MEASURING PAVEMENT CONDITION DATA FOR A LONG-TERM PAVEMENT PERFORMANCE STUDY ON NEW ZEALAND ROADS.

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ABSTRACT

New Zealand like most countries has "site specific" factors which influence pavement performance, some of which are not well investigated or covered in current pavement deterioration models. Apart from the wide variation in climatic conditions, New Zealand has an extensive roading network which is primarily constructed using an unbound aggregate base with a thin surface treatment layer or chip seal wearing-coarse.

This data collection project, now in its thirteenth year, was initiated to obtain condition data specific to the New Zealand network. The project brief specified the measurement of pavement roughness, rutting, and texture, using reference or class1 type measuring instruments, coupled with a detailed visual inspection of each calibration site. The aim being to:

- Accurately measure pavement condition over a period of years and define performance on the range of conditions found in New Zealand.
- Provide an accurate data base for subsequent research.

The end goal being better roading solutions, more accurate research, improved deterioration models, and cost effective improvements to the New Zealand road network.

This paper describes the equipment used and why it was selected. It details the equipment calibration procedures and ways to determine the accuracy of the measuring equipment. It also explains the methodology adopted to collect the pavement condition data, and discusses the difficulties encountered. It clarifies achievable levels of measurement repeatability, something that is not currently well defined, and highlights some unexpected results obtained on the different pavement surfaces encountered.

For those countries and road controlling authorities considering Long Term Pavement Performance (LTPP) studies or calibration experiments for pavement deterioration modelling, it is believed that this paper will provide useful information on the equipment needs, calibration, validation, and data collection methodology.

INTRODUCTION

Detailed network condition data collection has been dramatically refined over the past fifteen years and now sophisticated vehicle mounted transducers measure all manner of pavement condition including roughness, texture, skid resistance, and geometry. However this equipment is designed to collect network wide pavement condition data and is not specifically suited to measure the small changes that occur from year to year when monitoring and defining pavement performance.

In New Zealand a Long Term Pavement Performance (LTPP) project was established in 2000 to fill this void in precise pavement condition data by providing a carefully controlled data collection process; a process which uses accurate and repeatable instruments in such a way to ensure the data collected can provide the information needed for the year-to-year direct comparison of the performance of a particular section of pavement, and therefore eventually define pavement deterioration.

Both the measuring equipment and data collection techniques adopted had to be suitable for the different pavement types in New Zealand, were open to refinement over time without compromising quality and repeatability, and still meet the long term goals for this project. The data collected must be consistent with the information required by the deterioration models being adopted in New Zealand. Furthermore it is expected that the surface treatment methods adopted widely throughout New Zealand may in fact dictate that these models may need considerable refinement, adding more credence to the need to ensure data integrity through a controlled repeatable process that would have relevance over the expected life of the roads being assessed.

This paper outlines the equipment used to collect the required data, the data collection processes, equipment validation, and data quality. The paper highlights some of the factors that influence data quality, equipment selection, and the need for appropriate calibration and validation procedures, and discusses how pavement deterioration affects the suitability of the measurement technique.

EQUIPMENT

Data quality and accuracy is paramount for any long term monitoring of pavement performance. Therefore factors that influence data quality must be eliminated or minimised. Equipment must be accurate, repeatable, and easily operated to eliminate or at least minimise operator and equipment bias. Furthermore the equipment must have a calibration process that can withstand scrutiny over many years so that data collected in year one can be compared with that collected ten or fifteen years later. For this project all equipment was calibrated annually to an international standard or reference, thus minimising the possibility for equipment bias through fatigue or change in performance, ensuring the true measurement of deterioration or change in pavement characteristics.

Longitudinal Profile - Roughness

Roughness calculated from the longitudinal profile can be a difficult parameter to measure, and often measurements at the same location can produce quite different results when reported as the summary index IRI. This project and research to determine reference profiling equipment repeatability and validation criteria[1] has shown that even small changes in profile elevation within the space of a few meters can result in unexpectedly high variation in the reported IRI. This research also indicated that there may be temperature dependence, operator bias, and other site-specific factors which can significantly influence the results.

Bearing in mind this information and previous experience gained collecting pavement condition data the following factors have been identified for consideration when selecting equipment and developing data collection procedures to measure the longitudinal profile:

- The magnitude of the change in roughness; changes in roughness may not occur for several years therefore the equipment resolution and repeatability must be at a level to ensure that observed changes in the data reflect changes in the pavement and not just equipment variability.

1 Validation and Repeatability of Reference Measurements Used For Evaluating High Speed Roughness Data. D Brown S Fong Central laboratories Report No. 01-261496.00-801CL

- The skill and experience of the surveyors; The New Zealand model caters for a wide range of different environmental and physical conditions, the survey team must collectively have sufficient experience to be able to understand and interpret the results obtained on all sites.
- Transverse and longitudinal alignment; relatively small changes (100-200mm) in both the transverse and longitudinal location can have a significant influence on the data. It is important to select equipment and develop procedures which ensure the same or identical measurement location.
- Pavement crossfall and corners; both vertical and horizontal curvature have been found to influence both the magnitude and repeatability of the reported IRI. Minimising the effects of these features can be achieved through multiple surveys and by surveying the road profile in forward and reverse directions.
- Outlier or erroneous measurements; collecting multiple profiles can be used to identify when outlier or erroneous data has been collected.
- Quality assurance; with over 140 calibration sections taking approximately six months to survey, it is essential to have in place procedures which will detect any long term drift and or equipment faults. Deploying two or more profilers and establishing and using reference sites where equipment performance can be checked provides assurance that data integrity is not compromised.
- Data review and processing; on site processing and review of all data was found to be a key component in our quality control. Our review process provides an immediate check on the data and identifies where unexpected changes in the data have occurred. Where data is suspect or where repeatability limits are exceeded additional runs can be made.

To eliminate or minimise these factors a manual class 1 profiler, the ARRB Walking Profiler, was selected to measure the longitudinal profile, see Figure 1 below. This device utilises a precision military spec sensor with excellent accuracy, resolution, and long-term stability. Annual calibrations, which haven't changed significantly over the past ten years, confirm the stability of this instrument.

The profiler is manually operated and therefore able to be positioned to follow a specific profile or track and so measure exactly the same location each year. Measurement of the profile is relatively quick (for a reference instrument) albeit at 0.8km/hr, which allows sufficient time to measure multiple profiles, process and analyse the data and to complete any additional profile measurements.

Figure 1: Walking Profiler.

To minimise grade and cornering effects and eliminate transverse and longitudinal variance the sites are permanently marked so that the exact same profile can be surveyed each year. Two profilers are used to collect multiple profiles in both forward and reverse direction on both wheelpaths so that profiler comparisons can be made to ensure data integrity.

Where site specific grade or other irregularities occur a dedicated measurement procedure is developed. For example one site with a severe rut along the edge of the left wheelpath could only be profiled in the reverse direction. At another site the survey start point was adjusted so that a depression at 100m would always be recorded in the same 100m section. Procedures for profiling through and around potholes and other surface defects have also been developed.

The checking and analysis software developed for the project facilitates immediate data review and so provides a means to identify erroneous or outlier results. Where there is doubt over the data quality the survey team are able to examine the pavement for possible causes or to complete additional profile measurements to ensure a more accurate measurement is obtained.

Transverse Profile - Rut Depth

The following factors should be considered when evaluating the equipment and data collection procedure to measure the transverse profile and obtain the rut depth, the equipment should:

- Measure a continuous profile; taking spot measurements across the profile does not necessarily define the true pavement profile. Where spot measurements are 100 or 200mm apart the high and low points defining the profile may be missed leading to incorrect rut depth calculation.
- Have appropriate vertical and horizontal resolution; with expected changes in rut depth of 1-2mm per year a resolution ten times the expected change (0.1 - 0.2mm) is appropriate.
- Be robust, versatile, and relatively easy to use; preferably the process should require only a single operator, have a measuring width of up to 3.8m, not extend into oncoming traffic in adjacent lanes. Furthermore as ruts develop both the width and depth of the rut increases therefore the measuring width and height must be flexible rather than fixed or a set of fixed points over a nominal width.
- Not be site or surface specific; it should work equally well on a flat asphalt surface with little or no texture and on a coarse surface (large chip seal) with a lot of texture.
- Display the profile in real time, and be able to calculate the rut depth and display the position of the straight edge once the profile measurements are completed; this allows the operator to determine the validity of the measurement, and identify and correct unusual results.
- Have analysis software which can manipulate or position the straight edge when calculating the rut depth; measured profiles do not always fall into the characteristic or idealistic shapes and often the positioning of the straight edge needs adjustment to locate the true rut. Often on local authority roads with numerous underground services the deepest depression is not the wheelpath rut.

For these reasons the traditional method (the straight edge and wedge) to measure the rut depth and the multi-point profile measurement using a vehicle based laser profilometer were considered inappropriate for the measurement of reference transverse profile. A profile beam consisting of a motorised wheel supported by a precision machined 4m beam was developed, the final design is depicted in Figure 2 below. The wheel is free to move vertically on a linear bearing and the active sensors are precision rotary encoders, one to measure the displacement across the beam and the second to measure the vertical position of the wheel. The data acquisition and real time profile display is managed on a tablet computer mounted on the beam.

Texture effects are minimised by using a 240mm by 35mm wide wheel and by driving the wheel slowly across the road, so that it does not bounce as the wheel travels over the various texture elements. The rut depth under a 2m straight edge is calculated from the transverse profile through an iterative process to locate the profile high and low points over the left and right ruts.

Flexibility within the beam software facilitates most measuring widths, and post collection manipulation of data to position the straight edge over the rut. The beam extends beyond the support legs and as such can be positioned to capture the full pavement profile.

A vertical resolution of 0.2mm, and a horizontal resolution of 3mm were established, higher resolution is possible but not considered warranted.

