Validity of Skid Resistance Data Collected Under Western Australian Conditions

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ABSTRACT

Main Roads Western Australia manages an extensive arterial road network across the vast state of Western Australia. The maintenance of the network is managed through long term performance based maintenance contracts. Pavement condition data, including surface skid resistance, plays a crucial role in the monitoring of the Contractors' performance.

Given the highly important role of pavement condition data, it is essential that the data is both reliable and accurate to ensure confidence in its use in assessing the performance of the contractor during its maintenance of the network. In this paper, the authors discuss the validity of data collected using the methods and techniques adopted by Main Roads Western Australia for the purpose of monitoring skid resistance along the Western Australian arterial road network. In particular, the authors discuss the validity of estimating the International Friction Index (IFI) from the Rado Friction Model using data collected by variable slip testing under Western Australian conditions.

Given the validity of IFI estimates obtained using this approach, the authors discuss the limitations of the application of skid resistance data in monitoring road network performance.

1. INTRODUCTION

Main Roads Western Australia (MRWA) manages approximately 17,000 kilometres of National Highway, State Highway and State Main Road. Between 1998 and 2001, the maintenance of the State road network was contracted out into eight Term Network Contracts. These contracts take the form of outcome based, lump sum payment contracts, with payment adjustments being awarded according to the Contractors' performance over a period of ten years.

Whilst MRWA had been collecting road condition data in various forms, including the use of Laser Profilometers and Falling Weight Deflectometers, data collections were generally confined to the National Highway network or to specific projects. During 1998, road condition data was collected for the first time on a statewide basis. The main driving force behind the 1998 pavement condition survey was to obtain a baseline of pavement condition, in preparation for the introduction of long-term maintenance contracts.

Pavement and surface condition data plays a crucial role in the effective monitoring of the Contractors' performance in maintaining the road network. Hence it is crucial that pavement and surface condition data satisfy data validity and accuracy requirements, so that the data can be used with confidence.

At the commencement of the Term Network Contracts, MRWA conducted collections for roughness, rutting, texture, skid resistance and strength/stiffness. At the same time, a video survey captured images of the road condition, and road verge, along the entire State network.

The Norsemeter Road Analyser Recorder (RoAR) was selected for the skid resistance data collection for predominantly two reasons:

1. the availability of water is generally limited outside metropolitan areas. Consequently, the cost of using devices such as the SCRIM was prohibitive compared to operating the RoAR; and
2. the RoAR offered the ability to directly report the International Friction Index (IFI).

Following collection of the Skid Resistance data in 1998 a second network collection was commissioned for 2002, the long interval between the first and second collection being due to business reasons. Preliminary results from the 2002 collection raised concerns over the validity and accuracy of the skid resistance data collected during both 1998 and 2002. An experiment was undertaken during 2003 to investigate the suitability of using skid resistance data to monitor the performance of the Western Australian State road network.

It should be noted that apart from urban areas, the State roads predominantly have a chip seal, typically consisting of a 10mm or 14mm aggregate.

In this paper, the authors discuss the validity of data collected using the methods and techniques adopted by Main Roads Western Australia for the purpose of monitoring skid resistance along the Western Australian arterial road network. In particular, the authors discuss the validity of estimating the International Friction Index (IFI) from the Rado Friction Model using data collected by variable slip testing under Western Australian conditions.

2. ESTIMATING THE INTERNATIONAL FRICTION INDEX

The friction between a tyre and the road surface is a function of the slip speed – the relative speed between the tyre and the road. When a tyre is free rolling there is zero slip speed, but when a tyre is fully locked the slip speed is equal to the speed of the vehicle. During the braking process a point of peak friction is reached. The slip speed at the point of peak friction is termed the critical slip speed. Figure 1 displays the relationship between slip speed and the friction between the tyre and road surface during the braking process.

