MEASURING PAVEMENT CONDITION DATA FOR THE ESTABLISHMENT OF A LONG-TERM PAVEMENT PERFORMANCE STUDY ON NEW ZEALAND ROADS

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ABSTRACT

With the advent of high-speed computers and the introduction of a whole raft of pavement management and pavement analysis software packages the scope for the engineer to undertake pavement deterioration analysis is literally unlimited. However the availability of suitable reference data is not. To remedy this situation the road controlling authorities Transit New Zealand, who manage the NZ State Highway Network awarded a three year contract in 2001, recently (2004) extended for a further five years, and Land Transport NZ for the 21 participating Local Authorities, awarded a five year contract in 2003 for the collection of reference pavement condition data on the state highway and local authority roads respectively.

The collection of this data is being undertaken by R & D Consultants NZ Ltd, a company formed to fill the void in the measurement of precise of pavement condition data. Both contract specifications are very similar and called for the measurement of pavement roughness, transverse profile, and recording of a visual inspection of the pavement condition and the location and identification of the calibration sites using GPS equipment. Note the State Highway survey required the collection of pavement texture at selected sites. All data to be measured to a level allied to that restricted to equipment calibration and validation or research accuracy, using class 1 or better type reference measuring equipment and techniques.

This paper describes the equipment used and why it was selected, and explains the methodology adopted to collect the pavement condition data. It discusses the measures undertaken to achieve the specified level of repeatability and some unexpected results obtained on the different pavement surfaces encountered.

The scope of work and time available on these projects does not allow a full comprehensive analysis of the data available, and so this paper was prepared to present some of the analysed data and also some field observations made while collecting and validating the data over the past four years. It is intended that the information presented is a pointer to the possible solution or reasons for some of the unusual results that have been observed during the early stages of this project.

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

INTRODUCTION

While detailed measurement of our network condition continues using the sophisticated vehicle mounted transducers measuring pavement roughness, texture, skid resistance, and geometry there is still only a limited amount of data which could be applied or used to define the pavement deterioration models being developed in New Zealand. The survey equipment currently in operation collect network-wide data, data upon which the deterioration analysis is undertaken to implement network maintenance strategies, and while this data is measured accurately it is measured at a network level and consequently cannot be easily adapted or used in the site-specific pavement analysis needed to define the pavement deterioration model. Therefore a new strategy to collect the required data to facilitate this analysis was introduced.

The two projects currently being undertaken in New Zealand are specifically designed to fill this void in precise pavement condition data by providing a carefully controlled 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 the pavement deterioration model.

Transit New Zealand (Transit) manage the New Zealand State Highway Network, consisting of approximately 11,000 kilometres of sealed roads, while the local authorities collectively manage a much larger network. The majority of these roads are surface treated single carriageway roads, with some dual carriageway A/C surfaces in the larger urban areas.

Consequently four main pavement surface types form the bulk of the network and therefore the 145 pavements selected for the survey, these surface types are:

1. A/C, a machine laid smooth surface, the majority of which is open graded asphalt
2. Grade 3 Surface Treatment, a 20mm single size chip rolled onto a layer of hot bitumen
3. Grade 5 Surface Treatment, a 10mm single size chip rolled onto bitumen
4. A combination of grade 3 chip locked into position with a grade 5 chip

In addition the pavements could be expected to have a range of rutting anywhere from 1 to 50mm, and a texture depth (MPD) covering 0.8mm to 4mm.

Appropriate measuring equipment and techniques were required to facilitate measurement of pavement condition on all these different pavement types. These techniques must also be consistent with the information required by the models being adopted. In New Zealand, these being a combination of the dTIMS, HDM-III, and HDM-4 models, and a number of locally developed models. It is expected that the surface treatment policy adopted widely throughout New Zealand may in fact dictate that these models may not only need refinement but also may lead to the introduction of a completely new model. Therefore it is even more crucial to ensure that that integrity of the data collected to define these models is of the highest quality.

This paper outlines the equipment used to collect the required data, the data collection processes, equipment validation and data quality. The paper then highlights some interesting factors arising from the data collection and the results from some initial analysis of the first four years of surveys. This includes calibration and validation and equipment repeatability, and the effect the surface type has played in the data collection repeatability. It also discusses how pavement deterioration affects the suitability of the measurement technique.

EQUIPMENT

The data collected for this project is to be used to develop the New Zealand pavement deterioration model and therefore the quality of the model is totally reliant on the data used. Accordingly equipment must be capable of recording data to the highest accuracy possible and surveyors using the equipment must be well versed in its operation in order to minimise operator and equipment bias. Furthermore the repeatability of the measuring equipment must be defined and traceable to some international standard so that any analysis can distinguish between measurement variability and true deterioration or change in pavement characteristics.

Longitudinal Profile and Roughness

Roughness can be a difficult parameter to measure, and often it is possible, to get two seemingly identical profiles, which for no apparent reason when processed through the IRI algorithm have different IRI. Research to determine reference profiling equipment[1] repeatability and validation criteria 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 100m IRI or roughness. This research also indicated that there may be temperature dependence, operator bias, and other site-specific factors which can significantly influence the results. Therefore on this project it was decided that:

- Skilled and experienced surveyors be used, surveyors who are aware of the equipment limitations and the various factors that influence measurement accuracy.
- Multiple profiles were collected to overcome or minimise these factors identified in the research.
- Data be analysed immediately on site and compared with the actual pavement conditions, and where repeatability limits were exceeded additional runs could be made.

The ARRB Walking Profiler was selected to measure the longitudinal profile. This instrument has been shown to have long-term stability, and the advantage of being able to measure the profile relatively quickly (for a reference instrument) albeit at 0.9km/hr. This quick turn around in the collection of the data ensured there was sufficient time to measure multiple profiles, process and analyse the data and to complete additional surveys where necessary. The analysis and review process on site using purpose built software enabled the survey team to identify possible outlier results and complete additional profile measurements where necessary, thus giving a more accurate measurement of roughness.

Transverse Profile and Rut Depth

There are no traditional procedures for the measurement of reference transverse profile, and while it may be possible to use equipment specifically designed for longitudinal profile measurement, these instruments often have a relatively long (≈ 250mm) foot length which makes a single profile measurement inappropriate as adjacent measurement points are to far apart to adequately define the transverse profile. Therefore a transverse profile beam (TPB) was specifically developed for the project, the design criteria were:

- Produce a reference beam which could meet the accuracy specified in the ToR (± 0.2mm resolution)
- A beam that was relatively easy to use, requiring only a single operator
- A beam that could work equally well on a flat surface (A/C) with little or no texture and on a coarse surface (large chip seal) with a lot of texture.
- A beam that measures the profile as a “continuous” profile.

