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Review of Variability in Skid Resistance Measurement and Data Management

Austroads

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Review of Variability in Skid Resistance Measurement and Data Management

Austroads

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SUMMARY

This report presents research outcomes of Austroads project AT1488 (*Improving Skid Resistance Measurement*) carried out from July 2009 to June 2012. The main goal of the project was to improve the understanding of variability associated with skid resistance testing and measurement, so a more effective management plan can be devised balancing the practical limitations and the goal of providing safe roads. This report supplements the existing Austroads technical reports (e.g. *Guidance for the Development of Policy to Manage Skid Resistance*, AP-R374-11 (Austroads 2011a)).

Various issues in relation to the variability in skid resistance measurements (e.g. seasonal variation in the measurement) were comprehensively reviewed and are discussed in the report. Important findings from the review and recommendations are as follows:

- Harmonisation of the outputs of many different skid resistance devices is not considered possible at present. Therefore, jurisdictional standardisation (using a device of choice) should be addressed first, while retaining Australasian standardisation as a long term goal.
- Standard skid resistance test machines of a jurisdiction (or jurisdictions using the same standard devices) need to be routinely calibrated and examined to ensure consistency in mechanical characteristics as much as possible. Periodic inter-device and inter-jurisdiction correlation exercises are therefore recommended.
- SCRIM users in Australasia are using different data reporting methods. A statistical analysis demonstrated that the differences in the results from using these methods were significant. Harmonisation of the skid resistance data processing/reporting methods is therefore recommended as the first step towards inter-jurisdictional standardisation.
- New Zealand has developed the most comprehensive method for effective seasonal variation management. However, the method requires a significant investment and therefore should be implemented by jurisdictions where the value of having such system is warranted.
  - Jurisdictions where the NZ-level investment is not warranted should maintain the current practice (i.e. carrying out routine skid resistance surveys at the same time of the year or not accounting for seasonal variation) and use the data for asset management purposes. The use of network data for incident analysis should state the uncertainty involved.
- There have been a number of attempts to improve the current PSV/PAFV methods. Among the options trialled, the extended polishing cycle method was the simplest option and could be trialled without any major modification to the test device. It is therefore suggested that the feasibility of adopting the extended polishing cycle method into Australasia be further investigated.
- Other aggregate test methods may present certain advantages over the PSV/PAFV methods, but immediate implementation to Australasia is not considered possible.
- An aggregate assessment method recently developed in New Zealand was an innovative and promising method but only applicable in that country at present.
- For more effective skid resistance data management, monitoring of further developments in GIS/GPS technology should continue.

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1 INTRODUCTION

1.1 Project Background

Providing an appropriate level of skid resistance at all locations on a road network is an important component of a Safe System. Austroads has been, and continues to be, active in the area of skid resistance and has carried out a number of projects. Austroads project AT1488 *Improving Skid Resistance Measurement* was a three year project that commenced in October 2009 (to June 2012). This project followed a previous Austroads project on the subject: AT1131 *Management of Skid Resistance*. The main goal of the AT1488 project was to improve the understanding of variability associated with skid resistance testing and measurement. Understanding the nature of variability was an initial step towards a more effective management plan. Such a plan would need to balance the practical limitations and the goal of providing safe roads.

The project was under the guidance of the Skid Resistance Working Group (the membership is presented in Appendix A), which was established by the Asset Task Force (ATF). Early in the term of the project, the Group identified a number of key issues to be investigated, mainly related to the variability in skid resistance measurements. These could be broadly categorised as follows. Each topic is then comprehensively reported and discussed in the following sections.

- Variability associated with mechanical characteristics of skid resistance measurement devices:
  - There are many skid resistance devices in use worldwide. Each device has its own mechanical design/characteristics which could provide a different reading for the same road surface. Reviews of those devices and the issue of harmonisation is discussed elsewhere (Austroads 2011a, 2011b). In this report, more specific issues related to the devices currently used in Australasia, namely correlation exercises on SCRIM[1] and other devices, have been reviewed and are reported in Section 2 and Section 3 respectively.
- Variability associated with climate effects:
  - Skid resistance was found to vary depending on when the measurement was conducted, due to climate effects (e.g. rainfall). Each jurisdiction adopts a different management method to account for this variation. These are reviewed and discussed in Section 4.
- Variability associated with differences in jurisdictional policies, procedures or practices:
  - For SCRIM data reporting, each jurisdiction uses different data processing methods. The methods and their influence on the processed data are reviewed in Section 2.3.
  - As a tool for more robust skid resistance management, each jurisdiction has different practices for using the geographic information systems (GIS) and the global positioning system (GPS). These are reviewed and discussed in Section 8.
- Limitations of the current aggregate polishing resistance test methods:
  - The reliability of the current aggregate polishing resistance test methods in predicting field performance is under question amongst Australian and New Zealand practitioners. An investigation on alternative methods, or whether the current methods can be improved, has been carried out and is reported in Section 5, Section 6 and Section 7.

[1] Sideways-force Coefficient Routine Investigation Machine. This is the most widely used device by the road agencies in Australia and New Zealand.

1.2 Aim and Scope of the Report

This report provides a review of research and developments in skid resistance measurement methods. The aim is to provide a better understanding of the variability in skid resistance measurement (as discussed above), as it may apply to skid resistance management. This report supplements the following Austroads technical reports:

- *Guidelines for the Management of Road Surface Skid Resistance*, AP-G83/05 (superseded by the two guides below)
- *Guide to Asset Management Part 5F: Skid Resistance* (Austroads 2009a)
- *Guide to Asset Management Part 5G: Texture* (Austroads 2009b)
- *Guidance for the Development of Policy to Manage Skid Resistance*, AP-R374/11 (Austroads 2011a)
- *Review of Skid Resistance Measurement Methods*, AP-T177/11 (Austroads 2011b).

2 JURISDICTIONAL STANDARDISATION OF SCRIM

2.1 Background

There are many different skid resistance measurement devices used worldwide. There have been attempts to develop a harmonised friction value (aiming to be non-device specific), such as the PIARC International Friction Index (IFI). Reviews of those efforts (Vos & Groenendijk 2009, Austroads 2011a, 2011b) generally agreed that harmonising the outputs of a large number of different devices is a formidable task and may not be achievable (due to a large number of factors and the associated complex interactions). An alternative (and more practical) approach would be the standardisation of the type of devices used for network measurement.

There are different skid resistance measurement devices used in Australasia (Table 2.1) with the SCRIM being the most widely used device at present. Therefore, it has been agreed that, while retaining Australasian standardisation as a long term goal, establishing standardisation for the device of choice within a jurisdiction (as well as amongst those jurisdictions where the same type devices are used) should be addressed first. Australasian standardisation could then be achieved in the long-term by jurisdictions replacing old equipment with a more commonly used device, if deemed appropriate.

Table 2.1: Jurisdictional skid resistance measuring devices (and number of units) in Australia and New Zealand

SCRIM	Grip Tester	British Pendulum Tester (BPT)	Via Friction
New South Wales (2 units)	South Australia (3 units)	British made BPT – Available in most states	Queensland (1 unit)
Victoria (1 unit)		Italian made BPT – Queensland	
New Zealand (2 units)			
Tasmania (contracts one of the above)			
Queensland (contracts one of the above)			
ACT (contracts one of the above)			

Source: Based on Austroads (2011b).

An important requirement for jurisdictional standardisation is maintaining consistency of the mechanical characteristics of the device of choice (e.g. one SCRIM to another SCRIM), and the data processing/reporting methods. Therefore, the following tasks were carried out:

1. A review of Roads and Maritime Services (RMS) and VicRoads SCRIM correlation exercises: RMS and VicRoads are two main users of SCRIM in Australia and they have conducted a number of correlation exercises in the past. Reviewing those exercises will provide a valuable record for any future comparison of SCRIM correlation data.
2. A review of different SCRIM data management methods: it was found that, among the three main SCRIM users in Australasia (RMS, VicRoads and New Zealand Transport Agency (NZTA)), the data processing/reporting methods are slightly different. Therefore, the differences (and how significant they are) need to be understood.
3. Preparation of a proposal for a SCRIM correlation trial protocol: a SCRIM correlation trial protocol is needed to provide an agreed procedure for any future work.

Tasks 1 and 2 are presented in the following sections and Task 3 is presented in Appendix B. A review of the correlation exercises conducted for other devices (e.g. Grip Tester) is presented in Section 3.

2.2 Review of RMS/VicRoads SCRIM Correlation Exercises

RMS (formerly Roads and Traffic Authority (RTA)) and VicRoads are the two main users of SCRIM in Australia and have conducted a number of correlation exercises of their SCRIMs. The first was reported by Oliver (1992). Each user owned only one SCRIM at that time and the purpose of the study was to compare the two machines. The exercise was conducted on 11 test sites comprising a range of surfaces and surface conditions (mostly located on the South Gippsland Highway).

The RTA SCRIM was manufactured by WDM (UK) and had been in use for a number of years. The VicRoads SCRIM was a nominally identical machine, but was re-built using the key parts from an out-of-service VicRoads SCRIM which was manufactured by WDM. Prior to the trial, each machine was calibrated according to the normal calibration procedures used by each user. Both vehicles were operated in nominally identical testing conditions (i.e. target test speed of 50 km/h and water flow rate of 0.95 l/s).

The two machines travelled on the test sections, one behind the other to ensure the same wheelpath was tested, with the order of machine being changed for each run. Four runs were made at each test site and, to eliminate any variations of the test tyres, they were exchanged between the machines after each run. The skid resistance data (Sideway Friction Coefficient (SFC), in percentage scale) was collected at 5 m intervals. The findings of the trial (Oliver 1992) can be summarised as follows:

- The two machines gave different results when tested on the same surfaces. The mean differences over the test sites were 1.7 SFC for the left (outer) wheelpath and 4.7 SFC for the right (inner) wheelpath. These are about 4–10% of the mean SFC (about 45) over the 11 sites.
- In this trial, the RTA SCRIM always produced higher values than the VicRoads data. The reason was uncertain but believed to be due to the subtle differences in mechanical characteristics of the two machines. Although the machines were calibrated prior to the trial, perfectly synchronising any two machines would be impossible. Nonetheless, this emphasised the fact that equipment and operating procedure should be standardised as much as possible.
- The differences between the two machines were not constant across the sites. Therefore, it was not considered appropriate to develop a correction model to compensate for the differences.

A more recent exercise was reported by RTA (2009). This involved three SCRIMs, one from VicRoads (new updated vehicle) and the two existing RTA units. It was reported that VicRoads recently transferred their SCRIM equipment/components onto a new vehicle. The old machine appeared to be the one used in the earlier study reported above (Oliver 1992). The RTA owned two vehicles, namely the SCRIM and SRV. Both machines were equipped with upgraded data acquisition systems. It was reported that the two RTA machines had gone through rigorous validation trials at the completion of each upgrade. It was uncertain which RTA machine was used in the earlier study reported by Oliver (1992). It was also uncertain whether any of these machines were still active, or had undergone any major modifications.

The purpose of the exercise was to compare all three vehicles to identify any possible data quality and/or mechanical issues as a consequence of the recent upgrades done on the VicRoads SCRIM. Four sites of different wearing surfaces (comprising asphalt and seal surfacings) were selected for this exercise. These sites had been used by the RTA for vehicle validations for the previous two years.

All three vehicles were calibrated prior to the testing. All the sites were surveyed five times (i.e. five repeated runs made on a site). The target travel speed was 50 km/h, but one site had an additional survey at 20 km/h. The water flow rate was not reported but believed to be identical across the machines.

Repeatability of individual machines was evaluated by comparing data sets from each run (e.g. combined data of second run from all the sites) to the average of four runs (the first run was for conditioning and thus omitted from the analysis). The results are presented in Table 2.2.

Table 2.2: Repeatability of SCRIMs

Run no.	RTA SRV		RTA SCRIM		VicRoads SCRIM	
	Left SFC (R^2)	Right SFC (R^2)	Left SFC (R^2)	Right SFC (R^2)	Left SFC (R^2)	Right SFC (R^2)
1	Conditioning run (not included in the analysis)					
2	0.95	0.96	0.88	0.92	0.92	0.94
3	0.95	0.95	0.87	0.91	0.93	0.93
4	0.94	0.95	0.85	0.93	0.94	0.95
5	0.94	0.96	0.81	0.90	0.94	0.95

Source: Based on RTA (2009).

Comparison between RTA SCRIMs to VicRoads SCRIM was done by correlating the SFC data from one machine to another. The SFC of one machine was the average SFC of all four runs with all the sites combined. The results are presented in Table 2.3.

Table 2.3: Comparison of RTA SCRIMs to VicRoads SCRIM

Vehicle comparisons	Left SFC (R^2)	Right SFC (R^2)
RTA SRV vs VicRoads SCRIM	0.88	0.84
RTA SCRIM vs VicRoads SCRIM	0.81	0.85

The repeatability of all three vehicles was considered satisfactory displaying R^2 higher than 0.9 in most cases. The correlations between VicRoads SCRIM and RTA SCRIMs were considered reasonable with R^2 of 0.8 or higher.

The study (RTA 2009) evaluated the repeatability and inter-device correlation using the R^2 correlation method. Nonetheless, for this type of data, using the t-test for independent samples would be a more usual statistical approach.

2.2.1 Discussion of Correlation Exercises

The two independent studies demonstrated that, for the same type of skid resistance testing device, reasonable correlation is expected (e.g. R^2 of 0.8 or higher). The studies also indicated that the test machines need to be routinely calibrated and examined to ensure consistency in mechanical characteristics as much as possible. Conducting routine inter-device and inter-jurisdiction correlation trials, to the similar scale of the cases reviewed above, is therefore recommended. A SCRIM correlation trial protocol is presented in Appendix B.

2.3 Review of Different SCRIM Data Processing/Reporting Methods

This section presents a review of the SCRIM data processing/reporting methods currently used by the three main SCRIM users, namely the RMS, VicRoads and the NZTA. The differences between the methods were first reviewed. A SCRIM data set was then collected from a road in Victoria and was processed differently using each method. A statistical analysis was conducted on these ‘differently processed data (from the same VicRoads SCRIM data)’ to evaluate the consequence of applying different methods.

2.3.1 Review of Jurisdictional SCRIM Data Reporting Methods

The current SCRIM data processing methods used by the RMS, VicRoads and NZTA are described in Table 2.4 and the paragraphs below.

Table 2.4: Jurisdictional SCRIM data reporting methods

Jurisdiction	Data capturing intervals (m)	Number of test wheels and location	Data processing method
RMS	5	Two test pods – left and right wheel paths (minimum of both wheel path reported)	4-point rolling average, taking the mean of a point x, the two previous points (x-1, x-2) and the next point (x+1). The road is then divided into 100 m sections and the minimum value of all the data points within a given section (i.e. 40 data points covering for both wheel paths) is reported as the section value (i.e. any data points within the section are identical).
VicRoads	5	Two test pods – left and right wheel paths (reported separately)	Data reported at 5 m intervals (left and right wheel paths separately).
NZTA	5	Two test pods – left and right wheel paths (reported averaged)	The road is divided into 10 m sections and the average of the section (merging the left and right wheel paths) is reported as the section value (i.e. any data points within the section are identical).

The RMS processes SCRIM data based on the rolling average method. As data are collected at 5 m intervals, each data point is estimated based on a four-point rolling average for each wheel path. The road is then divided into 100 m sections and the minimum value of all the rolling average data points within a given section (i.e. 40 data points covering for ‘both wheel paths’) is reported as the section SFC. Therefore, all the data points within a section are assumed to have an identical SFC value. The differences between the left and right wheel paths are reported separately as supplementary information.

VicRoads collects SCRIM data at 5 m intervals (average of 20 data points taken over the 5 m interval) for the left and right wheel paths and reports each separately. Therefore, each data point is simply an observed data record and, unlike the RMS or NZTA methods, is not averaged over a certain length. It is noted that actual applications of the reported SCRIM data, such as for the use in their investigatory level guidelines, may be further processed such that direct relationship to 5 m intervals may no longer exist. For this study however, only the initial reporting format was used for simplicity.

The NZTA collects SCRIM data at 5 m intervals but reports in 10 m segments. The data points collected within a given segment are averaged (merging the left and right wheel paths) and reported as the segment SFC of the 10 m segments. Therefore, all the data points within a segment are assumed to have an identical SFC value. The differences between the left and right wheel paths are reported separately as supplementary information.

Further differences in the NZ method

It was noted that the NZTA applies a number of unique correction factors for the data reporting, namely the UK correction factor of 0.78 (also known as 'Index of SFC'), Mean Summer Sideway-force Coefficient (MSSC) and Equilibrium Sideway-force Coefficient (ESC) (see Section 4.1 and Section 4.3.1). The statistical analysis trialled in the section below mainly focussed on reviewing the differences in the averaging methods and therefore these extra factors were not considered in this analysis.

2.3.2 SCRIM Data and Analysis

The SCRIM data set used for this study was provided by VicRoads. The survey was conducted on a section of a road in Victoria for both wheel paths. The section length was approx. 4 km, so a large number of observation points (about 800) were collected. The SFCs prior to the temperature correction were used for the analysis, since how each jurisdiction currently corrects the data was not fully investigated at the time of writing. If different temperature correction methods are used, this will obviously complicate the issue even further.

The site provided an ideal data set for this study covering a wide range of SFCs (approx. 50–80) on the same road. Effectively, this was equivalent to the case of surveying a number of different roads, but in a shorter surveying length per road.

Figure 2.1 presents the SCRIM SFCs along the length of the road, measured by a single machine (VicRoads SCRIM), but processed differently using each processing/reporting method (see Table 2.4). The NZTA has another data series for which the UK correction factor of 0.78 was applied. The start point was set as 0 m and the end point was 4000 m.

