The New Zealand Skid Resistance Policy and Crash Rate and Skid Resistance Trending for the Different Site Categories

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ABSTRACT

The NZ Transport Agency and previously Transit NZ have implemented a skid resistance policy for state highways. This policy aims to improve the safety of road users by equalizing, across the state highway network, the risk of having a skidding crash in the wet.

Various studies have been carried out to determine the effectiveness of the skid policy in terms of crash reductions compared to costs and it has been found that the skid policy has a very good benefit:cost ratio (e.g. Cook et al., 2011).

This paper focuses on the effect the skid resistance policy has had over the period 2003-2012 in reducing wet crash rates and numbers by providing skid resistant road surfaces. The study for this paper therefore involved investigating the changes in crash rates and numbers over this 10-year time period for the various skid site categories for each of the 24 Highway Network Management Areas together with network skid resistance levels. Differences in wet crash rates and skid resistance levels between Network Management Areas were identified, highlighting the need to better promote skid resistance management practices within the roading industry.

The opportunity was also taken to update existing comparisons of state highway crash rates with territorial local authority crash rates to the end of 2012. This showed crash rates to be decreasing, but more so for state highways where a sound skid resistance policy is in effect.

Keywords: skid resistance, SCRIM®, crash, T10, NZTA, state highway, TLA.

1 INTRODUCTION

It is commonly accepted that the probability of a "wet" skidding crash is lessened when the road surface skid resistance is high (e.g. AASHTO, 2008). Although a sensibly high level of road surface skid resistance is often cited as an engineering measure that can provide very good value for money, very little supporting evidence has been provided, particularly for skid resistance management at a nationwide level. An exception is the paper of Cook et al. (2011) which specifically investigated the skid resistance policy for New Zealand's (NZ's) State Highway (SH) network and demonstrated that the policy was cost effective.

This current paper further investigates the effectiveness of NZ's current skid resistance policy for SHs by plotting crash numbers, wet:dry crash number ratios, crash rates and network skid resistance averages for the 24 Network Management Areas (NMAs) making up NZ's SH network.

In addition to this investigation, existing 1995-2008 SH and Territorial Local Authority (TLA) crash rate comparisons are extended to the end of 2012.

2 NZ'S T10 SPECIFICATION FOR SH SKID RESISTANCE MANAGEMENT

The NZ Transport Agency's (NZTA's) T10 specification for skid resistance investigation and treatment selection was introduced progressively from 1997 (Owen and Donbavand, 2005). There was an expectation that it would reduce significantly the occurrence of "wet" road injury crashes on NZ's SH network. Table 1 below reproduces Table 1 from the current T10 specification (NZTA, 2013a).

A major change to the T10 specification occurred in 2010 when the investigatory skid resistance level (IL) of rural curves with a horizontal radius of curvature of 400m or less became assigned on the basis of low, medium or high crash risk (Cenek et al, 2011).

Table 1: T10:2013 skid resistance site categories and corresponding investigatory and threshold Equilibrium SCRIM (Sideways-force Coefficient Routine Inspection Machine) Coefficient (ESC) levels (NZTA, 2013a)

Site category	Skid site description	Investigatory level (IL), units ESC					
		0.35	0.40	0.45	0.50	0.55	0.60
1	Approaches to: a) Railway level crossings b) Traffic signals c) Pedestrian crossings d) Stop and Give Way controlled intersections (where state highway traffic is required to stop or give way) e) Roundabouts. One lane bridges: a) Approaches and bridge deck.						
2	a) Urban curves <250m radius						
	b) Rural curves <250m radius			L	M	H	
	c) Rural curves 250-400m radius		L	L	M	H	
	a) Down gradients >10%. b) On ramps with ramp metering.						
3	a) State highway approach to a local road junction. b) Down gradients 5-10% c) Motorway junction area including on/off Ramps d) Roundabouts, circular section only.						
4	Undivided carriageways (event-free).						
5	Divided carriageways (event-free).						

Notes to Table 1:

- When using seasonally corrected data, ILs are for mean skidding resistance within the appropriate averaging length. This is referred to as the Skid Assessment Length (SAL). The SAL for each site category is detailed in table 2
- the curve risk rating on rural curves with radii 0-400m is shown as H, M or L (high, medium or low-risk curves) in the appropriate greyed IL band under site categories 2b and 2c. Two options are available for rural low-risk sites with radii between 250m and 400m. Urban curves with a radius less than 250m are site category 2a
- the units for IL in table 1 are ESC, being the average of the left and right wheelpaths. Where seasonally corrected data is not available, SCRIM coefficient (SC) may be used as an approximation to ESC with further checks undertaken when seasonal corrections are available
- where the length of the feature is less than the SAL, the actual length shall be averaged and considered.

3 INVESTIGATIONS OF THE EFFECT OF THE T10 SPECIFICATION

In order to assess the effectiveness of the T10 specification, two investigatory analyses were undertaken:

1. An analysis of SH crash rates and skid resistances by T10 skid site category over the 10-year period 2003-2012.
2. A nationwide comparison of SH and TLA Fatal (F) and Serious (S) injury crash rates over the 18-year period from 1995-2012. (This time period spans the introduction of the T10 specification, allowing both its initial and continuing impact on crash rates to be investigated.)

4 SKID RESISTANCE AND CRASH TRENDS ON SHs BY T10 SKID SITE CATEGORY: 2003-2012

4.1 DATABASE GENERATION

The method by which the database used for this skid site category analysis was prepared is outlined briefly along with a graph and numerical tables in Appendices A-C.