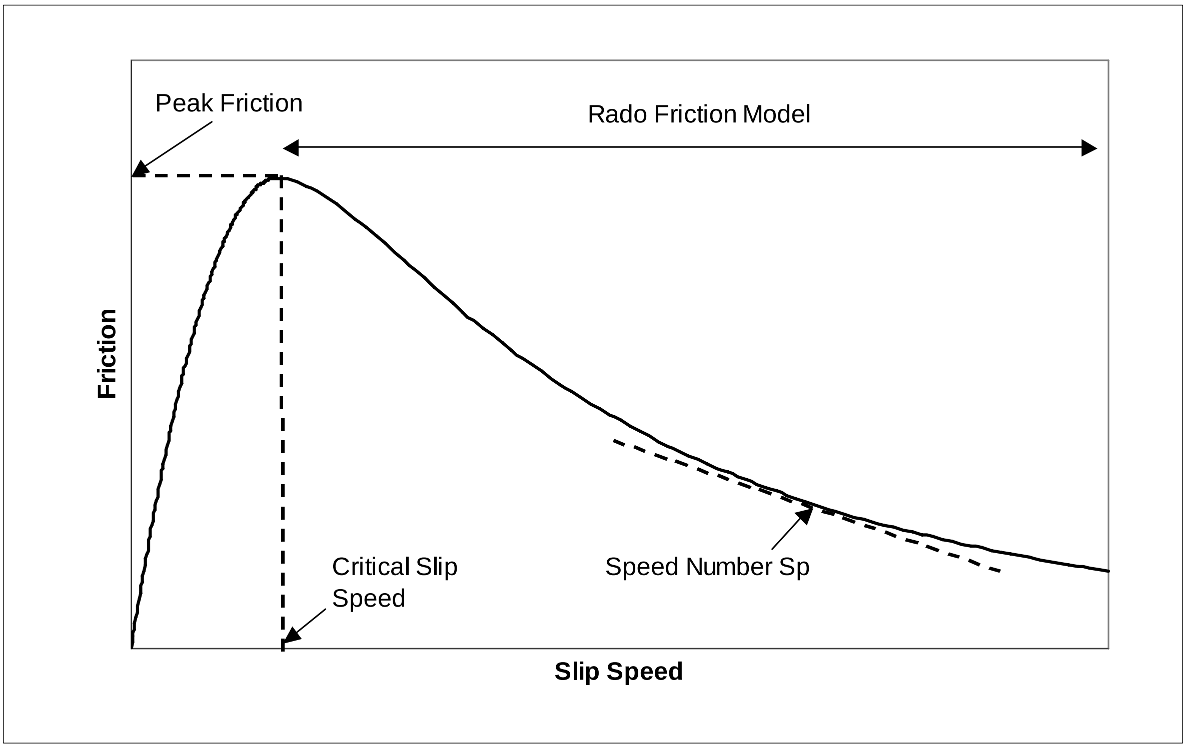

Figure 1. The relationship between slip speed and the friction between the tyre and road surface during the braking process.

Prior to reaching the critical slip speed, the tyre is considered to be the primary contributor to the level of friction. Once the critical slip speed has been passed, the road surface is considered to be the primary contributor to the level of friction.

In variable slip speed testing mode, the RoAR collects hundreds of friction force measurements together with the corresponding slip speed measurements. Having obtained hundreds of slip speed – friction force pairs, the RoAR computer fits the Rado Friction Model to the data pairs. The Rado Friction Model is applied to the slip speed – friction relationship from the point where the critical slip speed is attained. Norsemeter (200u) gives the simplified Rado friction Model as

$$FR(s) = A\,exp\left(-\left[\frac{1}{c}\,ln\left(\frac{s}{B}\right)\right]^2\right),$$

where

$\boldsymbol{FR(s)}$	denotes the measured friction at slip speed $\boldsymbol{s}$;
$\boldsymbol{A}$	denotes the peak friction;
$\boldsymbol{B}$	denotes the critical slip speed; and
$\boldsymbol{C}$	is a shape factor.

The International Friction Index consists of two parameters: the "Golden" or harmonised estimate of friction at 60km/h slip speed ($\boldsymbol{F}60$), and the speed number ($\boldsymbol{Sp}$) which is the slope of the friction-slip speed relationship.

The RoAR obtains an estimate for $\boldsymbol{F}60$ using a two-step process:

1. the measured friction value at 60km/h, $\boldsymbol{FR(60)}$, is estimated from the Rado Friction Model;
2. $\boldsymbol{F60}$ is estimated as $\boldsymbol{F}60 = \boldsymbol{a} + \boldsymbol{bFR(}60\boldsymbol{)}$ where $\boldsymbol{a}$ and $\boldsymbol{b}$ are calibration coefficients unique to the measuring device.