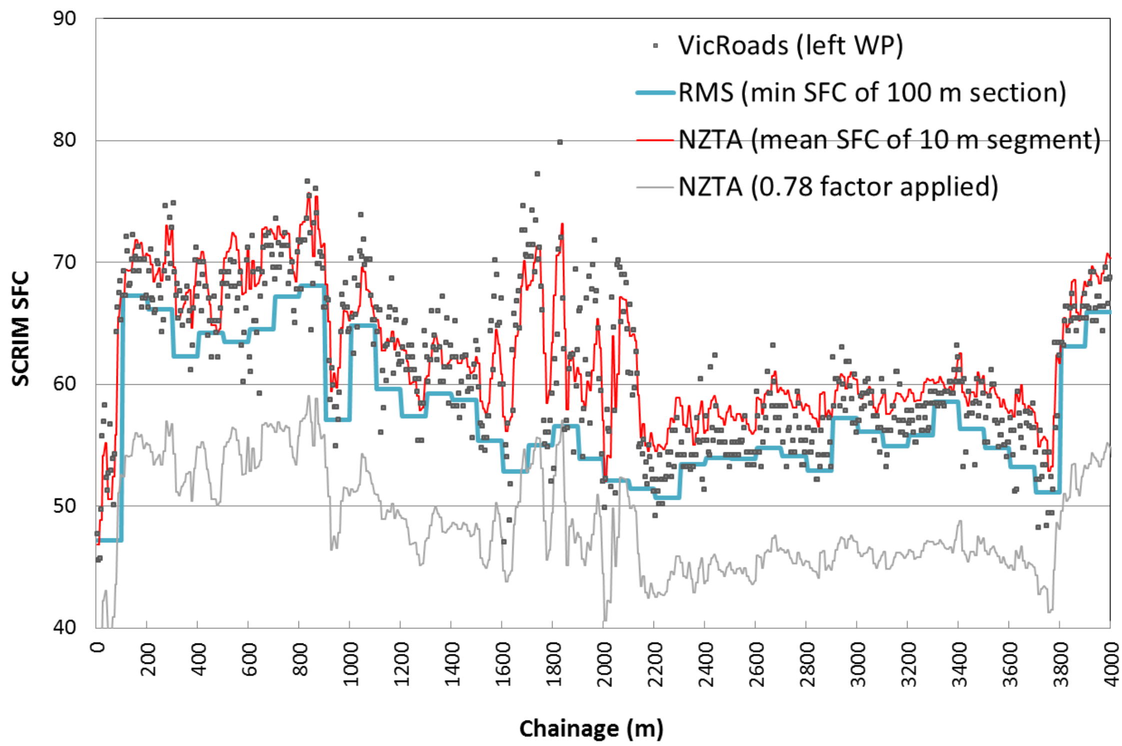


Figure 2.1: SCRIM SFC data processed using RMS, VicRoads (left wheel path) and NZTA methods

From Figure 2.1, a number of observations are noteworthy:

- The RMS data series exhibits a step-wise pattern (at 100 m intervals) whereas the VicRoads and NZTA data series are fluctuating in much finer intervals.
- There is a large difference between the minimum and maximum SFCs, particularly in the VicRoads data series. The difference becomes smaller as the averaged length becomes longer (e.g. up to 100 m in the RMS data series).
- The NZTA data series (with the 0.78 correct factor applied) understandably presented the lowest SFCs. If this was excluded, the RMS data series presented the lowest values at most observation points.
- The fluctuating patterns in broad scale are similar across the data series.

Another important observation from Figure 2.1 was that the VicRoads data series was from the left wheel path only (since the right wheel path was reported separately and the values are similar as seen in Figure 2.2), whereas the RMS and NZTA data series inherently included both wheel paths (since they were reported either averaged or combined). The VicRoads left and right wheel path data series are compared in Figure 2.2 and presented similar SFCs and fluctuation patterns. This suggested that the right wheel path data would display similar statistical variations as the left wheel path data displayed, if compared to the RMS and NZTA data series. Therefore, further variation analyses presented below only included the VicRoads left wheel path data for simplicity.

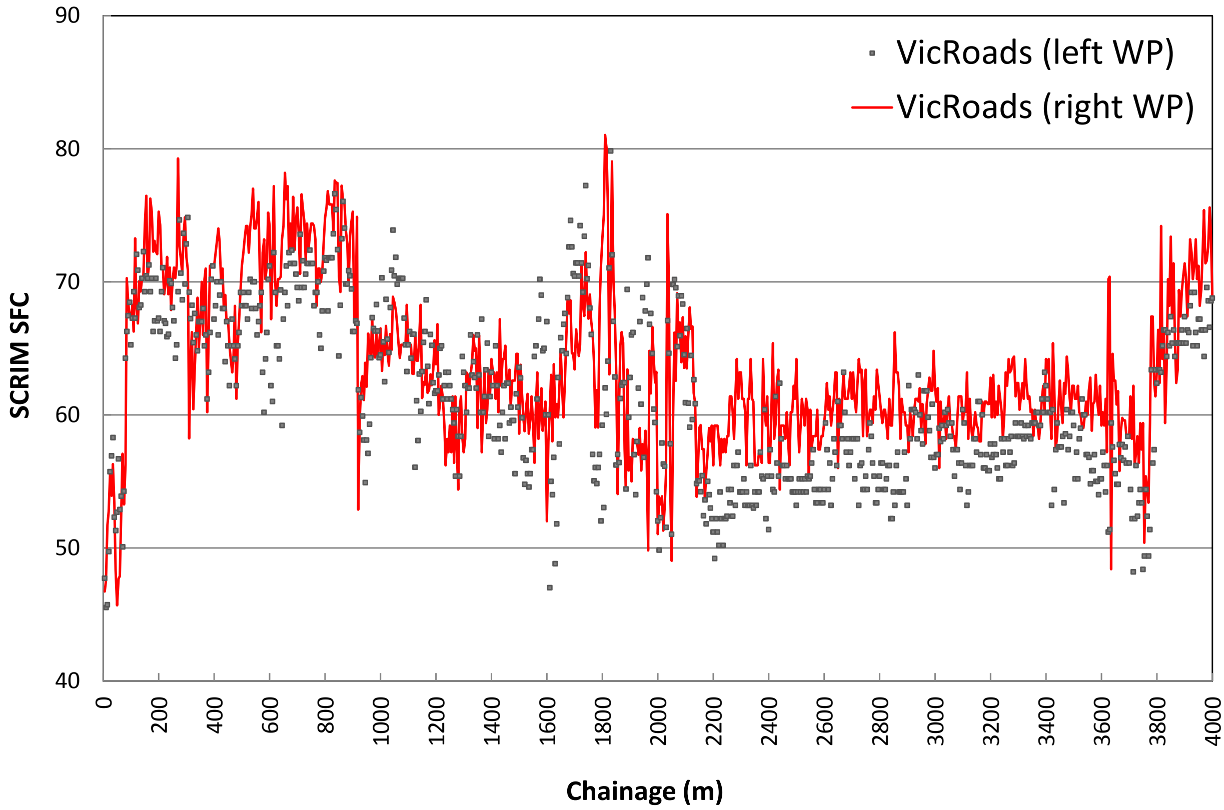


Figure 2.2: SCRIM SFC data of VicRoads left and right wheel paths

Figure 2.3 shows the unit difference in the SCRIM data when any two data series were compared. A comparison with the UK factor corrected NZTA data series was not examined since this will increase the variation for obvious reason as can be seen in Figure 2.1. The minimum and maximum differences are presented in Table 2.5.

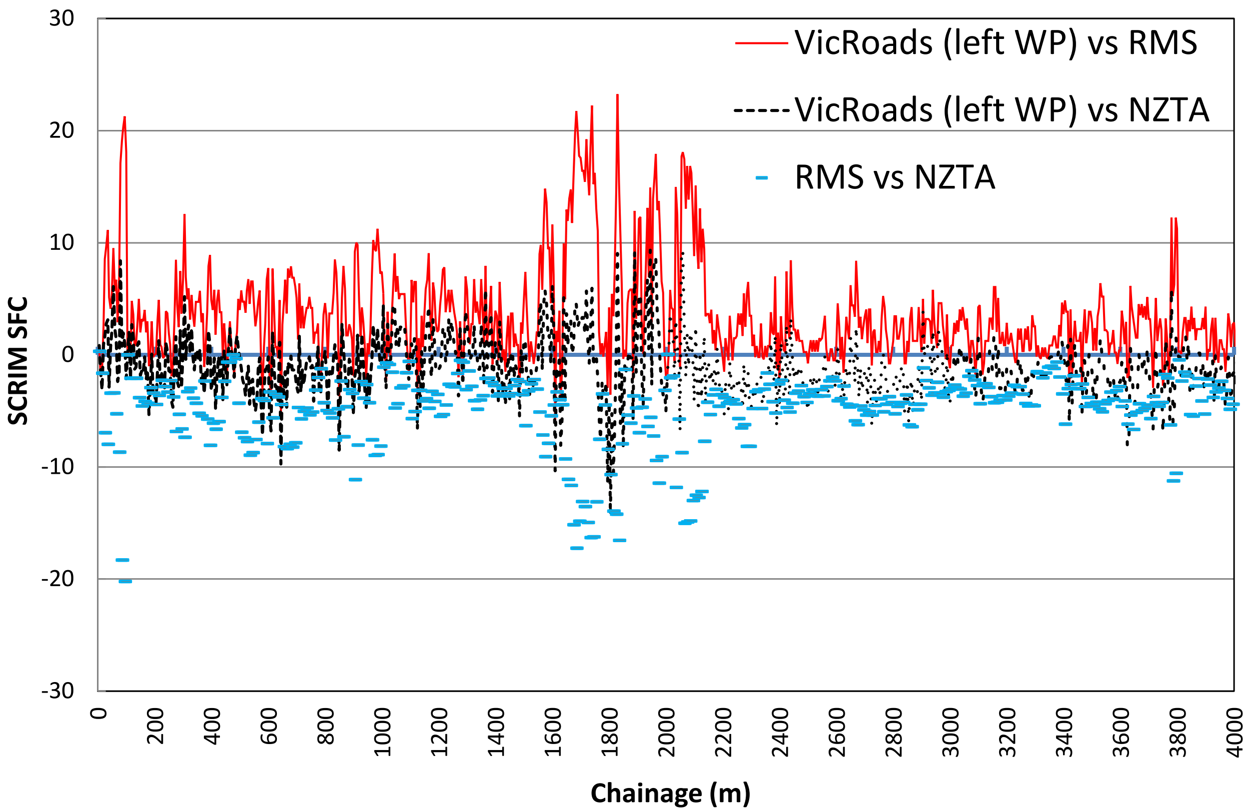


Figure 2.3: Differences in SCRIM SFC data

Table 2.5: Minimum and maximum differences in SCRIM SFC data

	Minimum difference (SFC)	Maximum difference (SFC)
VicRoads (left WP) vs RMS	5.86	23.26
VicRoads (left WP) vs NZTA	9.35	14.23
RMS vs NZTA	0.30	22.40

These initial observations in the SCRIM SFC data indicated that there were significant differences depending on which data processing/reporting method was applied. This was further examined in the following section.

2.3.3 Statistical Analysis

To examine the significance of applying different data reporting methods in the statistical sense, the t-test for interdependent samples was applied. This test is relevant when there is only one sample (i.e. data source) that is tested repeatedly and thus was believed more appropriate (than the t-test for independent samples) for this case.

The t-test results are displayed in Table 2.6. The observed and the critical t-values at the 95% confidence level were computed for the comparisons between VicRoads (left WP) and RMS, VicRoads (left WP) and NZTA, and RMS and NZTA, respectively. A comparison with the UK factor corrected NZTA data series was not examined. The main findings were as follows:

- **VicRoads (left WP) versus RMS**: The differences in the SCRIM SFCs between VicRoads and RMS methods were found to be significant as the observed t-value was greater than the critical value, falling within the critical region of the t-distribution.

- **VicRoads (left WP) versus NZTA**: As the observed t-value was greater (in magnitude) than the critical t-value, the SCRIM SFCs produced by the VicRoads and NZTA methods were significantly different at the 95% confidence interval.
- **RMS versus NZTA**: As the observed t-value was much greater (in magnitude) than the critical t-value, the SCRIM SFCs produced by the RMS and NZTA methods were significantly different at the 95% confidence interval.

Table 2.6: T-test results of SCRIM data processing/reporting methods

Variable	VicRoads (left WP) vs RMS	VicRoads (left WP) vs NZTA	RMS vs NZTA
No. of observations	800	800	800
Mean difference (SFC)	3.67	–1.14	–4.82
Standard error of the mean (SEM)	0.2	0.1	0.1
Observed t-value	23.45	–11.7	–42.6
Critical t-value (95% confidence level)	1.96	–1.96	–1.96

2.3.4 Recommendations for Harmonisation of SCRIM Data Processing Methods

The analysis has shown that applying different data processing/reporting methods to the same data produced significantly different results in the statistical sense. For every SCRIM measurement, the collected data may be stored as back-up data to the processed data used for jurisdictional reporting, and using these unprocessed data for inter-jurisdictional comparison may resolve the variability issues discussed here. It was however uncertain whether individual SCRIM devices in Australasia use exactly the same data capturing method. Further investigation on the data capturing method per individual SCRIM device, as well as whether each device has the capability of saving/reporting unprocessed data should therefore be carried out.

Even if the collected data is found to be identical across the devices, an issue still exists from a data application perspective. A good example is the use of investigatory level guidelines (an example is shown in Table 4.1). The same values assigned for the same site categories in the same guidelines could indicate different skid resistance levels depending on in which jurisdiction the data had been processed. This may result in an inconsistency in service levels across state borders.

To ensure comparability of skid resistance data and its application among the users, harmonisation of the data processing/reporting methods is recommended. This also applies to the jurisdictions where machines are sub-contracted from other jurisdictions (see Table 2.1). Harmonisation may resolve the issue of whether the sub-contracting jurisdictions should accept a particular service provider's method or specify their own jurisdictional method. Harmonisation could also assist in resolving the issue of changing the service provider to another provider who uses a different processing/reporting method.

For harmonisation, the following broad measures could be considered:

- Consistency in the data capturing process: It is uncertain whether individual SCRIM devices use exactly the same data capturing method.
- Consistency in averaging length: The averaging length of the VicRoads, RMS and NZTA methods are very different.
- Consistency in reporting left/right wheel path data: VicRoads reports both wheel paths separately whilst RMS and NZTA report either averaged or combined.
- Harmonisation of correction factors: Although this was not fully examined in this study, applying different correction factors would obviously increase the differences even further.

Further consultation among the SCRIM users is therefore needed in order to arrive at a harmonised approach to data processing and reporting.

3 GRIP TESTER AND BPT CORRELATION EXERCISES

3.1 Grip Tester Correlation Exercises (South Australia)

The DPTI (South Australia) is the only state road agency user of the Grip Tester (Table 2.1) and carried out a series of correlation exercises in 2009 and 2011. The main purpose was to observe the inter-device correlation between the Grip Testers and their BPTs, but it provided an opportunity to compare their two Grip Testers (referred to as Mark I and Mark II) as well. Information on the exercises was provided by the Working Group (Appendix A).

3.1.1 The 2009 Exercise

The exercise was carried out on various test sections presenting a wide range of skid resistance values (texture data was not available). On each test section, Grip Tester testing under varying speeds as well as BPT testing was carried out (Table 3.1). It is noted that the Grip Tester was also used at a speed of 20 km/h, but this was only done for the Mark II device. Since data from the Mark I was not available, analysis at this speed was not pursued. It was reported that both devices used a nominally identical water film thickness of 0.25 mm. The push mode testing presented in Table 3.1 is normally for spot testing (like BPT testing) whereas the tow mode testing is for network level surveys.

Table 3.1: Skid resistance data from the 2009 exercise

Test device		Grip Tester Mark I (GT158)		Grip Tester Mark II (GT397)		BPT
Test speed		Push (5 km/h)	Tow (50 km/h)	Push (5 km/h)	Tow (50 km/h)	Not applicable
Unit of skid resistance		Grip number		Grip number		BPT unit
Test sections (represented by surfacing type)	Back straight	0.79	0.73	0.78	0.73	70
	Concrete	0.77	0.66	0.78	0.69	67
	Pit lane	0.83	0.79	0.78	0.78	75
	Pit straight	0.75	0.69	0.77	0.75	70
	Plastic	0.30	0.12	0.30	0.16	24
	Vinyl	0.39	0.08	0.36	0.12	21
	Geotech	0.81		0.82		62
	Survey shed	0.55		0.54		43
	Montague Road	0.66	0.45	0.55	0.49	50

From the data in the table, correlations between the two Grip Testers are presented in Figure 3.1.

3.1.2 The 2011 Exercise

A similar exercise was carried out in 2011. The test sections used were different to those used in the 2009 exercise. Nonetheless, like the 2009 exercise, the 2011 sections comprised a wide range of skid resistance with varying texture depth. It should be noted that, unlike the 2009 exercise where the testing was done on the same day, the testing was done on separate days due to logistical issues. If the weather conditions were different, these may have affected the outcome. It was reported that both devices used a nominally identical water film thickness of 0.25 mm.