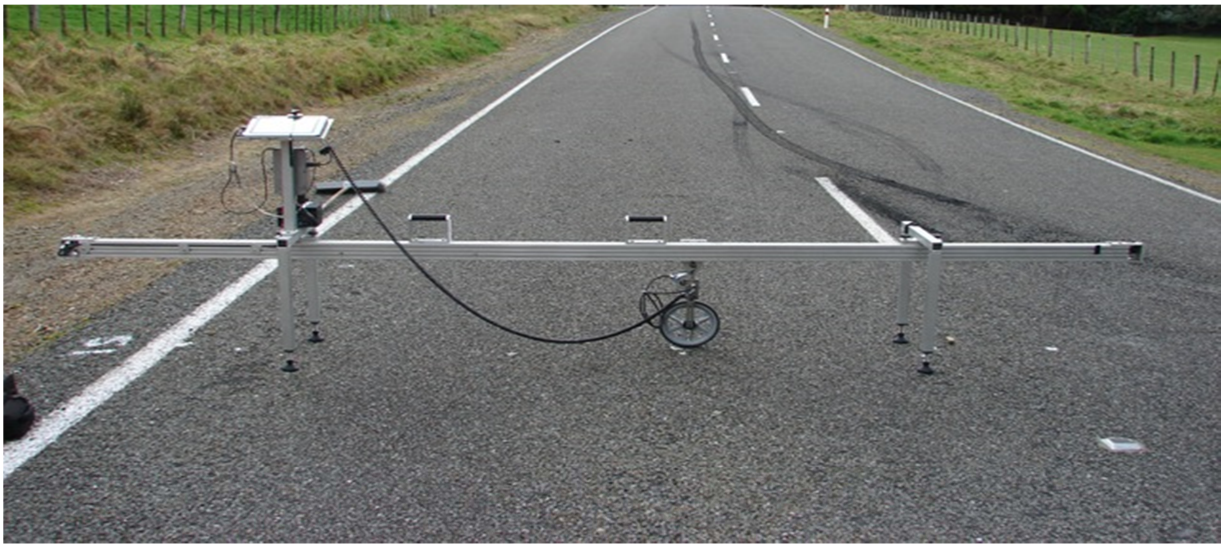

Figure 2: Transverse Profile Beam.

Texture

Texture is measured using the NZTA Stationary Laser profiler (SLP); the New Zealand texture reference. The design of the SLP was based on the profiler used by the Swedish Road and Traffic Research Institute and selected as the reference device for the international PIARC experiment (see Figure 3 below). The MPD is calculated from the pavement profile in accordance with ISO standard 13473-1, this divides the profile into 100mm segments and calculates the area under a straight edge placed across the section. The SLP is 1750mm in length and reports 16 individual MPD values per scan. The SLP has well documented calibration and validation procedures[2] and undergoes a daily performance checks to ensure it remains within calibration.

Figure 3: Stationary laser Profiler.

Factors to consider when measuring texture

- Measurement location; both transverse and longitudinal positioning of the profiler is very important as the texture (in New Zealand at least) is quite positional sensitive, especially on flushed surfaces.
- Ease of operation; the mobility of the instrument and its operation.

2 Replication of VTI's Stationary Laser Profilometer For Measuring Road Surface Profiles Cenek Brown et al Transfund New Zealand Report No. 84

- Visual display; a visual display of the measured profile is important so the operator can ensure data integrity and quality immediately.

Site Location - GPS Coordinates

It is imperative that once sites have been established that they can be found for future measurements. Each site start and end is identified with a metal spike hammered into the pavement at the road centre and a marker post at the road side. The position of site start and end location is recorded using a GPS receiver with better than 1m resolution. The validation of this equipment[3] is detailed in the project Validation Report.

Programming

To minimise environmental effects a data collection program was established in year one. This same program is followed each year so that the same sites are surveyed at the same time of the year.

Condition Rating

This project adopted a detailed condition-rating regime, one that would provide as much information about the test sections as possible. The distress types prevalent on the New Zealand network and the associated distress code are detailed in Table 1 below.

Distress Code	Description of Distress	Distress Code	Description of Distress
A1	Active Aggregate Loss	TCN	Transverse Cracks Narrow
A2	Stable Aggregate Loss	TCW	Transverse Cracks Wide
D1	Delamination	TCS	Transverse Cracks Sealed
M	Mechanical Damage	AGN1	Alligator Cracks Narrow in wheelpath
F1	Flushing Level 1	AGW1	Alligator Cracks Wide in wheelpath
F2	Flushing Level 2	AGS1	Alligator Cracks Sealed in wheelpath
F3	Flushing Level 3	AGN2	Alligator Cracks Narrow Outside wheelpath
LEN	Longitudinal Edge Cracks Narrow	AGW2	Alligator Cracks Wide Outside wheelpath
LEW	Longitudinal Edge Cracks Wide	AGS2	Alligator Cracks Sealed Outside wheelpath
LES	Longitudinal Edge Cracks Sealed	PCN	Parabolic Cracks Narrow
LWN	Longitudinal Wheel Cracks Narrow	PCW	Parabolic Cracks Wide
LWW	Longitudinal Wheel Cracks Wide	PCS	Parabolic Cracks Sealed
LWS	Longitudinal Wheel Cracks Sealed	SP	Surface Patch
LIN	Longitudinal Irregular Cracks Narrow	StP	Structural Patch
LIW	Longitudinal Irregular Cracks Wide	E	Edge Break
LIS	Longitudinal Irregular Cracks Sealed	S	Shoving

Table 1: Condition Distress Code and Type

An excel spreadsheet loaded on a handheld tablet was used to record the various distress features. An example spreadsheet is provided below in Table 2.

Date	Sub Sect	Dist St	Dist End	Dist Width	Dist Depth	Distress	Comments
26-Sep-14	5	7	14			lwn	lwp
26-Sep-14	5	8	11.3	400		sp	edgeline
26-Sep-14	5	19	50	500		f2	rwp
26-Sep-14	5	41.7	42	20	10	m	btwp
26-Sep-14	6	0	18	600		f2	rwp
26-Sep-14	6	0	8	1000		f2	lwp
26-Sep-14	6	7.7	8	300		agn2	btwp
26-Sep-14	6	8	9.5			lwn	lwp
26-Sep-14	6	8.1	10	1000		sp	lwp
26-Sep-14	6	9.4	9.6	100		agn1	lwp

3 Data collection on Long Term Pavement Performance Sites – Calibration and Validation Report 2101

Table 2: Example Condition Rating Data

Three levels of flushing are recorded and more recently we have introduced an additional parameter to record the percentage chiploss, these are the only distress parameters that require a degree of interpretation by the surveyor, all other condition items are measured directly on the road.

Each site is divided into 50m subsections and all the individual visible pavement distress within each subsection are recorded. The start and end point of each distress is recorded along with a width and or depth as appropriate. In the example above row 1 identifies a narrow longitudinal wheel crack in the left wheelpath of subsection 5 starting 7m from the start of the subsection and continuing to 14m from the start. Row four identifies mechanical damage in subsection 6 starting at 41.7m and continuing for 300mm the damage is 20mm wide and 10mm deep.

Note in year one of the project the drainage type and condition recorded.

This visual condition data is further processed to calculate the percentage of each section affected by each distress.

Visual condition rating is a very subjective process and we have endeavoured to minimise personal bias through a thorough testing and auditing process. In practice one person is responsible for the condition rating to minimise surveyor bias, and approximately half of the sites undergo repeat partial or full resurvey by the project team leader while doing the site report assessment. The two visual condition surveys are then checked to see if they are the same. Areas where discrepancies do occur are when the surveyor is required to assess the level of chiploss or the degree of flushing and to minimise this we have prepared specific photographic examples which can be used to determine the degree of distress.

The survey team also record and photograph all significant changes, surface defects, and site modifications that are likely to affect either present or future data. Furthermore a site report detailing where changes in either the data or the condition of the site are observed and the likely reason or effect of the change is prepared.

An integrated database for all sites is prepared at the completion of the annual survey this contains a photo table with a description of each photo and its location within the site, a table for all site reports and tables for 10, 50, 100m and 300m roughness, 10m and 50m rutting, 10m and 50m texture, the processed visual condition data, site start and end gps coordinates, and site location details.

Site Layout and Marking

Each calibration site is 300m in length and subdivided into twelve 50m subsections as depicted in Figure 4 below.

The wheel paths are located visually and marked at ≈500mm intervals to ensure repeatable measurement of the longitudinal profile. The transverse profile is measured at ten meter intervals along the site starting at the site “zero”. The location of each measurement is marked with a road nail at the profile start point near the road edge. Texture measurements are taken in left and right wheel-paths at each transverse profile location. The site length of 300m was considered to be the minimum length for roughness calibration (Henning and Riley, 2000). The subdivision into 50m sections was done to simplify the visual assessment of defects (Rohde et al., 1998) and is in line with international practice.

