Road Surface Friction: Measurement, Testing and Accuracy

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ABSTRACT

State road authorities act as the asset managers for their respective state road networks and it is their responsibility to maintain the road networks at a suitable operational level, thereby managing the risk on behalf of the respective governments. This responsibility translates to the public who are the main road users in a private or business capacity.

To this end a road authority addresses the issues of:

- Monitoring and measuring road condition.
- Determining performance criteria and measuring network conditions against them.
- Policy and Strategy determinations
- Processing, analysis and interpreting data
- Remediation strategies and materials/ processes for use
- Risk minimisation with regard to legal responsibilities

Road roughness, texture, cracking, pavement strength etc. in Transport SA have been monitored and addressed for many years. Road surface friction is emerging as an issue in need of attention. The funds of road agencies are not limitless and making regular full network surveys is not always possible. A prioritising system is therefore a necessity in order to select test sites.

Technical handling of this responsibility follows these steps:

- Acquisition of measuring and associated test equipment.
- Development of test and operational procedures
- Staff training
- Testing, accuracy and accreditation
- Selection strategies for network testing
- Policies

This paper will focus primarily upon the technical issues of handling this responsibility.

<u>Note:</u> *The views expressed in this paper are those of the author, and do not necessarily reflect those of the Department of Transport and Urban Planning.*

1. INTRODUCTION

State road authorities act as asset managers of the respective state road networks and it is their responsibility to maintain this asset at a suitable operational level, thereby managing the risk on behalf of respective governments. This responsibility includes the public who are the main road users, either in a private or business capacity.

Road condition monitoring covers parameters such as roughness, texture, cracking, pavement strength and surface friction. This paper focuses primarily upon the technical issues of handling the road surface friction measurement.

2. BACKGROUND

The emergence of risk is a significant issue and it is necessary to manage and minimise this factor by showing intent and having an operational process of monitoring, assessment and maintenance.

To achieve this a road authority addresses the issues of:

- Monitoring and measuring road condition.
- Determining performance criteria and measuring network conditions against them.
- Policy and strategy determinations
- Processing, analysis and interpreting data
- Remediation strategies and materials/ processes for use
- Risk minimisation with regard to legal responsibilities

3. DISCUSSION

The State Road Authorities of Australia recognise the importance of asset management and the need to measure the asset condition. The characteristics being measured are road roughness, texture, cracking, pavement strength and surface friction. The measurement, collection, processing and analysis of this information are undertaken either in house or by contract.

The collection of these data is made by various pieces of equipment, which are expensive to obtain and operate. Funds of road agencies are not limitless and undertaking of regular full network surveys is not always possible. A testing priority program is therefore a necessity. In doing so the asset manager must be assured that the risks have been addressed and the responsibilities completed.

The progress to technically handle this responsibility follows a series of steps as detailed here in:

3.1 ACQUISITION OF MEASURING AND ASSOCIATED TEST EQUIPMENT.

For many years skid testing within the Agency has been with a British Pendulum (BP) and testing for texture was undertaken using the sand patch technique. The work in this area was driven more on a reactive basis.

The British Pendulum is a device that tests only small areas of road. It is slow, labour intensive and an OHS&W issue and so it is best used as a research and laboratory tool. Similar problems exist with texture testing using the manual sand patch technique.

A review of the various pieces of equipment has been made but devices such as the SCRIM were not a financial possibility. It is also desirable to do smaller and more confined testing, so devices such as ROAR and the ASTM skid trailer are not suitable either in terms of cost or manoeuvrability. Contracting is a possibility but availability at an appropriate time is not always probable. The services of a SCRIM unit have been used successfully twice in South Australia in recent times.

The Griptester was selected as it can operate in a tow mode and test significant lengths of road or it can be used in a push mode testing shorter lengths or in confined areas. The device has proven to be very useful and versatile. A common example of short distance usage is the testing of road marking that need a certain level of skid resistance.