The speed number is calculated as $\boldsymbol{Sp} = \boldsymbol{c} + \boldsymbol{d} \times \boldsymbol{MPD}$, where $\boldsymbol{MPD}$ is the texture measure Mean Profile Depth, with $\boldsymbol{c}$ and $\boldsymbol{d}$ being calibration coefficients unique to the measuring device.

Reliable estimates of $\boldsymbol{F}60$ are dependent upon reliable estimates of $\boldsymbol{FR(}60\boldsymbol{)}$, obtained from the Rado Friction model. A measure of the reliability of the Rado Friction Model is the Coefficient of Determination, $\boldsymbol{r}^2$, $0 \le \boldsymbol{r}^2 \le 1$. The coefficient of determination can be interpreted as the proportion of variation in the data that can be attributed to the model.

From a statistical and modelling viewpoint, a valid model will have a $\boldsymbol{r}^2$ value that is close to one. This means that the model is describing the variation in the data. An $\boldsymbol{r}^2$ value that is close to zero indicates that any pattern occurring in the data can not be attributed to the model. Hence a fitted Rado Friction Model, with a $\boldsymbol{r}^2$ value that is close to zero, will give an unreliable estimate for $\boldsymbol{FR(}60\boldsymbol{)}$, and subsequently an unreliable estimate for $\boldsymbol{F}60$.

3. NETWORK LEVEL MONITORING

In this section we discuss the methodology used by MRWA to monitor skid resistance at the network level.

3.1 COLLECTION METHODOLOGY

Skid resistance data was collected by a RoAR, being towed at a speed of 60 km/h (± 5 km/h), in variable slip mode. The measurement cycle was two seconds. The towing speed was selected with reference to ASTM Standard E1859-97 (*Standard Method for Friction Coefficient Measurements Between Tire and Pavement Using a Variable Slip Technique*).

The collected data was reported on a lane basis. The following data fields were reported:

- Location – road and chainage;
- Towing Speed;
- Air Temperature;
- Peak Friction ($\boldsymbol{A}$);
- Critical Slip Speed ($\boldsymbol{B}$);
- Friction Number ($\boldsymbol{F}60$);
- Speed Number ($\boldsymbol{Sp}$);
- RoAR Correlation; and
- Data flags;

Data flags are used to highlight any occurrences that may affect the quality of the data - for example, road works and bridge abutments. The skid resistance data files are then linked to the Network Referencing System to create merged data files of skid resistance data against location and inventory details.

3.2 CRITERIA FOR VALID DATA

Initial data checks were performed on the collected data to determine whether the data was valid. Data was determined to be valid if:

1. Peak Friction ≤ 1.5;
2. Peak Friction ≤ $\boldsymbol{F}60$;
3. $16 \leq \boldsymbol{Sp} \leq 400$; or
4. Towing speed > 25 km/h.

In addition, prior to the acceptance of the collected data, the following criteria were required to be met:

1. More than 70% of records should have valid values;
2. More than 95% of valid records should satisfy $0.2 < \boldsymbol{F}60 < 1.5$; and
3. More than 80% of valid records should have $60 < \boldsymbol{Sp} < 400$.

3.3 DATA APPLICATION

The State network is divided into links – homogeneous road segments in terms on inventory parameters. The skid resistance data is processed in dTIMS to produce Asset Condition Profiles (in terms of skid resistance) for each link. The Asset Condition Profile is a cumulative distribution function for a road condition parameter. The performance of a Term Network Contractor is assessed by comparing the current Asset Condition Profile against target Asset Condition Profiles agreed to at the commencement of the contract. The comparison is conducted on a link-by-link basis. A typical Asset Condition Profile of skid resistance can be found at Figure 2.