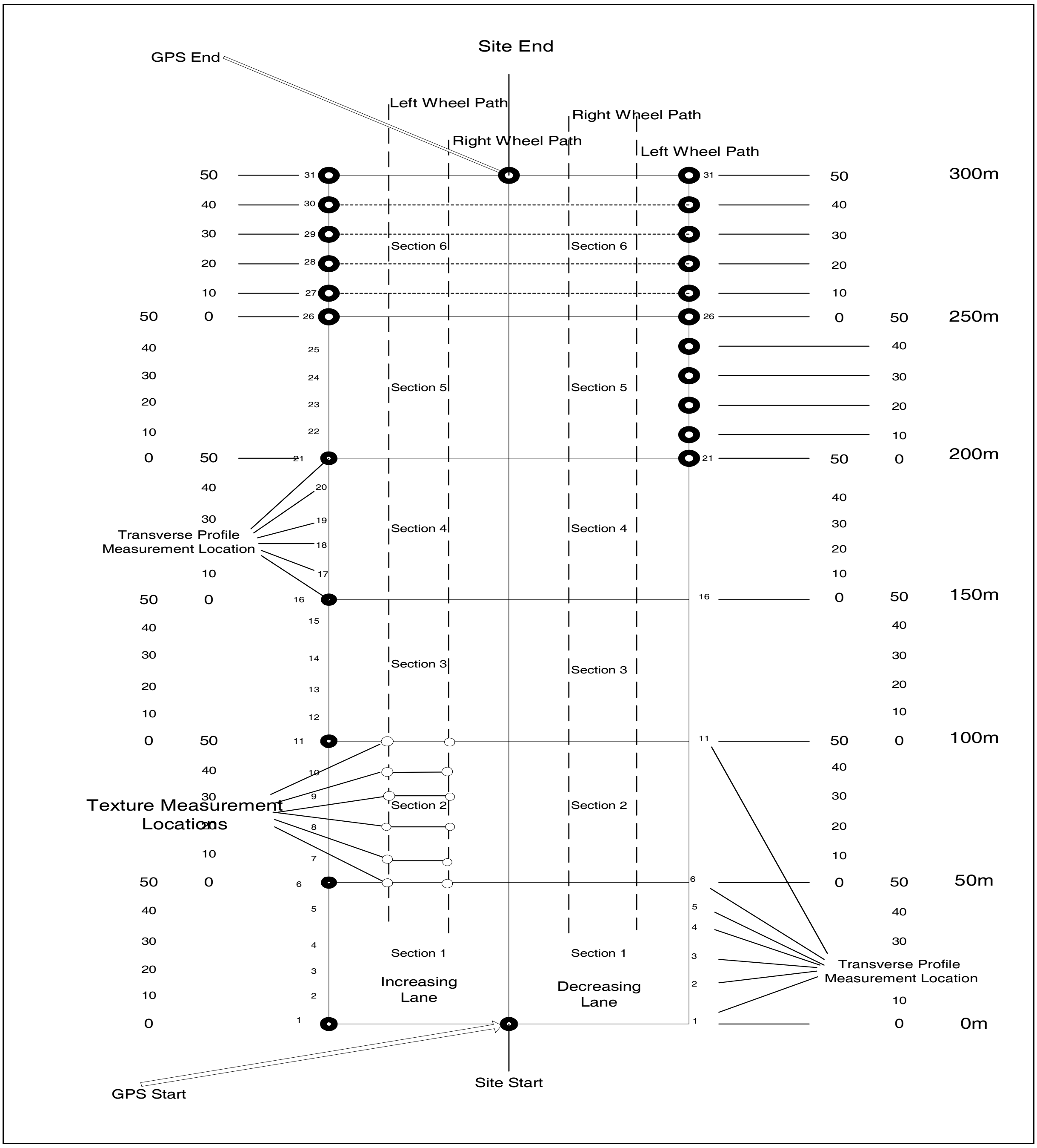

Figure 4: Calibration Site Layout.

CALIBRATION VALIDATION AND REPEATABILITY

The following points should be considered when undertaking equipment calibration and validation;

- All measuring equipment should have calibration certification to an international standard. This annual calibration to a standard that doesn't change is the first step in ensuring the measurements taken in one year are relevant to those taken in following years.
- Don't assume that equipment supplied or calibrated by the manufacturer is operating correctly. There have been too many examples on this and other projects where new equipment supplied by the manufacturer was faulty or measuring incorrectly. Calibration and validation procedures independent of those the equipment supplier should be developed.
- Validation sites should be selected to cover the range of conditions expected in the field. Preferably select sites should be homogeneous and likely to remain unchanged for several years. Repeat measurements on a site of known characteristics can identify possible

equipment variance not obvious on pavements of unknown characteristics. Ideally these would be located on low volume roads to facilitate the measurement process.

- Retain and use two or more profilers during the validation exercise and on site if possible as this provides an additional assurance to the validity of the measurements, where one instrument can cross reference the other.
- Retain data collected on the validation sites for future validation comparison. If the data collected demonstrably replicates that from previous years then this is further assurance that there has been no change in the equipment performance.

Roughness

Validation is undertaken each year before the site measurements commence. At each reference validation site repeat profile measurements in one wheel path are completed and the Mean, Standard Deviation, and Coefficient of Variance (CV) of the 50m and 100m IRI is calculated. Equipment acceptance is proven if the CV for the 100m IRI is less than 0.05.

Results

Some typical results from the 2012 validation are presented here.

Raiha St WP020, 024, 073 August 2012										
Loc	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std Dev	Cf Var	Std Err.
Profiler WP020										
100	2.33	2.28	2.35	2.31	2.3	2.35	2.32	0.028	0.001	0.012
200	2.84	2.84	2.84	2.79	2.85	2.91	2.85	0.038	0.001	0.016
300	3.41	3.31	3.41	3.4	3.34	3.39	3.38	0.042	0.001	0.017
Profiler WP024										
100	2.36	2.31	2.36	2.25	2.29	2.35	2.32	0.045	0.002	0.018
200	2.88	2.79	2.87	2.81	2.83	2.82	2.83	0.035	0.001	0.014
300	3.43	3.42	3.41	3.35	3.4	3.39	3.40	0.028	0.001	0.012
Profiler WP073										
100	2.27	2.29	2.36	2.29	2.36	2.33	2.32	0.039	0.001	0.016
200	2.86	2.92	2.94	2.77	2.87	2.8	2.86	0.066	0.003	0.027
300	3.37	3.43	3.46	3.43	3.55	3.36	3.43	0.069	0.003	0.028
Crowther Rd WP020, 024, 073 July 2012										
Loc	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std Dev	Cf Var	Std Err.
Profiler WP020										
100	3.13	3.21	3.29	3.20	3.22	3.14	3.20	0.058	0.002	0.024
200	2.85	2.84	2.88	2.93	2.79	2.87	2.86	0.046	0.002	0.019
300	2.06	2.14	2.11	2.15	2.14	2.14	2.12	0.034	0.001	0.014
Profiler WP024										
100	3.31	3.11	3.21	3.20	3.21	3.22	3.21	0.064	0.003	0.026
200	2.84	2.88	2.86	2.85	2.77	2.77	2.83	0.047	0.002	0.019
300	2.20	2.12	2.15	2.09	2.19	2.15	2.15	0.041	0.001	0.017
Profiler WP073										
100	3.23	3.21	3.19	3.18	3.18	3.15	3.19	0.028	0.001	0.011
200	2.86	2.85	2.89	2.91	2.88	2.83	2.87	0.029	0.001	0.012
300	2.10	2.08	2.18	2.11	2.21	2.2	2.15	0.056	0.002	0.023
Fenchurch Gr WP020, 024, 073 July 2012										
Loc	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Mean	Std Dev	Cf Var	Std Err.

Profiler WP020									
100	4.00	4.02	4.02	4.13	4.11	4.08	4.06	0.054	0.002	0.022
200	3.03	3.08	3.05	3.11	3.01	3.14	3.07	0.049	0.002	0.020
Profiler WP024									
100	4.12	4.08	4.08	4.03	4.09	4.05	4.08	0.031	0.001	0.013
200	2.98	3.04	2.98	3.13	2.97	3.06	3.03	0.063	0.003	0.026
Profiler WP073									
100	4.04	4.08	4.14	3.93	4.01	4.04	4.04	0.070	0.004	0.019
200	3.01	3.04	3	3.12	3.07	2.87	3.02	0.085	0.005	0.025

Table 3: 100m IRI Data WP024, WP073 and WP020.

Field Repeatability

The repeatability criteria adopted in the field includes reviewing the Mean and Standard Deviation of three repeat measurements. The project specification invariably accepted data that would benefit from additional or repeat surveys, consequently additional stricter review criteria was introduced for the IRI mean and standard deviation.

On asphalt surfaces standard deviations of 0.02 were easily achievable while on single grade chip seal a standard deviation of 0.05 to 0.10 was achievable. The locked grade 3 and 5 chip seal the coarsest of the surfaces surveyed presented the greatest difficulty and a standard deviation of 0.10 to 0.15 was often observed particularly when the pavement surface was less than two years old. These values seem in most cases to be independent of the actual level of roughness and may therefore be a characteristic of the pavement or the measuring equipment.

Distance	Lane	Run 1	Run 2	Run 3	Run 4	Mean	Std Dev
100	8A	1.68	1.69	1.69		1.69	0.01
200	8A	1.19	1.19	1.17		1.18	0.01
300	8A	1.76	1.77	1.78		1.77	0.01
Asphalt							
100	IL	2.49	2.59	2.46		2.51	0.07
200	IL	2.23	2.2	2.14		2.19	0.05
300	IL	2.31	2.29	2.25		2.28	0.03
Grade 5 Chip seal							
100	I	3.13	2.94	2.96	3.1	3.03	0.10
200	I	2.2	2.46	2.15	2.22	2.26	0.14
300	I	3.51	3.6	3.55	3.44	3.53	0.07
Grade 3-5 Locked chip seal							

Table 4: Field Repeatability

Table 4 above shows three examples of the typical repeatability obtained on asphalt, a grade 5 chip seal, and a locked grade 3/5 chip seal. Note on the coarse surface treatment, the grade 3-5 locked surface, four runs were made to improve the repeatability to an acceptable level.

Other factors also contribute to the repeatability and need to be considered when accepting data. The most significant being the crossfall of the pavement, and the extent of vertical and horizontal curvature in the test section. Often on sections with these features the forward and reverse run are different while runs in the same direction are almost identical.

Transverse Profile

At the commencement of the project there was little information available on rut depth repeatability and accuracy, and while the contract specifications refer to measurement accuracy of 0.5mm and repeatability within 95% of mean rut depth, it was considered more practical to adopt the Standard Error as the measure of the equipment accuracy and repeatability, and a standard error of less than 0.3mm was considered an appropriate measure of the equipment performance.

The dynamic validation of the Transverse Profile Beam (TPB) consists of repeat measurements on different sites and subsequent analysis of the calculated rut depth. Under normal field operation, two measurements are made, one in the forward direction as the wheel traverses the beam and a second as the wheel is driven back to the start point. During this process the software checks the variation between the forward and reverse runs and if found to be outside a set tolerance then a repeat run is required. Table 5 below presents the data from multiple measurements at three different validation sites. The mean, the standard deviation, and the standard error for 2, 4, 6, 8 and 10 measurements at each site are calculated to demonstrate repeatability. This also shows that the accuracy achieved from just two measurements is not significantly improved when additional measurements at the same location are made.