4.2 WET CRASH RATE "EQUALISATION"

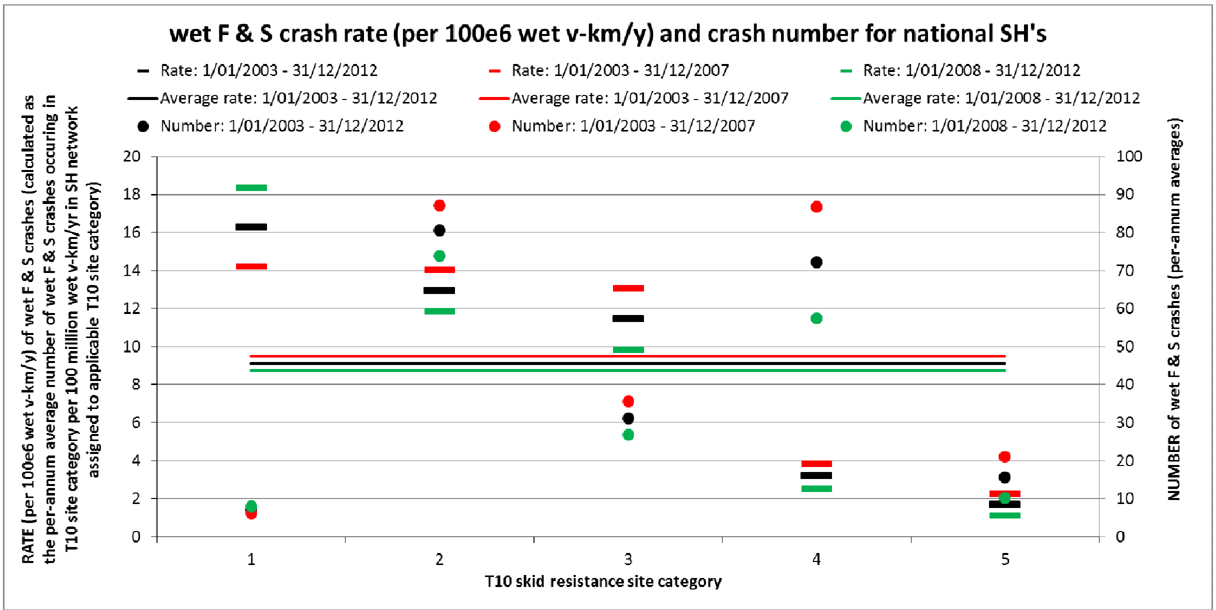

Figure 1: SH F and S crash numbers and rates

With reference to Figure 1, it appears that there may be scope for further fine tuning the application of the T10 specification to enhance meeting the T10 objective 3.2(1) of 'equalising the risk of a wet road or skidding crash across the state highway network'. (Of the five T10 skid site categories, category 1 (approaches to railway crossings, traffic signals, pedestrian crossings etc.) has the highest rate of "wet" F and S crashes. (It should be noted the actual number of "wet" crashes for this skid site category is low; the rate is high because the exposure is low (refer Appendix A).) At the other extreme, the number and rate of "wet" crashes is lowest for skid site category 5 (divided carriageways, event free).)

4.3 5-YEARLY WET CRASH RATE TRENDS

4.3.1 Variation with skid site category

With reference to Figure 1, for 4 of the 5 T10 site categories the 5-year "wet" F and S crash rates are lower in the period from 2008-2012 than they were in the earlier 5–year period from 2003-2007. It can be seen also that the average rates of these crashes is reducing (2003-

2007 average "wet" F and S crash rate = 9.5 crashes per wet 100e6 veh-km/yr, 2008-2012 average "wet" F and S crash rate = 8.7 crashes per wet 100e6 veh-km/yr).