The Griptester consists of a trailer which is either towed behind a vehicle (50 k/h) or pushed by hand (5k/h). (If necessary it can evaluate the friction characteristics of a road at other speeds.)

The equipment has three wheels, two road wheels and a third (test) wheel which is geared to rotate at a proportionally different rate, thereby skidding continuously. The drag force induced on the skidding wheel and the vertical force are monitored and the calculated friction value logged on a computer. Surveys are normally carried out on a wetted surface.

Both the Twin Laser Profilometer and TM2 devices have been acquired in recent years. The Twin Laser Profilometer is an ARRB product that was initially purchased for roughness measurement but the system can be used to determine pavement texture. The sensing lasers in the system have recently been upgraded to current generation Selcom lasers. This tool can undertake texture measurements at highway speed over significant distances. That is it can undertake network surveys.

The TM2 (WDM UK) is a device that determines texture over shorter distances and is used in a push mode, travelling at 5k/h. Both devices produce good results

3.2 DEVELOPMENT OF TEST AND CALIBRATION PROCEDURES.

Once the equipment was obtained, operational procedures were developed that included;

- Manufacturers operational, calibration and maintenance instructions.
- Testing protocols of operation and management of outputs.
- Safety requirements
- National and international standards. There are only International, no Australian Standards for the Griptester.

The production of procedures demonstrates that there is a reasonable safety and quality rationale of operation behind the whole process. Such procedures exist in the Quality Management System of the Materials Group. (Refer References)

3.3 TESTING ACCURACY AND ACCREDITATION

Testing with the Griptester commenced in a limited manner whilst the operating staff became familiar with the equipment and results being produced. Some parallel testing with the BP continued but this ceased as familiarity with the Griptester extended, returning the BP to a research and laboratory device.

3.3.1 Calibrations.

Equipment servicing by the manufacturer is not a simple operation, being on the opposite side of the world. Through close adherence to manufacturers requirements TSA utilised the skills of a dedicated scientific instrument maker who supervised maintenance operations.

As there was no local calibrating authority it was necessary to develop a suitable in-house method. This was achieved by relating it to the British Pendulum, which was regularly calibrated at a suitably accredited laboratory (NATA accredited)

A series of sites were selected to give a range of skid resistance results. As low as 20 and up to 80 BPN. A range of testing was undertaken by the BP at each site and a series of runs were made by the Griptester. From this data a correlation was determined with some statistical confidences. The results obtained were quite good, reinforcing the value of the method taken.

In general much of the testing work undertaken by contractors to Transport SA is required to be by NATA accredited laboratories and so it was considered necessary that the skid testing process be an accredited test. It helps in instilling some discipline in our own operations and gives a greater confidence to the client when reviewing the data produced.

It is not necessary to have the same test sites at all calibrations and correlations, but it is helpful. It is important however to have sites that are spread over the expected spectrum of the testing and separate from traffic. For the ‘push’ scenarios it is easier than towed, as less distance is needed for the former operations. Fortecon plastic and kitchen rubber floor coverings were used as low skid resistance surfacings and could be stored away for another time and are readily replicable. The old raceway at Victoria Park is a popular site as are side access roads. (Victoria Park is a horse race track in the Adelaide City parklands within which is located the pit area and main straight for the racing car street circuit)

Part of the process is to clean the test surface area as much as possible beforehand and during the testing to minimise variations due to loose material. The following is an example of skid resistance change and improvement with progressive testing and cleaning.