The design (see Figure 1 below) ultimately consisted of a motorised wheel which is driven along a 4m supporting beam on a linear bearing. The wheel is free to move vertically on a second linear bearing as it is driven across the beam. The active or sensing elements comprise two precision rotary encoders, one to measure the displacement across the beam and the second to measure the vertical position of the wheel with respect to the beam. The encoders have a digital output which is proportional to distance, and record the height at 3mm intervals across the beam thus giving an almost “continuous” profile of the pavement surface. Texture effects were minimised through the selection a wheel of sufficient diameter and width (200mm by

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[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

50mm wide), 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 high and low points on the profile.

Figure 1: Transverse Profile Beam and Walking Profiler.

Texture

Texture is measured using the Transit Stationary Laser profiler (SLP); this is the New Zealand reference device for measuring texture. 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. The SLP collects pavement texture data in the 0.5mm to 500mm wavelength which is converted through post processing to Mean Profile Depth (MPD) using the analysis detailed in ISO 13473-1.

This instrument has well documented calibration and validation procedures[2] and was calibrated by Transit prior to use on the project; furthermore a reference profile block is measured each day to ensure the equipment remains within calibration.

GPS Coordinates

The start and end of each site are identified with a metal spike hammered into the pavement at the road centre, and the position of this location is recorded using a GPS receiver with better than 1m resolution. A Trimble GeoXT palm type GPS receiver was used; this has a specified accuracy of approximately 0.2m. A minimum of ten measurements were recorded at each

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

location and the average coordinate location reported. The validation of this equipment[3] is detailed in the project Validation Report, and shows the 1m accuracy is easily attainable.

Condition Rating

The subjective nature of this work is widely recognised and therefore to minimise bias only the most experienced surveyors were used to rate the condition of the pavement. The ToR specified that a detailed condition-rating regime was to be adopted, one that would provide as much information about the test sections as possible. The distress types recorded are detailed in the table 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

The extent and location of surface distress within each 50 m section was measured with a steel tape and the data recorded directly into a condition table/spreadsheet contained on a hand held PDA. An example spreadsheet is provided below in Table 2.

Date	Sub Sect	Dist St	Dist End	Dist Width	Dist Dep	Distress	Comments
15-Jan	1	0	30.8	600		F2	lwp
15-Jan	1	0	30.8	600		F3	lwp
15-Jan	1	0	30.8	900		F3	rwp
15-Jan	3	22	30.3	1200		F2	rwp
15-Jan	3	0	30.3	700		F2	lwp
15-Jan	3	31.1	50	600		AGN1	lwp
15-Jan	3	30.3	50	3200		StP	full lane
15-Jan	3	34.2	38.4	50	10	P8	8 potholes lwp
15-Jan	4	0	4.4	3200		StP	full lane
15-Jan	4	0	4.4	500		AGN1	lwp
15-Jan	4	1.9	3.2	150		AGN1	rwp
15-Jan	4	3.5	4.6	1200		AGN1	rwp
15-Jan	4	3.5	4.6	70	12	P3	rwp 3 potholes
15-Jan	4	4.6	5.7	700		AGW1	lwp
15-Jan	4	5.7	22.8	1300		F2	lwp
15-Jan	4	5.7	22.8	1200		F2	rwp
15-Jan	4	22.8	48.8	3200		StP	full lane

Table 2: Example Condition Rating Data

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[3] Equipment Calibration and Validation Nov 2001 TNZ Contract SM3-688/P6/10 Report

Site Layout and Marking

Each of the 145 calibration sections consisted of a 300m long section of road subdivided into 12 50m subsections as depicted in Figure 2 below. The wheel paths were located and marked at 500mm intervals to ensure repeatable measurement of the longitudinal profile. The transverse profile locations were measured from the start or zero location, marked with a road nail at the seal edge, to the lane centre. Texture measurements were taken in each wheel path 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.

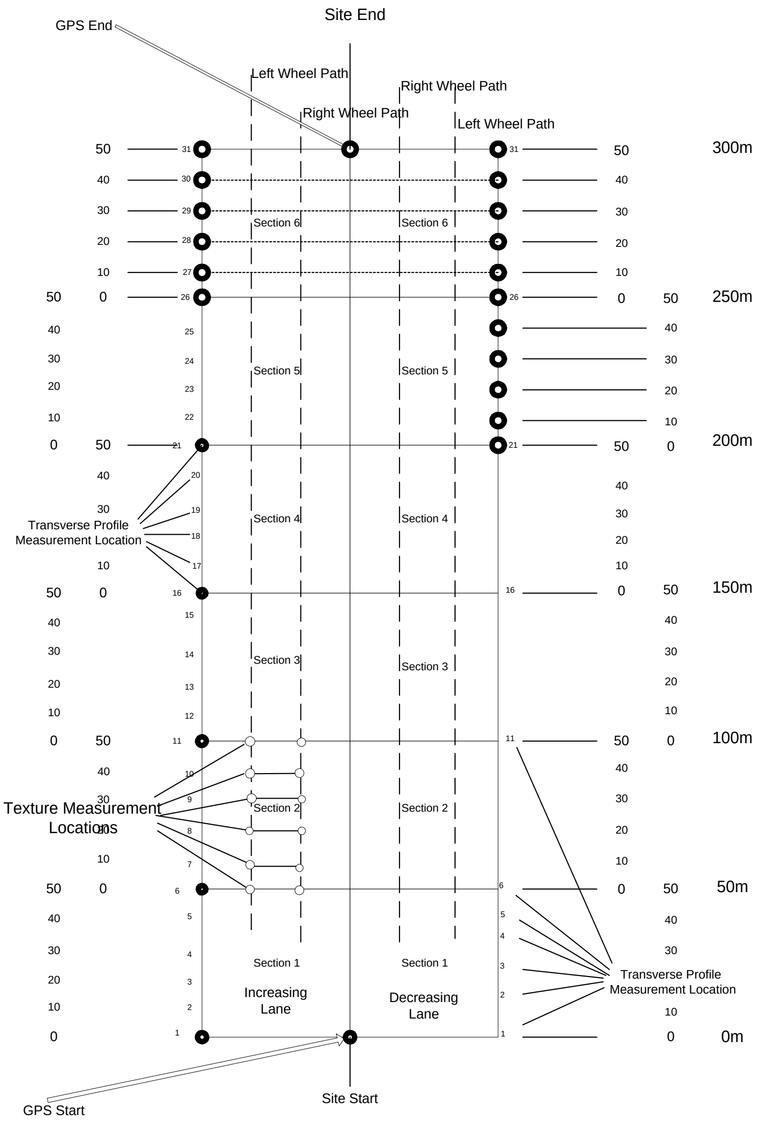

Figure 2: Calibration Site Layout.

VALIDATION AND REPEATABILITY

To ensure relevant year-to-year comparisons could be made all measuring equipment carries current calibration certification to an international standard.