4.3.2 Variation with NMA

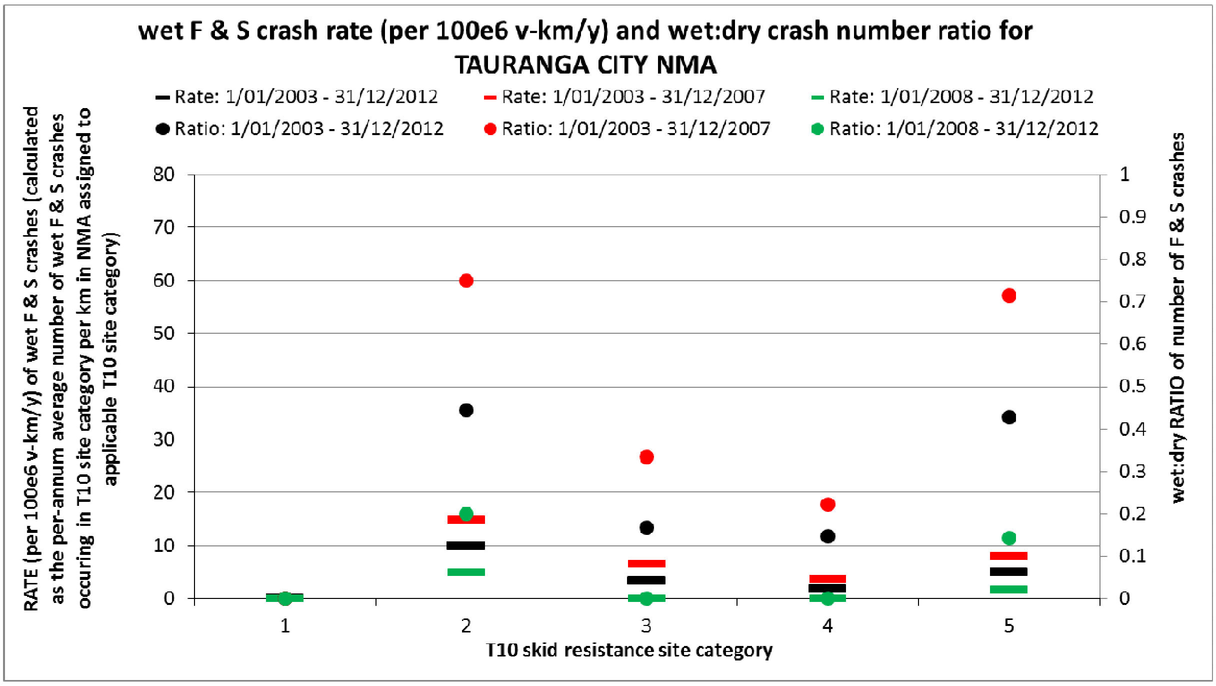

Figure 2: TAURANGA CITY NMA crash trending

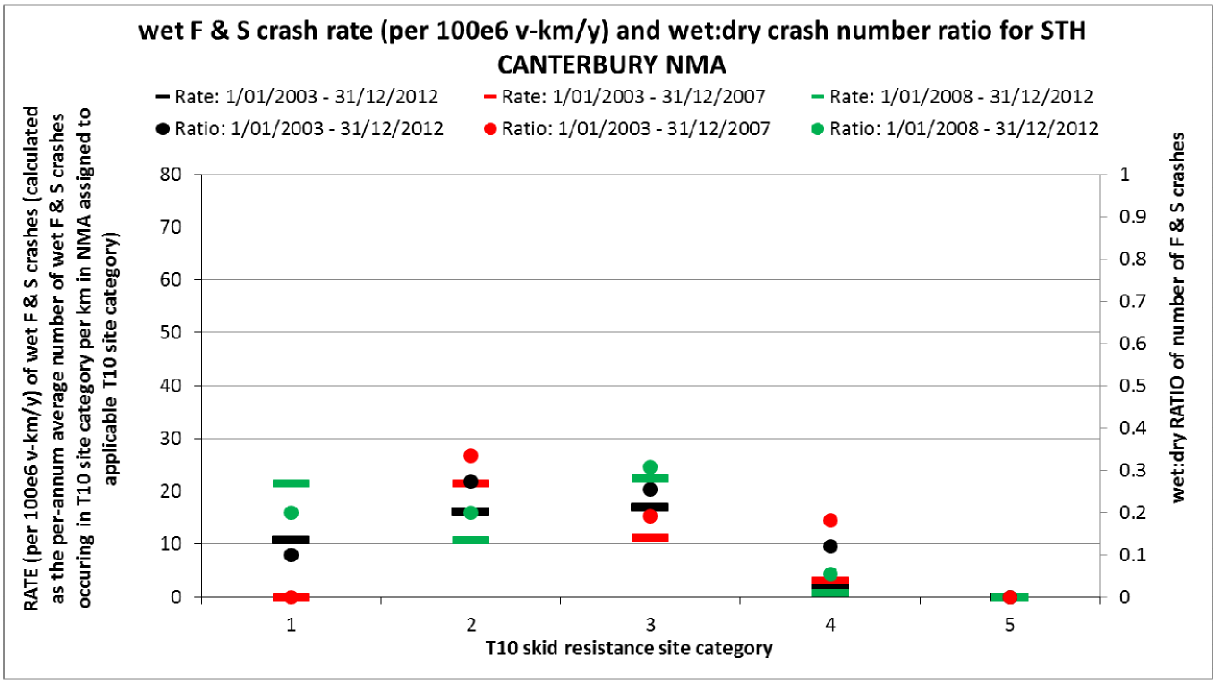

Figure 3: STH CANTERBURY NMA crash trending

Comparisons indicate that in some NMA regions, the "wet" crash rates and wet:dry crash number ratios increased over the period 2008-2012 compared with 2003-2007, while in other NMAs they decreased. For example, in Figure 2 (TAURANGA CITY NMA) the wet crash rates and wet:dry crash ratios for all T10 skid resistance categories trended down with time

or were static, compared with Figure 3 (STH CANTERBURY NMA) in which the "wet" crash rate and wet:dry crash ratios increased with time for some T10 skid site categories.

These two examples suggest that some NMAs may benefit from further training and application of road network safety management.

4.3.3 Variation nationally

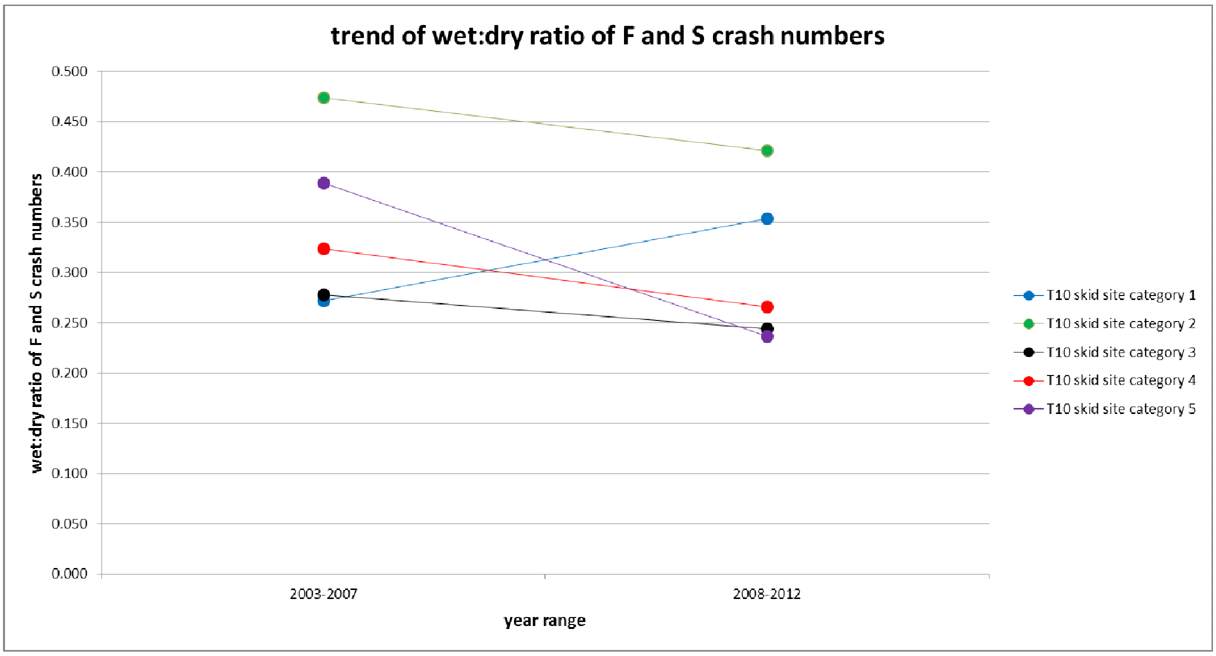

Figure 4: Trend of wet:dry crash numbers

It is apparent from Figure 4 that, nationally for the SH network, the ratio of wet:dry crash numbers is trending downward for 4 of the 5 skid site categories. The exception is T10 skid site category 1 (approaches to railway crossings, traffic signals, pedestrian crossings etc.).

It is interesting that this trend for crash number ratios is consistent with that for wet crash rates in Figure 1. Little significance should be given to the ESC generally trending downwards during the same period (Figure 6), as a host of non-T10 wet crash counter-measures have been introduced over the decade considered (e.g. adoption of cars with electronic stability control etc).

With reference to Figure 4, the ratio of wet:dry F and S crashes is highest for T10 skid site category 2 (i.e. curves, steep down gradients and metered on ramps).

