Are we afraid of the IFI?

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ABSTRACT

The 1993 Harmonisation Experiment for Skid Resistance, under the auspices of The World Road Association and ASTM was designed to harmonise the plethora of Skid Resistance technologies into one unit, which would be suitable for translating all existing data into a meaningful value enabling road technologists to move forward in an understanding of Skid Resistance.

It was confirmed that skid resistance is a combination of two elements F_{60} (the Coefficient of Friction at 60kph) and Vp (the critical slip velocity).

Other vital pieces of information were the form of the friction curve as the result of a rolling wheel travelling from free rolling to fully locked condition, including a value identified as Mu $_{PEAK,}$ – the maximum friction that can be expected for the friction at defined speed.

It was demonstrated that all existing measurement systems for both skid resistance and texture depth could be harmonised to this International Friction Index (IFI – F60, Vp).

This paper looks at the harmonisation of some skid resistance technology available in Australia and New Zealand to provide key performance measures and intervention levels for Road Asset Management Systems.

The paper demonstrates that a move to harmonisation of skid resistance methodology, enables the adoption of innovative technology to conduct ”loss of control analysis” as a means of identifying potential skidding accident sites.

1. BACKGROUND

Surface friction of pavements has and always will be of extreme importance in evaluating the safety of a road pavement. The Federal Highways Administration of the USA FHWA[1] reported that of over 25 million accidents, 19% occurred on wet pavements.

In Australia (2004), the President of the National Roads and Motorists Association (NRMA) – Mr Ross Turnbull in his keynote address to the Australian Roads Federation Roads Summit, raised the spectre of the cost of road accident trauma in Australia including such statistics as:

Road Accident Trauma costs the nation $15 Billion annually,
Five people are killed and 550 injured (of which 60 are seriously) on Australian roads every day.

Each fatality is said to cost the taxpayer $1.7Million. Serious injury cases can cost the taxpayer many times the cost of a fatality (refer Palmer ats Evans Shire Council and anor. 1998), where the plaintiff was awarded $16.3 Million damages for negligence on the part of the road owner and the sealing contractor, which resulted in her tetraplegia.

The Australian High Court Decision (Brodie ats Singleton shire Council – 2001) ruled that road owners have a positive duty of care to inspect, maintain and design roads that provide a safe environment for all road users.

This question of duty of care is frequently tested in Australian courts as litigants seek compensation for both personal injuries and property damage.

The writer is frequently called to provide expert testimony with respect to the “tyre-road interaction”, whilst courts struggle to apportion responsibility as a function of the “balance of probability” required in such matters under British law.

Three pavement conditions are mostly cited for the cause of accidents:

Inability to stop in time due to “slippery surface”,
Loss of control due to surface condition,
Loss of control due to Hydro (Aqua) planing.

For these several reasons it is imperative for public safety that pavement managers undertake, not only, surface friction surveys on a routine and regular basis. But also analyse results to demonstrate and understand the meaning and consequences of the measured parameters, in particular, both the personal and public risks associated with not providing that necessary “duty of care”.

Current methodology relies on a comparison of condition monitoring results at critical sites against tables of values for road geometry and accident severity. Such methods do not take to account the variability of the fundamental properties of tyre pavement interaction.

Much of the Australian and New Zealand “state of the art” in Skid Resistance emanates from seminal studies by The Transport and Road Research Laboratories of Great Britain.

2. THE NATURE OF SKID RESISTANCE

2.1 FACTORS EFFECTING SKID RESISTANCE

On a dry pavement the friction term (F) is the dominant factor in skid resistance, however, it has been shown that the frictional effect (F) diminishes on wet pavements and with increasing vehicle speed and could become negligible in the condition of “aquaplaning” or “hydroplaning”. This directly implies that on a wet pavement the distortion term (D) is far more important, since the action of stopping is the result of deformation of the tyre by the surface asperities and the ensuing energy dissipation of the rubber.

From this brief description it can be seen that the three variables influence skid resistance and can be concluded to be: the tyre, the vehicle travelling speed (i.e. relative speed between the two opposing objects), the minute surface structure between the interfacing contact areas (texture) and possibly, a fourth parameter, contamination of the pavement surface.