Crowther Site 1 TPB4 2012									
Left Rut	Run	Mean	St Dev	Std Error	Right Rut	Run	Mean	STD Dev	Std Error
10.00					3.82				
9.78	2	9.89	0.1579	0.1117	3.91	2	3.86	0.0576	0.0408
9.97					3.60				
9.89	4	9.91	0.0996	0.0498	3.91	4	3.81	0.1441	0.0721
10.04					3.65				
9.87	6	9.93	0.0979	0.0400	3.96	6	3.81	0.1474	0.0602
10.09					3.61				
9.90	8	9.94	0.1020	0.0361	3.89	8	3.79	0.1483	0.0524
9.91					3.79				
9.91	10	9.94	0.0910	0.0288	3.85	10	3.80	0.1321	0.0418
Crowther Site 2 TPB4 2012									
Left Rut	Run	Mean	STD Dev	Std Error	Right Rut	Run	Mean	STD Dev	Std Error
7.07					3.36				
7.06	2	7.06	0.0036	0.0025	3.29	2	3.33	0.0540	0.0382
6.89					3.41				
6.99	4	7.00	0.0815	0.0408	3.40	4	3.37	0.0565	0.0283
7.13					3.36				
7.12	6	7.04	0.0892	0.0364	3.28	6	3.35	0.0560	0.0229
6.97					3.41				
7.01	8	7.03	0.0799	0.0283	3.38	8	3.36	0.0528	0.0187
7.07					3.46				
7.07	10	7.04	0.0728	0.0230	3.43	10	3.38	0.0587	0.0186

Moores Valley Rd Site 1 TPB4 2012									
Left Rut	Run	Mean	STD Dev	Std Error	Right Rut	Run	Mean	STD Dev	Std Error
21.84					16.81				
21.50	2	21.67	0.2409	0.1703	17.11	2	16.96	0.2172	0.1536
21.72					16.79				
21.74	4	21.70	0.1433	0.0717	16.98	4	16.92	0.1523	0.0762
21.75					16.94				
21.51	6	21.68	0.1400	0.0572	17.07	6	16.95	0.1317	0.0538
21.87					16.93				
21.57	8	21.69	0.1445	0.0511	17.06	8	16.96	0.1189	0.0420
21.76					16.96				
21.76	10	21.70	0.1313	0.0415	17.05	10	16.97	0.1083	0.0343
Moores Valley Rd Site 2 TPB4 2012									
Left Rut	Run Num	Mean	STD Dev	Std Error	Right Rut	Run Num	Mean	STD Dev	Std Error
20.17					6.64				
19.90	2	20.03	0.1870	0.1322	6.54	2	6.59	0.0730	0.0516
20.23					6.84				
19.97	4	20.07	0.1569	0.0784	6.93	4	6.74	0.1802	0.0901
20.16					6.88				
19.92	6	20.06	0.1427	0.0582	6.68	6	6.75	0.1549	0.0632
20.09					7.00				
19.94	8	20.05	0.1284	0.0454	6.96	8	6.81	0.1688	0.0597
20.13					6.58				
20.13	10	20.06	0.1185	0.0375	6.70	10	6.78	0.1675	0.0530

Table 5: Rut Depth Repeatability

Figure 5 below is a typical profile plot obtained from the Moores Valley Rd site, and depicts the profile with the left and right 2m straight edge superimposed.

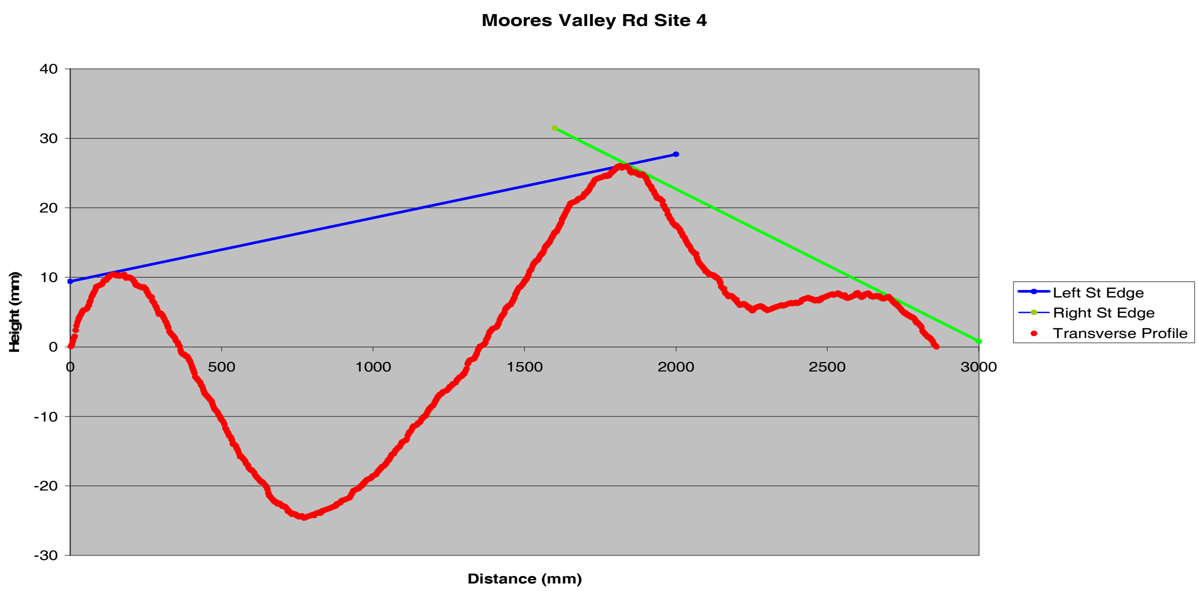

Figure 5: Typical Transverse Profile – Moores Valley Rd Site 4

Beam to Manual Rut Depth Correlation

To further demonstrate measurement accuracy the results from the beam measurements are correlated to those manually obtained using a 2m straight edge and wedge, refer figure 6 below. The sites selected for these measurements have a rut depth range from 2mm to 42mm which covers more than 90% of the expected range on the calibration sites.

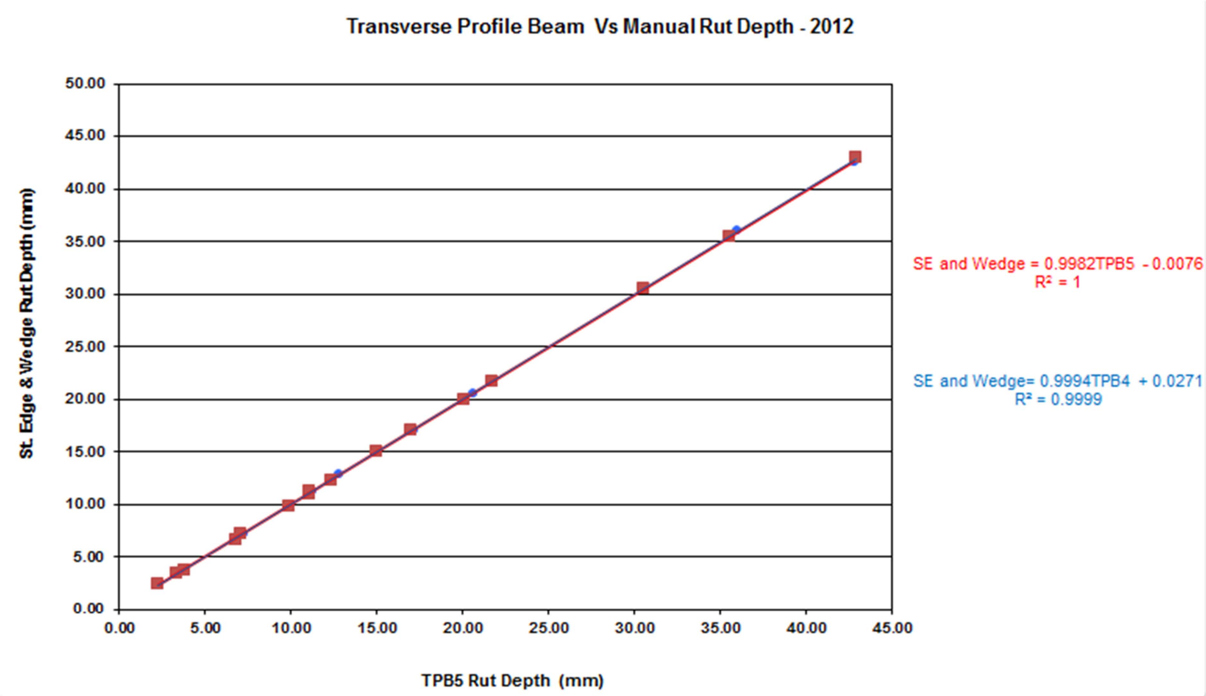

Figure 6: TPB5 and TPB4 Vs Manual Rut Depth

Texture

The texture was measured with the NZTA SLP; this instrument measures the profile as a laser travels the length of the support beam. The MPD texture is calculated from the profile in accordance with the procedure documented in ISO13473. To define the measurement repeatability a series of multiple measurements were carried out on sites with a range of texture. Table 6 below presents the results from these measurements.