4.4 SH ESC SKID RESISTANCE

4.4.1 Variation with skid site category

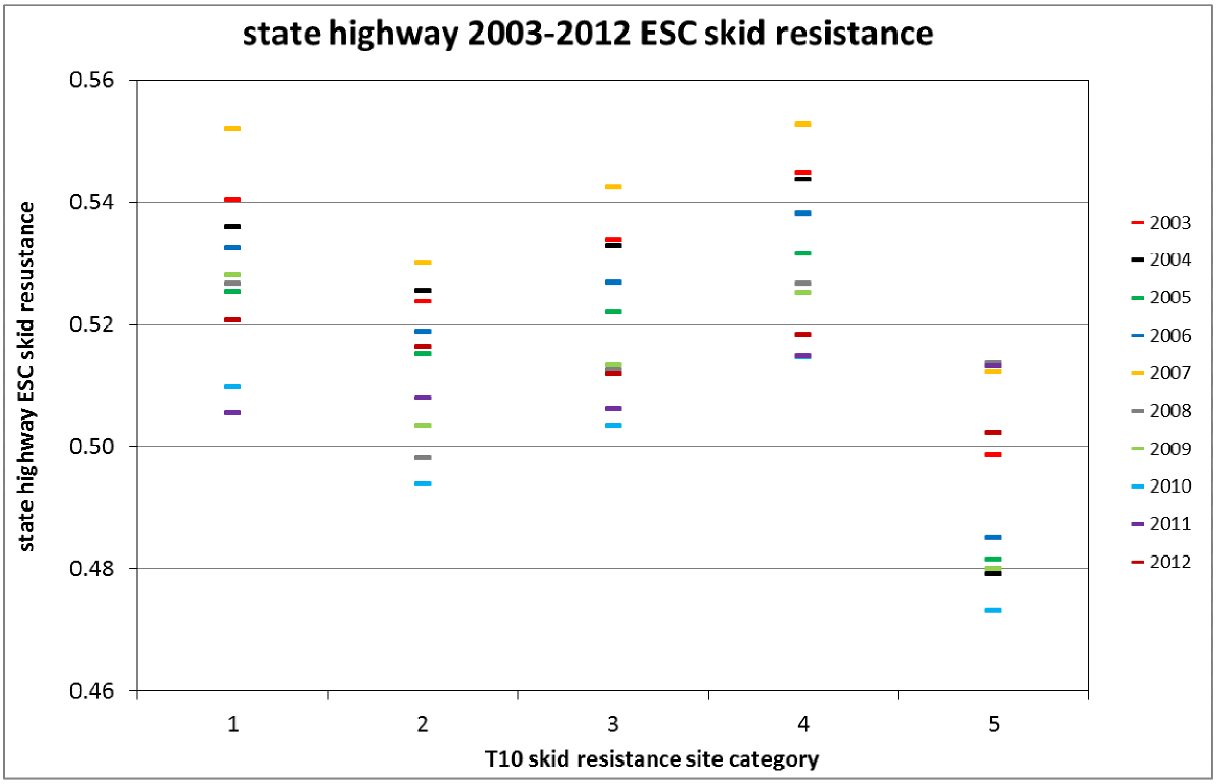

Figure 5: SH ESC by T10 skid resistance category: 2003-2012

Figure 5 shows the ESC skid resistance for the years 2003-2012 on the SH network. It is evident that the range of ESC skid resistance across the 5 categories for this 10-year period is moderate, with all values being encompassed by a range of less than 0.46-0.56It also appears that:

1. There is a trend of reducing ESC with year. (This trend is more clearly apparent from inspecting Figure 6 on the following page).
2. There may be opportunity to refine the manner in which the T10 specification is applied so that category 2 ESC > category 3 ESC > category 4 ESC (compare these actual ESCs with those specified in Table 1).

4.4.2 Trending over 2003-2012

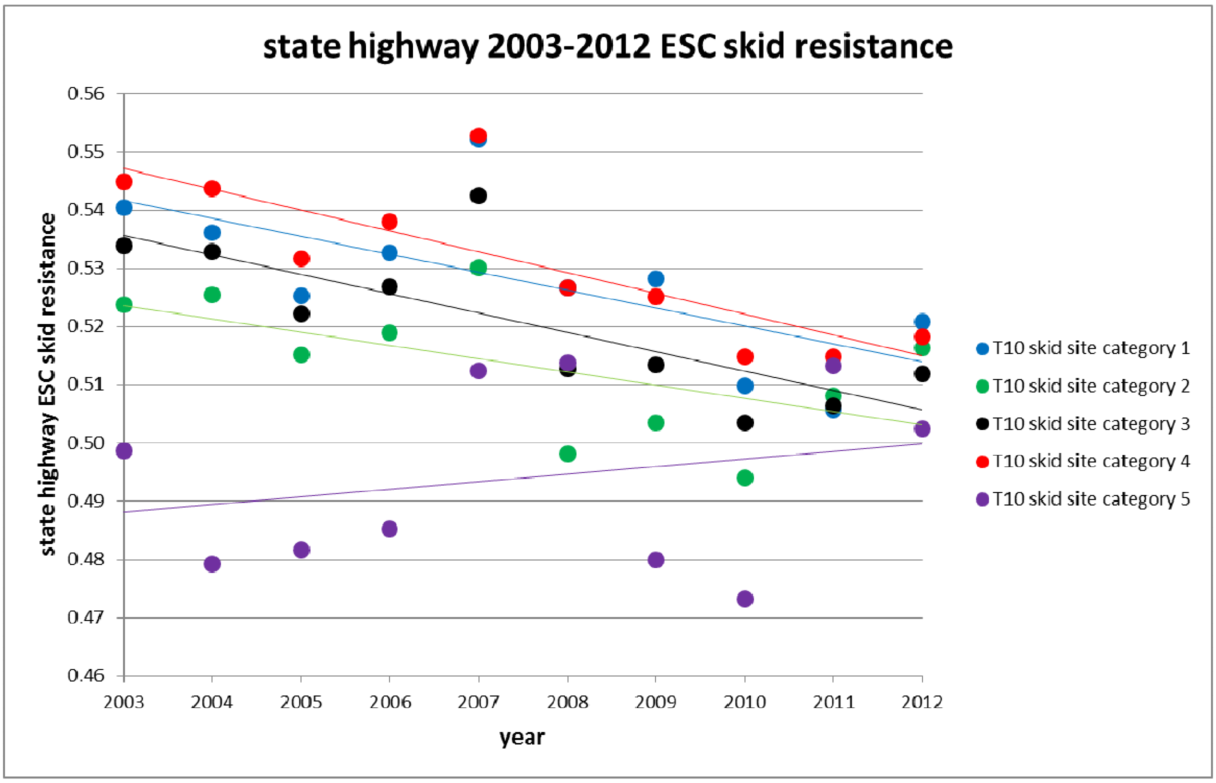

Figure 6: SH ESC trend over 2003-2012

For 4 of the 5 T10 skid site categories, Figure 6 shows there is a trend on the SH network of ESC decreasing slightly over the ten years from 2003-2012. (In the figure, the circle symbols are data points and the lines are least-squares linear fits.)