2.2 SURFACE TEXTURE EFFECTS

Texture is a key variable in the friction process. The two components of the friction (F) and (D) are in fact determined by the components of surface texture, Macro-texture and Micro-texture.

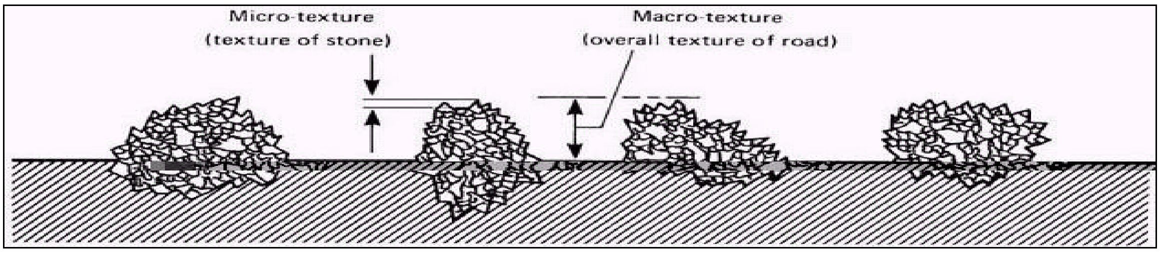

Figure 1 the components of surface texture.

2.3 FRICTION (F)

The sliding contact resistance (F) is determined by the properties of the material and the degree of polishing of the aggregates (i.e. the microtexture). The micro-texture of the pavement is the main contributor to the sliding contact resistance of the pavement surface (F) and is dependant on the tyres actually contacting the pavement surface. Micro-texture is the major factor in determining the wet skid resistance of the pavement surface at low to moderate speeds.

2.4 FEATURES AND FUNCTIONS OF MICRO-TEXTURE

- Micro-texture is the fine texture of a pavement aggregate and is defined as being less than 0.5mm deep.
- Micro-texture is determined by the nature of the road aggregate.
- Micro-texture is lost over time by the effects of polishing by vehicle tyres.
- Micro-texture is the dominant factor in skid resistance at low speeds.
- Micro-texture provides sliding contact resistance.
- Aggregates that have very fine surface micro-texture and are prone to polishing are generally excluded from use as sealing aggregates by specification of the road agency.

2.5 DISTORTION (D)

Loss of energy caused by non-elastic deformation of the tyre (D) is associated with the surface texture of the pavement (i.e. macro-texture) with its nature determined by the shape and layout of the aggregates. Macro-texture becomes the dominant factor at higher speeds allowing rapid drainage routes between the tyre and the pavement surface, also causing tyre rubber deformation (hysteric energy loss), even if surface contact does not occur.

When a water film is present on the pavement surface, penetration of the water film can only be achieved if there are sufficient sharp edges in the macro-texture on which the tyre can build up sufficient dry spots to establish a dry contact area between the pavement micro-texture and the tyre.

The faster the macro-texture asperities of the road hit the rubber the less the penetration will occur and therefore the smaller the real contact area. The smaller penetration also leads to less hysteresis energy loss (D).

This leads to:

- The faster the wheel spins the less friction there will be because of the lower contact area,
- The smaller the texture asperities in absolute size the lower the friction value will be.

i.e. the size of the macro-texture is the most dominant factor in determining rate of change in the effective pavement skid resistance.

2.6 FEATURES AND FUNCTIONS OF MACRO-TEXTURE

- Macro-texture is defined as the coarse texture of a pavement surface, in the range 0.5mm to 10mm.
- Macro-texture is determined by the size of the aggregate used.
- Macro-texture can be lost over time by the effects of flushing of the bitumen or loss of the surface aggregate.
- Macro-texture causes loss of a vehicle's kinetic energy (a function of mass and the square of the speed) through hysteresis (tyre rubber deformation).
- A suitable depth of macro-structure allows drainage paths for surface water to disperse.
- Macro-texture dominates the nature of skid resistance on wet roads and at high speeds.
- The magnitude of macro-texture controls the speed at which the tyre-pavement friction is insufficient to control the vehicle (the slip speed).