Site	Run 1	Run 2	Run 3	Run 4	Run 5	Mean	Std Dev	% of mean
Cal27C	2.5338	2.4943	2.5029	2.4913	2.5174	2.5079	0.0177	0.7042
Cal27R	2.1071	2.1290	2.1191	2.1149	2.1090	2.1158	0.0088	0.4151
Cs14C1	1.3933	1.3930	1.3979	1.3753		1.3899	0.0099	0.7157
Cs14F	0.8724	0.8484	0.8644	0.8489	0.8798	0.8628	0.0140	1.6241
Cs20C	1.9460	1.9310	1.9373	1.9299	1.9146	1.9318	0.0115	0.5966
Cs20R	1.6014	1.6164	1.6043	1.6022	1.5999	1.6048	0.0066	0.4142
Cs33c	2.6549	2.6676	2.6186	2.6623	2.6413	2.6489	0.0196	0.7412
Cs33fR	2.3872	2.3481	2.3537			2.3630	0.0211	0.8947
Cs33R	2.4315	2.3880	2.4183	2.3988	2.4724	2.4218	0.0329	1.3589
Cs33R	2.5941	2.5991	2.6082			2.6005	0.0072	0.2751

Table 6: Texture Repeatability

For the majority of the sites measured the standard deviation of the repeat measurements is less than 1% of the mean, a very acceptable value. Looking at the average texture change from one year to the next at site Cal36 (figure 7 below) it is clear that a change of between 0.1 to 0.4mm is not uncommon, and in most cases this is ten times greater than the standard deviation obtained in the repeatability exercise. Clearly texture repeatability for this measurement type using the SLP exceeds the expected measurement accuracy required to define texture change.

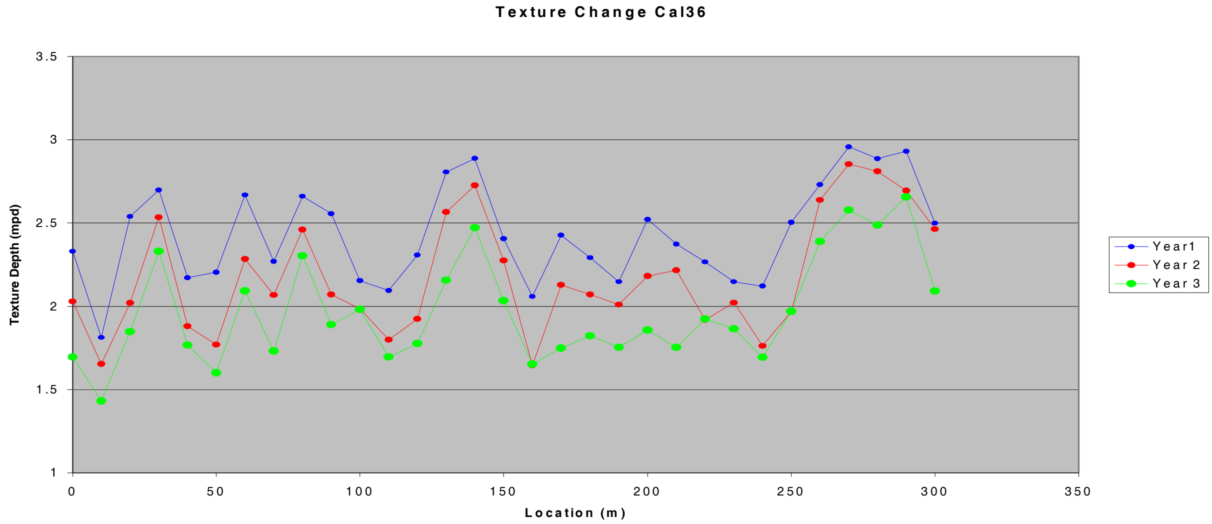

Figure 7: Texture Degradation over three years.

RESULTS TO DATE

It became apparent in year two and three of the project that changes in the data were occurring which were not consistent with current deterioration model predictions, and therefore some account of these changes and the possible causes needed to be identified. Where an unexpected change occurred a close examination of the pavement was undertaken to identify a possible cause for the change, this information was recorded and entered in a separate table within the integrated database. This site examination process and review of the measured data has led to a better understanding of what actually affects pavement deterioration and related observable changes in pavement condition. It is now possible to see how the various condition data elements interrelate. For example sites or subsections within a site that show structural defects or have been maintained show a corresponding change in roughness and rutting.

Changes in roughness from one year to the next are very small, and therefore it is essential to maximise measurement accuracy and minimise factors which are not directly related to pavement deterioration but which can influence the measured roughness.

With the project now into its thirteenth year there is an abundance of data available for analysis. One research project initiated in 2008 and continued again in 2011 analysed the change in spectral energy of the longitudinal profile data to determine possible deterioration modes. This has revealed a number of interesting facts and identified changes in long wavelength roughness that are not being detected within the IRI algorithm and do not show a visible change in pavement condition. Furthermore in 2014 a research project to ascertain crack progression on chipseal pavements, is using the condition data collected during the thirteen years of the project. The detail in this data has enable us to follow the change in individual cracks as they have developed and changed.

Variation in wheel path location and separation, the positioning of the straight edge across the profile, particularly on residential roads with underground services all affect the quality of the rutting data. Changes in traffic composition affect the lateral position of a rut, and as ruts develop both the width and depth increase. These and other facts will be discussed here in more detail.

Pavement Deterioration, Rutting - Roughness - Texture Relationship.

First expectations when starting this project were that the pavement would actually deteriorate with time, and that either no change or a slight increase in roughness and rutting and a reduction in texture from year to year would be observed. In fact roughness reduces and continues to reduce for several years after construction while the pavement and surface texture settle. Rutting tends to follow the characteristic trends but there are significant variations from site to site. Texture reduces but the rate of reduction also varies from site to site, this reduction rate appears to be dependent on the underlying structure and the wearing coarse composition. Texture affects both roughness and rut depth.

Pavement deterioration is dependent on a number of factors and it is becoming clear from the measurements and analysis that the data being collected defines some part of the equation and that interrelation between the different measurements cannot be ignored. Initially it was thought that the duration and extent of the reduction in roughness was directly related to the surface texture, the construction and seal type, or more likely the orientation and packing of the surface aggregate. However sites with excess flushing scrubbed to remove the excess binder and so increase texture showed no increase in roughness. This inter-relationship between texture, roughness and rutting is worthy of further investigation and discussion.

This paper does not attempt to quantify or define the changes observed rather just to highlight what has been observed and look at how this affects the measuring techniques currently adopted, both on this project and on the network surveillance projects used to define the network condition.

Figures 8, 9, 10 and 12 below show the progression of roughness on the four characteristic pavement types found in New Zealand. The following key facts are revealed in the figures;

- On all four pavement types roughness reduces with time.
- Resealing a site results in an increase in roughness on the chipseal pavements.
- Patching or repair work often results in increased roughness.

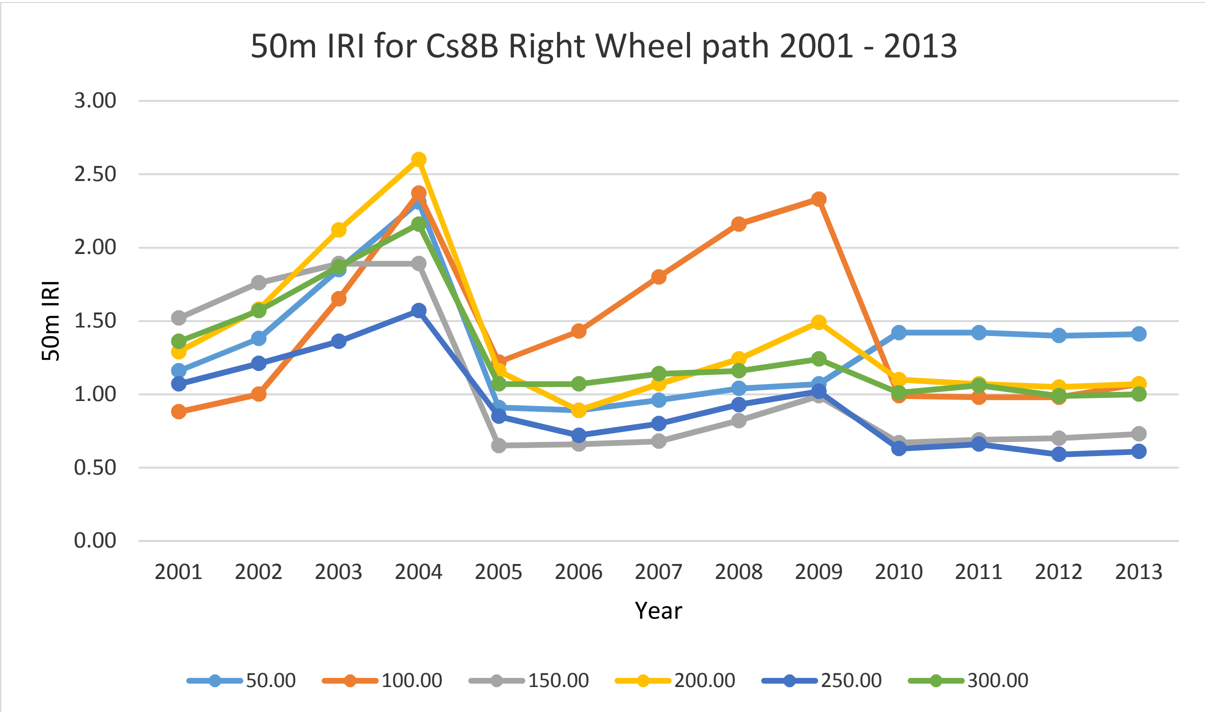

Figure 8: Roughness Progression Open Grade Asphalt.

This asphalt site underwent major rehabilitation work after 2004 and again after 2009 and clearly demonstrates the reduction in roughness resulting from the maintenance. There is some evidence to suggest that even the asphalt site has undergone some smoothing after the rehabilitation work.