The above figure shows that for all 5 T10 skid resistance categories in 2007 the average ESC was approximately 4% (0.02/0.51) higher than the trend lines. Investigations undertaken suggest that this appears to be due partly the ESC factor used (see Figure 11 in Appendix D). It is not thought to be due to an actual marked physical change in SH network skid resistance in 2007.

With reference to Figure 7 on the following page, there is no obvious effect on wet crash numbers of this 2007 ESC increase either, further suggesting that there wasn't an actual marked physical change in SH network skid resistance in 2007.

Since 2007, the data available for seasonal correction has improved with seasonal correction sites now using 5km of SFC data (in 2007 and preceding years it was 1km) and an increase in the number of seasonal correction sites to 114 (in 2007 and preceding years 70 were used). It is therefore anticipated that correction issues such as the above will be less frequent in future.

Darnell (2007) provides additional information on the ESC calculation for 2007.

4.4.3 Correlations

It is apparent from the R^2 correlation coefficients of Appendix E that the 5 skid resistance categories have widely differing sensitivities to the 10-year average of skid resistance. The two T10 skid site categories that have the highest correlations of "wet" F, S, M (minor injury) & N (non-injury) crash rate with skid resistance are T10 skid site category 2 (curves, steep

down gradients and metered on-ramps) and T10 skid site category 4 (undivided carriageways, event free). For these two T10 skid site categories, it would seem maintaining a satisfactorily high level of skid resistance is a particularly effective "wet" crash rate reduction measure.

The correlations in Appendix E are modest at best as there are a host of "wet" crash rate influences other than skid resistance (e.g. gradient, curvature, crossfall etc.).

4.5 THE RELATIONSHIP BETWEEN CRASH RATES AND SKID RESISTANCE

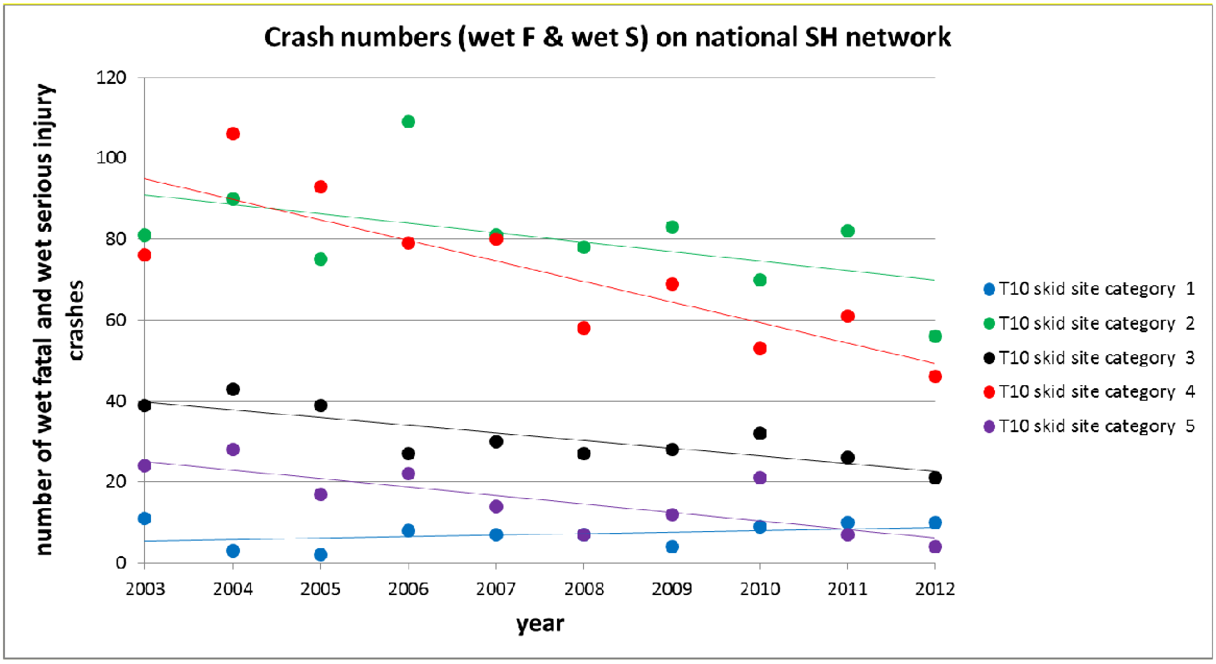

Figure 7: Wet crash numbers

Consistent with Figures 1-3, Figure 7 above shows that, generally, the number of wet fatal and serious injury crashes has been reducing over the period 2003-2012. During this same decade, Figure 6 shows that the SH ESC has been generally been reducing very slightly.

The T10 skid resistance policy was in effect during this decade of reducing crash numbers and ESC reductions. However, it is not thought possible to analyse the data in this section (i.e. section 4) to clearly show the T10 policies' might have contributed to these crash rate reductions. The comparative study in the following section (i.e. section 5) is more suitable for this, although the data is limited in that it is not pigeon-holed by T10 skid site category.

5 CRASH TREND COMPARISON ON SH AND TLA ROADS: 1995-2012

5.1 METHODOLOGY

Since 2004, it has been a requirement that all roading authorities implement a skid resistance policy in order to receive maintenance funding as part of the National Land Transport Programme (NLTP), administered by the NZTA. In comparison to the NZTA, TLAs are variable in their management of skid resistance. Historically, where traffic flows are high, many implement a skid resistance policy similar to T10, but it appears that not all implement this over the whole of their network. The relative effectiveness of the different approaches to skid resistance management of road networks adopted by the NZTA for SHs and TLAs for

local roads can be established through time-series movements of crash rates over the 18 year period from 1995-2012.

5.2 DATABASE GENERATION

The database of exposures, crash numbers and crash rates used for this comparative crash analysis along with the method by which it was prepared is outlined briefly in Appendices F-H.

5.3 RURAL CRASH RATE TRENDS

In the analysis that follows, the change in crash rate is taken from a base of 1998. This is because the T10 skid resistance specification was issued in 1997, but as a result of progressive implementation its full effect did not become apparent until a number of years later.

Figure 8 indicates that there was a substantial drop in crash rates between 1998 and 2000. This is thought to result partly from crash number database issues in this period.