2.7 THE INTERNATIONAL FRICTION INDEX (IFI)

In 1996 an international experiment on skid resistance, conducted jointly by the Permanent International Association of Road Congresses (PIARC) and the American Association for Testing and Materials (ASTM) [2], identified that skid resistance consisted of two (2) parameters.

?? F_{60} the coefficient of friction at 60kph, which is related to the micro-texture of the surface of the road aggregate.

?? V_p the velocity of sliding friction (or slip speed), which is related to the macro-texture or the depth of the gaps between the aggregate particles.

Both components need to be present on a road surface to ensure the drivers ability to control and stop a vehicle.

Methods are available for conversion of skid resistance parameters to the IFI [3].

2.8 THE EFFECTIVE FRICTION CURVE

The fundamental reasons for measuring friction is to predict the safe braking profile of the pavement, safe travelling speed of a vehicle, and an understanding of the variation in effective friction {? f (F+D)} in a longitudinal braking or cornering process.

Figure 2 – shows a typical effective friction curve, from which it is easily seen that friction is not constant nor should it be, and varies as a function of slip speed.

It is for this reason the use of one friction number can be totally misleading.

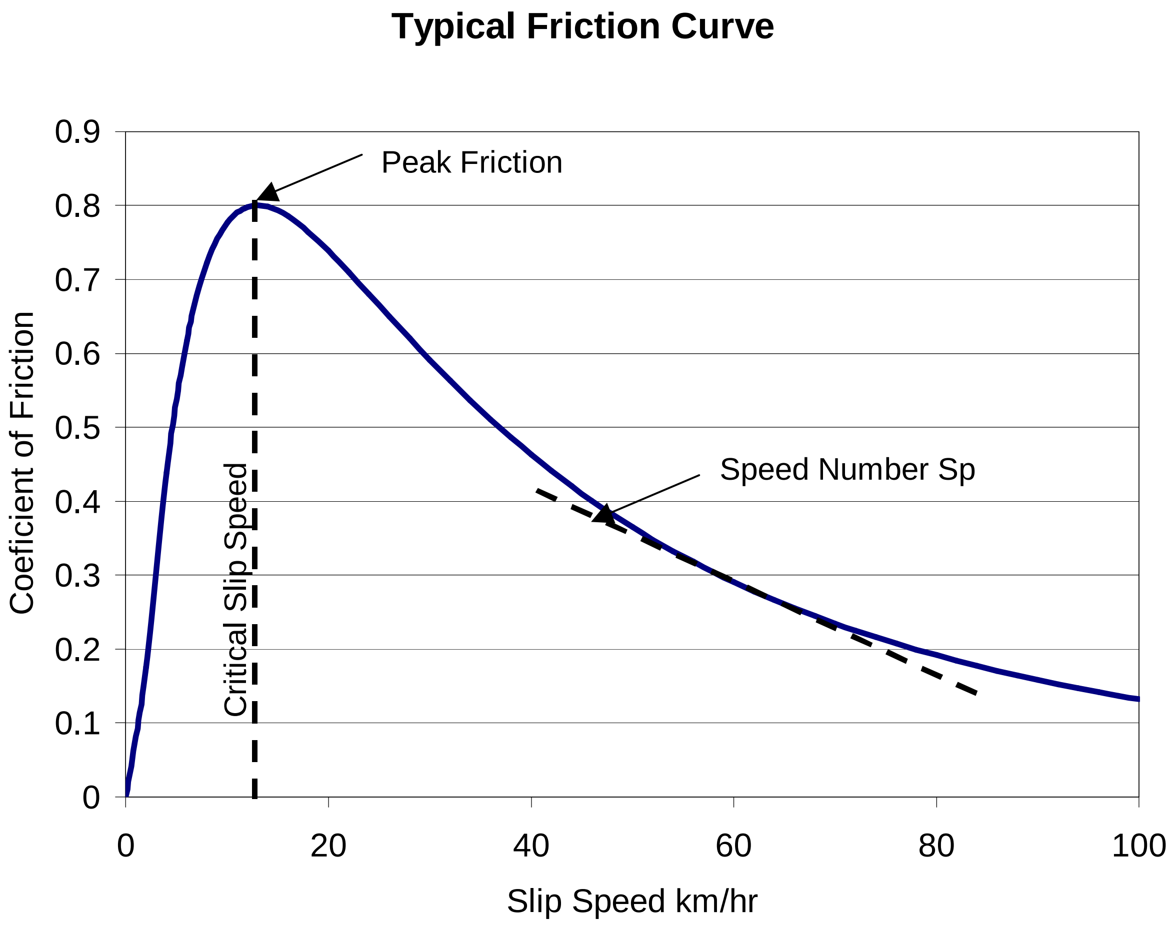

Figure 2 the tyre pavement friction curve.