Roughness

Each year validation is undertaken at two reference sites (Crowther Road Wainuiomata, TNZ Calibration site No.5 and Alexander Rd Upper Hutt, TNZ calibration site No. 2). At each site repeat profile measurements in one wheel path are completed and the mean, standard deviation and Coefficient of Variance (CV) calculated. Equipment acceptance is proven if the CV is less than 0.05. The sites are characteristic of the type of surfaces encountered on this project and TNZ 2 has the added feature of being constructed in three different sections with three different surface types. Normally this may not be considered sufficiently homogeneous for this type of equipment validation, however we considered that this variability as an added bonus in that it would provide a more rigorous test of the equipment and operator.

In the field a minimum of three measurements are made in each wheel path and the mean and standard deviation calculated. While the contract pass/fail criteria is also tested through the automated software analysis process we have preferred to also look at the standard deviation and set some rough guides for acceptance of the data based on this and on the pavement type/surface treatment and roughness level.

Results

A summary of the results and some points of interest are presented here.
Table 3, 4, and 5 below demonstrate the repeatability gained in the 100m IRI data for multiple measurements at the Transit Calibration sites in Alexander Rd Upper Hutt and Crowther Rd Wainuiomata for WP73. At both sites the data was within the specified tolerance (upper and lower limits) and had a coefficient of variance below 0.05 for all measurements. Note the upper and lower limits in Table 3 are calculated from the mean and standard deviation of the individual measurements. Table 5 presents the data collected using WP24, the backup Walking Profiler kept for this project. Comparing WP73 and WP24 at Crowther Rd shows both roughness-measuring instruments do in fact measure the same 100m roughness, with a difference of less than 0.04IRI, clearly demonstrating that either instrument can be used on the project.

Alexander Road Walking Profiler (073) - Measurements August 2004									
Distance	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Mean**	**Std Dev**	**Coeff Var**	**Low_Limit**	**Up_Limit**
100	3.28	3.47	3.30	3.45	3.38	0.10	0.0073	3.13	3.62
200	3.59	3.40	3.63	3.50	3.53	0.10	0.0078	3.28	3.78
300	2.24	2.21	2.24	2.21	2.22	0.02	0.0002	2.18	2.27
400	3.17	3.27	3.34	3.28	3.26	0.07	0.0037	3.09	3.44
500	2.72	2.78	2.72	2.69	2.73	0.04	0.0011	2.63	2.82

Table 3 Alexander Road 100m IRI Data

Crowther Road Walking Profiler (073) - Measurements August 2004									
Distance	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Mean**	**Std Dev**	**Coef Var**
100	3.09	3.33	3.31	3.08	3.13	3.24	3.20	0.1113	0.010
200	2.84	2.92	2.94	2.81	2.89	2.91	2.89	0.0501	0.002
300	2.18	2.15	2.18	2.16	2.28	2.16	2.19	0.0481	0.002

Table 4: Crowther Road 100m IRI Data WP73

Crowther Road Walking Profiler (024) - Measurements September 2004									
Distance	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Mean_L**	**StDev_L**	**Coeff Var**
100.00	3.11	3.20	3.10	3.13	3.27	3.12	3.16	0.07	0.004
200.00	2.79	2.86	2.81	2.90	2.88	2.94	2.86	0.06	0.003
300.00	2.14	2.16	2.22	2.22	2.28	2.24	2.21	0.05	0.002

Table 5: Crowther Road 100m IRI Data WP24

Figure 3 below shows the distribution of the data within the TOR specified limits at Alexander Rd. Clearly all measurements meet the TOR specification.

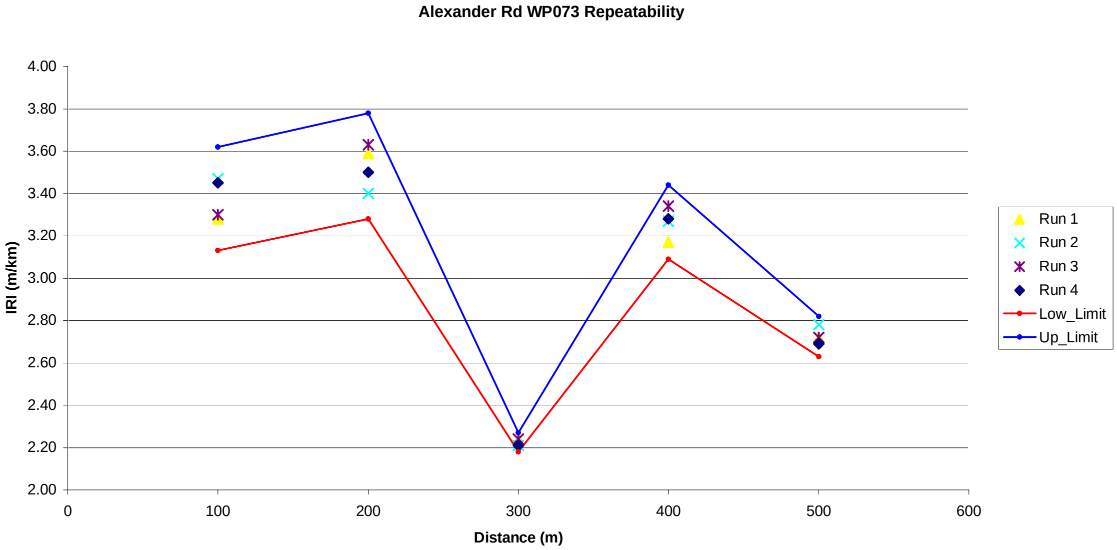

Figure 3: Repeatability of Walking Profiler 073 (Alexander Road)

Field Repeatability

The repeatability criteria adopted in the field includes looking at the Mean and Standard Deviation of the three repeat measurements. In the majority of cases we found that the project specification was accepting data that we considered needed repeat runs due to the spread of the results and therefore we also included an additional review of the mean and standard deviation when considering acceptance.

We also found that the results were dependent on the pavement type or surface texture. On A/C surfaces standard deviations of 0.02 were easily achievable while on single grade chip seal a standard deviation of 0.05 to 0.1 was usually attained. The locked grade 3 and 5 chip seal presented the greatest difficulty and often a standard deviation of 0.1 to 0.15 was often obtained. 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. Other factors also contributed to the repeatability and need to be considered when accepting data. The most significant of these were the crossfall of the pavement, and the extent of cornering in the test section. Often the forward and reverse run would be different while runs in the same direction would be almost identical. Table 6, 7, and 8 below show three examples of the typical repeatability obtained on Asphaltic Concrete, a grade 5 chip seal, and a locked grade 3/5 chip seal.

Clearly the surface texture has a significant effect on the equipment repeatability, and on further examination it is clear that texture also has a significant effect on the pavement roughness deterioration, and this will be further investigated in the trends observed over the past four years.