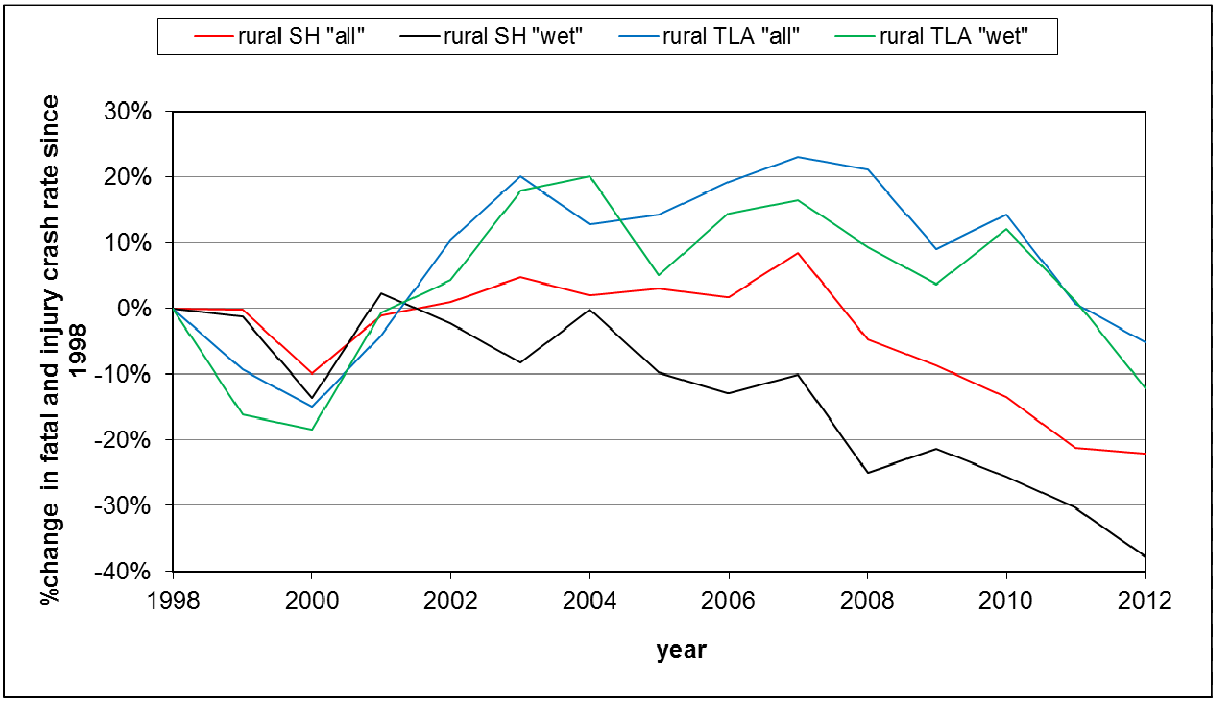

Figure 8: Rural road crash rate %changes since 1988

With reference to Figure 8, the crash rates on the rural SH network are trending downward for the period 1998-2012 – particularly for “wet” crashes (the black line in Figure 8). It is notable that the rate of trending downward seems to have accelerated post-2007. It is notable also that the TLA crash rates have been trending downward post-2007 after 10 years of increasing slightly or remaining substantially constant. A possible interpretation of this post-2007 downward trending in TLA crash rates is that a crash mitigation measure has been adopted post-2007 that is common to both SHs and TLAs.

5.3.1 Further analysis

Over the 1998-2012 period, crash reducing factors other than the introduction of the T10 specification are mainly common to both SH and TLA networks. Such factors included the introduction of the highway patrol in 2002, which was accompanied by reduced tolerance to

infringements by the NZ Police, together with other road safety engineering initiatives and education.

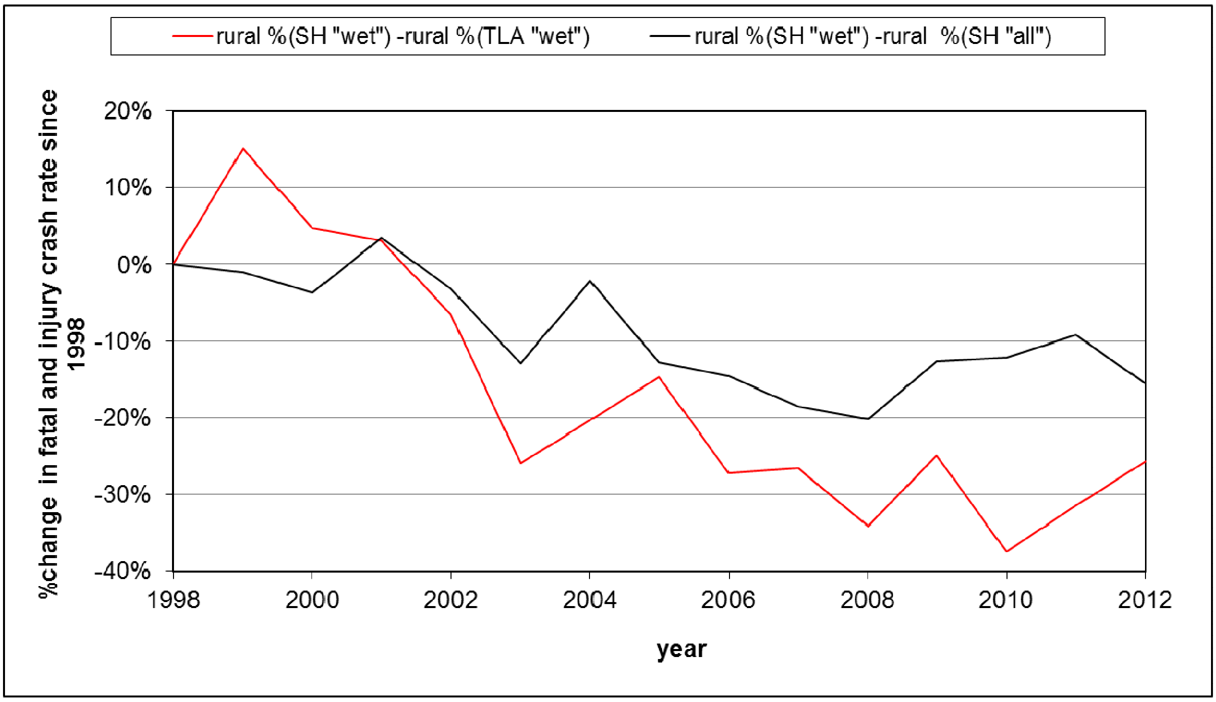

Figure 9: Rural road crash rate %changes

The effect of the introduction of the T10 skid resistance specification on crash rates on the SH network could be considered to be represented by either the difference in "wet" rural crash rates between TLAs and SHs, or between SH rural "all" and SH rural "wet" crash rates. Figure 9 suggests that it took until 2003 for significant differences between these two indicators to emerge.

