indicate:

- The Te Rapa and Ngaruawahua sections have large differences in $L_{CPX:P1,80}$ between the left and right lanes. This may be due to higher traffic volumes on the left lanes causing more rapid degradation of the left lane surfaces (increased texture and clogging of voids). The longitudinal plots show that the differences in $L_{CPX,P1:80}$ between the lanes are not consistent along the length of the road, suggesting that if there has been degradation over time some areas are worse affected than others.
- The Cambridge section has the most consistent $L_{CPX:P1,80}$ values between lanes, as well as some of the lowest acoustic variability values along the lanes. The longitudinal plots show that the lanes within each carriageway correlate relatively well with one another. Localised differences between the left and right lanes generally show higher $L_{CPX,P1:80}$ values in the right lanes, suggesting differences in the surfaces and/or underlying pavement were introduced during construction.
- The Te Rapa section right lanes show the lowest values of $L_{CPX,P1:80}$, however, the higher values in the left lanes suggest that the right lanes may be degraded over time and the values of $L_{CPX,P1:80}$ in the right lanes could increase to that of the left lanes.

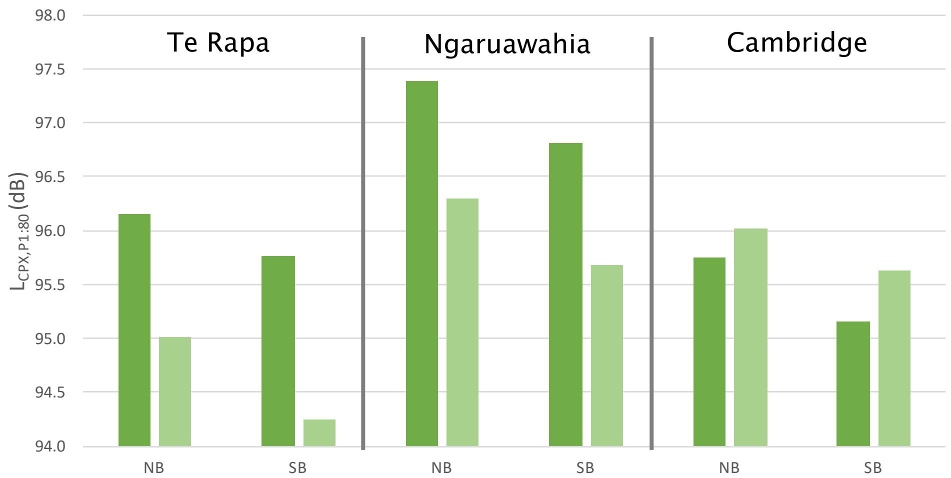


Figure 57 Waikato Expressway - $L_{CPX,P1:80}$ (dark shade = left lane, light shade = right lane)

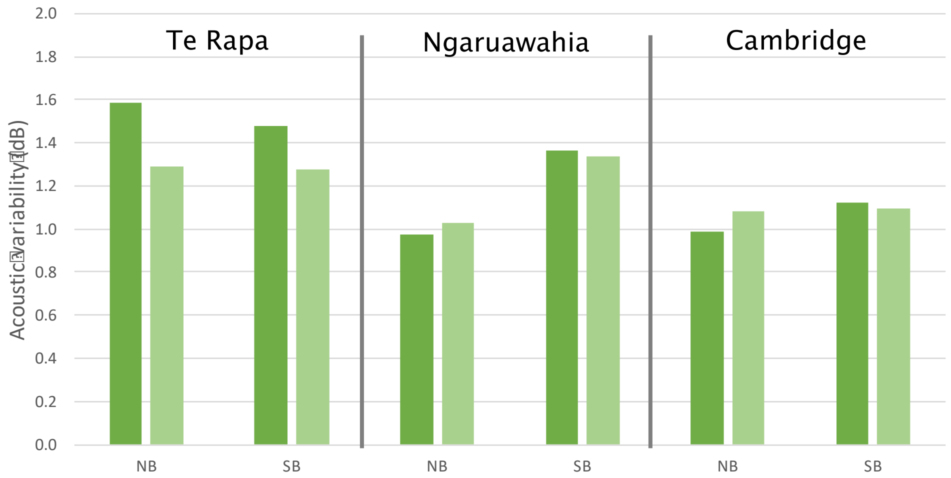


Figure 58 Waikato Expressway - Acoustic variability (dark shade = left lane, light shade = right lane)