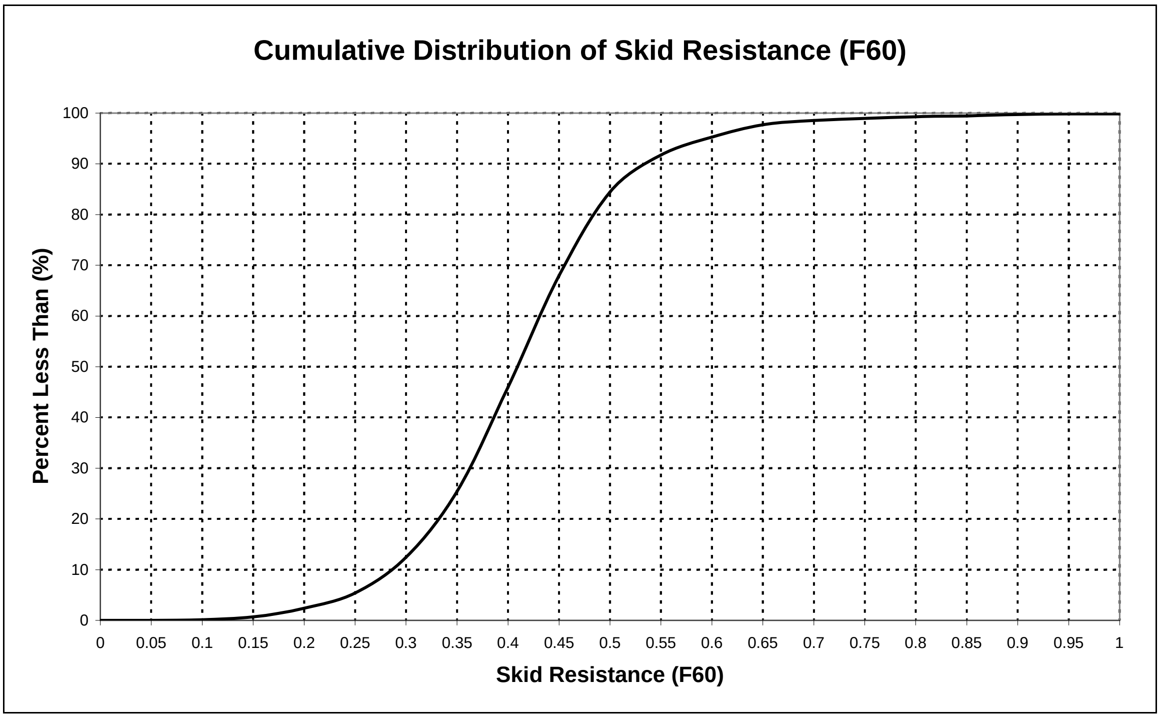

Figure 2. Asset Condition Profile for skid resistance for a typical link.

It should also be noted that the Term Network Contracts include specific intervention parameters to enable the assessment of sites deemed to be in particularly poor and/or unsafe condition. Under these circumstances, skid resistance data is measured with a British Pendulum.

4. DATA VALIDITY AND REPEATABILITY

Given the intended application of the skid resistance data, it is important that MRWA be confident of the validity and repeatability of the data. Invalid data impacts upon the ability of the maintenance Contractor to identify and apply treatments to road segments that require intervention in terms of skid resistance. This in turn impacts upon MRWA's ability to assess skid resistance related safety aspects of the network. The ability of MRWA to effectively manage the performance based maintenance contracts is also compromised by invalid data. This can lead to unnecessary disputes between MRWA and the maintenance contractors.

Following a preliminary analysis of the skid resistance data collected during 2002, it became apparent that the data might not be fit for the purpose of monitoring network level performance. An experiment was commissioned in 2003 to investigate the issue of data validity and repeatability.

4.1 EXPERIMENT METHODOLOGY

The aim of the experiment was to determine if:

- vehicle speed, water film thickness and temperature had an effect on the validity of $F60$ estimates obtained from the RoAR in variable slip mode; and
- vehicle speed and water film thickness had an effect on the repeatability of $F60$ values obtained by the RoAR in variable slip mode.

To determine these effects, test runs were undertaken by the RoAR over four test sites according to the following schedule:

Test Site	**Number of Test Runs**		
	Test Speed	**Water Film Thickness**	
		0.5mm	**1.0mm**
1	50 km/h	5	5
	60 km/h	5	5
	70 km/h	5	5
	80 km/h	5	5
2	60 km/h	1	1
	80 km/h	1	1
3	60 km/h	1	1
	80 km/h	1	1
4 (Day)	60 km/h	1	1
	80 km/h	1	1
4 (Early AM)	60 km/h	1	1
	80 km/h	1	1

Table 1. Summary of the number of runs undertaken by the RoAR over the test sites.

4.2 ANALYSIS

The analysis was conducted in two parts. Firstly, an analysis of the validity of the $F60$ measurements was undertaken incorporating the data collected over all four sites. Secondly, an analysis of the repeatability of the $F60$ measurements was performed utilising the data collected at the Test Site One.