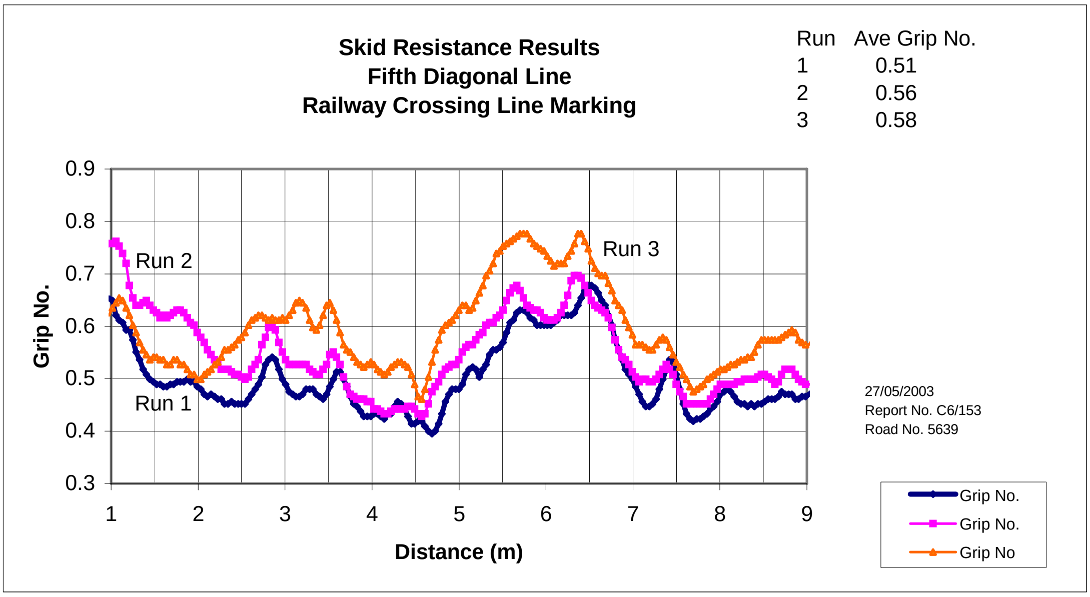

Figure 1: Effects of repeat testing and cleaning

3.3.2 Uncertainty of Measurement

To determine the accuracy of the test results a number of runs were made over a test site when estimating an uncertainty of measurement. When considering this estimation, reference was made to Cook "Assessment of Uncertainties of Measurement: For calibration and testing laboratories" (2002). A significant number of contributing factors were identified as influencing the test result and hence its accuracy. They were tyre pressure, tyre temperature, pavement temperature, water flows, tyre wear, tyre rubber hardness, vehicle speed, road smoothness, driving accuracy, pavement cleanliness etc. The specific nature and size of each influencing factor is not known. Consequently a 'Type A' assessment method was made using a large number of repeat tests over a range of possible test sites.

> Note: Australian Standard (Metrology, 1985):
> Uncertainty of measurement is that part of the expression of the corrected result of a measurement which defines the range of values within which the true value or, if appropriate, the accepted true value is estimated to lie. (U of M)
>
> Level of confidence is a numerical of quantitative statement of the probability that the actual values of a measured quantity will lie within certain limiting values.

3.3.3 Skid Resistance

Test Location	Average	Std Dev	95% Confidence Levels, % Average
Orange Plastic	0.25	0.03	1.74%
Floor Vinyl (Patterned Surface Up)	0.29	0.06	3.82%
Floor Vinyl (Back Surface Up)	0.19	0.02	1.66%
Concrete Floor	0.52	0.04	1.36%
Pavement Southern Car Park	0.74	0.04	0.95%
Pavement East Store Shed.	0.49	0.03	3.84%
Pavement West of Geotechnical Shed	0.68	0.05	1.43%
Victoria Park	0.79	0.02	0.61%
Roadway East Store Shed.	0.54	0.03	0.96%
Barli Crescent	0.72	0.03	0.56%
95% Confidence limits, Average			1.69%
Total number of readings			1100
Coverage factor k			2
Expanded Uncertainty	Use	±	5.00%

Table 1: GripTester (Push) Test Results

Examples:
For a high skid resistance reading of 0.8 the result is 0.8 ± 0.04
For a low skid resistance reading of 0.4 the result is 0.4 ± 0.02