Longitudinal plots - Te Rapa section

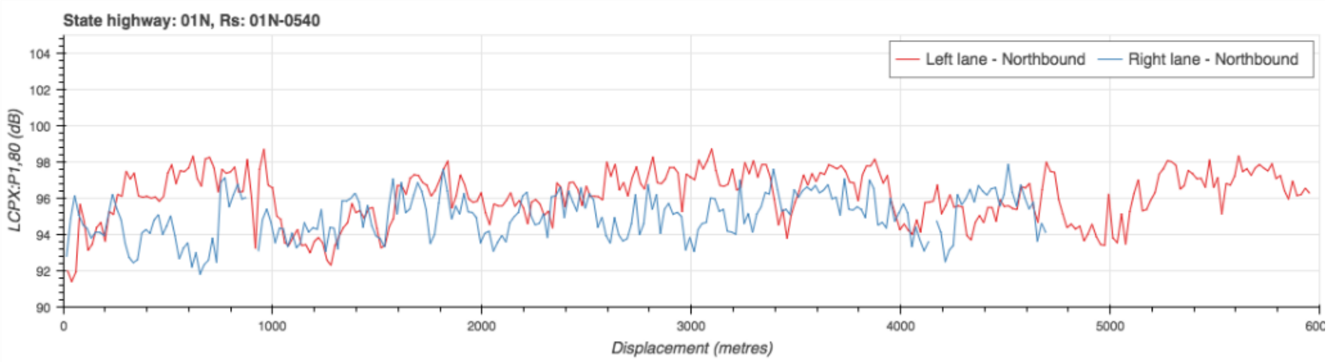


Figure 59 Waikato Expressway – Te Rapa section – Northbound

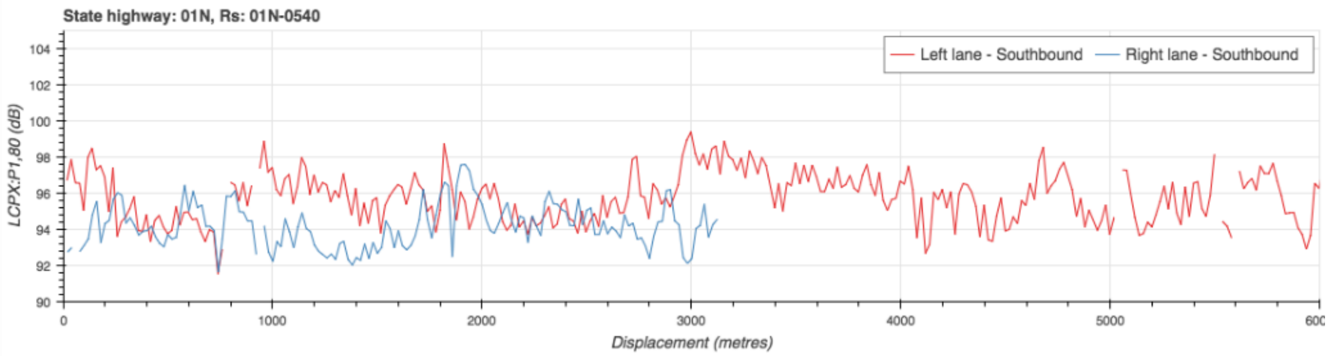


Figure 60 Waikato Expressway – Te Rapa section – Southbound

Longitudinal plots – Ngaruawahia section

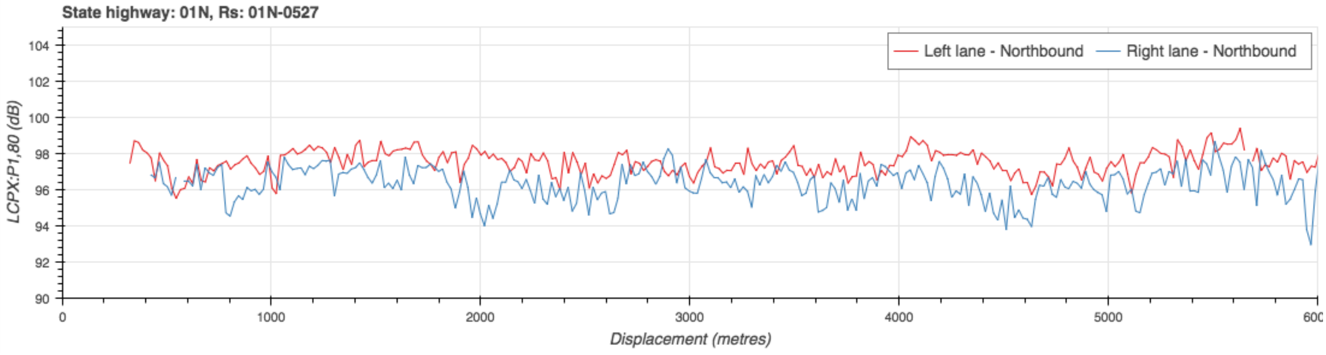


Figure 61 Waikato Expressway – Ngaruawahia section – Northbound, northern half

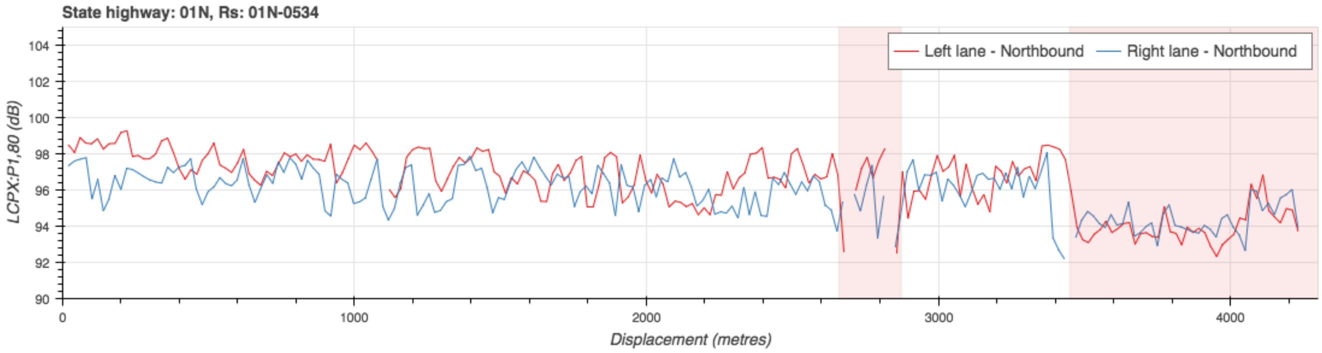


Figure 62 Waikato Expressway – Ngaruawahia section – Northbound, southern half

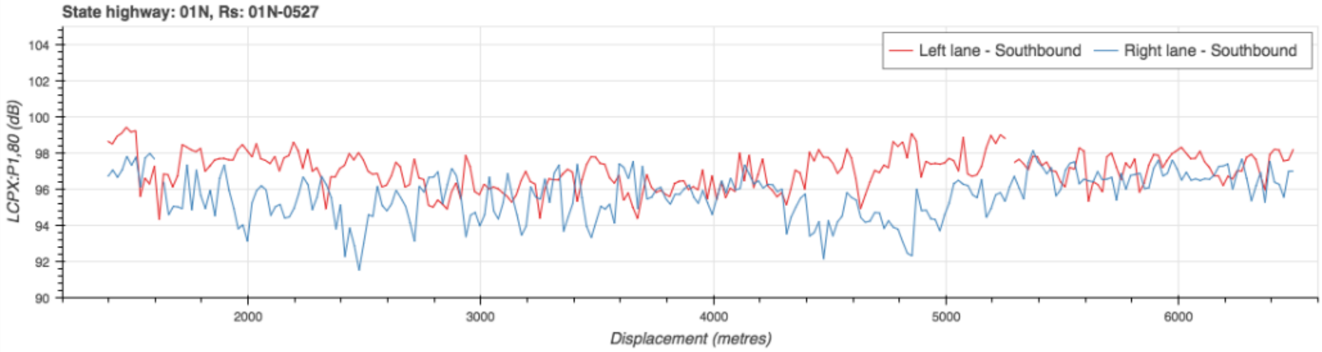


Figure 63 Waikato Expressway – Ngaruawahia section – Southbound, northern half