4.2.1 Validity of F60 Measurements

As discussed, valid estimates of $F60$ are dependent upon valid estimates of $FR(60)$, obtained from the Rado Friction model. A lack of confidence in the model fitting process implies a lack of confidence in the resulting $F60$ values. The following table summaries the r^2 values obtained during the experiment.

Test Site	Test Speed (km/h)	Water Film Thickness (mm)	Percentage of F60 estimates obtained from a fit to the Rado Friction Curve Model with $r^2 \leq 0.3$
1	50	0.5	67.9
		1.0	81.2
	60	0.5	79.6
		1.0	81.6
	70	0.5	88.6
		1.0	89.2
	80	0.5	92.5
		1.0	91.8
2	60	0.5	83.8
		1.0	78.6
	80	0.5	85.6
		1.0	87.5
3	60	0.5	74.1
		1.0	79.1
	80	0.5	85.7
		1.0	87.6
4 (Day)	60	0.5	72.9
		1.0	77.3
	80	0.5	85.5
		1.0	87.3
4 (Early AM)	60	0.5	77.5
		1.0	78.8
	80	0.5	85.3
		1.0	85.4

Table 2. Summary of r^2 values obtained during the variable slip experiment.

As can be seen from Table 2, for all sites tested, a large proportion of the $F60$ values have an associated r^2 of less than 0.3. That is, the vast majority of the reported $F60$ values obtained during the skid resistance experiment were unreliable – the model was only able to account for less than 30% of the variation in the measured data. The poor r^2 values obtained throughout the experiment indicate that the Rado Friction Model, utilised by the RoAR, does not capture the behaviour of friction force measurements under Western Australian conditions.

4.2.2 Repeatability of Results

The lack of evidence concerning the validity of $F60$ values estimated using the RoAR, in variable slip mode, prevents the reporting of any conclusive findings on the repeatability of $F60$ estimates. Data validity must be established prior to any analysis of data repeatability. However, for the sake of completeness, the following two figures summarise the repeatability results obtained for one of the eight testing scenarios conducted on Test Site One. These results are typical of the other seven scenarios.

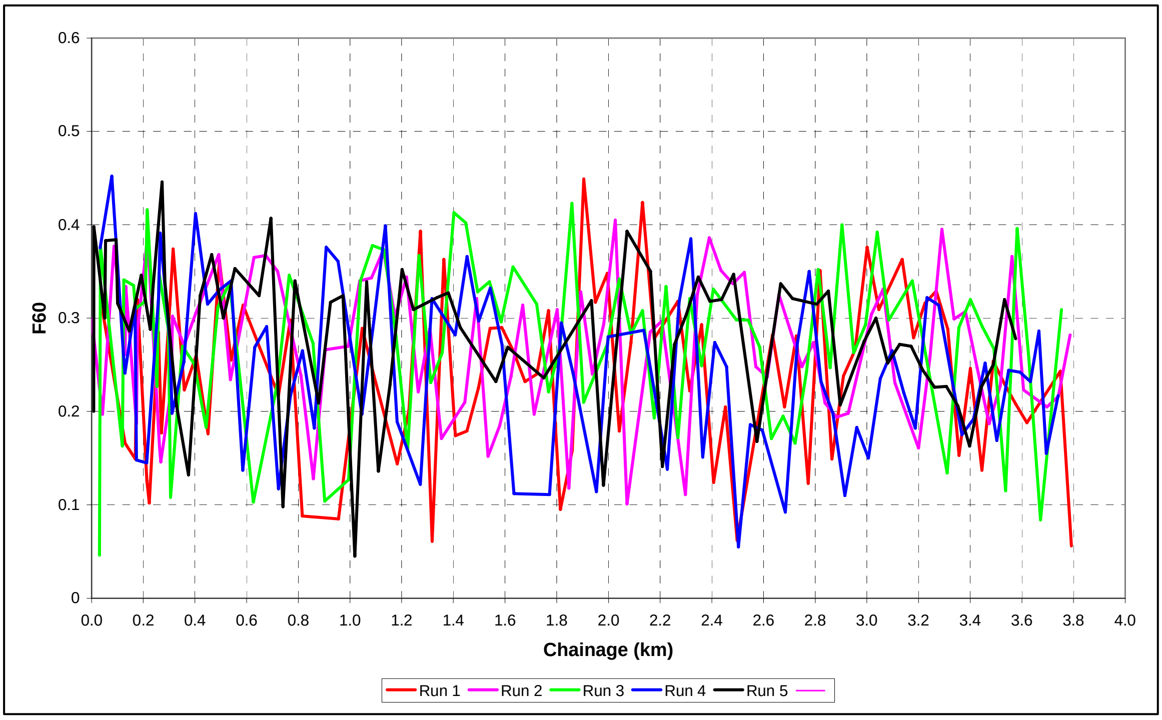

Figure 3. Repeatability of F60 values obtained from Test Site One.