Test Location	Average	Std Dev	95% Confidence levels, % Average
Roadway East Store Shed	65.2	4.7	2.01%
Vic Park Pit Straight	80.7	5.0	1.71%
Orange Plastic	22.7	2.2	2.74%
Southern Car Park	76.8	3.6	1.28%
Vinyl Top	24.8	2.4	2.71%
Vinyl Bottom	30.3	2.0	1.85%
Barli Cr.	68.2	5.8	2.34%
95% Confidence limits Average			2.09%
Total number of readings			350
Coverage factor k			2
Expanded Uncertainty	Use	±	5.00%

Table 2: British Pendulum Test Results

Examples:

For a high skid resistance reading of 80 the result is 80 ± 4
For a low skid resistance reading of 40 the result is 40 ± 2

In practice the uncertainties for this type of testing are so small that they could be lost in the variability of the actual test results. A decision to undertake remedial work based solely on such test results is not recommended and therefore site inspections are necessary.

3.3.4 GripTester & British Pendulum Correlations

The following graphics show the correlation of test results between the Griptester and the British Pendulum. The high R^2 result indicates a good relationship with only 5 to 6% of the variation unexplained using the data in the model. The F ratios are strong indicating that the model has significance. The Student's t are also strong at 12.8 and 11.1 respectively.