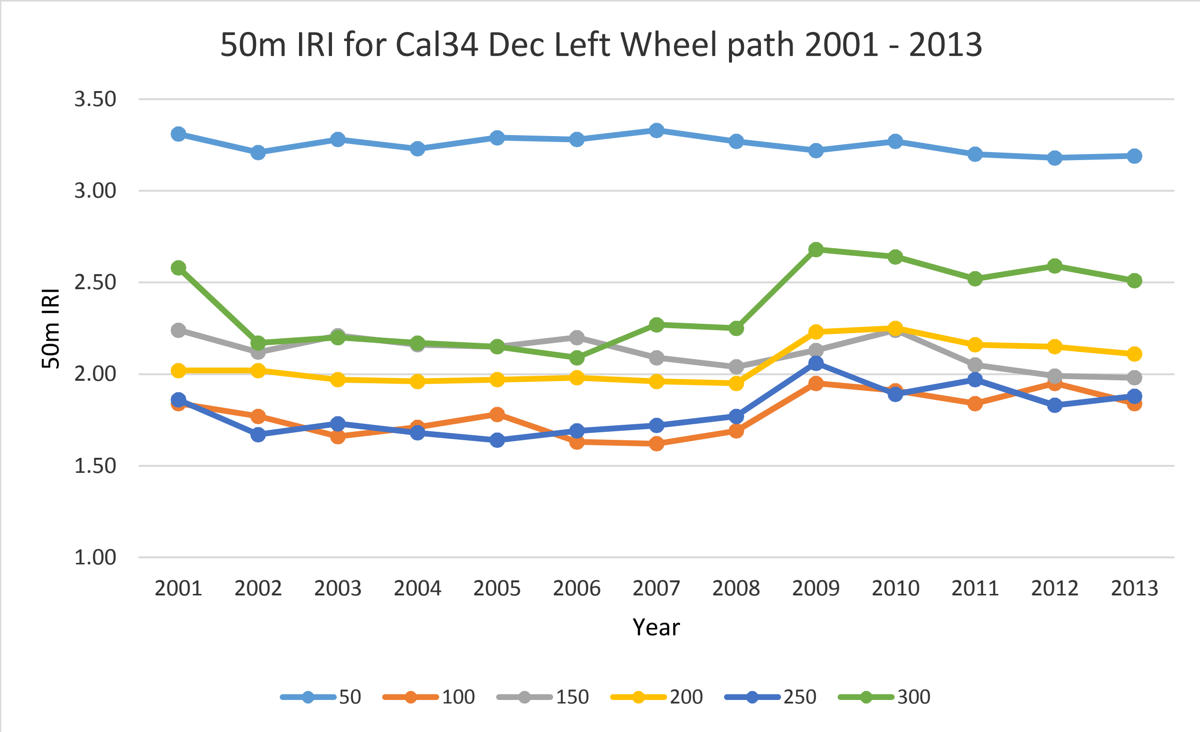

Figure 9: Roughness Progression Grade 6 Chip Seal

For the first five years the roughness decreased and then started to increase, when the site was resealed in 2009 there was a further increase in roughness followed by another gradual decline.

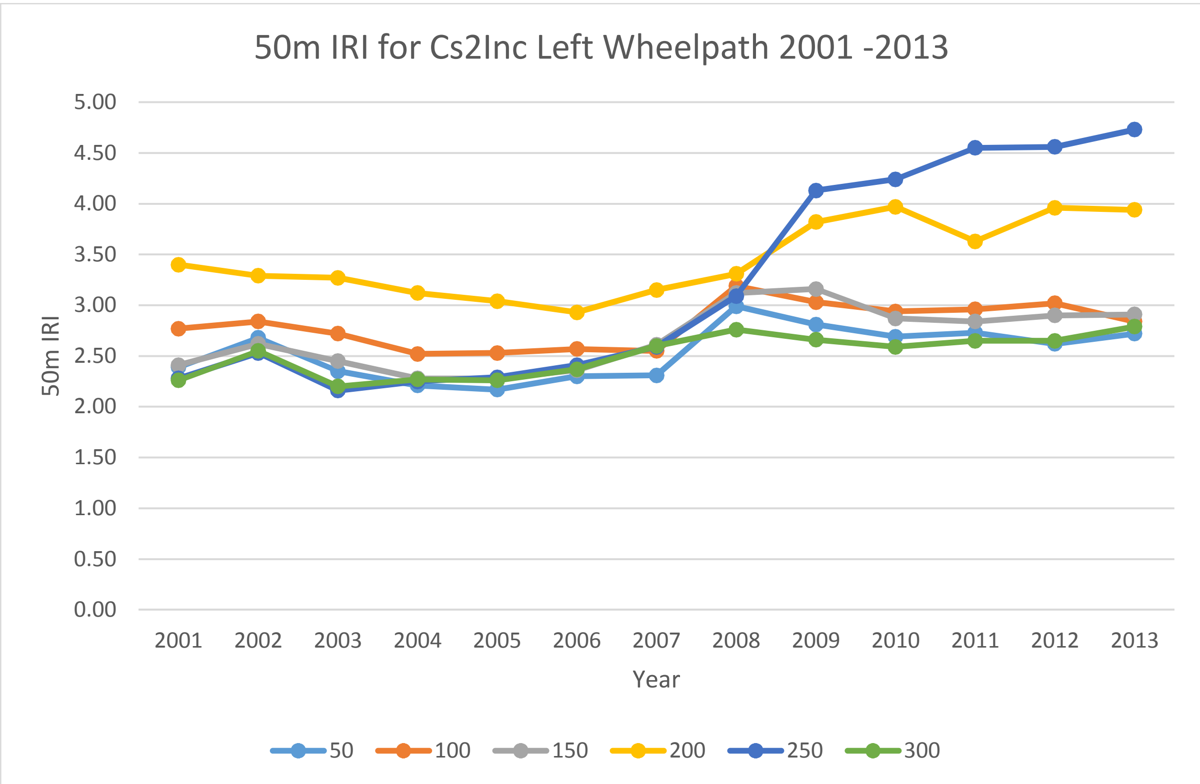

Figure 10: Grade 3 Chip Seal Roughness Progression

Roughness reduces for five years and then starts to increase, there is a significant increase after the reseal of 2007 followed by a reduction in four of the six subsections. The large increase in roughness in the 200 and 250m subsections resulted when a structural failure was repaired leaving a raised section of road over the patch, see Figure 11 below.

Figure 11: Patching causing increased roughness

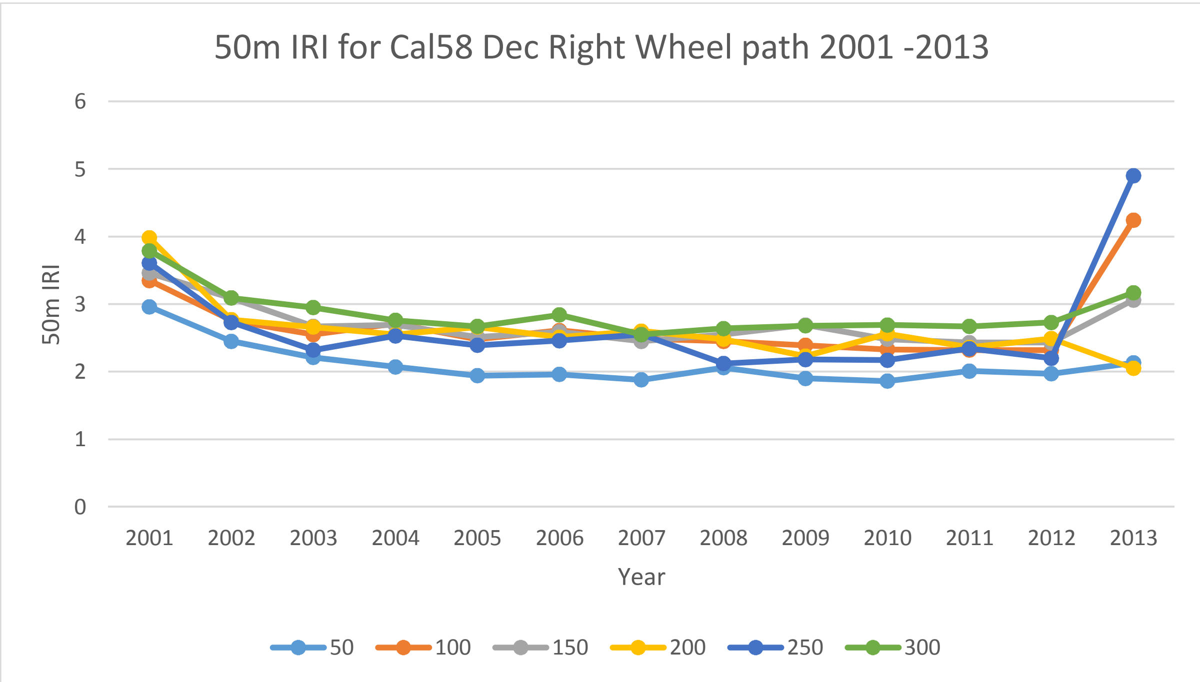

Figure 12: Grade 3/5 Locked Chip Seal Roughness Progression.

On this coarse chipseal surface (Figure 12 above) there is a gradual decrease in roughness for almost twelve years in most of the six subsections. Prior to the 2013 survey, the reseal of two structural repairs in the left wheelpath of the 100 and 250m subsections extended into the right wheelpath resulting in a large increase in roughness.

It appears that texture is the most likely reason for the reduction in roughness over time, sites with the highest texture showed a greater period of reduction in roughness. This assumption is given credence if we look at the texture profile of a newly constructed road compared to that of an older road, (Figure 13 below) it is clear that wavelengths most prevalent in the new road are not present on the old road. Significantly the wavelength corresponds to that overlap between what is classified as texture and what is considered roughness, the 0.2 to 0.8m wavelength. Figure 13 shows the profile obtained from a newly constructed locked grade 3 - 5 chip seal and that obtained from an older road section. Clearly the old surface has very little of the 0.2 to 0.8m roughness (appears flat), while the new surface has significant variation over the wavelength in question. It is therefore plausible that the smoothing of the surface as a result of the normal daily traffic reduces this short wavelength variation and as a result reduces the IRI.