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
100	8B	1.55	1.51	1.56		1.54	0.02
200	8B	1.97	1.95	1.98		1.97	0.02
300	8B	1.85	1.82	1.87		1.85	0.02

Table 6: Field Repeatability Open Grade Asphalt

Distance	Lane	Run 1	Run 2	Run 3	Run 4	Mean	Std Dev
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
100	IR	2.56	2.59	2.62		2.59	0.03
200	IR	2.26	2.11	2.18		2.18	0.08
300	IR	2.75	2.76	2.79		2.77	0.02

Table 7: Field Repeatability Grade 5 Chip Seal.

Distance	Lane	Run 1	Run 2	Run 3	Run 4	Mean	Std Dev
100	I	2.23	2.14	2.14	2.19	2.18	0.10
200	I	2.14	2.29	2.49	2.18	2.28	0.10
300	I	2.43	2.25	2.22	2.48	2.35	0.02
100	D	2.36	2.14	2.2		2.23	0.12
200	D	2.41	2.45	2.38		2.42	0.04
300	D	2.46	2.5	2.49		2.48	0.02

Table 8: Field Repeatability Grade 3-5 Locked Chip Seal

Transverse Profile

Currently there is 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 0.25mm 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. Tables 8 and 9 below show the repeatability of the TPB at the selected locations. 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 9A and B below present the data from multiple measurements at a single location. The mean, the standard deviation, and the standard error for 2, 4, 6, 8 and 10 measurements, are calculated to demonstrate repeatability, and show that the accuracy achieved from just two measurements is not significantly improved if additional measurements at the same location are made. Note; had an improved accuracy been obtained through increased measurements then the standard deviation and standard error would reduce as the number of measurements increased.

Crowther Road Site 1 Left Rut

Site1	Location	Rut Depth	Run Num	Mean	STD Dev	Std Error
Run 1	Left 1	10.21				
	Left 2	10.13	2	10.17	0.0542	0.0383
Run 2	Left 1	10.08				
	Left 2	10.08	4	10.12	0.0609	0.0305
Run 3	Left 1	10.06				
	Left 2	10.06	6	10.10	0.0574	0.0234
Run 4	Left 1	10.18				
	Left 2	10.08	8	10.11	0.0578	0.0205
Run 5	Left 1	10.05				
	Left 2	10.17	10	10.11	0.0587	0.0186

Table 9A: Multiple Runs Site 1 (Left Wheel Path)

Crowther Road Site 1 Right Rut

Site1	Location	Rut Depth	Run Num	Mean	STD Dev	Std Error
Run 1	Right 1	4.61				
	Right 2	4.72	2	4.66	0.0777	0.0550
Run 2	Right 1	4.63				
	Right 2	4.76	4	4.67	0.0699	0.0313
Run 3	Right 1	4.61				
	Right 2	4.78	6	4.67	0.0755	0.0286
Run 4	Right 1	4.62				
	Right 2	4.74	8	4.68	0.0738	0.0261
Run 5	Right 1	4.62				
	Right 2	4.82	10	4.69	0.0814	0.0258

Table 9B: Multiple Runs Site 1 (Right Wheel Path)

Crowther Road Site 2

	Location	Rut Depth	Run Num	Mean	STD Dev	Std Error
Site2	Left 1	7.17				
	Left 2	7.03	2	7.10	0.0975	0.0690
Site 2	Right 1	4.61				
	Right 2	4.63	2	4.62	0.0147	0.0104
Site 3	Left 1	15.66				
	Left 2	15.56	2	15.61	0.0731	0.0517
Site 3	Right 1	5.15				
	Right 2	5.12	2	5.13	0.0212	0.0150
Site 4	Left 1	25.62				
	Left 2	25.49	2	25.55	0.0923	0.0653
Site 5	Left 1	22.16				
	Left 2	22.13	2	22.15	0.0214	0.0151

Table 10: Rut Depth Repeatability Moores Valley Rd

Table 10 above shows the repeatability achieved at different locations for a range of different rut depths. It is clear from this data that on all occasions the standard error was below the specified tolerance of 0.25mm, confirming the measurement repeatability is well within the defined limits. There is no significant improvement or change to the data quality by increasing the number of measurements thus confirming our methodology maximises productivity without compromising accuracy. Of note is that repeat measurements consistently report the same level of rutting, as shown in the tables of results for 2, 4, 6, 8, and 10 measurements. This shows the very good repeatability of the equipment measuring system.

Beam to Manual Rut Depth Correlation

To further demonstrate measurement accuracy and to definitively demonstrate the transverse profile measurement is consistent with the generally accepted straight edge and wedge method the rut depth calculated from the measured profile and the rut depth measured using the 2m straight edge and wedge at the above locations are presented in Table 11 and Figure 4 below.
The calibration sites selected above for the repeatability have a rut depth range from 4mm to 25mm (90% of the expected range on the 64 calibration sites) it is therefore appropriate to also use this data to define the correlation between the TPB, and the manual rut depth obtained using the 2m straight-edge and wedge method.

Site	Manual	TPB4
Mor1L	18.6	19
Mor1R	18	18.2
Mor2L	15.4	15.6
Mor2R	5	5.2
Mor3L	25	25.4
Mor4L	21.3	22.2
Cro1L	9.4	10.1
Cro1R	3.8	4.7
Cro2L	6	7
Cro2R	5.2	5
Cro3L	14.2	14.8
Cro3R	3.2	3

Table 11: Rut Depths August 2004, TPB4, and Straight Edge and Wedge

From this data it is clear that rut depth measured by TPB4 is consistent with the data measured by the straight edge and wedge. The correlation (0.9887 – 0.2) further demonstrates the accuracy of this measurement system.