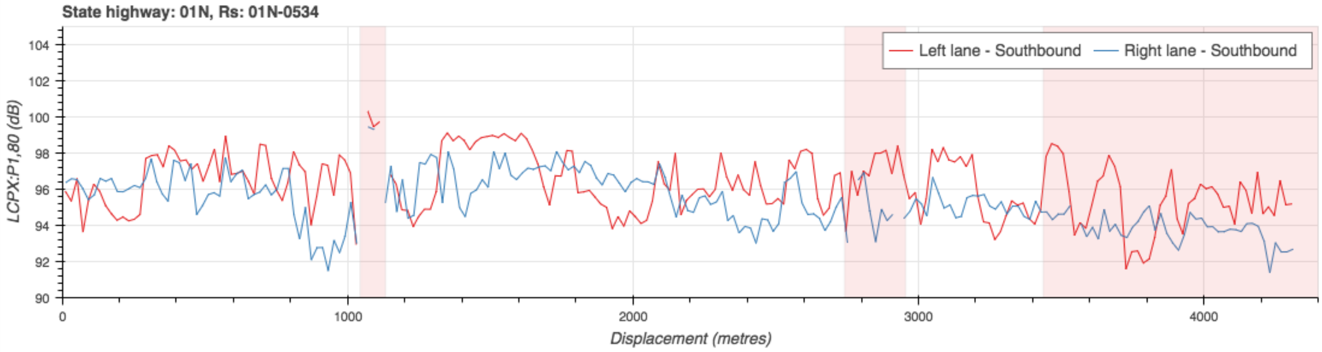


Figure 64 Waikato Expressway – Ngaruawahia section – Southbound, southern half

Longitudinal plots – Cambridge section

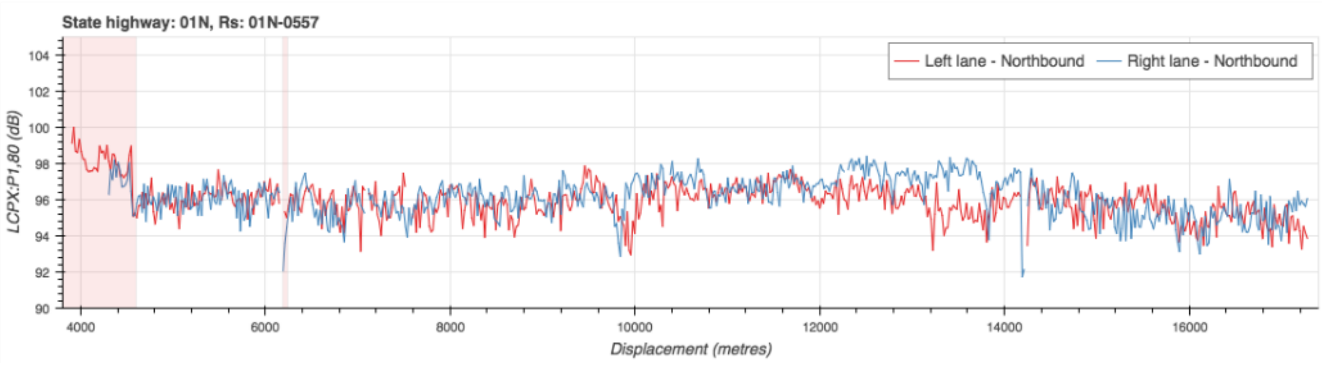


Figure 65 Waikato Expressway – Cambridge section – Northbound

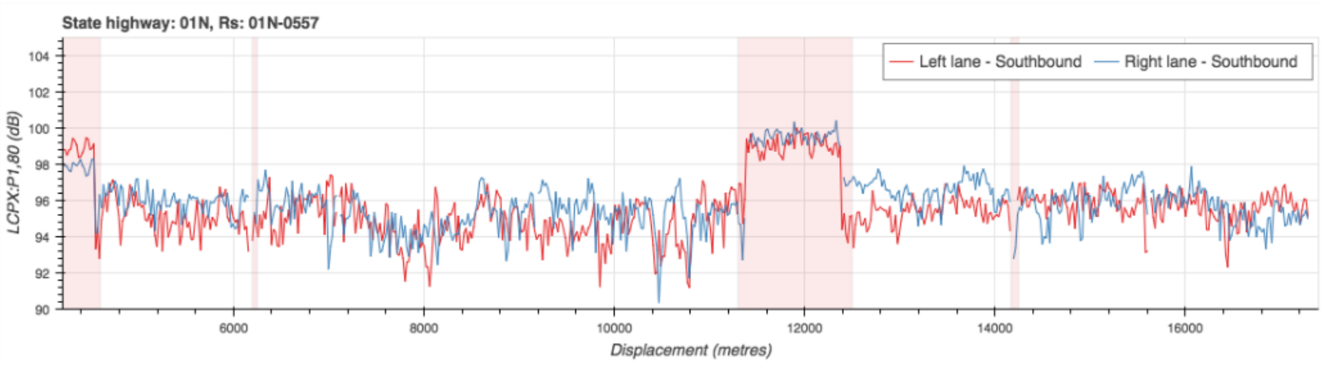


Figure 66 Waikato Expressway – Cambridge section – Southbound

5.7 Tairua chipseal

CPX measurements of two chipseal surfaces and one asphalt surface were made on State Highway 25 through Tairua in August 2017. The three surfaces measured are as follows:

- Grade 2/4 chipseal surface to the south of the town laid in late 2016
- Asphalt (AC10) surface in the town centre laid in 2000