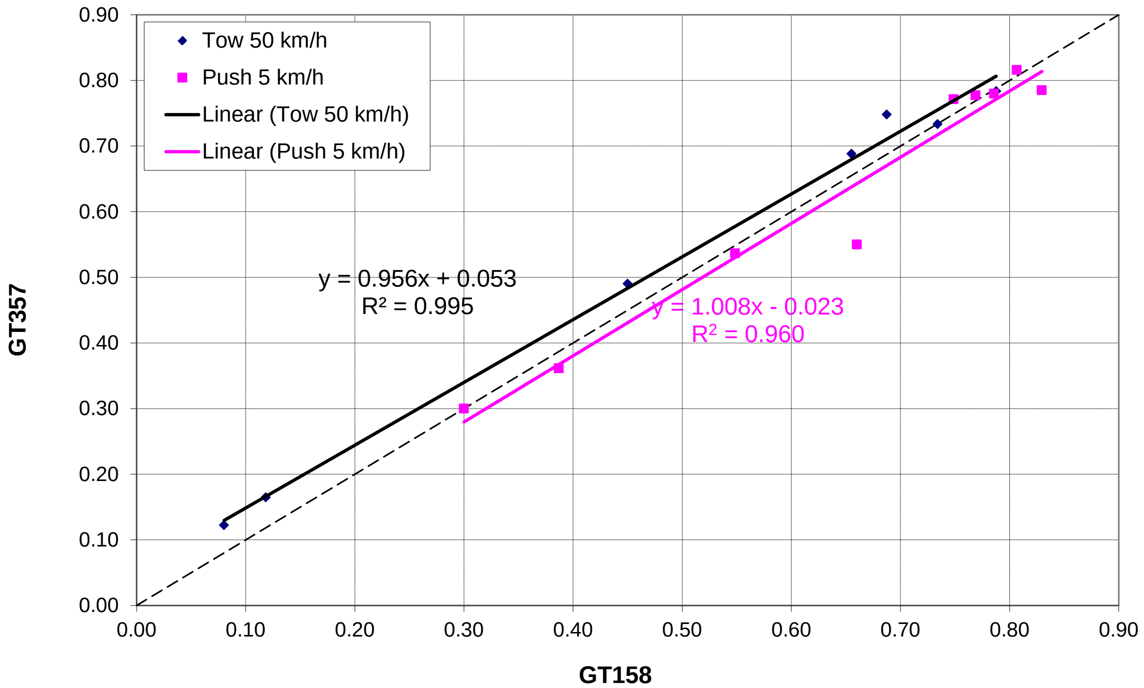


Figure 3.1: DPTI Grip Tester trial 2009

Table 3.2: Skid resistance data from the 2011 exercise

Test device		Grip Tester Mark I (GT158)		Grip Tester Mark II (GT397)		BPT
Test speed		Push (5 km/h)	Tow (50 km/h)	Push (5 km/h)	Tow (50 km/h)	Not applicable
Unit of skid resistance		Grip number		Grip number		BPT unit
Test sections (represented by texture depth)	N/A*	0.49		0.43		32
	N/A*	0.39		0.34		22
	< 0.2 mm	0.79		0.76		57
	0.91 mm	0.71	0.70	0.71	0.68	59
	0.79 mm	0.79	0.83	0.80	0.82	71
	2.77 mm	0.81	0.81	0.80	0.77	70
	0.66 mm	0.60	0.54	0.57	0.52	50
	N/A*	0.45		0.44		20
	N/A*	0.44		0.49		14
	N/A*	0.54	0.23	0.51	0.18	20
	N/A*	0.46	0.13	0.39	0.10	14

* N/A = not available.

From the data in the table, correlations between the two Grip Testers are presented in Figure 3.2.

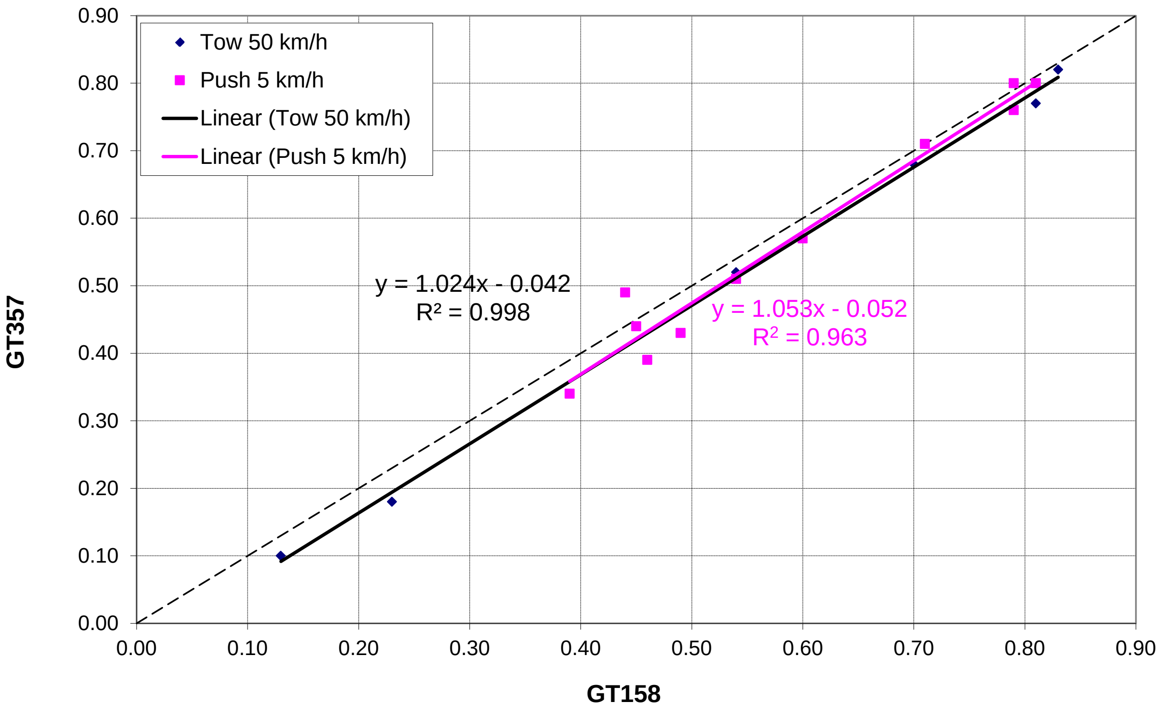


Figure 3.2: DPTI Grip Tester exercise 2011

In conclusion, the two Grip Tester devices demonstrated a satisfactory inter-device correlation (when compared at the same speed).

3.2 BPT Correlation Exercise: Italian and British Devices

An investigation was carried out by ARRB Group in 2010 to observe correlations between BPT devices of different manufacturers. Although those devices operate in essentially the same manner, some components (e.g. skid arm realising mechanism) have subtle differences in design. This work also provided an opportunity to observe the correlation between two devices of the same manufacturer. Information on the exercise is presented below.

The test was performed at ARRB Group where the sites comprised lightly trafficked asphalt, seal and concrete surfacings. Of the three BPT devices involved in the investigation, two devices were manufactured by the same Italian company, whereas the other one was manufactured by a UK company. The test was performed according to AS/NZS 4663 (2004). All the tests were conducted by a single operator. The results are presented in Table 3.3.

Table 3.3: Results of BPT correlation investigation (ARRB sites)

Site no.		Site 1	Site 2	Site 3	Site 4
Surfacing type		Asphalt	Asphalt	Seal	Concrete
Test result (BPT unit)	Tester 1 (UK)	78	73	71	54
	Tester 2 (Italian)	79	70	71	56
	Tester 3 (Italian)	75	66	62	49

The results clearly demonstrated that one device (Tester 3) produced noticeably different results to the rest. It should be noted that Tester 1 was a device routinely calibrated at ARRB and believed to produce correct results. This means that, although manufactured by the same company and having identical design, Tester 2 produced correct results while Tester 3 did not.

To rectify this, mechanical components of Tester 3 were carefully examined and compared to their counterparts in Tester 2. It was found that one of the components (i.e. a rubber pad tension spring) displayed a noticeably different characteristic to its counterpart. A simple adjustment was made to the component and skid resistance of the sites were re-tested. The results showed an obvious improvement in the correlation.

Table 3.4: Results of BPT correlation investigation (after adjustment in Tester 3)

Site no.		Site 1	Site 2	Site 3	Site 4
Surfacing type		Asphalt	Asphalt	Seal	Concrete
Test result (BPT unit)	Tester 1 (UK)	80	70	65	54
	Tester 3 (Italian)	78	71	64	53

This investigation demonstrated that satisfactory correlation between the BPT devices, including the devices of different manufacturers, is expected. However, this required certain mechanical calibration/adjustments of the key components to ensure those devices mechanically operate the same manner.

4 MANAGEMENT OF SEASONAL VARIATION

4.1 Background and Terminology

The skid resistance of a road surfacing has been shown to vary throughout the year. This variation has been generally observed to coincide with seasonal changes (e.g. highest in the winter and lowest in the summer). Numerous recent studies have been undertaken into this ‘seasonal variation’ phenomenon and these have been reviewed in Austroads reports (2011a, 2011b). In basic terms, the findings were that environmental factors (particularly rainfall) combined with the inherent aggregate characteristics (e.g. geological sources, age) are the main contributory factors. However these factors (and how one factor influences others) are quite complex, not easily isolated, and so the interplay is not well understood at present.

The term ‘seasonal variation’ has traditionally been used to describe this phenomenon, but there are other variations than simply seasonal effect. For example, there is a variation associated with a more ‘short-term’ weather effect. It is also noted that season variation changes over time due to yearly climate changes. Therefore, to describe this phenomenon correctly, more specific terms are needed as follows:

- **Seasonal variation**: Variation in skid resistance measurement due to the seasonal effect (e.g. summer/winter) within a year.
- **In-year variation**: Variation in skid resistance measurement within a year. This could be due to the seasonal effect, short-term variations (e.g. difference in measurement before/after a week of rainy weather), as well as repeatability in measurement.
- **Year-on-year variation**: Changes in seasonal/in-year variations over the years, due to the impact of unusual climate experienced over the years. For example, dry season this year started/ended much earlier than previous years; this year was unusually rainy throughout the year, etc.

Attempts to recognise these variations in practice include:

- **Mean Summer Sideway-force Coefficient (MSSC)** (as used in UK and New Zealand): Average of three consecutive measurements during a summer period in a year (i.e. when lowest skid resistance is expected). This is to account for seasonal/in-year variations.
  - For example, confining the test period to a specific time (i.e. during the summer months) is to account for the seasonal effect (because the value will be different if measured in spring), whereas conducting multiple measurements accounts for any short-term and test variations (i.e. a more reliable/representative result than a single measurement).
- **Equilibrium Sideway-force Coefficient (ESC)** (as used in New Zealand): Three year rolling average of MSSCs. This is to account for year-on-year variation.

4.2 Seasonal Variation: Australian and New Zealand Cases

A study carried out in Australia (Oliver et al. 1988) demonstrated that seasonal variation existed in most Australian regions. For New Zealand, Cenek at al. (1999) observed seasonal variation from a number of seal surfacing sites. Both studies observed the changes in skid resistance by conducting BPT measurements repeatedly (e.g. monthly measurements) in the field.

The variations observed from the two studies were:

- Victoria: About 15 British Pendulum Number (BPN)
- Tasmania: About 10 BPN
- Western Australia: About 15 BPN
- South Australia: About 10 BPN
- Queensland: Date variation was less than 10 BPN and there was no distinctive seasonal change observed
- New South Wales: About 15 BPN. Only SCRIM measurement was carried out in this state. The BPNs were converted from SCRIM SFCs using a pre-defined conversion equation
- New Zealand: About 15 BPN.

To evaluate the significance, these variations were compared to the current skid resistance investigatory level adopted in many states. The skid resistance investigatory level guidelines in most states in Australia (an example of SCRIM based guidelines is shown in Table 4.1) generally adopted a 0.05 SFC (= 5 SFC in percentage scale) increment for the site categorisation. It is considered that 1 BPN approximates to be about 0.01 SFC (= 1 SFC in percentage scale) (Oliver et al. 1988). This means that, depending on the location, the variations observed by Oliver et al. (1988) and Cenek at al. (1999) above could result in up to three level offset in the investigatory level categorisation. This indicates that seasonal variation is important and should be recognised and accounted for where applicable.

Table 4.1: Skid resistance investigatory level table for VicRoads/RTA

Site category	Site description	Investigatory level (SFC_{50})	
		Primary roads; secondary roads > 2500 vehicles per lane per day	Secondary roads < 2500 vehicles per lane per day
1	Traffic light controlled intersections Pedistrain/school crossings Railway level crossings Roundable approaches	0.55	0.50
2	Curves with radius ≤ 250 m Gradients ≥ 5% and ≥ 50 m long Freeway/highway/on/off ramps	0.50	0.45
3	Intersections	0.45	0.40
4	Manoeuvre-free areas of undivided roads	0.40	0.35
5	Manoeuvre-free areas of divided roads	0.35	0.30
		Investigatory level (SFC_{20})	
6	Curves with radius ≤ 100 m	0.60	0.55
7	Roundabouts	0.55	0.50

Source: VicRoads and RTA (1996).

4.3 Review of Jurisdictional Management Methods of Seasonal Variation

Historically, the greatest interest in seasonal variation has been in the northern hemisphere and its climates, where a stylised sinusoidal curve is often used to show how the highest/lowest values of skid resistance are obtained in the winter/summer months. This led to a common practice of testing being undertaken in the summer months. More modest variations in skid resistance were also found during the summer months, leading some jurisdictions to conduct three test runs during the course of the summer and to use an average value (e.g. SCRIM and its MSSC).

It was found that similar significant variations in year-on-year, and in-year skid resistance also applied in New Zealand. The established practice in that country is to test in the summer months and to adopt multiple test runs over seasonal sites to obtain MSSC. This is then further corrected for year-on-year variations to obtain Equilibrium Sideways-force Coefficient (ESC) as described in Section 4.3.1.

The practice of testing during the summer months has also been adopted by many Australian road agencies. This section provides a review of how Austroads jurisdictions currently account for the seasonal variation (and their positions towards future development), allowing a best approach to be discussed and recommended (in Section 4.4). The information in the following sub-sections was mostly provided by the Working Group member representing each jurisdiction (Appendix A).

4.3.1 New Zealand Transport Agency

NZTA considers that year-on-year and in-year seasonal variations in skid resistance are significant enough to be specifically covered by a documented policy and practice. NZTA operates an annual SCRIM survey across its network. This survey covers most lanes, with the SCRIM Coefficient (SC) measured in both wheel paths. Macrotexture is also measured.

The data is normalised for in-year and year-on-year variation. The normalisation process is the result of the identification of a series of seasonal zones and specifically, data collected from around 121 seasonal sites spread throughout these zones. The seasonal sites are typically 5 km in length but require a minimum 1 km of usable data to qualify for use as a variation site. In attempting to remove external factors other than seasonal variation, a ‘general condition’ is considered (i.e. lengths with flushing or maintenance treatment are excluded as are lengths of new surfacing for a period of two years).

In-year variation is catered for by testing the same seasonal site three times throughout each summer, one at the start, one in the middle and at the end and reporting the mean (MSSC). Additionally the seasonal site is further tested as part of the routine network survey. The reading obtained during the survey is then compared to the mean value to obtain an MSSC ‘correction factor’ to be applied to the test values within that seasonal zone. The correction factor is also calculated for each month, so that any survey work carried out in a particular seasonal zone can be corrected to the conditions closest to the survey date. At present, only the summer monthly correction factors have been established (i.e. for the survey season of November to March). This however is because that the SCRIM is available in New Zealand only for the survey season. Once the machine becomes available for all year round use, monthly correction factors for every month of the year can easily be established using the seasonal zones and references sites already established in the country.

The year-on-year variation is then calculated using the following process:

1 The average MSSC value for each seasonal zone for the survey year is calculated and combined with the previous three years average MSSC to get the rolling average value (i.e. ESC) for the seasonal zone. This is then compared to the survey year average MSSC value to obtain an ESC correction factor for each zone.

2 The reported ESC is then calculated by applying the zone MSSC factor nearest to the survey date and the zone ESC factor to each 10 m length of the machine measured SC data.

4.3.2 DPTI South Australia

DPTI considers that seasonal variation does exist in the region. The organisation currently accounts for the variation by carrying out the annual skid resistance network survey at a similar time each year (winter to spring).

From its local research into this issue, variations of 25–50% (which were believed to be associated with the seasonal effects) were sometimes observed and are in keeping with similar outcomes from other international work. However, the variations appeared to follow changes in local micro-climates (even to the scale of different sections on a same road), rather than a universal, regional-wide pattern. Therefore, formulating jurisdictional adjustment factors that are reliable enough in practice to improve the outcome is not considered possible. When it is necessary to test outside of the nominated time period (e.g. in response to an incident), the test results obtained are accepted as they are (i.e. no adjustment is made). The prediction of test results at other times of the year has also been found to have poor accuracy and therefore, such actions are not supported.

DPTI currently has an active review on its strategies of dealing with network level skid resistance. Once this is completed then the associated practical processes will be reassessed.

4.3.3 DIER Tasmania

DIER considers that seasonal variation does exist in the region. DIER currently accounts for seasonal variation by carrying out the annual skid resistance network survey in the driest months (i.e. March to April). However, it is recognised that the east and west coasts of Tasmania have quite different rainfalls which could affect the measurement.

Quality checks are undertaken during the biennial SCRIM surveys which include repeatability checks done on the DIER long term reference site (at the start and the end of each survey). The network survey takes approximately five weeks to complete.

4.3.4 VicRoads Victoria

VicRoads considers that seasonal variation does exist in its region. However, the VicRoads SCRIM software does not currently assess and report seasonal variations. Notwithstanding, when particular sites are being monitored in a periodic proactive testing program, it is usually carried out at the same time each year, to minimise any seasonal variation effects.

When assessing a site that clearly has seasonal variation (by reviewing data over different calendar periods), the assessor may highlight the seasonal effects by adjusting the test outputs by 5–10 SFC (in percentage scale), when reporting outcomes. This however appeared to be an agreed practice, rather than specified in formal guidelines.

4.3.5 TMR Queensland

An earlier study (Oliver at el. 1988) demonstrated that seasonal variation in Queensland was largely insignificant. However, a subsequent study on the skid resistance data collected from the TMR calibration/validation site at Nudgee Beach Road (for the period of 1998 to 2002) has since identified certain 'seasonal variation' existed as shown in Figure 4.1.