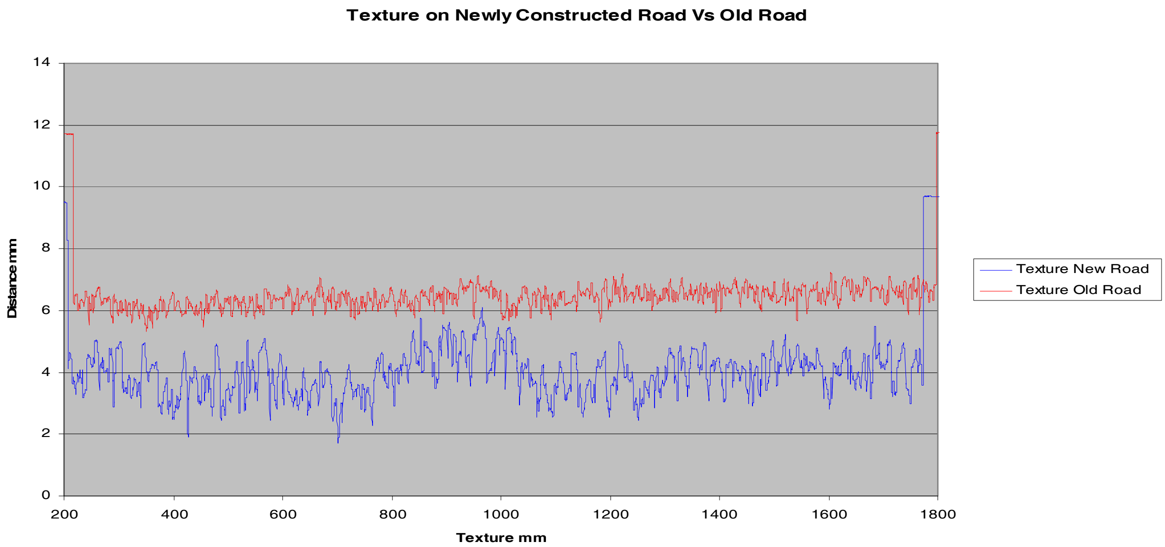

Figure 13: Texture profile on new and old pavement.

Furthermore if the rutting data on these sites is analysed, it is clear that some form of smoothing is taking place as rutting profile shows less texture and increased rut depth over time. As it is usual to expect increased roughness with increased rutting this "texture effect" is obviously the dominant factor influencing deterioration in the first few years after resurfacing or reconstruction, and this may be masking deterioration in the longer wavelengths.

Rutting

Rut depth progression is both site and location dependent; Figure 14 below shows the rut depth on Cal13B. For the first six years the rutting in all subsections are relatively consistent increasing at about 0.25mm per year. However after 2006 subsection 3 (150m) starts to increase at a much greater rate while all others continue at the same rate. On examining the condition data for this site it is not apparent that a structural failure is developing until 2009, when cracking associated with this type of failure is observed.

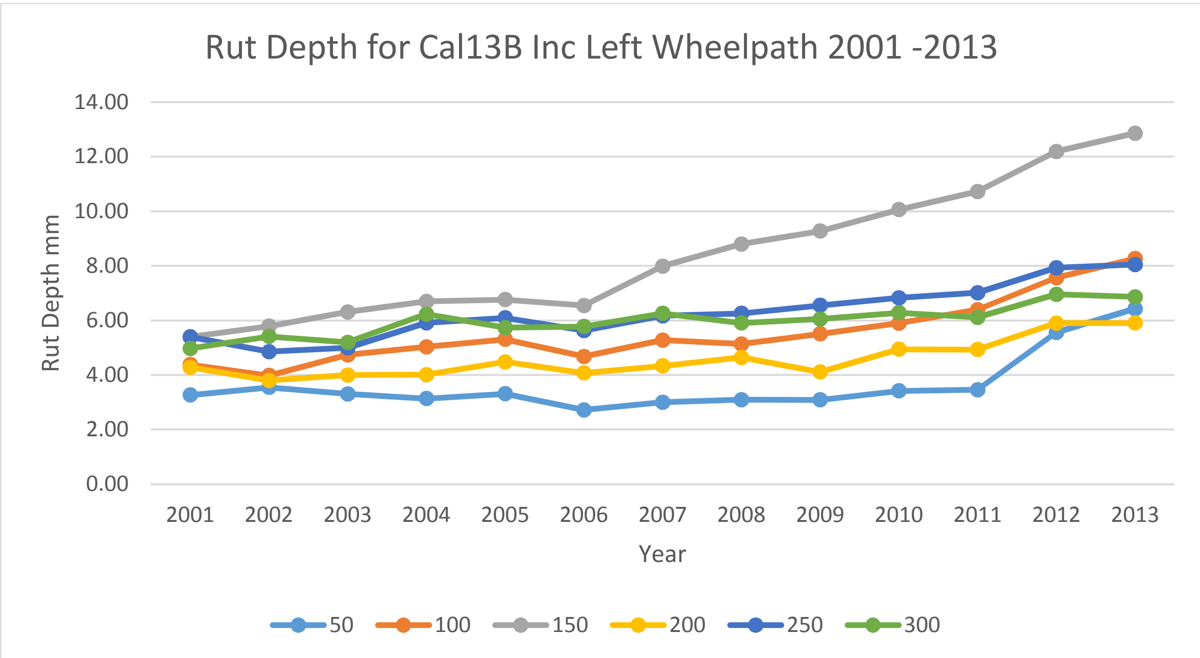

Figure 14: 50m Average Rut Depth Change

Rut Location

As a rut develops and deepens the measurement width needed to capture the entire rut also increases. Therefore the measuring system must be flexible enough to not only capture the change in profile shape (see Figure 15 below) but also the location of the high and low points from which the rut depth is calculated. At some sites the start point may have to be moved as much as 500mm toward the shoulder to incorporate the full rut, thus changing the whole dynamics of the measurement and comparison. Fortunately the transverse profile beam can accommodate these changes and the analysis software facilitates processing of different pavement widths.

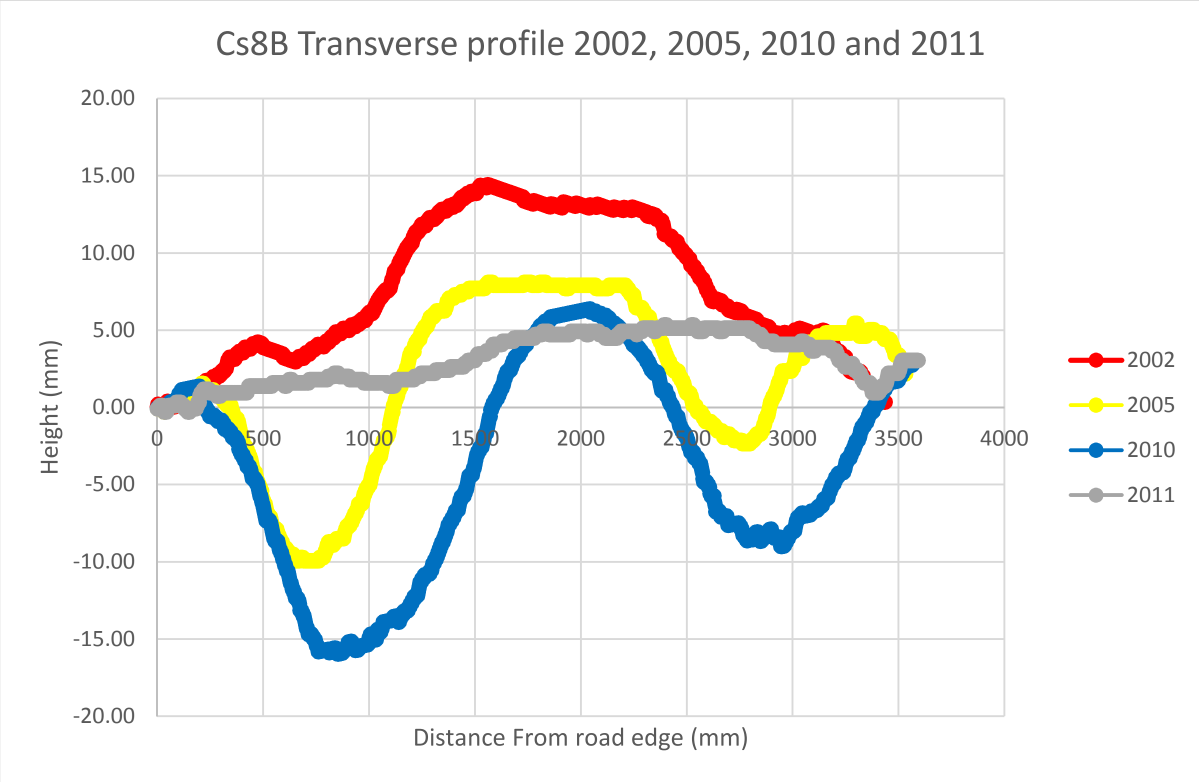

Figure 15: Change in rut profile from 2002 to 2011.

In this example the rut width has increased by 800mm in the left wheelpath from 2002 to 2010. The site was machined and resealed after the 2010 measurements giving the profile recorded in 2011.

Furthermore a change in the traffic volumes or composition of traffic can change the location of the wheel paths over the space of one or two years, at one site in particular this was obvious during a period when a large number of logging trucks passed through the site.

It is important when considering the type of equipment used to survey the network to ensure that the equipment is capable of measuring the full width (up to 3.8m) of the transverse profile in order to adequately define the shape of the profile and calculate the rut depth.

Texture

The rate of texture loss appears to be dependent on several factors, with the nature of the underlying surface having a significant bearing on the rate of decline in the texture. Where a new wearing course is added to a previously flushed surface the reduction in texture can be significantly quicker. More recently some sites which have been resealed where flushing was a problem have lost all texture within six months of the reseal.

Other points of interest when measuring texture are:

1. The width of flushed surface can on some pavements be quite narrow, flushing width of 200mm observed at some locations. Where this occurs the tolerance for locating and measuring this low texture become critical especially for the network survey equipment where the position of the measuring transducer is fixed.
2. The position and width of the wheel path varies from road to road.

3. Where shoulder widening occurs the join between the new and old sections tend to loose texture definition and become badly flushed in quite a narrow band.