- Grade 3/5 chipseal surface to the north of the town laid in early 2015

The measurements were made in both the northbound and southbound lanes at a reference speed of 50 km/h.

The average $L_{CPX:P1,50}$ for each surface type, are given in Table 13 and Figure 67 below. Graphs of the detailed longitudinal data are presented in Figure 68 and Figure 69.

The results indicate:

- No significant differences in $L_{CPX:P1,50}$ were measured between the two chipseal surfaces.
- The new grade 2/4 surface has marginally higher $L_{CPX:P1,50}$ (0.5 dB) than the older grade 3/5 surface. Differences can be seen in the frequency spectra, with the grade 2/4 surface having slightly higher $L_{CPX:P1,50}$ values below 1,000 Hz, as expected for a new chipseal surface.
- $L_{CPX:P1,50}$ values from the Tairua grade 2/4 chipseal surface were found to be similar to a grade 2/4 chipseal surface surveyed in Hamilton to provide a comparison.
- The asphalt surface in Tairua has $L_{CPX:P1,50}$ around 3 dB less than the chipseal surfaces. The asphalt surface is affected by surface defects.

Table 13 Average $L_{CPX:P1,50}$ for State Highway 25

SURFACE	$L_{CPX:P1,50}$	ACOUSTIC VARIABILITY, s_r	ROAD SECTION LENGTH
Grade 2/4 chipseal	93.1 dB	0.7 dB	860 m
Grade 3/5 chipseal	92.6 dB	0.6 dB	960 m
AC10	90.3 dB	0.7 dB	320 m