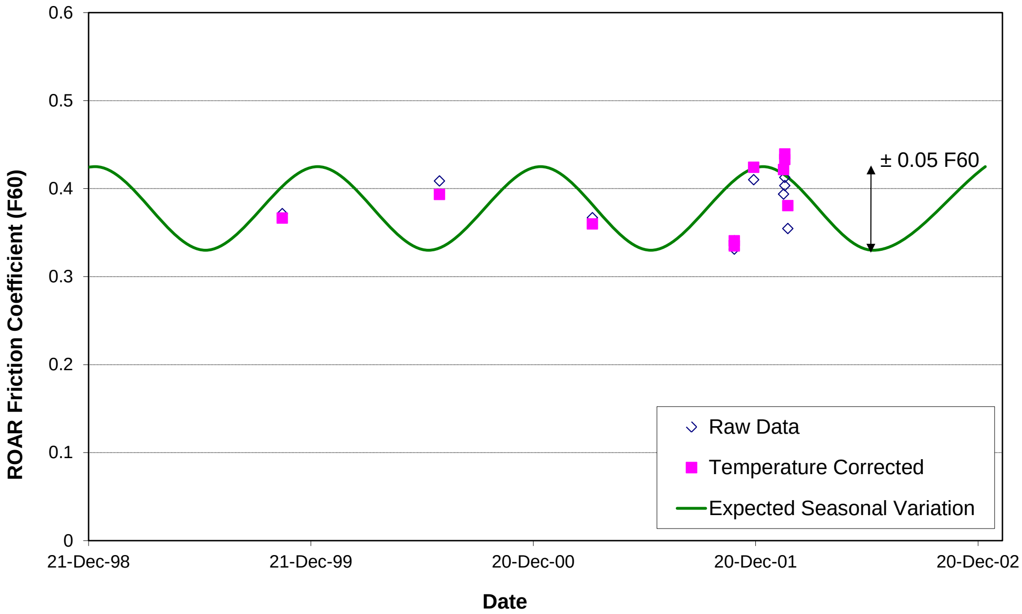


Figure 4.1: Seasonal variation observed from the TMR reference site

In Figure 4.1, the skid resistance was measured using a ROAR device (in the standard locked wheel mode) and the temperature-corrected friction coefficient (on the y-axis) was presented in F60 (i.e. ROAR friction coefficient at 60 km/h slip speed). The green curve represents the 'expected seasonal variation in Queensland', such as higher skid resistance in late summer (following the wet season) and low resistance during the winter months (generally dry). The expected trend in the graph is different to what would be normally expected from other parts of the world due to climatic differences. It was found that, although there were certain variations, the trend did not follow the ideal sinusoidal curve. The variation is instead believed to follow significant rainfall events which in Queensland are not regular (particularly in South Eastern areas) and, therefore, not easily represented by a simple sinusoidal trend.

Based on this study, although TMR considers that 'seasonal variation' exists, correcting for the variation is not possible due to irregularity in the weather/rainfall patterns in the region. Nonetheless, given regular monthly monitoring of selected test sites, TMR may be able to develop its own relationship between skid resistance variations and rainfall events.

The current survey practices of TMR can be summarised as follows:

- The main criteria for determining the frequency of network skid resistance surveys are rainfall, network priority, traffic volume, accident rate and traffic speed.
- An annual survey is carried out for all state-controlled roads with Annual Average Daily Traffic (AADT) higher than 10 000 vehicles per day.
- An annual survey is conducted on high speed off-ramps, with high speed on-ramps collected at intervals not exceeding two years.

- A survey is carried out at intervals not exceeding two years for sections with an average annual rainfall exceeding 800 mm per year.
- Critical sites are included within the annual survey as required. Critical sites include high risk sites as determined by high crash rates.
- A survey is carried out at intervals not exceeding four years for any sealed part of the Priority Road Network.

4.3.6 RMS New South Wales

RMS considers that the seasonal variation does exist in the region. It was reported that the organisation also endeavours to test a location at the same time each year, to account for this variation, wherever practicable.

4.3.7 Main Roads Western Australia

MRWA does not have extensive experience in collecting network level skid resistance data. WA expects there to be a seasonal variation and would attempt to counter this by programming collection at a consistent time of year, directly after the wet season in each climatic region.

4.4 Discussion and Recommendations for Best Practice

The current jurisdictional practices for managing seasonal variation are summarised in Table 4.2.

Table 4.2: Summary of jurisdictional practices for managing seasonal variation

Jurisdiction	Seasonal variation		Survey practice		How seasonal variation is accounted for?	
	Does it exist?	Led to formal local policy?	Survey period	Network coverage	For network survey	For project/specific survey (e.g. accident sites)
New Zealand	Yes	Yes	November to March	Whole network	NZ has many reference sites (121 sites) across the country and established monthly adjustment factors applicable for each seasonal zone. When the skid resistance is measured in the annual routine survey, the values are compared (and corrected) to the MSSC (and ESC) of the corresponding seasonal zones.	Skid resistance measurement done during the survey season in any region can be corrected for seasonal variation. This approach allows skid resistance data to be applied for more comprehensive incident analysis any time of the year, once the remaining monthly factors are established (currently established for November to March only).
South Australia	Yes	Yes	Winter to Spring (five months)	Part of the network (High risk sites and designated sites by regions)	Carry out the annual skid resistance survey in a specific time of the year.	Skid resistance measured outside of this period is not adjusted (use as it is).
Tasmania	Yes	Yes	March to April	Whole network	Carry out the annual skid resistance survey in a specific time of the year.	No adjustment is made to account for seasonal variation. Tasmania has long-term reference sites used for repeatability checks, but not used for seasonal variation adjustment.
Victoria	Yes	No	September to November	Part of the network (high risk sites only)	If particular sites are monitored in periodic proactive program testing, the survey is carried out at the same time each year.	For the sites where seasonal variation is obvious, the assessor may adjust the output by 5–10 points.

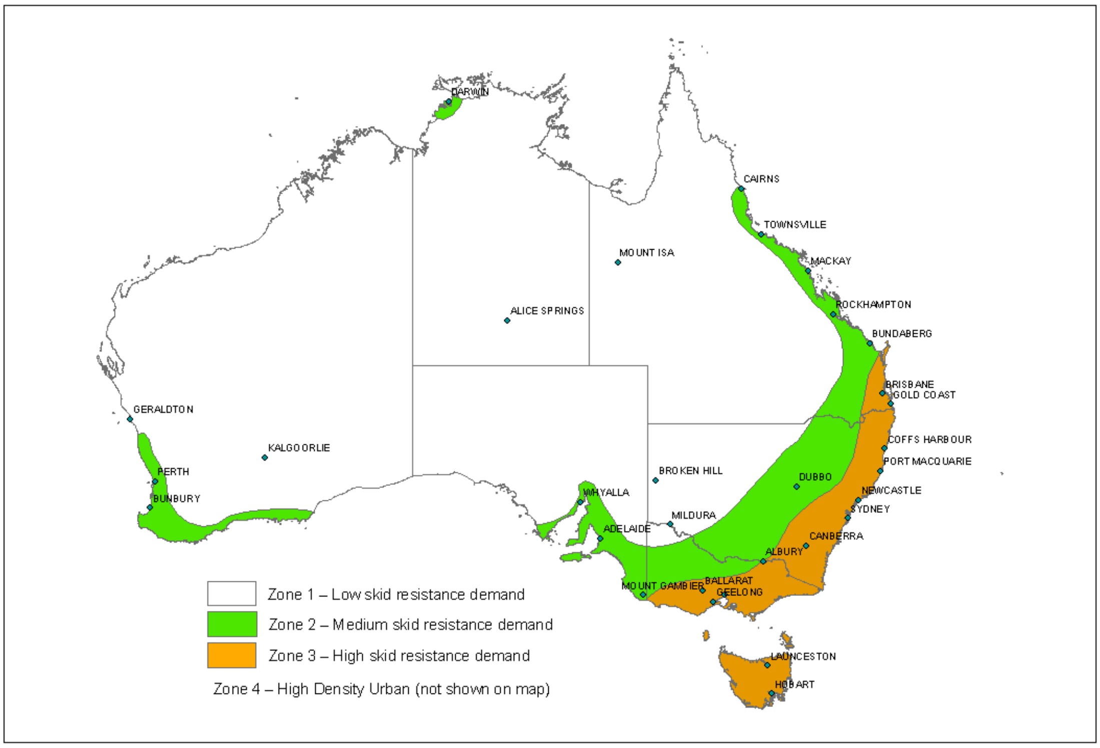
Jurisdiction	Seasonal variation		Survey practice		How seasonal variation is accounted for?	
	Does it exist?	Led to formal local policy?	Survey period	Network coverage	For network survey	For project/specific survey (e.g. accident sites)
Queensland	Yes	No	No specific survey period	Part of the network (see Section 4.3.5)	No adjustment is made to account for seasonal variation.	No adjustment is made to account for seasonal variation. Correction for seasonal variation is not considered possible due to irregularity in weather (particularly rainfall) in the region.
New South Wales	Yes	Yes	November to March	Part of the network (selected portion of the network)	Carry out the annual skid resistance survey in a specific time of the year.	No adjustment is made to account for seasonal variation.
Western Australia	Yes	No	No specific survey period assigned	Not known	Texture depth is the current network level skid resistance indicator in WA. Seasonal variation is irrelevant to texture depth.	

From the Table 4.2, most Australian state road agencies carry out the annual survey in a specific time of the year (usually during the period when the lowest skid resistance is expected). For the case where skid resistance data is measured outside of the routine survey period (e.g. for incident analysis), most jurisdictions do not adjust for seasonal variation. This approach may be sufficient for asset management purposes (i.e. to broadly compare section lengths, monitor gradual skid resistance degradation and to develop/prioritise a remedial program). On the other hand, New Zealand has established the most far-reaching system. By establishing seasonal zones across the jurisdiction, skid resistance measurement done during the survey season (November to March) in any region can be corrected for seasonal variation (using monthly correction factors established). This approach allows skid resistance data to be applied for more comprehensive incident analysis as well, particularly if the remaining monthly factors are established.

The New Zealand method however inevitably requires a significant investment, such as establishing reference sites, and frequent skid resistance measurement (minimum three times a year). It is believed that this level of investment is warranted only if the jurisdiction gains value from having such system (i.e. be able to correct for seasonal variation, even for incident analysis). Such jurisdictions would need to meet all the following conditions:

- Seasonal variation in the jurisdiction is considered large enough to be significant.
- Seasonal variation in the jurisdiction is considered to follow a predictable trend.
- Skid resistance data has a key role in incident analysis in the jurisdiction.

It is therefore recommended that, the jurisdictions where the New Zealand level investment is not warranted should maintain the current practice (i.e. carrying out routine skid resistance survey at a designated period of the year or not accounting for seasonal variation) for asset management purposes. The use of network data for incident analysis should state the uncertainty involved. Where necessary, the incident site should be tested again. On the other hand, for the jurisdictions who intend to adopt the New Zealand method due to the reasons listed above, a risk based approach would be recommended. The risk based zones as established in Austroads (2011a) (shown in Figure 4.2) could be used for this purpose.



Source: Austroads (2011a).

Figure 4.2: Indicative zones of skid resistance demand

In the Figure, the New Zealand method could be considered for the high skid resistance demand areas, as in Zone 3 (or higher). This can then be further extended to Zone 2 (or lower) as appropriate.

5 IMPROVEMENTS IN PAFV/PSV METHODS

5.1 Background

Road surfacing aggregates have to have a number of desired inherent properties. One of these is that the aggregate must be sufficiently resistant to polishing to provide (and maintain) the desired level of microtexture during service. The polishing resistance of aggregate has traditionally been defined by the level of 'retained skid resistance', after the aggregate had been polished to a certain degree. This is based on the fact that the aggregate needs to be in a near-equilibrium status to better emulate field conditions. For this reason, laboratory polishing resistance measurement methods (to predict the level of skid resistance in service) normally require conditioning of the aggregate samples by undergoing a polishing stage, prior to skid resistance measurement. This provides a common background to all the known polishing resistance test methods, including the UK Polished Stone Value (PSV) and Australian Polished Aggregate Friction Value (PAFV) tests.

Comprehensive reviews on these methods are found in Austroads (2011a, 2011b) and Neaylon (2009). Those reviews generally found that neither aggregate parameter (PSV or PAFV) demonstrated satisfactory correlation to field skid resistance. In addition to the literature review, the reliability of PSV/PAFV testing in predicting field skid resistance is under question amongst Australian and New Zealand practitioners. This is likely due to the uncertainties associated with:

- the polishing process: whether the polishing mechanism experienced in the field can be satisfactorily simulated by the laboratory polishing process
- the skid resistance measurement method: whether the skid resistance measured in the laboratory can properly represent that in the field. For example, the BPT (used in the PSV/PAFV tests) is predominantly affected by the microtexture of the aggregates, whereas field skid resistance tends to be affected by the macrotexture, as well as the microtexture.

Those reviews also found that there are alternative test methods in use or under development worldwide. It would therefore be prudent to review what advantages they would provide over the current Australian PSV/PAFV methods. This was carried out and is presented in Section 6. The review in Section 6 found that, while recognising certain benefits of those methods, viable test alternatives are not immediately available without the need for further investigation in Australia (particularly for seal surfacings).

A unique method of assessing aggregate skid resistance has recently been developed in New Zealand. Instead of relying on questionable assessment made by the PSV test (current standard test method in New Zealand) or any other laboratory devices, this method uses a statistical aggregate ranking tool which was developed from correlations between aggregate sources and 'in-service' skid resistance at locations where those aggregates had been placed. This is considered to be an innovative and noteworthy approach and is thus reviewed separately in Section 7. The aggregate ranking tool was however found to be only applicable to known aggregate sources in New Zealand (i.e. it is not applicable to other jurisdictions in Australia without developing their own aggregate ranking tools).

In conclusion of the reviews of possible alternative test methods (in Section 6 and Section 7), Australia will need to rely on the current PAFV (or PSV in Victoria) test method at least into a foreseeable future. Therefore, while search for new improved methods should continue, another worthwhile activity would be to investigate whether the current methods can be improved any further. A study on feasibility of modifying the current PSV/PAFV methods was consequently carried out and is presented in the following sections.

5.2 Review of PSV/PAFV Modification Trials

A number of studies have examined various modification options to the PSV test method. These are summarised in Table 5.1. A draft test method currently under development in New Zealand was added in the same table for comparison. No documents reporting modifications of the PAFV method were found at the time of writing.

Table 5.1: Summary of PSV modification trials

Reference	Key modification	Finding
Woodside (1981)	Non-standard test conditions to examine the effect of load, contact area, contact length and contact stress with tyre pressure.	Contact stress and contact area were directly related to the rate of polishing.
Woodward (1995)	Extended polishing to 12 hours. The polishing duration for each step of the test was increased to six hours (from the standard three hours per step).	Further 10% reduction in PSV was observed, compared with the standard polishing procedure.
Perry (1996)	Polishing with a 20° skewed test wheel for the standard polishing duration.	Further 24% reduction in PSV was observed, compared with the standard polishing procedure.
Jellie (2003)	Comprehensive investigation of varying polishing conditions, such as: ▪ wet and dry testing without abrasive, or coarse/fine abrasive only ▪ skewed test wheel (with varying angles of 3°, 6° and 10°) ▪ extended polishing duration of 50 hours, including additional roughening cycles (to renew micro-texture), or freezing cycles to simulate winter roughening condition.	The skewed wheel test (particularly at 6° angle) was reported to be most promising, as a quick and simple method.
Woodward et al. (2004)	Polishing with a 6° skewed test wheel.	Following standard polishing procedure, additional three hours of polishing with a 6° skewed test wheel was given. This resulted in further 27% reduction from the standard PSV.
Woodward et al. (2005)	Review of skid resistance research projects, namely SKIDPROJECT and SKIDGRIP. The projects investigated the effect of varying polishing conditions, such as: ▪ wet and dry testing without abrasive, or coarse/fine abrasive only ▪ skewed test wheel (with varying angle of 3°, 6°, 10° and 20°) ▪ extended polishing duration of 33 hours ▪ use of roughening cycles to renew skid resistance ▪ use of freeze/thaw cycles to renew skid resistance.	Aggregate skid resistance was influenced by complex interaction between factors such as strength, soundness or differences in source rock-type.
VicRoads (2009)	Extended polishing cycles. Once the standard polishing procedure was complete, extra polishing cycles (with a single test wheel, rather than two test wheels as required in the standard test method) were applied repeatedly up to six cycles.	Up to 10% further reduction from the standard PSV was observed.
NZ Transport Agency (PSV12 – draft test method)*	Draft test method of extended polishing cycles (under development). Once the standard PSV polishing procedure is complete, additional nine hours polishing is applied. The PSV measured after this additional procedure is recoded as 'PSV12'.	Preliminary results from PSV12 testing in NZ indicated that the reduction in BPNs between PSV and PSV12 was less for aggregates that provided better skid resistance in the field (i.e. poor performing aggregates displayed much reduced BPNs when tested using the PSV12 method).

* Reference was not available at the time of writing. The information was provided by the Working Group member representing New Zealand (Appendix A).

Source: Based on Woodward et al. (2004, 2005) and VicRoads (2009).

From the Table 5.1 the common goal of the modifications was to achieve a harsher polishing action than that given by the standard procedure. This is based on an assumption that the current polishing procedure in the PSV method (established over 50 years ago) would not be harsh enough to emulate the in-service polishing action of today's traffic.

To make the polishing action harsher, the use of a skewed test wheel was found to be the most effective way. For example from the studies of Woodward (1995) and Woodward et al. (2004), applying a skewed wheel angle of 6° for the standard polishing duration (i.e. six hours) could achieve nearly three times more polishing than the extended polishing time of 12 hours. However, it should be noted that this modification could not easily be trialled without compromising mechanical design/characteristics of the PSV device.