In the first phase of the friction curve the wheel rotation is gradually reduced from free rolling to a locked state (i.e. the relative velocity of the wheel increases). The tyre – road friction shows that there is a distinct maximum point in the available friction, this point is commonly called the "critical slip" speed value and corresponds to the peak friction on the pavement surface (Mu_{PEAK}).

2.9 THE FUNDAMENTALS OF SKID RESISTANCE

?? Tyre/pavement friction provides the forces necessary to stop a moving vehicle.
?? Increasing speed produces decreasing penetration of tyre rubber by aggregate particles and thus less available tyre/pavement friction.
?? Available tyre/pavement friction is dependent on slip speed.
?? Slip speed is defined as the vehicle speed minus the tyre speed.
?? Peak friction Mu $_{PEAK}$ is the maximum available friction and occurs at the critical slip speed.
?? Every time the brakes are applied, the tyre/pavement interaction follows the path of the effective friction curve from left to right.
?? At the instant when the brake is first applied, tyre speed = vehicle speed and slip speed is zero.
?? As the slip speed increases towards the critical slip speed, the tyre is the major factor affecting the tyre/pavement interaction and available friction increases.
?? At speeds in excess of the critical slip speed there is always a component of slipping between the tyre and the pavement, therefore the available friction is less than the peak friction.
?? When the brakes are fully locked, slip speed equals vehicle speed and the available friction is low.

This is the behaviour of the ABS braking system. ABS increases average available friction by preventing the brakes from becoming fully locked and keeping the available friction close to Mu $_{PEAK}$. Under braking, the braking forces are applied and the slip speed increases until the critical slip speed, and peak friction, is reached. The braking forces are then removed, returning the slip speed to zero, and reapplied. This rapid and continuous removal and reapplication of the braking forces keeps the tyre/pavement interaction in the early part of the effective friction curve and results in higher average available friction.

Eventually the vehicle speed is reduced and higher components of friction are available as the vehicle stops or return to control.

3 MEASUREMENT OF SKID RESISTANCE

Three principal methods are currently available in Australia and New Zealand for the measurement of skid resistance these are the SCRIM, Griptester and the British Portable Tester BPT.

Two methods are available for determination of texture depth The Mean Profile Depth and Sand Patch Method.

At this time none of these methods provide the full friction curve. The Norsemeter ROAR, in the variable slip mode, is one test device that provides the full friction curve at this time – Norsemeter units are available in Australia and New Zealand, but have been plagued by mechanical and operational problems with most authorities abandoning this promising technology.

3.1 SCRIM- THE (SIDEWAYS-FORCE COEFFICIENT ROUTINE INVESTIGATION MACHINE (REFERENCE 2)

SCRIM was developed by the Transport and Road Research Laboratory of Great Britain in 1977. Two smooth tyres are free rolling parts of a test truck and run at an angle of 20? to the direction of travel in each wheel path. A water tank in the vehicle keeps the road in front of the wheel wet and the test wheel has its own deadweight and suspension. Electrical resistance load cells measure the sideways force produced. The operating speed is usually 50 to 80km/h and the test output is the lowest 20m of SFC in each 100m. Seven SCRIM devices took part in the PIARC harmonization experiments.

The relative velocity between the rubber and the pavement surface for these devices is in the order of 17km/h slip speed; therefore these vehicles produce a low speed measurement even though the vehicle velocity is high. Since they are low speed systems they are primarily sensitive to micro-texture, therefore reported results are generally below peak friction (see figure above).

For this reason they are generally used today in conjunction with a macro-texture measurement.

SCRIM tests are generally measured in each wheel path (left and right) and reported as such.

SCRIM at 50 kph (SFC_{50}) results can be harmonised to the International Friction Index $F_{\mathbf{60}}$.