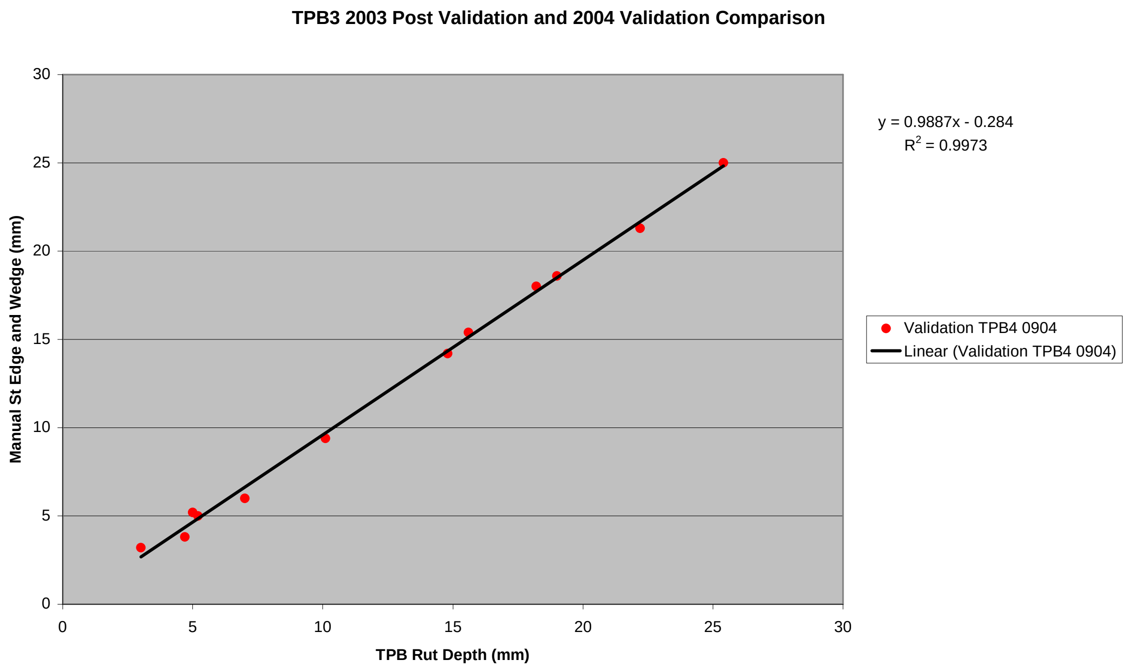

Figure 4: TPB4 Vs Manual Rut Depth August 2004

Texture

Technically there are no specific requirements to demonstrate repeatability of the texture measuring equipment; however the final analysis of the data will require some indication of the repeatability of the measuring equipment. This will ensure that changes in texture are "true" changes and not just the error associated with the measurement.

The texture was measured with the Transit SLP this instrument measures the profile during a single scan of the laser along the 1.7m beam. This produces sixteen 100mm texture measurements, from which the individual 100mm MPD is calculated in accordance with ISO13473. Texture repeatability was determined through several repeat measurements on sites which cover the expected measurement range on the calibration sites being measured.

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

Table 12: Texture Repeatability

With the exception of 1 site the standard deviation is less than 1% of the mean value; see Table 13 below, and it should be noted that the site where the 1% tolerance is exceeded has very low texture. Looking at the average texture change from one year to the next we see that a change of between 0.1 to 0.4mm is not uncommon, factor of ten times the standard deviation from the mean obtained in the repeatability exercise, refer Figure 5 below. Clearly texture repeatability for this measurement type using the SLP exceeds the expected measurement accuracy required to define texture change.

Site	Mean	Std Dev	% of mean
Cal27C	2.5079	0.0177	0.7042
Cal27R	2.1158	0.0088	0.4151
Cs14C1	1.3899	0.0099	0.7157
Cs14F	0.8628	0.0140	1.6241
Cs20C	1.9318	0.0115	0.5966
Cs20R	1.6048	0.0066	0.4142
Cs33c	2.6489	0.0196	0.7412
Cs33fR	2.3630	0.0211	0.8947
Cs33R	2.4218	0.0329	1.3589
Cs33R	2.6005	0.0072	0.2751

Table 13: Percentage Variance from the Mean value

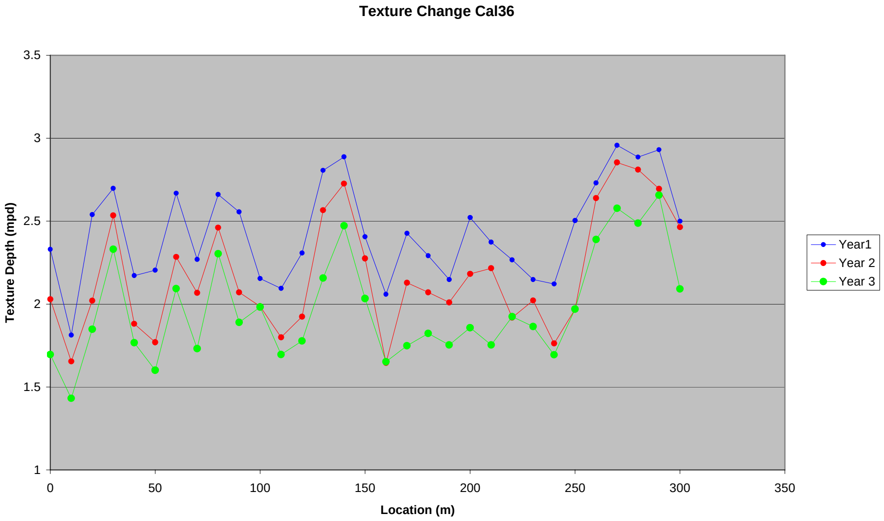

Figure 5: Texture Degradation over three years.

RESULTS TO DATE

One key aspect of the project not originally conceived, which became immediately apparent in year two, was the need to closely examine the pavement condition to explain any differences in the current survey data when compared with data obtained the previous year. This close examination of the pavement and the measured data has led to a better understanding of what actually affects the pavement condition. Trying to determine what has caused a particular change in pavement condition data has meant that we can now more easily look at the results and point to specific changes in the field that contribute to the change in the data. We can see how the various condition data elements interrelate. For example Cal25 had increases in roughness in one subsection and not in other adjacent sections, a closer examination of the pavement revealed a slight pavement structural failure, and a reseal of a short section which can be attributed to observable changes in roughness, texture, and rutting.

Another example is where an increase in roughness occurred on a bend with no obvious defects, further examination of the site in the evening showed visible evidence of “wheel bounce” induced roughness.

However even more interesting is the fact that pavement deterioration has not followed expected trends, that the variation in wheel path placement and separation is so variable, and that the location and width of rutting migrates out toward the road shoulder as the rut forms, 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 we would see either no change or a slight increase in roughness and rutting, and a reduction in texture from year to year. We have however found that in fact the roughness continues to reduce for up to four years while the pavement and surface texture settle. Rutting tends to follow the characteristic trends with a slow increase followed by a more rapid increase as the pavement ages. Texture definitely reduces but the rate of reduction varies from site to site, this reduction rate appears to be dependant on the underlying structure.

The deterioration equation is clearly dependant on a number of factors and it is becoming clear from the measurements we are taking that all data collected defines some part of the equation and that interrelation between the different measurements cannot be ignored. At first glance it was thought that the duration and extent of the reduction in roughness appeared to be directly related to the surface texture, the construction and seal type, or more likely the orientation and packing of the surface aggregate. This inter-relationship between texture, roughness and rutting is worth further discussion.

Deterioration models predict pavement deterioration, and so when roughness is reducing over a period of three and four years then the existing models no longer meet their intended purpose and new models may be required. 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 6 to 9 below show the progression of roughness on the four characteristic pavement types found in New Zealand. The most significant factor here is that on all but one pavement (machine laid asphalt) the roughness reduces with time. It is also possible that this trend may occur on the open grade asphalt example as this pavement was several years old when first surveyed. The most dramatic change being observed on the locked grade 3-5 chip seal.