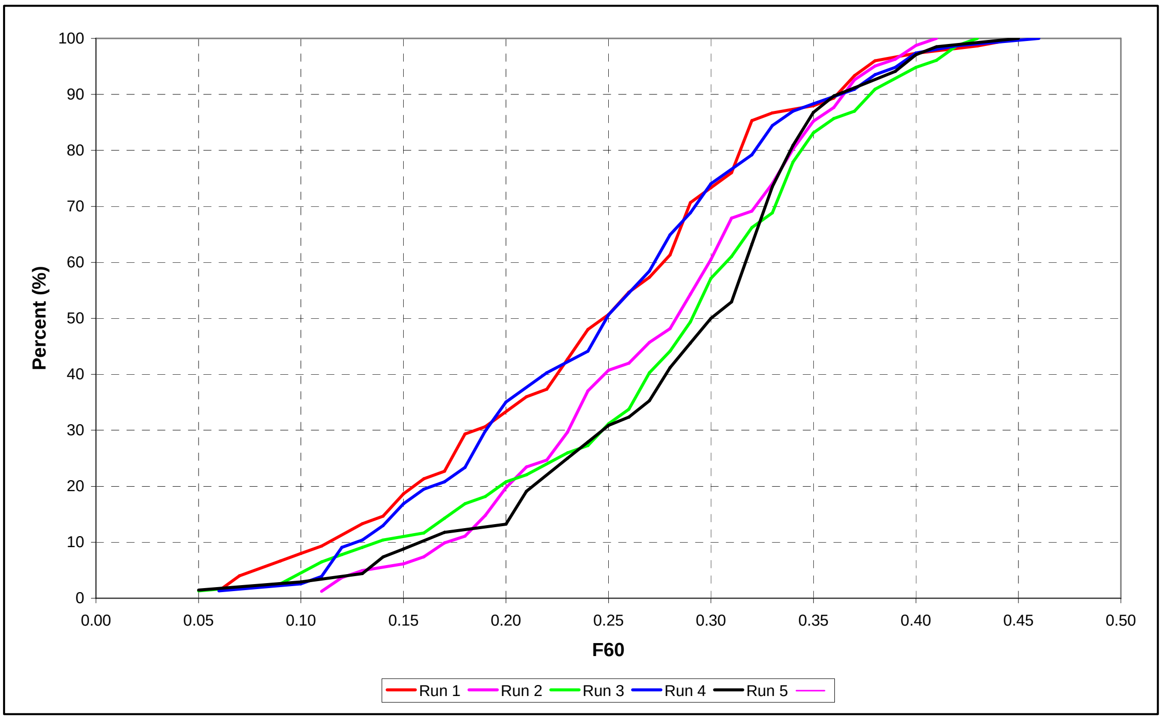

Figure 4. Cumulative distributions of F60 values obtained from Test Site One.

The above results suggest that under Western Australian conditions, estimates for $F60$ obtained from the RoAR, do not demonstrate the level of repeatability required to confidently apply the data for its intended purpose. However, it must be stressed that it is difficult to draw conclusions on the repeatability of $F60$ estimates given the issue of data validity under Western Australian conditions.

5. CURRENT POSITION

The skid resistance data collected to date has been shown to be unreliable on all surfaces tested in Western Australia. For this reason the data collection commenced in 2002 was suspended before the entire State network had been surveyed. Network level assessment of skid resistance has been suspended pending further research into the most appropriate and reliable methods to suit Western Australian conditions. It may be the case that Main Roads Western Australia had unreasonable expectations of being able to assess skid resistance, in a cost effective manner, over the large State road network of Western Australia.

6. REFERENCES

Norsemeter (200u), A Primer on Modern Runway Surface Friction Measurement, *Norsemeter Friction AS,* OSLO Norway.