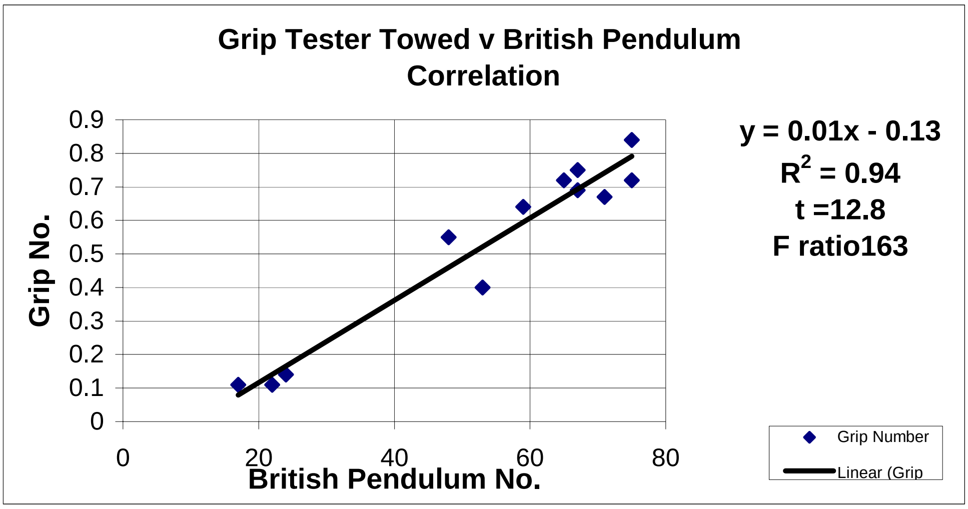

Figure 2: Grip Tester Towed v British Pendulum Correlation

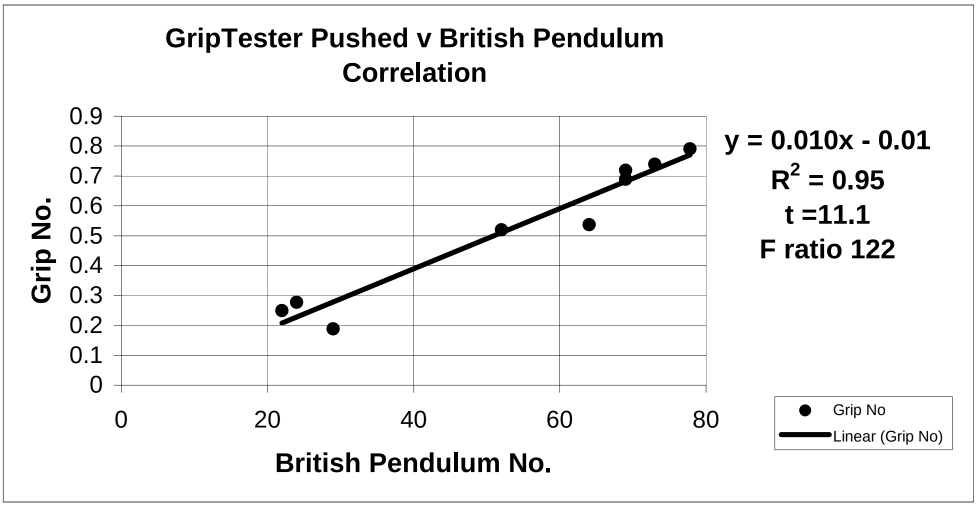

Figure 3: Grip Tester Pushed v British Pendulum Correlation

When using a BP the process of preparation and test ensures that the test surface is clean before the final test is undertaken, whilst in practice the Griptester is a once through device and so loose material left on the test surface may have an effect on the outcome.

With a correlation/calibration exercise such as comparing the Griptester with a British Pendulum the uncertainties of measurement are combined and follow the process as detailed in AS 2833. (Metrology, 1985)

$U_{total} = (U_1^2 + U_2^2)^{0.5}$

For the pushed mode U of M = ± 2.69%. Using a coverage factor of 2 this U of M is now ± 5.4%.

3.3.5 Texture.

Texture is a significant property for drainage purposes and is therefore important when considering skidding on roads. Similar work has been undertaken to develop relationships for the various texture measurement procedures. Agency staff are able to measure texture using the twin laser profilometer (ARRB) and the TM2 (WDM) and in worst case scenarios the manual sand patch method (traditional).

The manual method is seen as the traditional way and most engineers within the Agency have an understanding of this method, so it has been correlated with the two automated systems.

A similar approach was taken with the texture evaluation process and a series of sites were repeatedly tested to accommodate the various uncertainty components and the degrees of influence that each would have on the result.

Test Location	**Average**	**Std Dev**	**95% Confidence levels, % Average**
West of Geotechnical Shed	0.82	0.11	2.5%
East of Rear Shed	2.07	0.15	1.39%
Barli Cr.	2.05	0.16	3.19%
Southern Car Park	1.13	0.10	0.02%
Victoria Park, 1	0.92	0.07	1.03%
Victoria Park, 2	0.89	0.08	1.18%
Balaclava, 1	0.99	0.11	1.48%
Balaclava, 2	0.34	0.04	0.50%
Balaclava, 3	1.40	0.12	1.64%
Owen, 1	0.76	0.11	1.25%
Owen, 2	0.77	0.09	0.98%
95% Confidence limits Average			1.55%
Total number of readings			2100
Coverage factor k			2
Expanded Uncertainty	Use	±	5.00%

Table 3: TM2 Test Results

Test Location	Average	Std Dev	95% Confidence levels, % Average
Barli Crs, 1	2.25	0.25	1.95%
Barli Crs, 2	2.42	0.25	1.87%
Southern Car Park	1.38	0.23	2.94%
Eastern Road	2.32	0.23	1.77%
Victoria Park, 1	0.68	0.10	2.06%
Victoria Park, 2	0.72	0.12	2.23%
Balaclava, 1	0.81	0.17	1.73%
Balaclava, 2	0.23	0.14	1.54%
Balaclava, 3	0.94	0.19	2.29%
Owen Seal 1, Seal 1	0.75	0.13	1.57%
Owen Seal 1, Seal 2	0.54	0.14	1.64%
Owen Seal 2, Seal 1	0.70	0.21	1.80%
Owen Seal 2, Seal 2	0.77	0.23	2.01%
Average of 95% Confidence			1.95%
Sample Size			3300
Coverage factor k			2
Expanded uncertainty	Use	±	5%

Table 4: Twin Laser Test Results

Examples
For a high texture, 2.0 mm the result is 2.00 ± 0.10 mm
For a low texture, 0.5 mm the result is 0.50 ± 0.03 mm