An Australian study was reported by VicRoads (2009) where adding extra polishing cycles to the standard PSV method was examined. Victoria is the only jurisdiction in Australia which uses the PSV method identical to the UK procedure (BS EN 1097.8: 2009) as a standard method. Four aggregates were selected (Table 5.2) and an extended cycle polishing test was carried out. For this particular experiment, it was noted that a simplified procedure of using only a single test wheel was adopted (two test wheels are required if the VicRoads standard PSV test method is to be followed). Therefore the PSVs used in this particular experiment were not the standard PSVs. The standard PSVs and the modified PSVs of the aggregates are compared in Table 5.2 for information.

Table 5.2: Aggregates used in VicRoads study (2009) and their PSVs

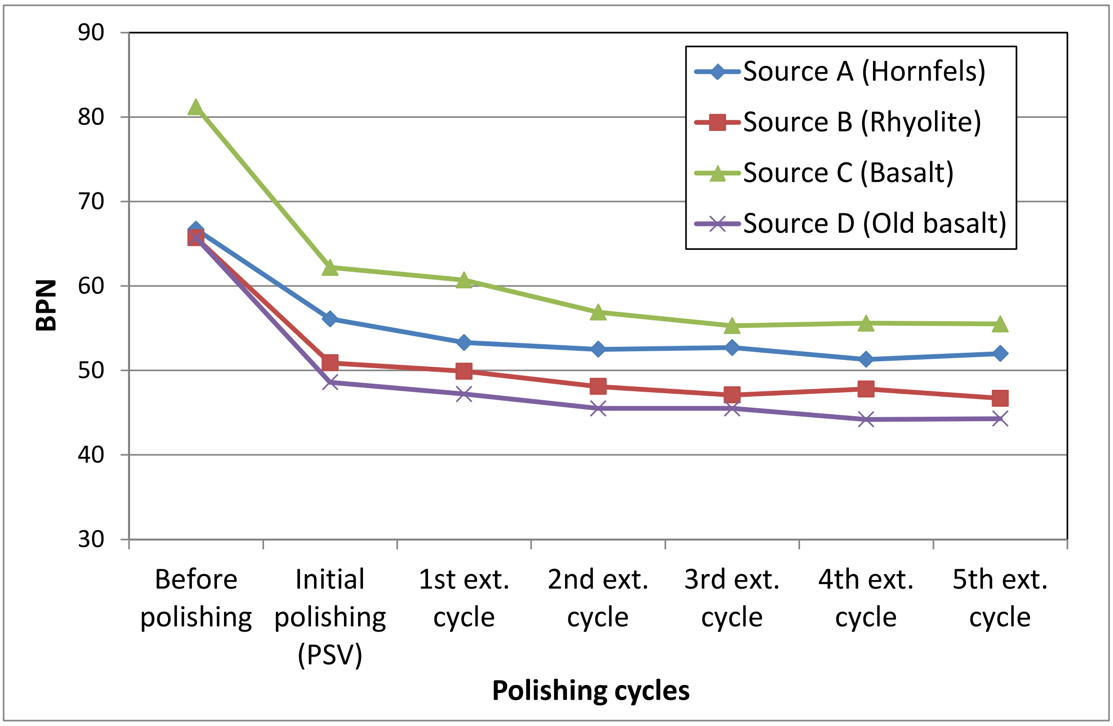
Source	Aggregate type	Assigned PSV (BPN)(1)	Modified PSV (BPN)(2)
A	Hornfels	59	56.1
B	Rhyolite	54	50.9
C	Basalt	60	62.2
D	Older basalt	53	48.6

1 PSVs assessed by the VicRoads standard PSV test method (rounded to a whole number).
2 PSVs assessed by the simplified PSV test method used for this particular experiment.

Source: VicRoads (2009).

Residual skid resistance was measured by a BPT device once each polishing cycle was complete and the British Pendulum Number (BPN) results are presented in Figure 5.1. From this, the initial polishing procedure provided the most polishing action (i.e. reduction of BPNs were largest). All the aggregates nonetheless displayed approximately 10% further reductions in BPNs (from the values after initial polishing) at the last polishing cycle. The amount of further reduction was comparable to that observed by Woodward (1995), who used an extended polishing duration of 12 hours (see Table 5.1).

An important fact to note from this study was that the aggregates did not display any cross-over in their performance ranking (i.e. the extended polishing provided the same ranking as the standard PSV method). It was uncertain whether a harsher polishing procedure, such as the skewed wheel trial of Woodward et al. (2004), would result in different ranking.



Source: Based on VicRoads (2009).

Figure 5.1: Test results of extended polishing cycle PSV testing

5.3 PAFV Testing with Extended Polishing Cycles

Within the jurisdictions in Australia, only VicRoads imports and uses the British reference materials and performs the testing according to the UK procedure (BS EN 1097.8: 2009). All the other jurisdictions use the PAFV method, either the vertical wheel method (AS 1141.40: 1999) or the horizontal bed method (AS 1141.41: 1999). Since no documents reporting modifications of the PAFV method had been found, a laboratory experiment was conducted using the vertical wheel PAFV as this is a more widely used method.

The experiment essentially followed that of VicRoads (2009) with an aim to compare the two studies. Three aggregate samples (Table 5.3) were tested using the PAFV method as described in AS 1141.40 (1999). Once the standard polishing procedure (i.e. a total of five hours of polishing, comprising coarse/fine abrasives) was complete, the residual skid resistance was measured using a BPT device. The samples then underwent further polishing cycles (up to five cycles). The extended polishing procedure was simply repetition of the standard polishing procedure.

Table 5.3: Description of aggregate samples

Aggregate	Description
Victorian hornfels	A surfacing stone typically found in Victoria. Identical aggregate to Source A of VicRoads (2009).
UK reference stone	This is the reference stone used in the UK. This has been used for the reference stone for the PSV testing (standard method in the UK, Victoria and New Zealand) and will soon be used as the reference stone for the Australian PAFV testing as well.
Panmure stone	This is the current reference stone for the Australian PAFV testing. Due to a shortage of the supply, this will soon be replaced by the UK reference stone above.

Residual skid resistance was measured using the same BPT device once each polishing cycle was complete and the results are presented in Table 5.4. The PAFV results are also plotted in Figure 5.2 which included the BPN data of Source A aggregate (imported from Figure 5.1) for comparison. Source A aggregate was reportedly from the same source as the Victorian hornfels aggregate but displayed different values as seen in the graph.

Table 5.4: Test results of extended polishing cycles PAFV method

No. of polishing cycles	Aggregate source and PAFV (BPN)		
	Victorian hornfels	Panmure stone	UK reference stone
Pre-polishing	63.5	70	66.8
Standard polishing cycle (AS 1140.40: 1999)	52.4	50.4	47.7
1st extra polishing cycle	48.1	47.5	43.7
2nd extra polishing cycle	46.4	44.2	42.7
3rd extra polishing cycle	45.1	42.8	40.7
4th extra polishing cycle	46.1*	43.1*	40.6
5th extra polishing cycle	43.8*	40.5*	39.3
% reduction from the standard PAFV (after the 5th extra polishing)	16%	20%	18%

* Some of the sample shoes were broken during the polishing process. The broken samples were excluded from the subsequent BPT testing.

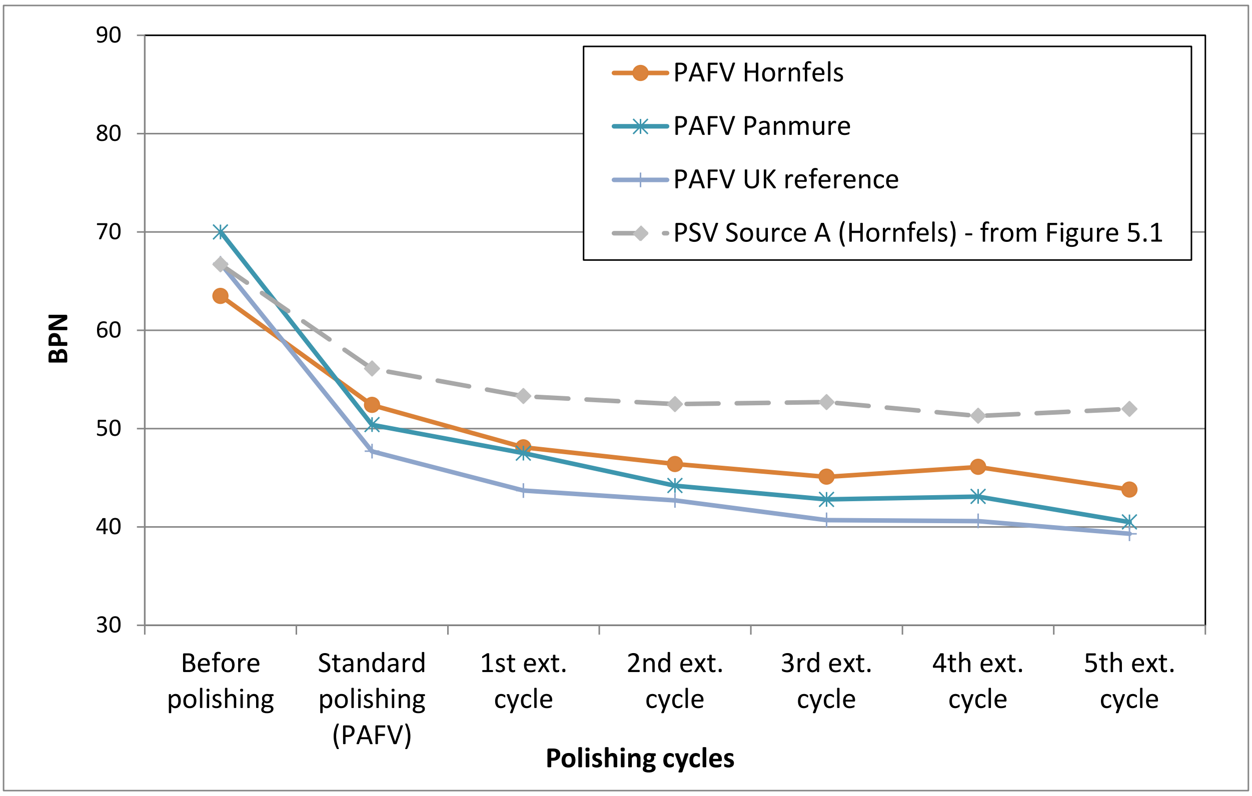


Figure 5.2: Test results of extended polishing cycle PAFV testing

It can be seen in Figure 5.2 that the greatest change in BPN occurred during the first polishing cycle (i.e. during the standard polishing procedure). Further polishing resulted in decreased BPNs and, after the last polishing cycle was applied, up to 20% reduction from the standard PAFVs was observed. The amount of further reduction in PAFV was larger than that observed in the VicRoads (2009) study above and that of Woodward (1995), and indicated that the polishing action in the PAFV method was relatively harsher than that of the PSV method.

As for the case observed in VicRoads (2009), the aggregates did not display any cross-over in their performance ranking (i.e. the extended polishing provided the same ranking as the standard method). The range of aggregates examined in the study was nonetheless very limited and therefore further investigation using a wider range of aggregates would be needed. The investigation should include aggregates that have been identified as satisfactory in the laboratory PAFV testing, but found to have less than expected skid resistance performance in the field. Testing of these aggregates would identify whether the extended polishing cycle procedure used in this study is sufficient, or an even harsher polishing action is required. If a harsher polishing action is desired, the skewed wheel trial of Woodward et al. (2004) should be considered, as extending the polishing cycle any further would be impractical due to the increased operation time/labour, as well as due to the issue of sample shoe breaking as experienced in the current study.

6 ALTERNATIVE POLISHING TEST METHODS

Due to certain limitations experienced with the traditional PSV/PAFV testing (discussed in the previous section), alternative polishing resistance test devices used overseas are gaining attention from part of the Australian highway engineering community. This section provides a review of those devices.

6.1 Wehner–Schulze Machine

A brief description of the device/method is as follows:

- **Test device**: the Wehner–Schulze (W–S) machine is a testing device to assess the polishing resistance of aggregate (Figure 6.1). The tester comprises two units: polishing and friction measuring workstations. The device was developed in Germany during the 1960s and now has wide acceptance in Germany.
- **Test procedure**: the samples are of the actual surfacing (Figure 6.2), not individual aggregate pieces, and these can be either laboratory produced or field cored. The sample is first placed in the polishing workstation where rotating rollers polish the sample in a defined procedure. The sample is then transferred to the friction measuring workstation where the skid resistance is measured using a rotating disk equipped with rubber pads.

Source: Courtesy of Transport Research Laboratory.

Figure 6.1: Wehner–Schulze machine

Figure 6.2: Various Wehner–Schulze test samples

Austroads (2011a) provides a comprehensive review of the W–S machine. The review is summarised in Table 6.1. Following the table, up-to-date information on more recent references is added.

Table 6.1: Summary of the review of the Wehner–Schulze machine

Reference	Country	Reference summary	Advantages noted in the reference
Ledee et al. (2005)	France	The Wehner–Schulze machine was examined from the French point of view.	This system enables greater accuracy than the traditional PSV test, and in addition wearing course samples cored from pavements can also be tested.
Do et al. (2007)	France	The Wehner–Schulze machine was investigated using the French LCPC procedure (e.g. no grit blasting used).	Not only could the results be correlated with PSV, but results were far more accurate and could include samples taken from the field.
Allen et al. (2008)	UK	A comparative evaluation of the PSV and Wehner–Schulze test methods for a range of UK asphalt mix and aggregate types was carried out.	The greatest attraction of the Wehner–Schulze method was that test samples are of the actual surfacing, not individual aggregate pieces, and these can be either laboratory produced or field cored. The sample diameter is also the same as that of the circular texture meter.
Dunford (2008b)	UK	Because of growing opinion that the performance of aggregate in roads is not sufficiently characterised by the PSV test, the TRL undertook in situ trials on an aggregate that was a candidate for extensive use in a road network.	The capability of the Wehner–Schulze machine to test asphalt mixtures (both laboratory-prepared and paver-laid) as well as crushed, uncoated aggregate is a key advantage of the machine over alternative testing methods.
Roe and Caudwell (2008)	UK	Due to concerns that the PSV test has its limitations, alternative devices/methods were reviewed/discussed. They identified the Wehner–Schulze test, which is now becoming more widely considered outside Germany with the availability of commercially-produced test equipment, as a possible alternative.	If the new test has a role in the UK, then there will be the challenge of introducing it into routine use, whether for source approval or verification of material compliance.

Source: Based on Austroads (2011a).

Dunford (2008a) carried out a review on the W–S machine, particularly in relation to the PSV test. The report mainly presented literature reviews from France and Germany including discussions with the experts in those countries. Those reviews/discussions essentially agreed with the review summary in Table 6.1 above, stating the benefits of the W–S machine were:

- good correlation with the Polished Stone Value (PSV) test
- good correlation with skid resistance testing equipment

- better precision or range of readings than PSV or skid resistance testing equipment
- ability to test aggregate samples, as well as laboratory manufactured and field cored asphalt samples.

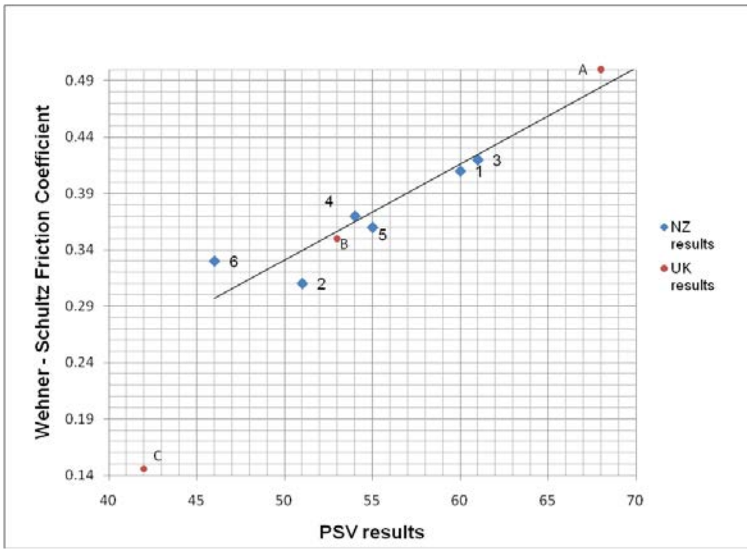
Dunford et al. (2011) reported a comprehensive experimental study on the Wehner–Schulze machine. The main objective was to investigate how realistic the polishing process of the W–S machine was. This was done by comparing the polishing action of traffic in the road with that of the W–S machine. A number of nominally identical specimens were manufactured in the laboratory. Some of the specimens were inserted into the road surface to undergo realistic traffic polishing. At certain intervals over a period of almost four years, those samples were taken to the laboratory and the skid resistance was measured using the W–S machine. These data were compared with the skid resistance of the other specimens which were instead polished using the W–S machine at varying polishing cycles (up to 180 000 cycles). They concluded that satisfactory correlations were found between traffic polishing and W–S machine polishing. They nonetheless commented that it was not straightforward, and possibly erroneous, to compare the polishing cycles in the W–S machine with a length of time on the road.

Another aspect investigated in the study was comparison of different polishing regimes used in Germany and France. They found both methods provided similar results despite subtle differences in the procedures. In conclusion, Dunford et al. (2011) stated that the W–S machine enabled a qualitative comparison of one surfacing material to another, with the expectation that the same comparison would present during in-service performance.