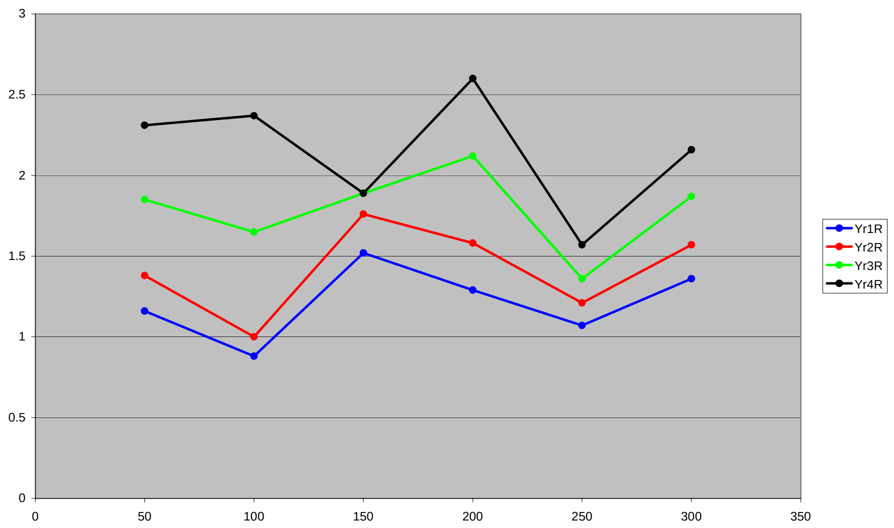

Figure 6: Roughness Progression Open Grade Asphalt.

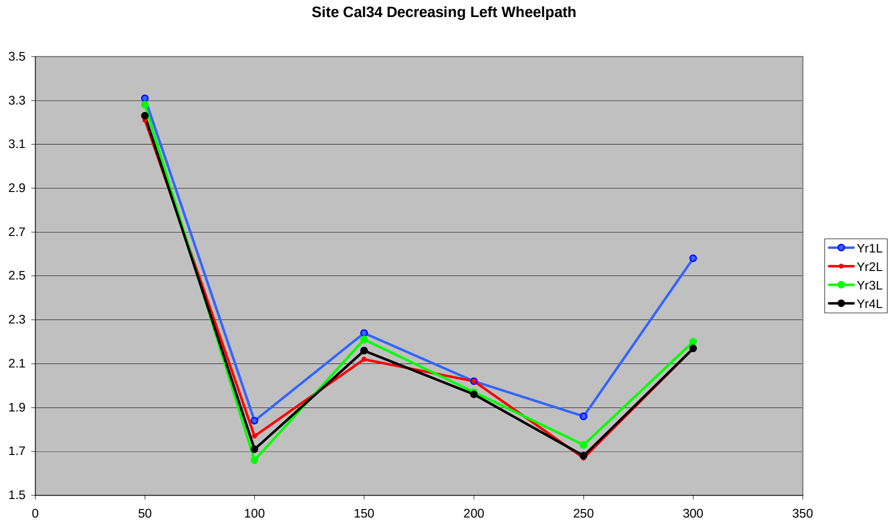

Figure 7: Roughness Progression Grade 5 Chip Seal

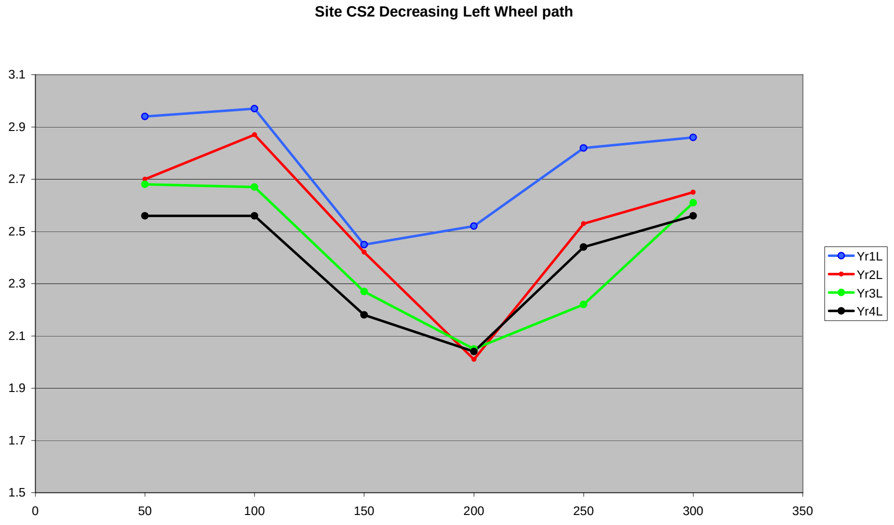

Figure 8: Grade 3 Chip Seal Roughness Progression

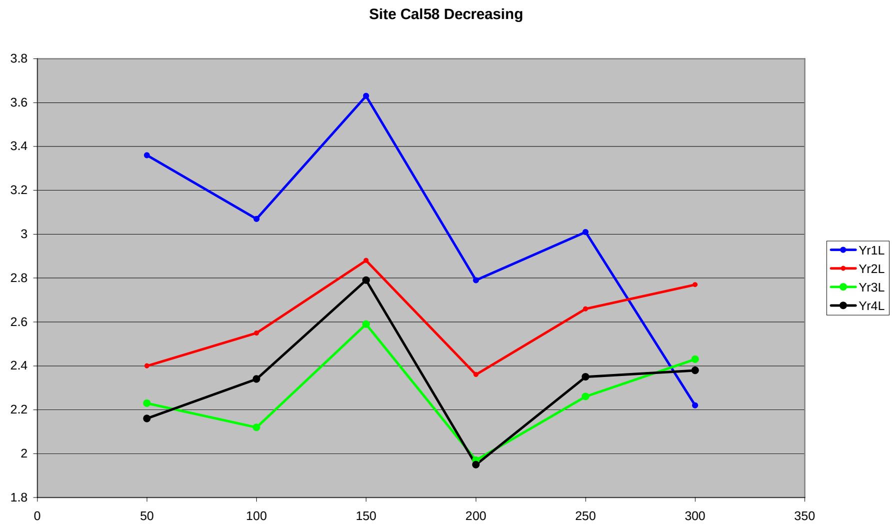

Figure 9: Grade 3/5 Locked Chip Seal Roughness Progression.