Wheel Path Location

The location and distance between wheel paths can vary from year to year, and site to site. Wheel path separation can vary from 1.4m to 2.0m depending on the pavement width and the traffic composition. The wheel path distribution observed on the 82 Local Authority sites is detailed in Table 13 below. These are predominantly residential roads where the bulk of the traffic is cars. On the 19 sites which could be considered to have similar vehicle distribution to the state highways, with significant truck volumes the distribution is significantly different with the average wheel path spacing moving from 1600 to 1800mm.

This variation in wheelpath width can cause problems for survey equipment with fixed transducers. To further complicate the matter the position of the wheel path with respect to the lane edge and centre can also vary. On narrow roads with no shoulder the wheel paths are usually centrally positioned within the defined lane, while on roads with wide shoulders the truck left wheel path is often outside the white edge line. In some extreme situations three wheel paths have been observed, one wide right wheel path for all vehicles and two left wheel paths one for trucks and one for cars. Furthermore on the narrow rural roads with no lane delineation the right wheel path for the increasing lane can be in the decreasing lane, and the right wheel path for the decreasing lane in the increasing lane, or there may be a single central wheel path for both lanes. This makes locating and measuring the rut depth, texture, and roughness very difficult for systems with fixed measurement transducers.

Wheel Path Separation (mm)	Number of Sites, all local authority sites	Number of Heavy Vehicle Sites
1400	5	
1500	25	2
1600	25	4
1700	15	5
1800	8	4
1900	4	4

Table 13: Wheel Path Separation.

The importance of accurately defining the measurement location and ensuring the measurements are made at the same location each year became evident when measurements were undertaken to quantify the effect transverse position had on the roughness.

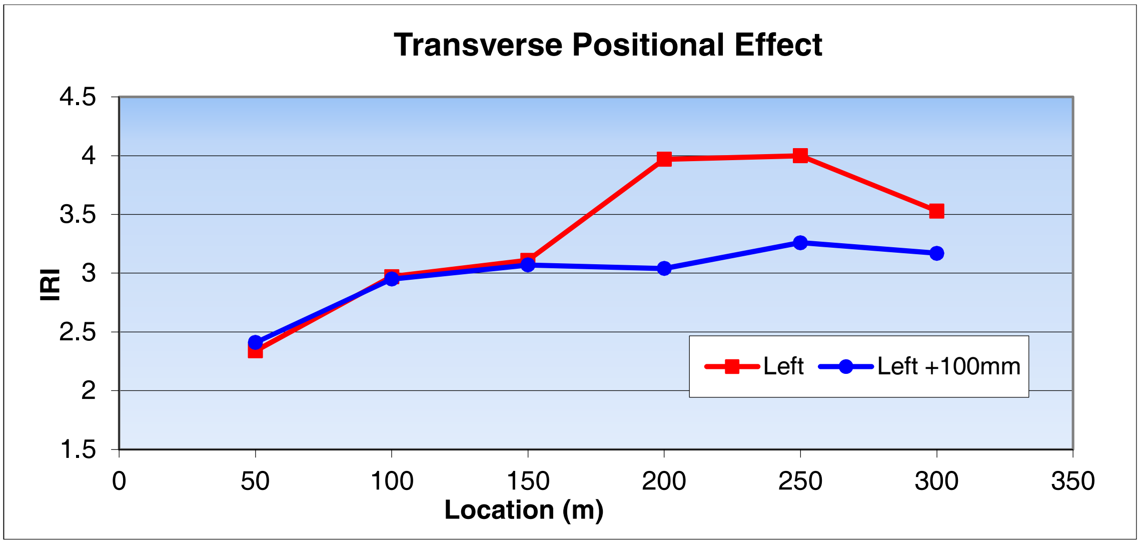

Figure 16: Measurement Location

Figure 16 above shows the IRI for two parallel profile measurements separated by 100mm.

Pavement Maintenance or Repair Techniques

Two points immediately emerge when looking at the maintenance techniques adopted to repair pavement defects, these are:

- Matching of the two surfaces between the repair and the adjacent or original seal
- The quality and type of the repair itself.

Seal Joins

It is clear that the maintenance procedures adopted can have a detrimental effect on the measured roughness, often the join between a repaired section and the existing road is not a smooth transition resulting in a marked increased roughness for the section. Previous research has demonstrated that a 3 or 4mm step can change the 100m IRI by as much as 0.3IRI. As with any filtering algorithm the response (IRI) to the input wave (longitudinal profile) is always greatest when the incoming waveform is a square wave, this is further exaggerated when the wavelength is close to the most responsive portion of the filter. The equivalent square wave on the road is a step up onto a repaired section followed by a step down to the old road surface, and the dominant frequency or period of the IRI algorithm is in the 2 – 20m, exactly corresponding to the length of many of the patches, repairs and seal joints. Consequently poor repairs or construction joints can significantly affect the measured roughness.

Repair Quality and Type

Single wheel path structural repairs of rutting, shoving and flushed surfaces are becoming more common throughout New Zealand. One such repair occurred between year one and year two on site CS39 in Nelson, the resulting change in the 50m roughness was a surprising 4IRI, see Figure 17 below. This shows the roughness for the subsection and the preceding and following sub-sections for each year from year 1 to year 10. The increase in year two is clearly visible.

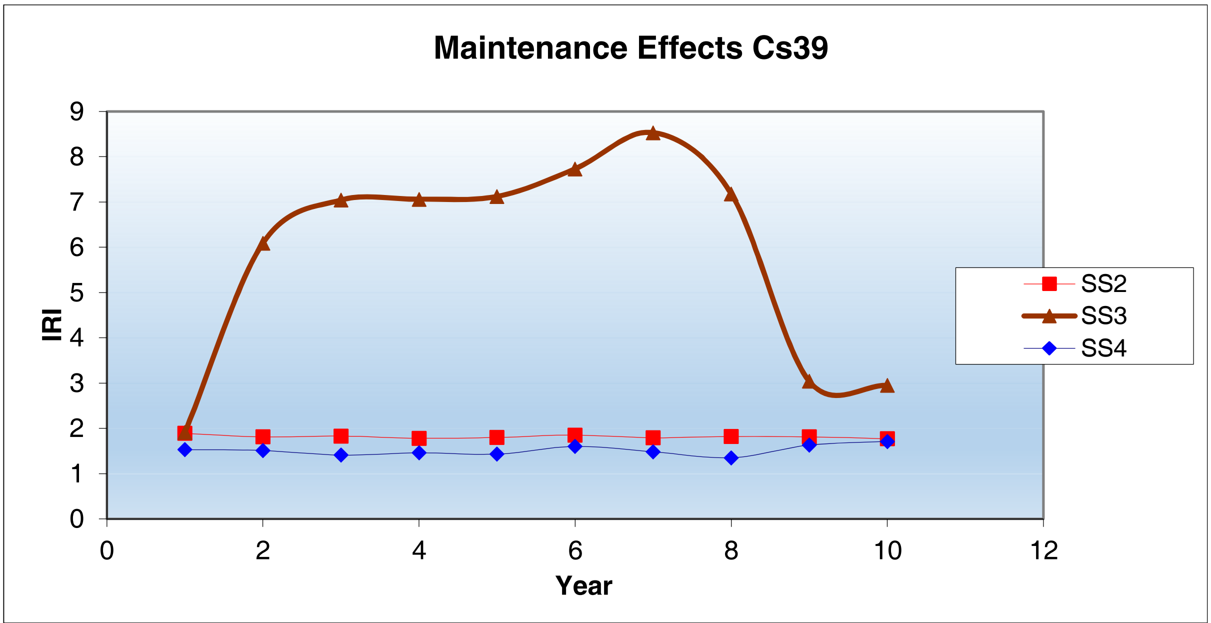

Figure 17: Variation in Roughness as a Result of a Pavement Repair.

The site had additional spot patching most years until another full repair was undertaken in 2008 reducing the roughness to 3IRI.

Other examples where a simple patch or reseal of a short section can have a dramatic effect on the collected data for several years have been recorded. The problem for the data analyst is that it is unlikely he will have an intimate knowledge of each site and therefore is unlikely to be aware of the repair therefore it is up to the data collection team to identify these features, and provide site notes detailing features which will affect the data.

While the case cited is an extreme example, changes in condition resulting from repairs can distort the outcome of any analysis.

SUMMARY AND CONCLUSIONS

The implementation of a long-term Pavement Performance study as part the national implementation of Pavement Deterioration Modelling in New Zealand, has successfully recorded reference condition data on 145 sites which reflect the spectrum of pavement construction, traffic composition and climatic zones experienced throughout the country. The quality of the data and information obtained over the past thirteen years has vindicated the stringent calibration, validation, quality control, and chosen methodology, and the equipment selected to collect this data.

The procedures adopted to identify and record visible changes in the calibration sites along with the detailed photographic evidence provide researchers with a valuable tool to isolate outlier data or data that has had undue external influences.

Be aware of all factors that may influence the longitudinal and transverse profiles, the texture, the interaction between each of these parameters, and the need to include all available information before using the data to evaluate deterioration and performance parameters. It is vital to ensure that the equipment is accurate and repeatable and adopt calibration and validation procedures which will ensure the integrity of the measurement systems adopted. Don't rely on equipment manufacturers/suppliers to ensure that the equipment is properly calibrated and measuring correctly. Build in redundancy in staff and equipment to ensure data is collected on time.

It is critical that all data collected be of the highest quality, and to document site conditions and changes in condition through the condition rating data and site notes. This will provide a better overall picture of each site and in the end will ensure pavement performance is better understood.

With such a large project extending over thirteen years it is impossible to cover every aspect of the project and therefore this review does not consider any detailed analysis of the large amount of data already collected, rather it is a review of some of the more obvious points noted regarding the equipment and data collection procedures adopted.

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2 HENNING, T.F.P. and RILEY, M. (2000) Calibration Guidelines for Pavement Deterioration Models and Work Effects Models in dTIMS, HTC Infrastructure Management, Auckland.