Results are normally averaged over a 20m section and aggregated as a “rolling average“ to provide a value for each 100m increment.

F_{60} can be directly computed from SFC_{50} by the relation:

$F_{60}=SFC_{50} * \exp(-43/Vp)$
Vp = the slope of the effective friction at a given slip speed; where Vp = A + b*Tx

Where Tx is the measurement of texture depth as the Mean Profile Depth (MPD) (ASTM E-1845-01)

$Vp = 14.2 + 89.7\ MPD$

Where Tx is the measurement of texture depth using the “Sand Patch“ method (ASTM E965-96; re-approved 2001)

$$Vp= -11.6 +113.6* Tx$$

3.2 THE GRIPTESTER (COURTESY D. WILSON – UNIVERSITY OF AUCKLAND NZ)

The GripTester is manufactured by Findlay Irvine Ltd in Scotland and consists of a small three-wheeled trailer (one measuring test wheel and two bogey drive wheels) weighing approximately 87kg in weight. It is a Continuous Friction Measuring Equipment (CFME) device that can be operated between speed ranges of 5km/h, (generally in push mode) and up to 130km/h when towed behind a vehicle. It is commonly used for friction measurements allowing testing on roads, airfields, helipads and footway surfaces and can be used for research purposes or more recently for monitoring road networks. The GripTester is a compact, flexible and highly manoeuvrable tool that is relatively inexpensive to operate.

The GripTester is a fixed slippage device with the measuring wheel fitted with a smooth ASTM standard tyre that is geared to rotate at a proportionally different rate, thereby producing a 14.5% slip relative to the drive wheels. The drag force induced on the slipping wheel and the vertical force are monitored, and the calculated friction coefficient (called GripNumber - GN) is logged on a computer file.

As the GripTester has only one test wheel, results are typically obtained for the left wheel path only, but can be obtained from the right wheel path given appropriate traffic management. GripTester Surveys are normally carried out on a wetted surface. Water can be applied by an automatic pump system that applies a nominal specified depth of water under the slipping wheel based upon the testing speed. The GripTester has undergone comprehensive evaluation in Europe in terms of its precision and correlation with other friction devices and took part in the original PIARC harmonisation experiment in 1992.

The Griptester produces a Friction value called the Skid number (SN).

Results are normally averaged over a 20m section and can be converted to F_{60} by the relationship:

$$F60=SN*\exp(-50.6/Vp)$$

Where Vp is as defined above.

3.3 THE BRITISH PORTABLE TESTER

The British Portable Tester has been recognized for over forty years as a standard method for determination of the friction at the tyre/road interface. The major limitations for this device are occupational health and safety issues, with personnel required to be physically on the road during the testing phase.

BPT results *BPN) can be converted to F60 values through the relationship:

$$F_{60}=0.0436+0.0095*BPN *\exp(-50/Vp)$$

Where Vp is as defined above for both MPD and Sand Patch method.

4 INTERPRETATION OF RESULTS

4.1 SCRIM RESULTS

New Zealand specification for Skid Resistance Investigation and Treatment Selection (TNZ T10: 2002) provides a useful document for categorizing both investigation and action levels for skid resistance in terms of SCRIM, site conditions and road geometry (curvature and gradient). It is interesting to note, however, that a critical component for loss of control accidents that is cross fall (or camber) is not specified. Table 1, from that document is reproduced following.

4.1.1 Table 1

Site Category		Investigatory Level (IL)	Threshold Level (TL)
1	Approaches to: Railway level crossings Traffic lights Pedestrian crossings Roundabouts Stop and give Way controlled intersections (where the State Highway traffic is required to stop or give way) One Lane Bridges (including bridge deck)	0.55	0.45
2	Curve <250m radius Down gradients >10%	0.50	0.40
3	Approaches to road junctions (on the State Highway or side roads) Down Gradients 5 – 10% Motorway junction area including On/Off Ramps	0.45	0.35
4	Undivided carriageways (event-free)*	0.40	0.30
5	Divided carriageways (event-free)*	0.35	0.25

Investigatory Skid Resistance Levels
(Reference 5)

*Event-Free = Where no other geometrical constraint, or situations where vehicles may be required to brake suddenly, may influence the skid resistance requirements**.**

4.2 TEXTURE DEPTH

Texture Depth in terms of the Mean Profile Depth (MPD) is defined by the State Highways Asset Manual (reference 9) as being required for the RAMM database from the annual SCRIM survey. This document does not, however, provide a detailed specification for texture depth and for this purpose we must turn to the lecture notes by Transit's Surfacing Engineer – David Cook – reference 8. The following table is extracted from that source.