Our initial impression was that the texture was the most likely reason for this phenomenon, as the sites having the highest texture showed the largest reduction in roughness. These sites also affected the operation of the Walking Profiler and the repeatability of both roughness and rutting measurements. However if we compare the texture profile of a newly constructed road with high texture to that of an older road, it is clear that one of the wavelengths most prevalent in the new road is 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, and it is therefore understandable why the repeatability of the measuring equipment is affected. Figure 10 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 possible that the smoothing of the surface as a result of the normal wear and tear resulting from the daily traffic reduces this short wavelength variation and as a result reduces the pavement roughness. Clearly there is insufficient evidence to date to categorically deem this as fact but it seems a logical assumption.

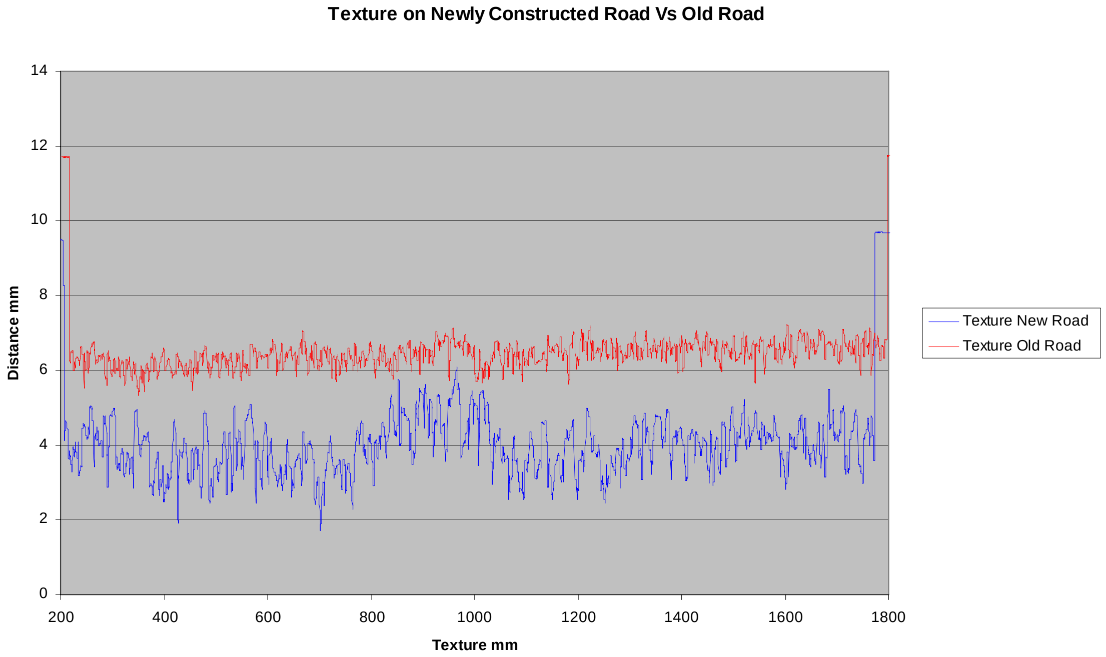

Figure 10: Texture profile on new and old pavement.

Furthermore if we look at the rutting data on the sites affected, it is clear that deterioration is taking place as rutting is developing, and therefore it would seem that roughness should also be increasing. However the “texture effect” is obviously the dominant factor in the deterioration equation in the first few years after resurfacing or reconstruction.

If we look at roughness and rutting on a site-by-site basis there is a good correlation between rutting and roughness, i.e. where rutting is highest then usually the roughness is also highest, see Figure 11 below. Therefore we could rightly conclude as the rutting increases so should the roughness.

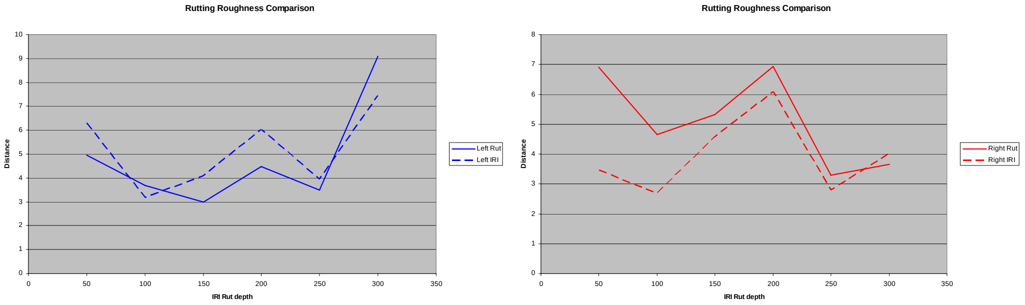

Figure 11: Rutting – Roughness comparisons

Rutting

To date the progression of rutting has not been too dramatic although there are indications this year, year 4 of the Transit project, on some of the busier roads the increase in rut depth has exceeded the increases of the previous three years. This leads to our next observation that as rut depth increases so too does the rut width, and on an increasing number of sites we have had to increase the measuring width to ensure the full rut is measured. Figure 12 below shows the progression of rut depth on one motorway site in Auckland over the past four years while Figure 13 shows the individual transverse profiles in one 50m subsection at the same site. It is also clear from Figure 13 that the deepest rut is also the widest rut.

Rut Location

As a rut develops and deepens the width of the rut also increases and we are finding at more and more sites that it is necessary to start the transverse profile measurement outside the original start point previously marked with the road nail. Also noted is that as the rut forms a shove also forms (usually on the road shoulder) changing the shape of the pavement at the edge. In extreme situations the start point may have to be moved as much as 600mm onto 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. This is further complicated if the pavement width is increased through an increase in shoulder width, as trucks are driven as far from the road centre line as possible. With the continued increase in heavy vehicles the whole driving line can change completely over the space of one or two years. This is important when considering the type of equipment used to survey the network, equipment must be capable of measuring the full width of the transverse profile in order to adequately define the shape of the profile and calculate the rut depth.

Rut Type

Three distinct rut types are evident on the Roads in New Zealand, one a wide shallow rut and the second a narrow and often quite deep rut, and the third is not a true rut but rather a depression formed where a shoulder or pavement widening exercise has occurred. The ridge or depression at the pavement join can be several millimetres thick and therefore appear as a rut for the next four or five years or until the ridge is flattened out or an actual rut develops elsewhere.