By 2012, the difference between "all" and "wet" SH rural crash rates was approximately 15% and the difference between TLA rural "wet" and SH rural "wet" crash rates was approximately 30%. Therefore, it could be considered that the introduction of the T10 skid resistance policy has had a marked effect in reducing the "wet" SH rural crash rate.

5.3.2 Reduction in post-2007 TLA crash rates

It is evident from Figure 8 that the downward trend in SH rural crash rates apparent in 2008 is maintained to 2012. It is also evident from Figure 9 that the difference between SH and TLA rural "wet" crash rates has plateaued over the past 4 years. This appears to be due to TLA crash rates decreasing post-2007.

6 SUMMARY OF KEY FINDINGS

1. For the national SH network, the rate of "wet" Fatal and Serious Injury crashes trended down for the period 2003-2012. The T10 specification is considered to be partly responsible for this.
2. A minority of individual NMA's had crash trends contrary to the above. This suggests that it might be worthwhile for some NMA staff to undertake additional training on skid resistance management and then apply this to their network.

3. Depending on the degree of scatter deemed acceptable, it seems that it may be worth refining application of the T10 specification to better meet the T10 objective 3.2(1) of 'equalis[ing] the risk of a wet road or skidding crash across the state highway network'.
4. Investigation of SH ESC skid resistance showed that category 2 ESC < category 3 ESC < category 4 ESC. Accordingly, it may be worthwhile to take the opportunity to refine application of the T10 policy so that, as intended, category 2 ESC > category 3 ESC > category 4 ESC.
5. The 5 T10 skid resistance categories appear to have differing crash rate sensitivities to skid resistance with categories 2 and 4 having the highest correlations with the 10-year average of skid resistance.
6. As with the earlier paper of Cook et al. (2011), the comparative study of SH versus TLA "wet" Fatal, Serious Injury and Minor Injury crash rates on NZ rural roads showed that rate reductions were greater for SHs than for TLAs. This difference is likely to be attributable to the T10 policy.

7 CONCLUDING REMARK

The NZ Transport Agency has targeted significant funding to improve the skid resistance of surfacings across the entire 11,000 km sealed state highway network. Despite the random nature of crashes, the number of wet road loss of control crashes have decreased over the 15 years since the introduction of the skid resistance policy while vehicle travel increased over the same period. Therefore, it can be concluded that the skid resistance policy introduced in the mid 1990's has had a part to play in reducing road trauma and saving lives.

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8 ACKNOWLEDGEMENT

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A APPENDIX: SH EXPOSURE GRAPH

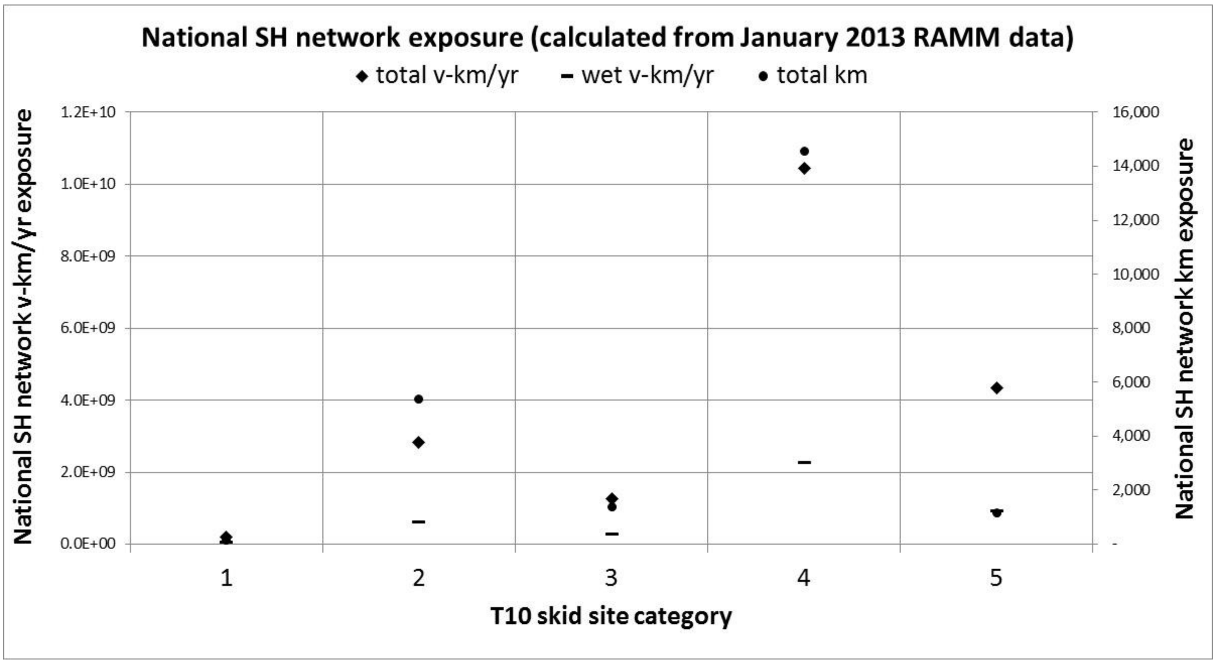

Figure 10: SH exposures

Figure 10 shows that the exposure of the 5 T10 skid resistance categories varies widely (e.g. category 1 (approaches to railway crossings, traffic signals, pedestrian crossings etc.) has a relatively low level of exposure, while skid site category 4 (undivided carriageways, event free) has a relatively high level of exposure). It is notable too that the ratio of the “total veh-km/yr” exposure to the “total km” exposure can vary widely between the 5 site categories (e.g. skid site category 4 compared with skid site category 5). This is presumably because undivided carriageways (category 4) can often have a low level of trafficking compared with motorways (category 5). Finally, a note of explanation: for all 5 T10 skid resistance categories, the “wet veh-km/yr” exposure is approximately 22% of the “total veh-km/yr” exposure. This 22% is a constant since rainfall is assumed to effect all skid site categories equally.