4.2.1 Table 2

Texture Depth

Site conditions	Investigation Level Texture (MPD)	Threshold Level Texture (MPD)
Posted Speed >= 70 km/hr	0.9mm	0.7mm
Posted Speed < 70km / hr	0.7 mm	0.5mm

The Sand Circle Test may measure the texture depth of a pavement. For this test a known quantity of a single sized sand (or glass balls) is placed on a pavement and screeded with a rule to form a circle of sand filling all the interstices between the aggregate particles. The diameter of this circle is measured and used to compute the Average Texture Depth of the seal [4].

4.3 PEAK FRICTION

Peak Friction (Mu PEAK) is the maximum tyre/road friction that can be achieved, just prior to a slip component of friction developing in the friction curve. This is the desired value, to which ABS designers aspire. Unless a test device can compute the full Friction/Slip speed curve (figure 1) the value of friction (Mu) will invariably by less than this value. There is no harm in this except results will generally be sub optimal and less than that which is achievable.

5 INVESTIGATORY LEVELS FOR SKID RESISTANCE IN TERMS OF IFI

Therefore if we combine table 1 and Table 2 to include the fundamentals of the IFI we can develop a new table as follows.

Site category 1 will seldom be signposted at speed > 70 km/hr therefore the requirement for texture depth is a minimum of 0.7mm and 0.5mm respectively, to give:

5.1.1 Table 3

Site Category		Investigatory Level (IL)	
For Speeds less than 70 km/hr		**IFI**	**IFI**
1	Approaches to: Railway level crossings Traffic lights Pedestrian crossings Roundabouts Stop and give Way controlled intersections (where the State Highway traffic is required to stop or give way) One Lane Bridges (including bridge deck)	(0.30,75)	(0.26,60)

Investigatory levels for Skid Resistance (IFI)
Site Category 1

Site categories 2, 3, 4 & 5 clearly can have speeds signposted at more than 70 km/hr therefore two criteria apply;

5.1.2 Table 4

Site Category		Investigatory Level (IL)	
For Speeds more than 70 km/hr		**IFI**	**IFI**
2	Curve <250m radius Down gradients >10%	(0.32,95)	(0.23,75)

Site Category		Investigatory Level (IL)	Threshold Level (TL)
For Speeds less than 70 km/hr		**IFI**	**IFI**
2	Curve <250m radius Down gradients >10%	(0.32,75)	(0.23,60)

Investigatory levels for Skid Resistance (IFI)
Site category 2

5.1.3 Table 5

Site Category		Investigatory Level (IL)	
For Speeds more than 70 km/hr		**IFI**	**IFI**
3	Approaches to road junctions (on the State Highway or side roads) Down Gradients 5 – 10% Motorway junction area including On/Off Ramps	(0.30,95)	(0.20,75)

Site Category		Investigatory Level (IL)	
For Speeds less than 70 km/hr		**IFI**	**IFI**
3	Approaches to road junctions (on the State Highway or side roads) Down Gradients 5 – 10% Motorway junction area including On/Off Ramps	(0.30,75)	(0.20,60)

Investigatory Levels for Skid Resistance (IFI))
Site Category 3

5.1.4 Table 5:

Site Category		Investigatory Level (IL)	
For Speeds more than 70 km/hr		**IFI**	**IFI**
4	Undivided carriageways (event-free)*	(0.25,90)	(0.17,75)

Site Category		Investigatory Level (IL)	
For Speeds less than 70 km/hr		**IFI**	**IFI**
4	Undivided carriageways (event-free)*	(0.25,75)	0.17,60)

Investigatory Levels for Skid Resistance (IFI)
Site Category 4

5.1.5 Table 6

Site Category		Investigatory Level (IL)	
For Speeds more than 70 km/hr		**IFI**	**IFI**
5	Divided carriageways (event-free)*	(0.22,95)	(0.17,75)