Test Location	Average	Std Dev	95% Confidence levels % Average
Karoonda, Site 1	0.93	0.08	2.63%
Karoonda, Site 2	0.98	0.09	2.90%
Roadway East Store Shed	2.19	0.14	3.04%
Roadway West Geotech Shed	0.76	0.08	1.70%
Southern Car Park	1.13	0.14	2.96%
Vic Park Pit Straight, Site 1	0.80	0.05	0.99%
Vic Park Pit Straight, Site 2	0.83	0.06	1.38%
Barli Crs	2.51	0.20	2.53%
Balaclava, Site 1	1.19	0.07	3.15%
Balaclava, Site 2	0.42	0.05	2.20%
Owen, Site 1	0.77	0.08	3.31%
95% Confidence limits			2.44%
Total number of readings			520
Coverage Factor k			2
Expanded Uncertainty	Use	±	5.00%

Table 5: Sand Patch Test Results

Examples:

For a high texture, 2.0 mm the result is 2.00 $\pm$ 0.10 mm
For a low texture, 0.5 mm, the result is 0.50 $\pm$ 0.03 mm

Neither error could be used with certainty to prove a change in safety. Few people could visualise such a change in a road surface texture.

3.3.6 Texture Correlations

The following is the correlation graph between the TM2 and Sand patch testing.

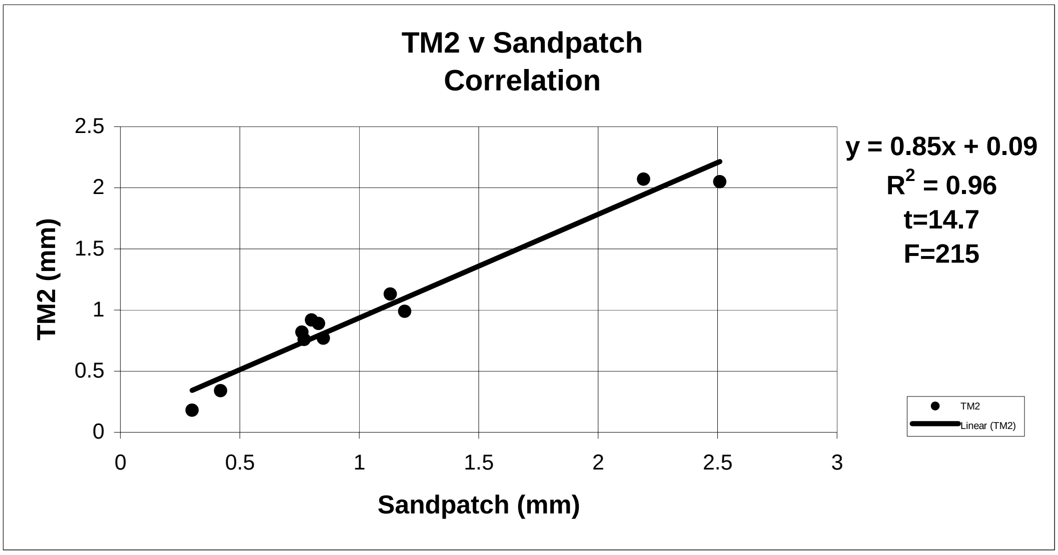

Figure 4: TM2 v Sandpatch Correlation

The graph above shows the correlation of test results between the TM2 and the Sandpatch test. The high R^2 result indicates a good relationship with only 4% of the variation unexplained using the data in the model. The F ratio is strong indicating that the model has significance. The Student's t is also strong at 14.7.

With a correlation/calibration exercise such as comparing the TM2 with the sand patch test the uncertainties of measurement are combined and follow the process as detailed in AS 2833. (Metrology, 1985)

$U_{total} = (U_1^2 + U_2^2)^{0.5}$

For the combined U of M = $\pm$ 2.90%. Using a coverage factor of 2 this U of M is now $\pm$ 5.8%.