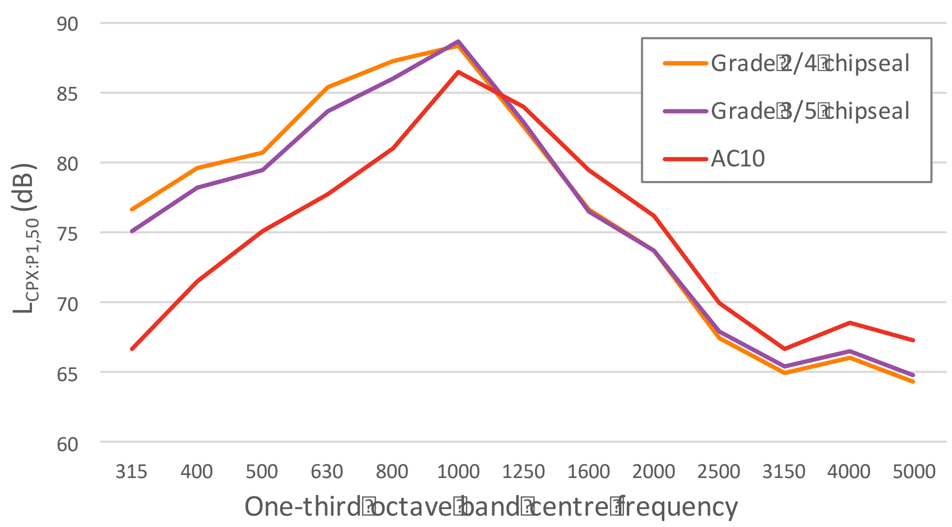


Figure 67 One-third octave band $L_{CPX:P1,50}$ for State Highway 25

Figure 68 State Highway 25 – South of bridge

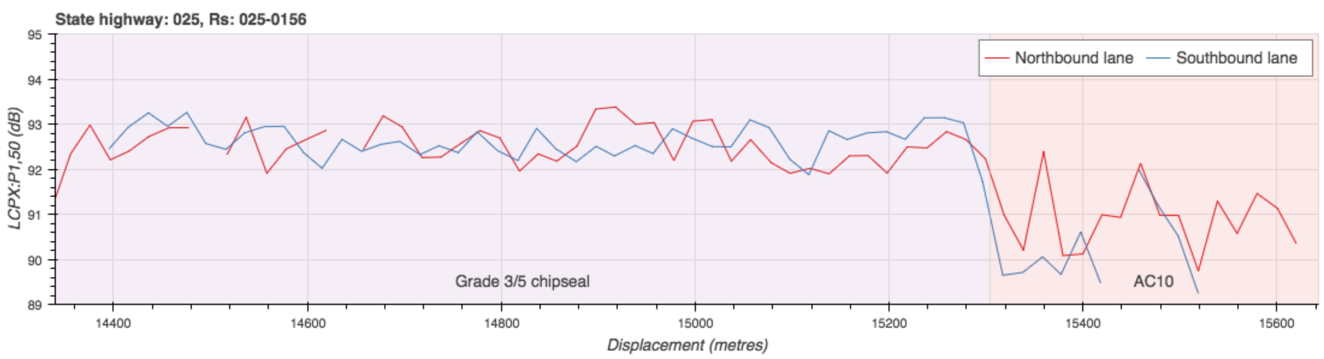


Figure 69 State Highway 25 – North of bridge

5.8 Research questions

The initial findings presented above have highlighted numerous areas where further investigation may assist in developing quieter surfaces. Several research questions have also been raised by the reference group. The following research questions and opportunities are recommended for further work.

Table 14 Summary of key research questions and opportunities

TOPIC	QUESTION/OPPORTUNITY	RECOMMENDED ACTION
CPX system	Is the relative performance of surfaces different for real-world tyres compared to the P1 test tyre?	Test a range of surfaces with the P1 and H1 test tyres, and tyres more commonly used on typical vehicles in the NZ fleet.
Porous asphalt	Early results indicate that smaller chip sizes (EPA7) provide noise reduction. Is this reduction sustained over time?	Conduct trials of an EPA7 surface.
	Is the improvement from a high voids surface more apparent at a wayside rather than close proximity position?	Make pass-by measurements at the Christchurch high voids trial site.
	Can acoustic performance be improved or made more consistent with better temperature control/uniformity?	Conduct measurements of temperature and CPX levels for paving using a shuttle buggy that provides temperature regulation.
	Does compaction practice/paving width alter CPX levels?	Make measurements at another site with different width paving runs.
	Does initial traffic control alter long term CPX levels?	Record traffic controls used for paving at all test sites and investigate correlations.
	Are certain aggregate shapes and sources quieter?	Obtain details of aggregate properties for all trials and investigate correlations.
	Are loud test segments dominated by a small patch of road or controlled by the entire test segment?	Use the research mode to investigate longitudinal variability by looking at shorter test segments.
	By actively engaging with all major contractors, further insight to paving practices may be gained.	Continue to work with Downer, Higgins and Fulton Hogan to make measurements on recently laid porous asphalt surfaces.
Chipseal	Is there a basis for complaints that racked-in chipseals are noisier than two-coat seals?	Measure CPX levels of grade 3/5 two-coat and racked-in surfaces laid in the same season in the same area.
	Can chipseals be optimised to continue to meet other engineering requirements but reduce sound generation?	Measure CPX levels for a range of existing chipseal surfaces and develop a trials programme to optimise performance.
	How long does it take for chipseals to bed-in?	Measure CPX levels a single coat and two-coat chipseal periodically over two years from new.