Site Category		Investigatory Level (IL)	Threshold Level (TL)
For Speeds less than 70 km/hr		**IFI**	**IFI**
5	Divided carriageways (event-free)*	(0.22,75)	(0.15,60)

Investigatory Levels for Skid Resistance (IFI))
Site Category 5

6 USING IFI FOR PAVEMENT MANAGEMENT

By developing F60 as a function of the Slip Speed (Vp) it is possible to prepare a plan for the management of skid resistance issues. For example in the following table we have determined critical F60 values for Category 1 sites as a function of both investigation and intervention levels from which it can be seen that the lower the MPD, the less tolerant is the pavement skid resistance.

6.1.1 Table 7

		SCRIM=0.55	SCRIM=0.45
MPD	Vp	F60 Investigation	F60 Intervention
0.3	40	0.19	0.16
0.5	60	0.27	0.22
0.7	75	0.31	0.26
0.9	95	0.35	0.29
1.1	115	0.38	0.31
1.3	130	0.40	0.32
1.5	150	0.41	0.34
1.7	165	0.42	0.35
1.9	185	0.44	0.36

Investigatory and Intervention Levels for SCRIM as a function of MPD

This table can be transcribed to a graphical format enabling the Pavement Engineer to evaluate the response required to deal with the problem. Clearly methodologies described by Sullivan (Reference 5) and in papers submitted to this conference, by the same author, are invaluable in considering this safety issue within the policy of both sustainability and risk amelerioration.

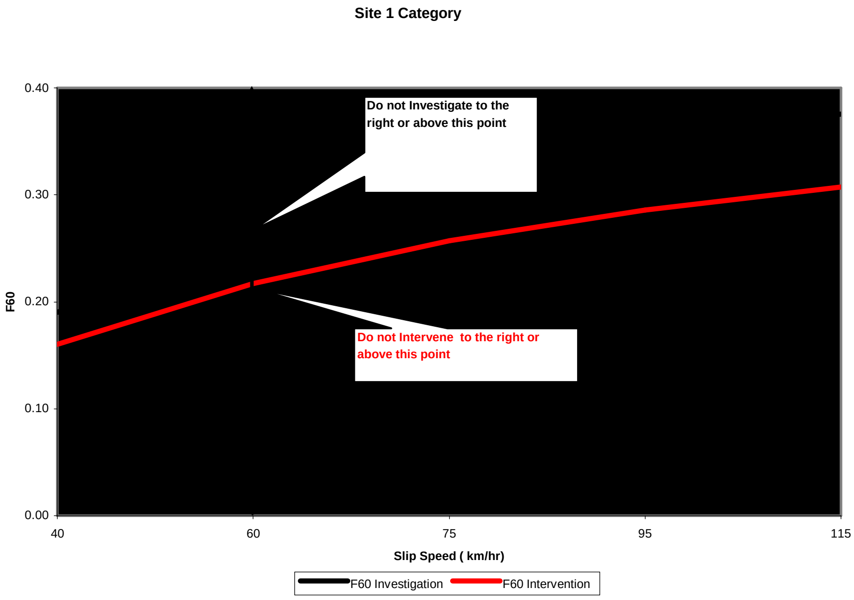

Figure 3: Investigation tool For Site 1 Category

7 CONCLUSIONS

1. The International Friction Index (IFI) represents a method for reporting both components of the tyre/road pavement interaction, which we call “Skid Resistance”.

2. The IFI provides a methodology for incorporating both the parameters of SCRIM and Mean Profile Depth as criteria for investigation of subject sites and maintenance response.

3. The IFI provides a tool for harmonizing the three test methods currently available in New Zealand and Australia against a controlled experiment, conducted and supervised by leading testing and analysis authorities. Why therefore should we adopt a policy of localized calibration to convert backwards, when clearly we have the tools to move forward without loss of previously held data, taking advantage of innovative technologies available elsewhere?

4. The tools are available to enable pavement engineers, irrespective of the technology available to them to test, evaluate, respond to maintenance requirements at the same time as developing innovative technology.

5. Why then are we afraid to embrace the IFI technology?

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