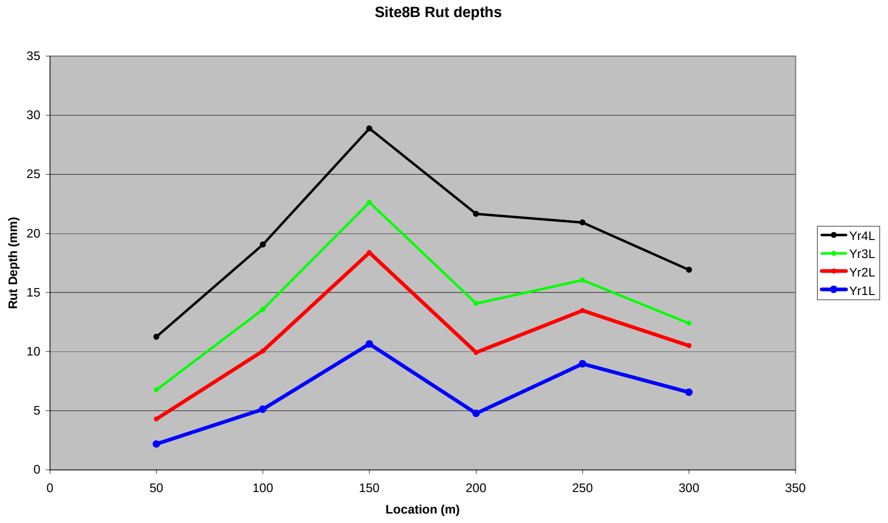

Figure 12: 50m Average Rut Depth Change

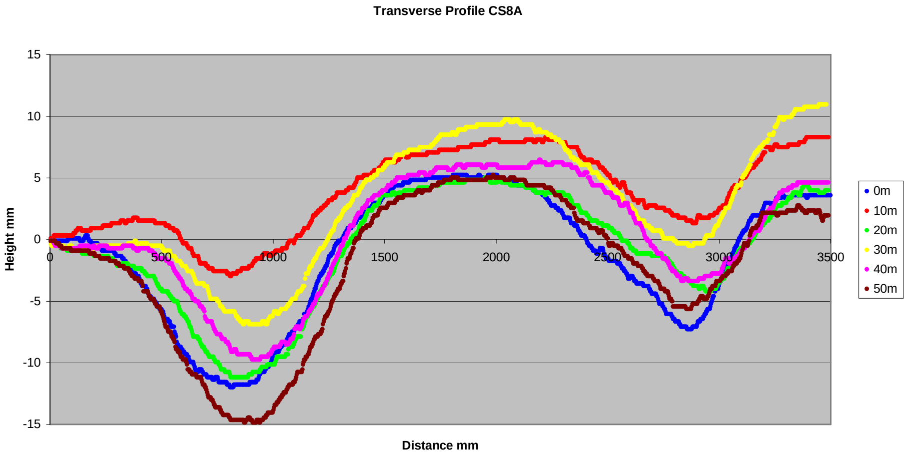

Figure 13: Transverse Profiles in a single 50m subsection.

Texture

While the texture data has only recently been made available for analysis some interesting results are already showing up. The rate of texture loss appears to be dependant on several factors, with the nature of the underlying surface having a significant bearing on the rate of decline in the texture. Where the surface was previously flushed the reduction in texture with time is significantly quicker.

Other points of interest when measuring texture are:

1. The width of flushed surface can on some pavements be quite narrow, with the flushed area being as narrow as 200mm 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.

Network survey equipment has by necessity the position and separation between left and right measuring transducer fixed, (1500mm in New Zealand). Where the road wheel path separation varies outside this it will not be possible to measure both left and right texture correctly. For example if the wheel path separation is 1900mm on the road then if the left wheel path is measured correctly the right wheel path will be 400mm outside the measured location, and will result in the texture depth being overestimated.

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 Transfund sites is detailed in Table 13 below, these roads are predominantly residential roads where the bulk of the traffic are 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. Clearly such a variation in wheelpath width can cause problems for survey vehicles with fixed measurement spacings for transducers measuring texture roughness and rutting. To further complicate the matter the position of the wheel path with respect to the lane edge and centre also varies. 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 a single central wheel path is also common. This makes locating and measuring the rut depth, texture and roughness very difficult.

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.

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 data collection on site CS39 in Nelson, the resulting change in the 50m roughness was a surprising 4IRI, see Figure 14 below. This shows the roughness measured on the site in 2003 (year 2) and the expected maximum variation from the data collected in 2002.The increased roughness was clearly visible, and is probably a result of the adopted repair process. The repair was in effect a narrow longitudinal trench dug to repair a rut that had developed in the outside wheel path, however the width of the trench precluded compaction using a roller and it appears that there was no graded surfacing, resulting in significant 1- 2m unevenness as evidenced in the huge increase in roughness.

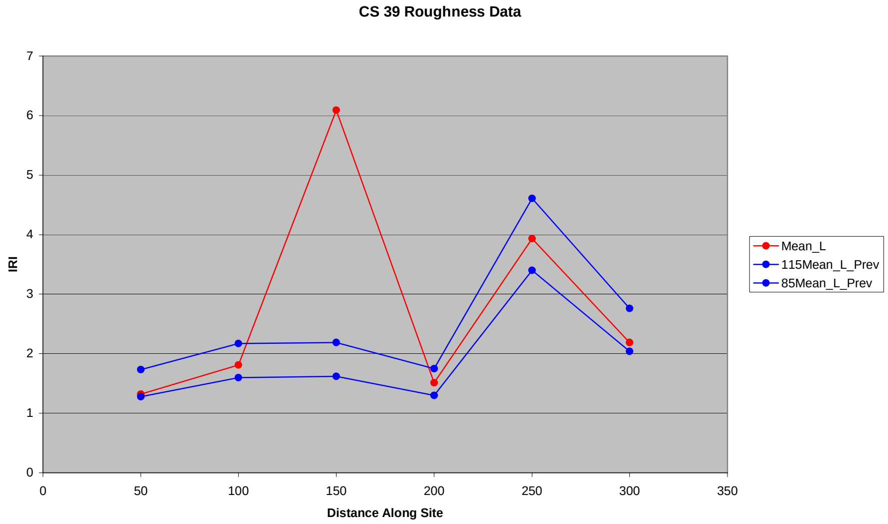

Figure 14: Variation in Roughness as a Result of a Pavement Repair.

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 data and information obtained to date from these projects have vindicated our stringent calibration, validation, quality control, and chosen methodology, and the chosen equipment.

It is clear from the observations described that any pavement deterioration model developed for New Zealand conditions will need to be New Zealand specific and take account of construction and maintenance techniques adopted in New Zealand. The changes in roughness observed following a reseal are just as likely to be observed on a newly constructed road section or large structural repair. The increase in roughness observed in the narrow wheel path repair is also likely to have a significant influence on pavement deterioration analysis as the magnitude of change in roughness resulting from these repairs influence data aggregated over 100m and 1km.

It is important to be aware of all factors that may influence the pavement roughness, transverse profile, and texture, the interaction between each of these parameters and the need to include all available information before using the data to calculate deterioration.

It is therefore 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 the deterioration model can account for these factors.

This review of the project to data 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. A more detailed comparative analyses between the network level HSD measurements and the manual calibration survey measurements has been undertaken[4] and also highlights the need to ensure data quality, and identified that network data differed significantly from the manual calibration survey measurements, indicating that further refinement of our network survey process may be required.

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[4] Henning TPF