Arampamoorthy and Patrick (2011) carried out an investigation on the Wehner–Schulze machine from New Zealand's perspective. One of the objectives was to observe the correlation between the W–S test and the PSV test. A series of aggregates with varying PSV values were collected from different quarries. For each aggregate sample, a portion was sent to Germany for W–S testing while the rest underwent PSV testing in New Zealand. The result agreed with the general observations in the references presented above and demonstrated satisfactory correlations between the two test methods (Figure 6.3). In the figure, they also included other correlation data observed from a UK study (Woodbridge et al. 2006) to support their case.

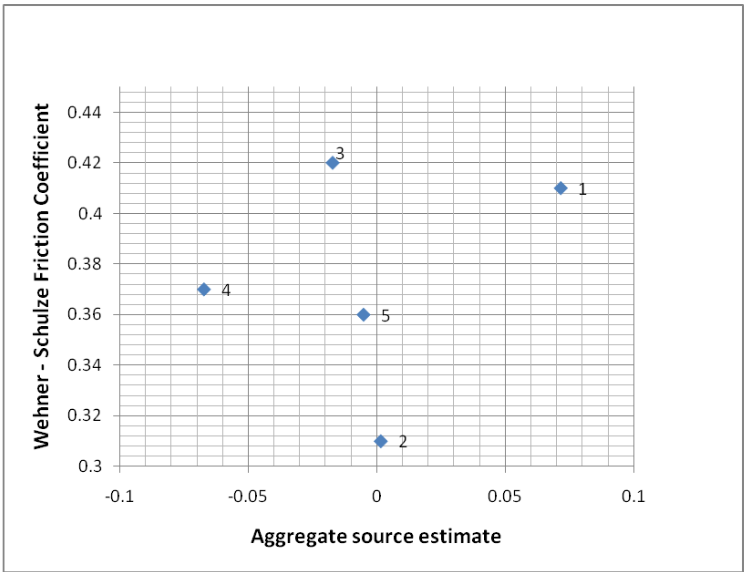
Another objective of Arampamoorthy and Patrick (2011) was to investigate the correlation of the W–S test to field skid resistance. This was examined by comparing the W–S test data to the Aggregate Source Estimate (ASE) parameter (this is reviewed in detail in Section 7). The reason was that, in an earlier study in New Zealand (Cenek et al. 2008b), the ASE parameter had demonstrated a satisfactory correlation to the field skid resistance (measured using a SCRIM). If the W–S test had correctly predicted the field SCRIM value, then a satisfactory correlation between the W–S value and the ASE parameter should have been observed. This was not the case as demonstrated in Figure 6.4.

Therefore, their study has not confirmed that the W–S is any better than the PSV test in terms of predicting the field performance of seal surfacings. The reason was thought to be the inherent difference of laboratory manufactured seal samples and seal surfacings in the field. The W–S specimens were, like the case of the PSV test, manufactured by carefully packing the chips to obtain a flat surface. In the field, neatly packed seal surfacings to this extent rarely exist. One of the advantages of the W–S machine universally noted in many overseas references is the capability of using field cored asphalt surfacing samples. For seal surfacings however, Arampamoorthy and Patrick (2011) found that the W–S machine could not cope with the very coarse nature of the surfacing. This was the reason that their study could only test the laboratory prepared seal samples. It was therefore concluded that the W–S test in its present form is not appropriate for use in New Zealand where seals are the predominant type of surfacing.



Source: Arampamoorthy and Patrick (2011).

Figure 6.3: Correlation between the W–S and the PSV test results



Source: Arampamoorthy and Patrick (2011).

Figure 6.4: Correlation between the W–S test data and the ASE parameters

6.1.1 Equipment Cost and Availability

It was reported that the W–S machine was manufactured by a German company 'BPS–Wennigsenno'. At the time of writing, the cost of a unit was reportedly about €100k in the European market. With no local supplier found in Australia, cost of importing to Australia was unknown.

6.2 Micro–Deval Test

A brief description of this device/method is as follows:

- **Test device**: The Micro–Deval (M–D) tester is a testing device to assess the abrasion resistance of aggregate. The tester comprises steel drums and a testing base which drives the drums (Figure 6.5). This test was developed in France in the 1960s (Tourenq 1971) and accepted in the European Standards (CEN 2011). The test is also used in Canada (Ontario Ministry of Transportation 1996) and in the US (AASHTO 2009, ASTM 2010) but some variations (e.g. sample weight, container size, etc.) were made when adopted.
- **Test procedure**: Coarse aggregate samples are loaded into the steel drums with the steel balls (Figure 6.5), in the presence of water. The drums are then revolved at 100 rpm for two hours (to achieve 12 000 revolutions). The aggregate stones are abraded by interactions with steel balls (and other aggregates). The sample is then washed and oven-dried. The weight loss (per cent weight of aggregate passing the designated sieves to the original sample) is calculated and reported. It should be noted that there are subtle differences between the European and North American methods. These are reviewed in Table 6.2.

Source: Myers Associates (nd) and Pavement Interactive (2011).

Figure 6.5: Micro–Deval apparatus and components (AASHTO/ASTM version)

The M–D test was developed in France in the 1960s (Tourenq 1971) and later accepted in the European Standards (CEN 2011). It was first introduced to North America by use in Quebec (Fowler et al. 2006). When the method was adopted by the Ontario Ministry of Transportation (1996), some variations in the procedure/equipment were made following further studies, such as influence of sample size, soaking time, etc. For example, the larger size aggregate sample of 1.5 kg in the Ontario method is likely to improve repeatability (Rogers 1998). The Ontario version of the test was adopted and is currently used in the US (AASHTO 2009, ASTM 2010). The differences between the two methods are reviewed in Table 6.2. It was reported that the French/European method is still used in Quebec (Rogers 1998).

Table 6.2: Comparison of the European and North American Micro–Deval tests

	North American version	European version	Note
Specifications	AASHTO T327 ASTM D6928	EN 1097	In Canada, Ontario uses the North American version test, while Quebec uses the European version test.
Sample weight	1500 g	500 ± 2 g	
Sample size	12.5 mm nominal size 16 mm nominal size 19 mm nominal size	10–14 mm	Each size has defined grading.
Container dimension	194–202 mm external diameter 170–177 mm internal height	200 ± 1 mm internal diameter 154 ± 1 mm internal height	
Addition of water	2.0 ± 0.05 L	2.5 ± 0.05 L	
Sample pre-immersion duration	Minimum of one hour	No pre-immersion required	The original French method used pre-immersion of 24 ± 4 hours, but this was not adopted in the EN 1097.
Steel ball diameter	9.5 ± 0.5 mm	10 ± 0.5 mm	
Steel ball charge	5000 ± 5 g	5000 ± 5 g	
Drum rotation speed	100 ± 5 rpm	100 ± 5 rpm	
Test duration	120 ± 1 min for 19 mm sample 105 ± 1 min for 16 mm sample 95 ± 1 min for 12.5 mm sample	2 hours	
Post-test screening sieve size	1.18 mm	1.6 mm	
Weight loss calculation method	Percentage weight loss to the original weight	Percentage weight loss to the original weight (M_{DE})	
Test base	Drive two drums in stack	Drive four drums in tandem	Local supplier in Australia has the European apparatus.

The M–D test aims to assess the abrasive resistance (or soundness) of aggregate stones. Another well-known test for aggregate soundness is the Los Angeles test (AASHTO 2006). In the LA test, the aggregate stones are subjected to severe impacts from mostly ‘lifting and dropping’ actions as the drum rotates. The M–D test on the other hand provides gentler rolling actions. The aggregate stones therefore tend to be abraded by rubbing actions of steel balls (and other stones) while the nominal size and shape are relatively unaffected (Figure 6.6). Another unique feature of the M–D test is the presence of water which is thought to provide some indication of weathering susceptibility, as well as resistance to mechanical degradation (Wu et al. 1998).

A number of studies (Fowler et al. 2006, Hossain et al. 2007, Rogers 1998, Wu et al. 1998) investigated whether the M–D test was able to discriminate aggregate quality (e.g. abrasion resistance, soundness) better than other tests (namely the LA test). Those studies generally agreed that the M–D test provided better correlation to the field performance than the LA test. The reason was thought that aggregates may not experience such heavy impacts (as simulated by the LA test) during the production stage and in the field. The M–D test was designed to provide more ‘rolling’ abrasion actions which may better represent what aggregates typically undergo.

Source: Pavement Interactive (2011).

Figure 6.6: Example of aggregate stones before/after Micro–Deval test

Providing a wet testing condition is also an important feature in the M–D test. Poorer quality rock types tend to slake or at least to have reduced strength when wet (Rogers 1998). In addition to the satisfactory correlation to the field performance, the precision of the M–D test has universally been reported as being excellent (Fowler et al. 2006). The reason appeared to be due to the simple, non-operator dependent testing procedure.

6.2.1 Micro–Deval Test as a Polishing Resistance Tester

The M–D test was originally developed to assess the abrasion resistance of aggregate. However, its unique testing configuration (i.e. rolling action with the presence of water) appeared to provide certain polishing actions as well. The use of the M–D test as a polishing resistance testing device is recently gaining attention.

A number of studies (Luce et al. 2007, Masad & Rezaei 2009, Masad et al. 2009, Rezaei & Masad 2011, Rezaei et al. 2009) investigated the M–D test as an aggregate polishing resistance tester, with respect to the skid resistance of road surfacing. In these studies, a series of asphalt slabs were made using different aggregate sources. The slabs were then polished using a NCAT three wheel polisher (see Figure 6.8) in the laboratory, while skid resistance was measured (by a Dynamic Friction Tester, DFT) in-between the polishing cycles.

Additionally, various properties of the aggregates, such as the Los Angeles test, PSV test and weight loss in the M–D test were measured. It should be noted that the standard M–D test parameter (i.e. weight loss after the testing) is meant to be representing ‘abrasion resistance’ and therefore was considered inappropriate for assessing ‘polishing resistance’. Instead, a new test parameter of ‘microtexture change before/after the testing’ was introduced. The new test parameter was assessed using an Aggregate Imaging Measurement System (AIMS) (Figure 6.7).

Source: Pine Instrument (2009).

Figure 6.7: Aggregate Imaging Measurement System

A multiple regression analysis was performed to identify which aggregate parameters were statistically important to the skid resistance of the asphalt slabs. It was stated that the main aggregate properties affecting the mix skid resistance were found to be the PSV, microtexture change before/after the M–D test, residual microtexture after the M–D test (measured by AIMS). The standard parameter of the M–D testing (i.e. weight loss) was not statistically important in relation to the mix skid resistance.

6.2.2 Equipment Cost and Availability

A local supplier of the M–D tester was located but only supplies a European version of the tester (conforming to CEN 2011). The American version of the M–D tester (conforming to AASHTO 2009), which was used in the skid resistance studies above, may have to be imported. At the time of writing, the cost of the European version tester was reportedly about A$9000.

In relation to polishing resistance and skid resistance, researchers recognised the importance of aggregate microtexture. This indicates the need for an AIMS device (as a microtexture measurement device), in addition to the M–D tester (as a polishing device). The AIMS device is manufactured by an American company ‘Pine Instrument’. At the time of writing, the cost was reportedly about $40k. No local supplier was found, but the equipment can be imported.

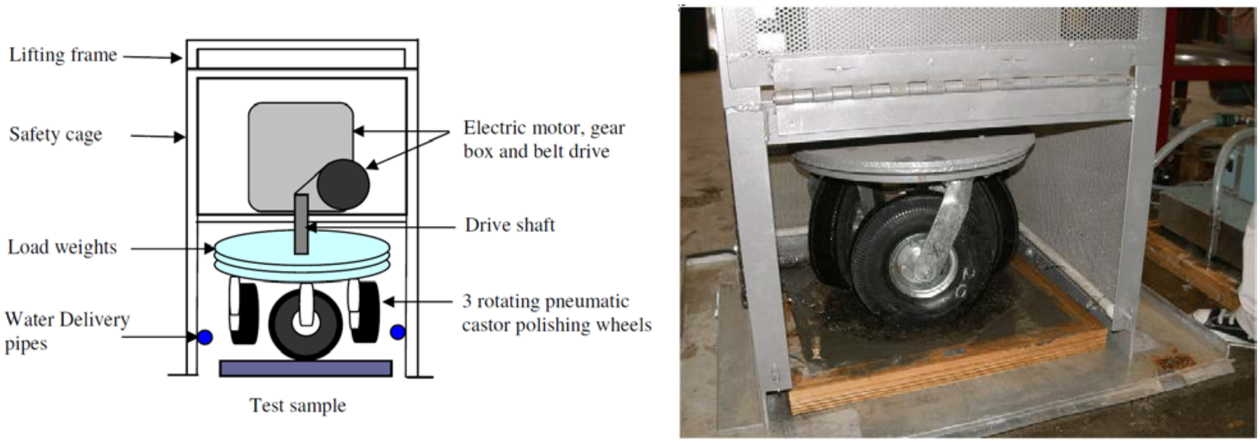
6.3 Auckland Pavement Polishing Device (APPD) and NCAT Three Wheel Polishing Device

Brief description of the device/method is as follows:

- **Test device**: This is a slab polishing device developed in New Zealand. It was largely based on the NCAT three wheel polishing device (TWPD) developed in the US (Figure 6.8), but some modifications to the mechanical components and load controller had been made. This was to take account of the higher macrotexture and irregularities of seal samples common in New Zealand (Wilson 2006).
- **Test procedure**: The tester has three rotating wheels equipped with pneumatic tyres (Figure 6.9). A slab specimen is placed in the machine and polished under the action of rotating wheels (in defined conditions: e.g. tyre pressure, rotation speed) for a certain period. Water is delivered by incorporated pipes. For simulation of seasonal variation, a more complex polishing process can be followed (Wilson 2006). This involves applying certain contaminants (with or without water) in a multiple-step polishing process. The machine was designed to polish the surface in a circular shape, which provides an ideal specimen for the following skid resistance measurement (using the DFT).

Source: McDaniel and Coree (2003).

Figure 6.8: NCAT TWPD layout



Source: Wilson (2006).

Figure 6.9: APPD (schematic and photo)

6.3.1 APPD in Relation to Skid Resistance

Cao and Nataadmadja (2011) carried out a study to correlate the laboratory polishing process by an APPD. In the field, 114 sections on two-coat sealed surfacings (equivalent to double/double seals), where a single aggregate source (G4 Auckland Greywacke) had been used, were selected. Those sections were constructed at different times, and thus comprised varying ages from 1 to 11 years. Cao and Nataadmadja (2011) plotted the skid resistance on those sections (measured using a Grip Tester) against the respective ages. This was compared to the data of Kumar (2009) who observed a skid resistance reduction trend of laboratory prepared samples (using the same Greywacke aggregate) under the APPD polishing process. Both laboratory and field studies demonstrated similar skid resistance reduction trends. From this observation, Cao and Nataadmadja (2011) stated that the laboratory polishing action of the APPD reasonably reflected the traffic induced polishing action experienced in the field. However, it was noted that further research with a wider range of aggregate sources is required to ensure applicability.

6.3.2 Price and Availability

It was reported that the NCAT tester is manufactured by an American company 'Sims Machinery Co, Inc.'. At the time of writing, the cost of a unit was reportedly about US$12 000 for the American market. With no local supplier or agent found in Australia, the cost of importing to Australia is unknown. The APPD appeared to be available in New Zealand but information on the cost and supplier was not found. It should be noted that, due to the unique size of the slabs required for the testing, a specific slab compactor may need to be purchased as well.

6.4 Alternative Polishing Test Methods: Summary and Discussion

6.4.1 Wehner–Schulze Machine

The review on the Wehner–Schulze machine found a number of references from Germany, France and the UK. Those references generally agreed that the device has many advantages over the traditional UK PSV test in relation to skid resistance of asphalt surfacings. However, a recent study carried out in New Zealand recognised that the device may not be able to cope with the high stress of coarse seal surfacings. If this limits the application of the W–S testing to laboratory manufactured specimens only, then it would appear to share the same problem (i.e. difficulties in manufacturing realistic field seal specimens in the laboratory) with the traditional PSV testing.

In conclusion, the Wehner–Schulze machine is considered to have certain benefits in assessing polishing resistance of asphalt surfacings. The device nonetheless presented certain limitations for the testing of seal surfacings. It may be more applicable to certain small sized seal surfacings, which tend to have relatively smooth texture, but the applicability needs to be investigated.

6.4.2 Micro–Deval Tester

The Micro–Deval tester has been used for aggregate testing for decades. The philosophy behind the Micro–Deval test is to focus on abrasion (rather than impact) resistance of individual aggregate stones. This configuration enabled the M–D test be used as a polishing resistance tester which was gaining attention of researchers. Recent studies have noted certain values of the method in predicting skid resistance of road surfacings.

It was noted that there were philosophical differences between the Micro–Deval test and other polishing methods. What other methods universally attempt to achieve was simulation of the polishing process by the traffic loads in the field. For example, the polishing procedures in those test methods typically used rubber materials (either flat pad or rolling wheel) for simulation of vehicle tyres. Additionally, those methods required a sophisticated sample manufacturing process. These efforts to simulate realistic sample and traffic loading naturally increased complexity of the testing equipment/procedure, while their effectiveness remains questionable. Obvious disadvantages were the increased uncertainly and operator dependency of those methods.

The Micro–Deval test was, on the other hand, an empirical test and could only provide information on the relative performance of individual aggregate stones. It was obvious that the abrasion action of the steel balls used and the immersed testing condition would not be experienced in the field. In compensation however, the M–D test instead provided a much simpler procedure leading to less variability and operator dependency. For example, the use of steel balls would remove variations associated with using the rubber tyres (e.g. tyre type, compound, wear, pressure control). It is thought that this simplistic approach may be the reason for good correlation between the microtexture and field skid resistance as observed in a number of studies (see Section 6.2.1).

Although the principle is nominally identical, there are subtle differences in the European and American version Micro–Deval tests, meaning that the outcome could be different, particularly in correlation with skid resistance. Therefore, if the M–D test is introduced to Australasia, a decision must be made as to which device (and testing procedure) to adopt across the jurisdictions.