APPENDIX A – CPX TRAILER OPERATING GUIDE

APPENDIX B – CERTIFICATION RESULTS

Test A.2 - Sound reflections against an enclosure and other objects close to the microphone

Date	15/03/18
Operator	John Bull

Measurement system

Hardware	NZTA artificial sound source and microphone mounts fitted to plywood mounting plate.
Instrumentation	Compact DAQ and NI 9234 microphone module CPX trailer microphones and microphone cables PLX 2502 power amplifier Neutric signal generator (white noise)
Software	NZTA sound reflection test LabVIEW program.

Measurement settings

Measurement duration	10 seconds
Sampling rate	25,600 Hz
Signal generator gain	-26 dB
Amplifier gain	Max.

Measurement details

Microphone positions	1, 2
Enclosure	Left

Number of hemi-anechoic measurements	6
Number of enclosure measurements	6

Measurement results

Hemi-anechoic	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Leq, all microphones (dB)	63.1	67.0	74.3	74.5	70.5	67.5	68.1	68.6	67.9	64.9	64.2	68.6	59.4
Range (dB)	0.34	0.36	0.25	0.12	0.25	0.3	0.21	0.24	0.11	0.17	0.15	0.09	0.25

Enclosure	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Leq, all microphones (dB)	61.0	67.4	72.0	74.3	72.4	69.1	69.5	70.8	68.0	66.5	64.9	69.7	60.6
Range (dB)	0.26	0.28	0.32	0.13	0.3	0.41	0.22	0.16	0.15	0.1	0.13	0.09	0.06

Device dependent correction

	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Device dependent correction, Cd (dB)	2.12	-0.43	2.35	0.26	-1.91	-1.58	-1.41	-2.23	-0.11	-1.68	-0.75	-1.09	-1.13

Pass/Fail	PASS

Trailer configuration

50mm polyester absorption on sides of the enclosure. Rubber skirt on all four sides, apart from the area immediately behind the microphone, which has been removed. Front and rear rubber skirts angled inwards. Felt polyester layer on the lower timber members in the vicinity of the microphones. Small aluminium microphone bracket mounted to the enclosure. Road and tyre temperature sensors mounted to the enclosure roof.

Trailer configuration - photographs

Test A.3 & A.4 - Background noise from the test vehicle itself or its operation, and background noise from towing vehicle

Date	3/04/18
Operator	John Bull Robin Wareing

Measurement system

Hardware	NZTA external wheel assembly.
Instrumentation	Compact DAQ and NI 9234 microphone module CPX trailer microphones and microphone cables
Software	NZTA CPX LabVIEW program.

Measurement settings

Sampling rate	51,200 Hz
Road section length	20 metres
Weighting	A

Measurement details

Location	Ruapuna raceway
Test section length	300 metres
Target speed	80 km/h & 50 km/h

Measurement results (dB)

LAeq, all microphones	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
80 km/h	68.9	68.8	70.0	72.6	73.6	74.7	76.3	72.9	72.3	70.2	67.5	63.2	59.7
50 km/h	63.8	64.9	65.0	66.5	68.0	68.3	69.5	66.3	64.8	62.9	60.7	56.8	53.4

Performance requirements (dB)

Performance requirement	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Required level difference	4.3	4.3	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9

Lowest valid measurement levels (dB)

80 km/h	73.3	73.1	76.9	79.4	80.5	81.6	83.1	79.8	79.2	77.1	74.4	70.1	66.6
50 km/h	68.1	69.3	71.9	73.3	74.8	75.1	76.4	73.2	71.7	69.7	67.6	63.6	60.3

Trailer configuration

50mm polyester absorption on sides of the enclosure. Rubber skirt on all four sides, apart from the area immediately behind the microphone, which has been removed. Front and rear rubber skirts angled inwards. Felt polyester layer on the lower timber members in the vicinity of the microphones. Small aluminium microphone bracket mounted to the enclosure. Road and tyre temperature sensors mounted to the enclosure roof.

Test A.3 & A.4 - Background noise from the test vehicle itself or its operation, and background noise from towing vehicle

Trailer configuration - photographs