The following graph is the correlation between the sand patch technique and the twin laser profilometer

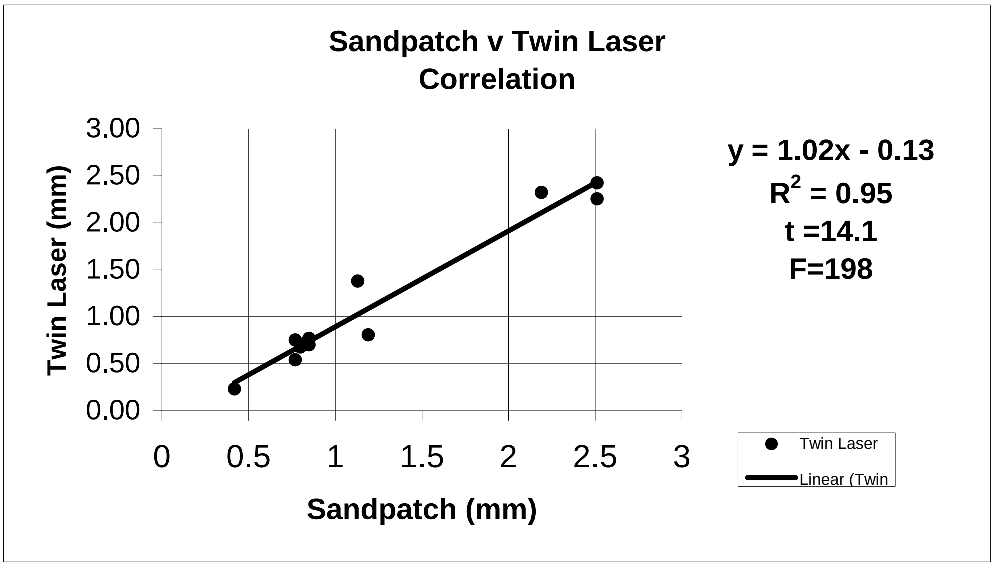

Figure 5: Sandpatch v Twin Laser Correlation

The graph shows the correlation of test results between the Sandpatch test and the Twin Laser profilometer. The high R^2 result indicates a good relationship with only 5% of the variation unexplained using the data in the model. The F ratio is strong indicating that the model has significance. The Student's t is also strong at 14.1.

With a correlation/calibration exercise such as comparing the Twin Laser with the sand patch test the uncertainties of measurement are combined and follow the process as detailed in AS 2833. (Metrology, 1985)

$U_{total} = (U_1^2 + U_2^2)^{0.5}$

For the combined U of M = $\pm$ 3.10%. Using a coverage factor of 2 this U of M is then $\pm$ 6.2%.

4. STAFF TRAINING

Suitably qualified staff are an important component of the system to test and report skid resistance issues. To operate such a system at least three proficient operators are needed. The number may seem high but experience indicates that sickness, leave and other work demands will soon erode any staffing reserves.

To assist in reducing labour demands and allow the technical staff to operate freely traffic control operations are contracted out to specialists.

5. SELECTION STRATEGIES FOR NETWORK TESTING

A more strategic approach to an annual field testing program consisting also of a proactive component has been developed recently.

A Skid Resistance Test Index (SRTI) has been derived from corporate data systems to identify, in a systematic manner, sites where skid resistance may be of high risk to road users and will be refined in the near future. The index is based on multi-criteria risk assessment, as per AS 4360 Risk Management and they are detailed in the following table together with relative weightings applied to each factor.

With multiple factors being taken into account the influence of any one parameter is limited hence the system is more a filter than an index.

When the system is applied to the road network a list of small road sections generally results. Quite often the sections of road are too small to test economically in isolation, therefore larger sections of that road are tested. The test roads are then grouped and work undertaken in blocks so that testing of the network can be completed in a few weeks of the year allowing staff to move onto other programmed work. Accident work and specific test requests continue to be undertaken on demand.