In conclusion, the M–D test was considered promising in assessing polishing resistance of both asphalt and seal surfacings (since aggregate stones are assessed). However, immediate adoption of the device is not considered possible due to the device availability, additional need for a more sophisticated image analyses device (AIMS) and the fact that correlation to field skid resistance of seal surfacing has not been examined yet.

6.4.3 Auckland Pavement Polishing Device (APPD)

The APPD is considered likely to provide improved simulation of the polishing process experienced in the field, contributed by the use of pneumatic wheels, the large size of the wheel, the large size of specimen, etc. The APPD was the only test method specifically designed for seal surfacing application and had improved mechanical systems to cope with harsh surfaces of seals which was the common problem for other methods.

It was reported that research is currently being undertaken in New Zealand with the aim of standardising test protocols and procedures. This suggested that, in the future, the method could become a specified method as a replacement for the PSV method and the device is able to be purchased by industry. However, an important point is whether the device would be sustainable. In the past, test devices which had limited use in Australasia experienced difficulties in sustainable production and maintenance.

6.4.4 Comparison of the Methods

The relative feasibility of adopting the identified methods into Australasia is compared and reviewed in Table 6.3. A number of factors were considered and presented in the table, in a perceived order of their importance (from left to right). The equipment sustainability is considered the most important factor, since a test method relying on unsustainable equipment is not warranted, no matter how satisfactory the performance is. This was followed by ‘capability of testing seals’ as the importance of seal surfacings in the Australasian road networks is paramount, but is often overlooked in overseas test methods. The factor of ‘correlation to field performance’ was placed last as this is meaningful only when the other factors have been satisfied first. Another important point is that a satisfactory (or not satisfactory) correlation observed in a particular study may not be repeated, if a further study is carried out. Therefore, a particular test method having a number of studies carried out in the past may be considered beneficial, but should not be considered as a decisive factor.

Table 6.3: Comparison of alternative test methods

Test method	Is equipment available and expected to be sustainable?	Capable of testing seal samples?	Capable of testing asphalt samples?	Correlation to field performance examined?
Wehner–Schulze machine	Yes ▪ Large market in Europe.	No	Yes	A number of studies for asphalt surfacing reported. A New Zealand study found that correlation to seal surfacing was not satisfactory.
Micro–Deval tester	Yes ▪ Large market in Europe and North America.	Yes ▪ Individual stones are tested, thus applicable to any surfacing type.	Yes ▪ Individual stones are tested, thus applicable to any surfacing type.	A number of studies for asphalt surfacing reported. No report found regarding seal performance.
APPD	No ▪ Available in New Zealand only at present. Even if Australian users adopt, the market is considered very limited.	Yes ▪ Only test method designed for seal sample application.	Yes	A New Zealand study found satisfactory correlation to the field performance of seal surfacing.

From the assessment made in Table 6.3, the Micro–Deval test was found to be the most promising test method, but further study regarding correlation to field performance in Australia and New Zealand is needed.

7 NEW ZEALAND METHOD OF ASSESSING AGGREGATE SKID RESISTANCE

The assessment of aggregate polishing resistance has traditionally been made based on a skid resistance parameter (e.g. PSV number) measured by a certain laboratory tester. The in-service performance is predicted by applying a specified polishing procedure in the laboratory, prior to the skid resistance measurement. This is based on a hypothesis that, if an aggregate underwent the same polishing procedure and presented higher residual skid resistance than other aggregates, it would perform better in the field as well. This provided a common background to all the known polishing resistance test methods.

The success of this laboratory based approach relies on how reliably the laboratory polishing (and skid measurement) methods emulate those mechanisms experienced in the field. The ultimate challenge for any existing and new laboratory test methods (such as those reviewed in Section 6) is therefore: how to achieve more realistic, field-like polishing and skid measurement methods in the laboratory over others?

An innovative method of assessing aggregate skid resistance has been developed and is reported in a number of documents (Cenek et al. 2004, 2008a, 2008b) with the latest and most comprehensive work reported by Cenek and Davis (2012). Instead of relying on a questionable assessment made by the PSV test or any other laboratory methods, this NZ method uses a statistical aggregate ranking tool which was developed from correlations between aggregate sources and in-service skid resistance at locations where those aggregates had been placed.

The principles of this NZ method are:

- New Zealand has a comprehensive road assessment and maintenance management (RAMM) database which contains data from the annual road condition and geometry surveys of the entire sealed state highway network in the country.
  - The database records an extensive range of road condition information, namely skid resistance (measured by SCRIM), surface texture (measured by laser profilers), geometry (e.g. gradient or curvature) and roughness.
  - The RAMM also has other information such as traffic volume information and surfacing records (i.e. type/size of surfacing).
  - The data in RAMM is recorded in the same location format. Therefore, all the road information in any given position on a road can be identified and linked each other.
- In additional to this usual information in the RAMM, the aggregate source information was added into the database. This required an aggregate source identification code (e.g. Quarry A) and the location of where that aggregate had been placed. Once the location is confirmed, the aggregate source can be linked to all the other network data in the RAMM database.
- A sophisticated statistical analysis was carried out using the RAMM database to establish a linear regression formula which calculates skid resistance (as in SCRIM SFC), in terms of a number of independent variables (e.g. aggregate source, curvature, traffic volume, etc.).
  - The statistical analysis was essentially linear regression analysis but, to account for the complex nature of those independent variables, a more comprehensive, two levels of randomness method was used. For the method, the first level of randomness was associated with each SCRIM measurement, whereas the second level of randomness was associated with the different surface layers (e.g. seal size, site category).

— The statistical model was linear but some of the input parameters were expected to have non-linear relationships to the predicted SFC. Therefore, those parameters were converted into new parameters having a linear relationship in the model (e.g. by converting into logarithmic numbers).

- This method allows aggregate PSV to be added into the formula. For example, if a mean PSV of Quarry A was 52, this PSV value could be added into the database using the same location information given for Quarry A. However, this was not included in the latest national level analysis, since an initial regional level analysis already demonstrated that the aggregate source was a better predictor than the PSV.
- The established formula can then be used to predict in-service SFC of any newly constructed road, if all the input parameters for that road are obtained. This is typical information needed for any new road design, such as geometry, expected traffic volume, site category and, most importantly, name of the quarry where the aggregate would be sourced for the construction.

Because of the complex form of the SFC prediction formula, it was not presented in the report (Cenek & Davis 2012) and is only available in a computer program (*Aggregate Selection for Skid Resistance,* NZ Transport Agency 2012).

Some of the key conclusions of Cenek and Davis (2012) were:

- The input parameters found to have the most influence on in-service skid resistance in decreasing order of significance were: aggregate source, curvature, traffic volume and seal size.
- Aggregate source was shown to have the greatest effect on predicted in-service skid resistance. For example, the difference between best and worst performing aggregate sources was 0.15 SFC, while all the other parameters (when maximum/minimum values were compared) displayed smaller differences, generally less than 0.10 SFC.
- The correlation between predicted in-service SFC and PSV was not very strong. For example, an aggregate with a high PSV was found to have low SFC in the field (i.e. displayed a different ranking than the SFC based ranking). This finding suggested there is at least one other factor (e.g. aggregate shape effect) which is not accounted for by the PSV method.

The NZ method appeared to be a promising method and effectively resolved the previously identified issue of: how best to achieve realistic, field-like polishing and skid measurement methods? By directly using in-service characteristics and field information (i.e. no laboratory measured characteristics were used). Another important point to note is the use of the aggregate source identifier that inherently encompasses not only PSV but also all other important influencing factors such as aggregate shape, hardness, mineralogical properties and crusher type (Cenek & Davis 2012).

It was, however, noted that the most important parameter for the model (i.e. aggregate source identifier) was only available for established quarries with known performance histories. For example, if a new quarry opens, the quarry would need to go through a certain validation process (e.g. field trial) to allocate an appropriate place in the existing aggregate source ranking list. Another critical aspect of the model is that, for the assigned performance ranking to be meaningful, the aggregate from a defined source should maintain its characteristics over time. Therefore, the consistency in aggregate characteristics may have to be routinely monitored by a laboratory test (e.g. PSV test).

The NZ method as it stands is not applicable to other jurisdictions in Australia since only aggregate sources in NZ are accounted for in the developed model. The methodology however could be followed, if other jurisdictions wish to adopt this method. The jurisdictions would need to gather and use their own field performance and network information. The success depends on the comprehensiveness of their current road asset database so all the necessary information (e.g. information on aggregate sources and where they were placed) is available and in robust format (i.e. presented with a harmonised location record). This is not always readily available.

8 USE OF GIS FOR SKID RESISTANCE MANAGEMENT

8.1 Background

Skid resistance data has traditionally been measured in linear referencing format (e.g. chainage of a road) with the data stored/presented in tabular form or manually prepared strip maps. There is however growing interest in introducing/integrating skid resistance data into the jurisdictional geographic information systems (GIS) with a number of benefits expected. This would enable the skid resistance data to be coordinated with other network data typically available in the GIS, such as crash data, condition rating, road classification, traffic volume, geometry, and would greatly assist network management. Nonetheless, there are currently some technical limitations in implementing skid resistance data into the GIS and therefore further development is required in most jurisdictions.

Section 8.2 provides a review of the current status of jurisdictional use of GIS, and issues involved. To be implemented in the GIS system and coordinated with other data, the skid resistance data would need to be aligned with appropriate location referencing data. Typical location referencing format used in the GIS system is either a linear referencing system (i.e. by road section, e.g. RMS of NSW RoadLoc systems, or distance from a referencing point on a known road) and/or a geographic coordinate system (e.g. Global Positioning System (GPS)). Therefore, the review essentially involved discussions on the current location referencing methods for the skid resistance network survey adopted by the jurisdictions.

8.2 Status of the use of GIS/GPS for Skid Resistance Data Management

8.2.1 New Zealand Transport Agency

The NZTA is beginning to report road condition data on their GIS. This is currently done by consultants who take the network data and upload it into the GIS. It was reported that not all condition data has been added to the NZTA's GIS tools. The NZTA currently considers proposing a five year strategy with an aim to increase their GIS capacity.

The SCRIM used by the NZTA is equipped with GPS 'tagging' which records geographic coordinates at the start and the end of each ten metre section where the skid resistance data is averaged. Linear referencing data is also recorded based on the GPS coordination.

8.2.2 DPTI South Australia

Grip Tester test results have been uploaded to the corporate server since 2006. The DPTI uses a linear road referencing system, then back-calculates to GPS coordinates, but is also able to use GPS coordinates directly.

Skid results are measured at ten metre intervals and analysed in 100 m segments. Skid data is available texturally or through the corporate GIS and can be analysed against all other DPTI data sets that are currently available in the GIS (e.g. traffic, crash and asset data). Pre-defined interactive maps visually present skid results against crashes, pavement condition, surfacings, traffic, structures and more.

Investigatory Levels (ILs) are generated by proximity to certain features e.g. intersections, school crossings, curves. Information about the surfacing history and skid test results is displayed for the last five years. Further to this, information can be hyperlinked to access various data in more detail, including graphical presentation of skid results for the last five years. This information is available to all DPTI staff and is used to prioritise sections for treatment.

8.2.3 DIER Tasmania

The DIER reported that GPS coordination records are used for all the network surveys and the survey units are equipped with GPS devices. There is nonetheless a need to address a small portion of the network (about 5%) where a GPS signal is not accessible. The skid resistance data is stored in linear referencing format.

8.2.4 RMS New South Wales

The RMS uses its RoadLoc linear referencing system as the primary location reference on its skid resistance devices. GPS coordinates are also recorded, but GPS alone cannot be fully relied upon due to loss of satellite signal on portions of the network. While the RMS uses Gipsi-Trac as a dead reckoning backup system in some devices (not SCRIM), there are still technical challenges before GPS can be applied as the sole referencing system. For example, even if only small portions of the network are subject to signal loss, GPS cannot be relied upon as the sole reference (particularly where the drop-outs are unpredictable). It is not simply a matter of stopping the test and waiting, nor implementing a dead-reckoning system to fill in the gaps. Fundamentally, this relates to attributing a test result to an interval on the road, including the expectation of repeatability.

The RMS also has the facility to readily convert between linear referencing and GPS coordinates (e.g. latitude/longitude, eastings/northings) using software.

8.2.5 VicRoads Victoria

VicRoads currently uses a linear referencing system called the Standard Road Referencing System (SRRS) to manage skid resistance data. This linearly referenced data can be converted to GIS format on a regular basis for display in a range of different desktop and browser-based mapping applications throughout VicRoads. However, the linear references held against SCRIM skid resistance data are not updated as changes occur in the road network, meaning that skid resistance data cannot be compared with data from other systems with a high degree of confidence.

VicRoads has recently implemented a system called the Location Referencing System (LRS), which provides a set of web services to translate between several different location referencing methods (i.e. linear references, geodetic coordinates (latitude/longitude), literal descriptions (a description of the nearest intersecting road) and street addresses). These services are also able to validate location information entered into business systems, and keep location information up to date and in synch with the latest version of the road network. It is anticipated that VicRoads will soon integrate the LRS with its Road Asset System (which holds skid resistance data), so that this data is maintained against the same location reference network as information held in other systems across the organisation. This will allow VicRoads to bring together information from otherwise disparate systems on a map based interface, and have confidence in the integrity of the location information presented. VicRoads SCRIM data includes GPS coordination information and can be uploaded into the GIS system.

8.2.6 TMR Queensland

The TMR skid resistance measurement devices (Via Friction) are equipped with GPS and tripmeters (for linear referencing).

8.2.7 Main Roads Western Australia

The MRWA currently does not collect network wide skid resistance data. However, if and when it commences collection, then the data will be the same as all other high speed data and referenced according to the Network Control System (NCS).

The NCS is an integrated linear and spatial referencing system that allows for transformation between either location methods. On this basis, skid resistance data could be integrated with any other road related data, as well as any other spatial data from external sources. Accordingly, in future MRWA would be able to implement a combination of spatial referencing combined with linear data streams to obtain absolute referencing of all condition data. It is hoped that this will eventually result in a repeatable location in the order of 1–2 metres.

8.3 Issues Involved in the use of GIS/GPS

It was found that skid resistance data from the jurisdictions are currently collected with location referencing data which are either compatible with their GIS, or can be converted into a compatible format. This means that, technically, most jurisdictions are ready to use the GIS for skid resistance management. A good reference on the topic is provided in Austroads (2011c).

However, the challenge in the use of GIS was that by using consumer-quality GPS, current location referencing data is not accurate enough to be used at the project or forensic level. The identification of an exact spot to corresponding skid resistance is essential for typical tasks, such as incident investigations, identifying and prioritising locations for consideration for maintenance, coming up with the best treatment option etc. Therefore, the issues are more related to the GPS accuracy, such as listed below:

- In GPS coordinates, 20 m accuracy was all that can be reasonably expected.
- Accuracy of linear referencing relies upon records of road network changes being updated and GPS is helpful in resolving discrepancies in linear referencing systems.
- Road geometry, particularly horizontal curves need to be carefully considered in any locational referencing systems (either GPS or linear) because it is generally required to match recorded data as being adjacent for lane changes referenced from a known point.
- Data received from such pickup is rarely ‘GIS friendly’, as it is not always directly relatable to the information already in the GIS. For example, data going into GIS may not directly be related to a Road ID, it would be a point item with latitude and longitude reference point picked up at a specific point in the road, and therefore may not be applicable for the entire section of road which it falls on. However, there is no benefit in splitting a road segment to match the skid resistance measurements as there are too many other factors (i.e. roughness, rutting, texture, etc.) which may not match the same segment length.

Certain improvement in location referencing accuracy is expected by using the following options:

- Use of differential and/or inertial GPS may provide the improved accuracy required for skid resistance data management. However, the accuracy tends to drop when surveying at speed.
- Use of a dead reckoning system can be considered in open roads but will still have some limitations in mountainous areas, among city buildings and in tunnels.
- Video surveying is identified as good value for helping locate and understand problems from a desktop aspect.

8.4 Recommendations

The GIS is a robust tool for network data management and is also available for managing the skid resistance data. However, the challenge is that the location referencing (typically GPS coordinate) is not accurate enough to be used at the project or forensic level. Therefore, the use of GIS in relation to skid resistance data management will depend on the advancement in the GPS technology (e.g. use of differential and/or inertial GPS). Monitoring of further developments in GIS/GPS technology should therefore continue.

Once the use of GIS becomes a more routine practice for skid resistance data management, a question should be raised regarding 'what analysis the jurisdictions will want completed from their GIS data?' This will determine whether it is better to link all the data in the one table or if it is more suitable to create separate layers for each data set. Essentially, if it is to be kept in the one table, the skid resistance data would be an average over the carriageway section. Raw data can easily be aggregated 'on the fly' to match any user-specified road segment. Therefore, there is no need to pre-aggregate the data just to spatially enable it.

9 SUMMARY AND CONCLUSIONS

The research outcomes of Austroads project AT1488 *Improving Skid Resistance Measurement* carried out from July 2009 to June 2012 are presented in this report. Up-to-date information on the major issues has been collected and reviewed. Important findings from the review and discussion for each topic are briefly presented in the following sub-sections.

9.1 Correlation of SCRIM and Other Skid Resistance Measurement Devices

There are many different skid measurement devices used worldwide and harmonising the outputs of those devices is not considered achievable at present. Therefore, establishing jurisdictional standardisation (using a device of choice) should be addressed first, while retaining Australasian standardisation as a long term goal.

The first issue to be resolved for the standardisation is 'how to ensure (and maintain) acceptable correlations between the device of choice within a jurisdiction?'. The next step would be to ensure compatibility across jurisdictions where the same devices are used (i.e. inter-jurisdictional standardisation). A review of correlation exercises of SCRIM and other devices currently used in Australasia was therefore carried out.