Likelihood Causal Factors					
Theme	**Parameter**	**Coeffs**	**Range Min**	**Max**	**Explanation**
Macro texture	Laser Texture	**0.05**	**0.3**	**1**	Ability for water to be shed off the road
Rut Depth	Rut Depth	**0.15**	**5**	**15**	Aquaplaning
Xfall	XFALL	**0.05**	**0**	**1.5**	Ease of water runoff away from road surface
Rainfall	Thornthwaite	**0.09**	**-52.5**	**45**	Higher rainfall, higher chance of skidding
Surface Age	Years Age	**0.02**	**10**	**25**	Older surfaces have higher polishing
Surface Type		**nil**	**nil**	**nil**	Various surface types will have different risk.
Horiz Radius	Road Radius (m)	**0.12**	**250**	**2500**	Tight radii equate to higher risk of vehicle running off the road
Vert grade	Gradient	**0.02**	**3**	**7**	Worse vertical gradient, the higher the risk of water flowing across vehicle path
Consequence Causal Factors					
Speed	Speed Limit	**0.15**	**60**	**110**	Higher the crash speed the higher the damage
Traffic	Traffic	**0.15**	**1000**	**30000**	Higher traffic levels increase accident chances
Heavy Vehicles	% Commercial	**nil**	**nil**	**nil**	Higher the number of commercial vehicles, the higher the consequence
Intersections	Intersections	**0.15**	**0**	**1**	If at an intersection, chances of a collision rise
Road space width	Carriageway Width	**0.05**	**6**	**10**	Narrow the road, the less chance to manoeuvre

Table 6: Intervention criteria (Skid Resistance Management Framework, 2004 [draft])

The resultant SRTI is an index ranking from 100 (low risk) to 0 (extreme). Currently the sites with a risk rating less than 60 are proposed to be test within 2 years.

Skid Resistance Risk Bandings	**SRI**	
	Low	**High**
Extreme	0	40
High	40	60
Fair	60	70
Low	70	85
Negligible	85	100

Table 7: Skid Resistance Risk Bandings
(Skid Resistance Management Framework, 2004 [draft])

6. CONCLUSIONS

1. The outcome is that all the elements of a suitable testing control system now exist and operate.

2. Acceptable U of M for the various test of skid resistance and texture have been determined and can be used when reporting test results.

3. Acceptable correlations between tests have also been determined between the old and new systems of measurement

7. REFERENCES:

Calibration of a British Pendulum Skid tester; CP472, (2001), Transport SA, Adelaide, p 3.

Calibration and maintenance of a Griptester; CP471, (2002), Transport SA, Adelaide, p 3.

Calibration of the WDM TM2 texture profiler; CP473, (2002), Transport SA, Adelaide, p 3.

Cook RR, (2002), Assessment of uncertainties of measurement: For calibration and testing laboratories, NATA, Melbourne, p56.

Determination of Pavement Surface Roughness and Texture using the Two Laser Profiler, TP348, (2003), Transport SA, Adelaide, p4.

Determination of Skid Resistance with the Griptester; TP344, (2003), Transport SA, Adelaide, p10.

Determination of Skid Resistance with the British Pendulum portable skid tester; TP345, (2001), Transport SA, Adelaide, p 6.

Metrology-symbols for expressing uncertainty of measurements; AS 2833, (1985), Standards Association of Australia, Sydney, p8.

Risk Management; AS 4360, (2004), Standards Association of Australia, Sydney, p39.

Skid Resistance Management Framework, (2004), Transport SA, Adelaide, p22. (draft)

9. ACRONYMS:

BP	British Pendulum
ARRB	Australian Road Research Board
OHS&W	Occupation Health Safety and Welfare
ROAR	Roadway Analyzer and Recorder
SCRIM	Sideways-force Coefficient Routine Investigation Machine
ASTM	American Society for Testing Materials
AS	Australian Standard
TM2	Texture Measurement, version 2
WDM	WDM Equipment, Surveys, Software and Consultancy for Highway Maintenance, Bristol
SRTI	Skid Resistance Texture Index
U of M	Uncertainty of Measurement
TSA	Transport Services Agency
NATA	National Association of Testing Authorities