The SCRIM correlation exercises of the two main users in Australia demonstrated reasonable correlations (e.g. R^2 of 0.8 or higher). The studies also indicated that the test machines need to be routinely calibrated and examined to ensure consistency in mechanical characteristics as much as possible. Conducting periodic inter-device and inter-jurisdiction correlation exercises, to a similar scale of the cases reviewed in this report, is therefore recommended.

Studies of correlations between other devices, such as Grip Testers and BPTs, were also carried out. This investigation demonstrated that satisfactory correlations existed between the Grip Testers and the BPTs. For the BPTs of different manufacturers however, certain mechanical calibration/adjustments of the key components were needed to ensure the devices operate in mechanically the same manner.

Differences in SCRIM data processing/reporting methods (adopted by each SCRIM user) were reviewed. A statistical analysis was conducted and demonstrated that the differences were significant. Harmonisation of the data processing/reporting methods is therefore recommended as the first step towards inter-jurisdictional standardisation.

9.2 Management of Seasonal Variation

It is considered that seasonal variation in skid resistance measurement exists in most jurisdictions in Australasia. Since this is a natural phenomenon and cannot be prevented, the focus should be on identifying an effective management method. The jurisdictional seasonal variation management methods were therefore reviewed to identify a best practice.

New Zealand appears to have the most comprehensive method of managing seasonal variation. However, adopting this method requires a significant investment (e.g. establishing reference sites, and undertaking frequent skid resistance measurements) which may not be warranted in other jurisdictions.

It is therefore suggested that, for jurisdictions where the NZ-level investment is not warranted, the current practice should be maintained (i.e. carrying out routine skid resistance survey at the same time of the year or not accounting for seasonal variation) and the data is to be used for asset management purposes. The use of network data for incident analysis should state the uncertainty involved. Where necessary, the incident site should be tested again. For jurisdictions where seasonal variation follows a predictable trend, is large enough to be significant, and the skid resistance data has a key role in incident analysis, the New Zealand approach could be considered.

9.3 Improvements in PSV/PAFV Tests

Aggregate on road surfaces must be polish resistant to maintain the desired level of microtexture during service. This is an important requirement for surfacing aggregates and has traditionally been assessed by the PSV or PAFV tests in Australasia. With certain limitations of these tests being recognised by practitioners, the feasibility of improving the current PSV/PAFV methods was investigated.

The investigation found that the common goal of previous modification trials was to achieve a harsher polishing action than that given by the standard procedure. The philosophy behind these efforts was that simulating the in-service polishing action of today's traffic would need a harsher polishing action than that of the current testing procedure.

The extended polishing cycle approach was a simple modification of the test procedure and did not require any modifications in the testing device, other than prolonged testing time. Further investigation using a wide range of aggregates would nonetheless be needed.

9.4 Alternative Methods of Assessing Aggregate Skid Resistance

A review of polishing resistance test methods used overseas was carried out. Important aspects of the reviewed methods are briefly presented in Table 9.1. The review included an innovative method developed in New Zealand which does not involve any laboratory test methods. This method is nonetheless presented in the table along with the other laboratory tests for comparison purposes.

Among the laboratory tests, the Micro–Deval test was found to be the most appropriate test method but the correlation to field performance needs to be examined, particularly for seal surfacings (see Section 6.4.4). The NZ method (Section 7) was an innovative approach and already in place in New Zealand. Other jurisdictions however need to develop their own tool, if this method is to be used.

In conclusion, there is no alternative method available for immediate implementation across Australasian jurisdictions without the need for further investigation/development. Monitoring of alternative aggregate polishing test methods should nonetheless continue, with particular attention given to the Micro–Deval test.

9.5 Use of GIS for Skid Resistance Management

The GIS is a powerful tool for network data management and is also available for managing the skid resistance data. However, the challenge is that the location referencing (typically GPS coordinate) is not accurate enough to be used at the project or forensic level. Therefore, the effectiveness of using the GIS in relation to skid resistance data management would depend on advancement in the GPS technology (e.g. use of differential and/or inertial GPS). Monitoring of further developments in GIS/GPS technology should therefore continue.

Table 9.1: Summary of alternative methods of assessing aggregate skid resistance

Test method	Description	Benefits	Limitations	Feasibility of implementing in Australasia
Wehner–Schulze machine	Developed in Germany during the 1960s and now has wide acceptance in Germany and under review in the UK.	Large number of studies carried out and considered to have many advantages over the PSV test in testing asphalt materials, such as: ▪ large sample size ▪ capable of testing field samples ▪ automated procedure.	Not appropriate for testing of seal samples (not able to cope with the high stress of coarse seal surfacings).	Only applicable to asphalt materials, subject to local field correlation study.
Micro–Deval tester	Developed in France in the 1960s and used in Europe and North America. Abrasion/polishing resistance of aggregate is assessed using a steel drum and steel balls.	The polishing process is very simple leading to less variability and operator dependency. The method can test both asphalt and seal surfacings since individual aggregate stones are assessed. A number of studies observed good correlations between microtexture and the field skid resistance of asphalt surfacing.	An empirical test and does not attempt to simulate the abrasion action in the field (e.g. use of steel balls instead of rubber tyre). A more sophisticated image analysis device is required. Correlation to field skid resistance of seal surfacing has not been examined.	Applicable to asphalt and seal materials, subject to further field correlation study.
Accelerated Polishing Machine (NCAT three wheel polishing device)	Developed in New Zealand based on the NCAT three wheel polishing device developed in the US. Certain modifications to the mechanical components and load controller were made to account for the higher macrotexture and irregularities of chip seal samples common in New Zealand.	Improved simulation of the polishing process experienced in the field is expected, contributed by the use of pneumatic wheels, the large size of the wheel, the large size of specimen, etc. The only test method designed for seal surfacing application.	Availability and sustainability of the device due to limited market in Australasia is a concern.	Applicable to asphalt and seal materials, subject to further field correlation study.
NZ method	The method uses an aggregate source performance ranking tool which was developed by statistically analysing in-service skid resistance performance.	Limitations of any laboratory tests were overcome by using only the field performance data. The development was done using an extensive, nationwide database promoting the reliability of the method.	The most important parameter required for the method (i.e. aggregate source identifier) is only available for established quarries with known performance histories. The aggregate from a defined source should maintain its characteristics over time.	Currently applicable within New Zealand for the aggregate sources covered in the database. Not applicable to Australia but the methodology can be utilised if a new tool is to be developed by other jurisdictions.

10 RECOMMENDATIONS

The following recommendations are made:

- Jurisdictional standardisation (using a device of choice) should be addressed first, while retaining Australasian standardisation as a long term goal.
- To ensure consistency of the skid resistance test machines, periodic inter-device and inter-jurisdiction correlation exercises are recommended.
- Harmonisation of the skid resistance data processing/reporting methods is recommended as the first step towards inter-jurisdictional standardisation.
- Jurisdictions should consider the need for developing seasonal variation adjustment factors where climatic conditions and/or skid risk warrant such investigation.
- The use of a more robust aggregate assessment method (in order to provide a better representation of skid resistance performance in the field) could be considered by jurisdictions.
    - The extended polishing cycle PAFV method should be further investigated with a wide range of aggregates.
    - Monitoring of alternative aggregate polishing test methods should continue, with particular attention given to the Micro–Deval test.
    - In situ performance monitoring methods should be considered by jurisdictions in addition to aggregate polishing tests (see example methodology in Section 7).
- Monitoring of further developments in GIS/GPS technology should continue.

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APPENDIX A SKID RESISTANCE WORKING GROUP

The Skid Resistance Working Group was formed to guide the AT1488 project (*Improving Skid Resistance Measurement*). The members list is provided in Table A 1.

Table A 1: Skid Resistance Working Group members (2010 to 2012)

Affiliation	Name	Status
DPTI SA	Mick Lorenz	Chairman, Austroads Project Manager
DPTI SA	Darren Holloway	Active
DPTI SA	Grant Mackey	Active
ARRB	Steve Patrick	Secretary
ARRB	Kym Neaylon	Active, ARRB Project Technical Leader
ARRB	Dr Young Choi	Active, ARRB Principal Author
ARRB	Paul Hillier	Active, ARRB Quality Manager
MRWA	Steve Boston	Resigned in April 2012
MRWA	Michael Hayward	Active from April 2012
MRWA	Ross Keeley	Corresponding
DIER Tas	Jan Lang	Active
TMR Qld	Justin Weligamage	Active
DPI NT	William Moodie	Active
DPI NT	Shane Tepper	Corresponding
VicRoads	Klaus Kiesel	Active
VicRoads	Dr Hossein Parsa	Corresponding
RMS NSW	David Pratt	Resigned in Dec 2011
RMS NSW	Zahid Hoque	Active from Jan 2012
RMS/PTRP	George Vorobieff	Active from Jan 2012
NZTA	David Whitehead	Active

APPENDIX B SCRIM CORRELATION TRIAL PROTOCOL

An important requirement for jurisdictional standardisation is maintaining consistency of the standard device (e.g. one SCRIM to another). This Appendix therefore provides a general trial protocol for a correlation exercise of SCRIM devices (to be location independent). For the jurisdiction relying on other devices (e.g. Grip Tester), this work plan can be amended to suit those devices.

The main objective of this work is to observe how much variability (repeatability/reproducibility) exists within the same type of machines (i.e. one SCRIM to another). The speed and water film thickness dependency would also be investigated.

B.1 Site Selection

The first action is to find appropriate test sites. The sites need to satisfy the following:

- Reasonably trafficked roads. Road sites currently in service should be selected
  - the sites need to be at least five years in service (to ensure equilibrium status).
- A dual carriageway with wide shoulder width is recommended
  - the trial should be carried out on the left hand lane (i.e. Lane 1), with Lane 2, the right hand lane, open to traffic
  - the shoulder could be used for a 'taxiway' (acceleration lane) to the starting point.
- Minimum one asphalt road site and one seal road site should be selected
  - although not essential, two sites located in close proximity would be beneficial for logistics
  - inclusion of a concrete road site is to be at the discretion of participants
  - depending on budget, more sites with varying friction levels (skid resistance and/or surface texture) should be sought.
- The site should have a 300 m section on straight and flat roads, with an aim to use the data collected from the last 100 m section (with homogeneous surface conditions within the section).

B.2 Test Plan

The skid resistance measurement would be done using the SCRIM devices and the test plan as follows:

- From the devices listed in Table 2.1, at least one device per jurisdiction should be invited to the trial (i.e. a minimum of three SCRIMs would participate).
- Five test runs will be required per testing condition, as follows:
  - three test speeds (km/h): 20, 50 (i.e. current standard operating speed), 90 (if feasible)
  - two nominal water film thicknesses (mm): 0.25, 1 (if feasible)
  - two sites: asphalt and seal
  - with four devices and five repetitions a total of 240 runs will be required.
- At the test site, the measurement would be done from one end to the other (about 300 m in length). However, only the data in the last 100 m section to be analysed (first 200 m section for conditioning purposes).

- Air and surface temperature to be measured separately to the on-board temperature record.

The SCRIM test data is to be recorded as in Table B 1.

Table B 1: Example of SCRIM test data template (per device / per speed)

Site information	Speed (km/h)	Water film (mm)	Test run	SCRIM (left)	SCRIM (right)	Note
Asphalt site Road name: Surfacing type: Chainage: AADT: Age:	25 / 50 / 90	0.25	1			Date: Temperature (air): Temperature (pavement): Weather: Other:
			2			
			3			
			4			
			5			
			Average			
		1	1			
			2			
			3			
			4			
			5			
			Average			
Seal site Road name: Surfacing type: Chainage: AADT: Age:	25 / 50 / 90	0.25	1			Date: Temperature (air): Temperature (pavement): Weather: Other:
			2			
			3			
			4			
			5			
			Average			
		1	1			
			2			
			3			
			4			
			5			
			Average			

B.3 General Issues

This section provides general issues associated with the trial. These issues may (or may not) need to be addressed depending on specific situations of any future trials (e.g. number of SCRIMs invited, number of test sites secured, allocated budget for the trial, etc.). Therefore, these are presented separately in the following sub-sections to provide extra notes and also to be added into the main protocol above as appropriate for future trials.

B.3.1 Expert Advice

The SCRIM correlation trials in the UK are considered the most comprehensive and longest running example of SCRIM trials. Seeking expert advice from the UK for establishing Australasian trials would therefore be worthwhile.

B.3.2 Test Surfacings and Preparation for the Trial

Recommendations made by previous trials in relation to site selection include:

- Newly laid materials should be avoided.
- Roads with varying friction levels (skid resistance and/or surface texture) should be sought.

These features had been taken into account in the proposed work plan above. It is advised that, prior to the trial, the sites be prepared as follows:

- The sites should be machine-swept and visually inspected for any debris/defects (and recorded to enable back-analysis of data as required).
- The test sections should be identified, such as where the section starts and ends.
- The drive line should be marked (by an offset) to assist the operators to follow the same trail.
- A SCRIM should be run several times. This is for pre-conditioning of the surface as well as collecting benchmark data for the main trial. For example, the first SCRIM run in the main trial can be compared to this benchmark data to confirm that the machine is operating correctly.

B.3.3 Test Conditions

The following test conditions were identified as important to control:

- **Health and safety**: The test should be conducted with appropriate concern given to safety of operatives, devices and traveling public.
- **Test duration**: It is advised to complete the testing in one day (with preparation on the day before, as described above). This is to ensure the data is not significantly affected by any short-term variation. If this is not feasible, testing on one site (e.g. the asphalt surfacing site) should at least be completed in one day (i.e. testing for the two sites to be completed in two consecutive days).
- **Test speeds**: The operation should be carried out conforming to the designated test speeds. Actual speed recorded during the data collection should be reported for data analysis. The speed could be cross-checked using a separate laser speed detection system at the site.
- **Test line**: This should be controlled by providing markers to define the measurement line to be followed.
- **Local temperature conditions**: Trials should be carried out when conditions are reasonably stable. Rapidly changing temperatures can affect the measurements, so measurements of air and road surface temperature should be made so that, if necessary, any effects on the results from this source can be identified.
- **Weather conditions**: Tests should not be made in very heavy rain (preferred no rain) or windy conditions since these may influence the measurements through build-up of water on the surface or by causing undesirable variations in the test line.
- **Control of water on the surface**: Build-up of water on the surface from frequent passes of several machines can occur and influence the measurement. Where necessary, time should be allowed for this to dissipate. Testing on surfacings with well-draining geometry would also be desirable.
- **Test tyres**: Generally, the same test tyre should be used by a device throughout the test program. If a tyre has to be replaced, this should be noted since, even with careful product control within defined specifications, some variation in tyre properties can occur. It may be considered appropriate to use a common set of tyres and interchange these between machines.

- **Equipment condition**: Prior to the trial, the participants should carry out routine functionality checks (e.g. load cell calibration) of their SCRIM devices as in the case of a network survey.

B.3.4 Test Procedures

It is advised that careful attention is paid to the practical aspects of the test procedures in order to ensure smooth and safe running of the trials. Matters to consider include:

- **Staff requirements**: It is advised that each SCRIM device should be operated by the usual crews for their own network survey.
- **Traffic control**: Traffic management will be required along with a Memorandum of Consent (MOC) from the pertinent local SRA. If the testing on two sites is done in one day, travel time between the sites would need to be accounted for by the traffic control service.
- **Marshalling and control**:
  - It must be clear to all who is ultimately in charge of the trial. A Trial Director must be identified and appointed with sole jurisdiction over the trial and any decisions made during the trial.
  - Marshals should be available with 2-way communication to ensure smooth and safe operation of the test runs.
  - Vehicles not involved in a test run should be well clear of the operating area.
  - There should be a clear program of work and test sequence and it should be clear who is responsible for making decisions regarding any variations in the test program that might be necessary to take account of the changing circumstances or vehicle breakdowns that will inevitably occur.
  - Regular checks on the test lines and speeds for individual devices should be included as the trial progresses so those potential sources of error in the data can be identified and rectified.
- **Order of testing**: It is suggested to change the order of testing. For example, instead of completing five repetitions of one device and moving on to the next device, complete one round of testing with all the devices and then carry out the second (and third) rounds.
- **Instructions to participants**: Clear written instructions should be provided to participants, preferably in advance of the testing. These should define where the test surfaces are, where machines are to park or turn around, what identifying marks are to be used, what the planned order of testing is and so on. The written instructions should be reinforced by an on-site briefing/s as required.

B.3.5 Data Recording and Processing

This is clearly a critical aspect of any trial. A decision will need to be made at the planning stage as to what data is required. For example:

- Is raw data to be provided by the operators for analysis by the trial team?
- Are the operators to provide 'average' values for each test section?

It is recommended that a standardised reporting format is used. Since SCRIM is the only device proposed to participate in this trial, it is recommended that standard operating methods and recording formats should be used, to allow the reporting of raw data for processing with standard software. This approach is used in the UK Annual SCRIM Correlation Trials, for example.

INFORMATION RETRIEVAL

Austroads, 2013, **Review of Variability in Skid Resistance Measurement and Data Management**, Sydney, A4, pp.64. **AP-R444-13**

Keywords: Skid resistance, literature review, correlation, seasonal variation, test method.

Abstract:

This report presents research outcomes of Austroads project AT1488: Improving skid resistance measurement, carried out from July 2009 to June 2012. The main goal of the project was to improve the understanding of variability associated with skid resistance testing and measurement, so a more effective management system can be devised balancing the practical limitations within the overall objective of providing safe road networks.

Various issues in relation to the variability in skid resistance measurements (e.g. correlation of skid resistance devices, seasonal variation in the measurement and how to best manage it) were comprehensively reviewed and discussed in the report. Important findings were drawn from the review and recommendations for local development, both on a national and local basis, were made accordingly.