B APPENDIX: SH EXPOSURE DATA

Table 2: SH exposures

network management area	T10 skid site category	km	veh-km/yr	percentage of hours for which (rainfall in NMA > 0)×2	"wet" veh_km/yr
AUCK ALLIANCE	1	9.16	19,080,668	22.2%	4,236,080
AUCK ALLIANCE	2	53.58	228,357,097	22.2%	50,697,326
AUCK ALLIANCE	3	37.41	143,534,523	22.2%	31,865,953
AUCK ALLIANCE	4	112.64	553,009,301	22.2%	122,773,030
AUCK ALLIANCE	5	660.10	3,145,533,498	22.2%	698,336,678
BOP EAST	1	2.58	1,085,652	19.7%	213,487
BOP EAST	2	255.41	74,415,485	19.7%	14,633,386
BOP EAST	3	29.50	13,570,904	19.7%	2,668,642
BOP EAST	4	395.77	191,752,111	19.7%	37,706,972
BOP EAST	5	0.00	-	19.7%	-
BOP WEST	1	0.67	1,181,067	20.6%	243,013
BOP WEST	2	78.89	109,636,993	20.6%	22,558,584
BOP WEST	3	29.55	46,675,075	20.6%	9,603,726
BOP WEST	4	184.97	275,191,602	20.6%	56,622,612
BOP WEST	5	0.92	1,575,574	20.6%	324,185
CENTRAL WAIKATO	1	2.16	2,224,003	24.1%	536,115
CENTRAL WAIKATO	2	239.66	132,314,531	24.1%	31,895,546
CENTRAL WAIKATO	3	76.93	54,079,107	24.1%	13,036,230
CENTRAL WAIKATO	4	805.16	536,086,686	24.1%	129,228,267
CENTRAL WAIKATO	5	1.54	2,147,461	24.1%	517,664
COASTAL OTAGO	1	10.57	17,930,756	17.0%	3,049,059
COASTAL OTAGO	2	289.61	126,809,822	17.0%	21,563,542
COASTAL OTAGO	3	115.54	82,624,699	17.0%	14,050,025
COASTAL OTAGO	4	1086.23	522,401,618	17.0%	88,832,466
COASTAL OTAGO	5	39.52	92,805,773	17.0%	15,781,279
EAST WAIKATO	1	5.79	5,832,530	23.1%	1,345,189
EAST WAIKATO	2	350.91	210,250,898	23.1%	48,491,327
EAST WAIKATO	3	62.79	58,541,942	23.1%	13,501,852
EAST WAIKATO	4	632.80	581,441,342	23.1%	134,101,031
EAST WAIKATO	5	0.57	961,808	23.1%	221,827
EAST WANGANUI	1	6.33	8,005,580	22.9%	1,833,083
EAST WANGANUI	2	137.40	111,732,383	22.9%	25,583,999
EAST WANGANUI	3	69.56	72,993,091	22.9%	16,713,643
EAST WANGANUI	4	777.58	750,006,601	22.9%	171,733,276
EAST WANGANUI	5	7.53	9,742,961	22.9%	2,230,901
GISBORNE	1	4.23	1,160,707	24.0%	278,452
GISBORNE	2	274.24	57,224,337	24.0%	13,728,020
GISBORNE	3	34.11	16,203,904	24.0%	3,887,289

network management area	T10 skid site category	km	veh-km/yr	percentage of hours for which (rainfall in NMA > 0)×2	"wet" veh_km/yr
GISBORNE	4	350.88	108,466,392	24.0%	26,020,901
GISBORNE	5	0.00	-	24.0%	-
MARLBOROUGH	1	3.47	2,317,834	13.1%	302,857
MARLBOROUGH	2	105.55	60,944,858	13.1%	7,963,285
MARLBOROUGH	3	27.64	20,929,299	13.1%	2,734,701
MARLBOROUGH	4	390.22	207,134,325	13.1%	27,064,951
MARLBOROUGH	5	0.00	-	13.1%	-
NAPIER	1	6.03	6,004,240	19.4%	1,166,688
NAPIER	2	271.34	109,982,956	19.4%	21,370,869
NAPIER	3	52.73	33,108,015	19.4%	6,433,243
NAPIER	4	642.42	472,049,104	19.4%	91,724,210
NAPIER	5	6.36	9,668,091	19.4%	1,878,614
NELSON	1	4.39	6,005,913	22.3%	1,337,429
NELSON	2	256.59	93,278,130	22.3%	20,771,680
NELSON	3	44.13	32,046,990	22.3%	7,136,398
NELSON	4	467.09	291,334,691	22.3%	64,875,990
NELSON	5	0.62	2,434,535	22.3%	542,136
NORTHLAND	1	8.05	6,449,778	21.8%	1,406,726
NORTHLAND	2	499.05	227,065,435	21.8%	49,524,020
NORTHLAND	3	116.44	81,408,907	21.8%	17,755,658
NORTHLAND	4	882.90	571,668,475	21.8%	124,683,534
NORTHLAND	5	2.94	4,756,974	21.8%	1,037,518
NTH CANTERBURY	1	12.78	25,292,758	16.3%	4,125,383
NTH CANTERBURY	2	314.04	154,204,236	16.3%	25,151,528
NTH CANTERBURY	3	76.67	83,288,423	16.3%	13,584,783
NTH CANTERBURY	4	1079.70	1,005,774,663	16.3%	164,047,176
NTH CANTERBURY	5	82.05	173,842,595	16.3%	28,354,648
OTAGO CENTRAL	1	4.25	5,446,054	16.7%	908,717
OTAGO CENTRAL	2	219.91	77,371,551	16.7%	12,910,047
OTAGO CENTRAL	3	63.88	35,747,360	16.7%	5,964,726
OTAGO CENTRAL	4	787.24	309,543,282	16.7%	51,649,712
OTAGO CENTRAL	5	0.00	-	16.7%	-
PSMC 005	1	1.02	1,944,649	22.0%	428,453
PSMC 005	2	88.52	102,561,977	22.0%	22,596,897
PSMC 005	3	27.77	42,235,141	22.0%	9,305,428
PSMC 005	4	145.57	212,918,165	22.0%	46,911,047
PSMC 005	5	0.00	-	22.0%	-
PSMC 006	1	2.06	1,718,287	25.5%	438,584
PSMC 006	2	271.41	106,929,601	25.5%	27,293,245
PSMC 006	3	41.56	25,803,885	25.5%	6,586,312

network management area	T10 skid site category	km	veh-km/yr	percentage of hours for which (rainfall in NMA > 0)×2	"wet" veh_km/yr
PSMC 006	4	382.13	215,031,247	25.5%	54,885,648
PSMC 006	5	0.00	-	25.5%	-
ROTORUA DIST	1	4.04	7,134,166	23.1%	1,650,862
ROTORUA DIST	2	85.14	71,280,270	23.1%	16,494,418
ROTORUA DIST	3	28.93	33,811,481	23.1%	7,824,055
ROTORUA DIST	4	303.06	270,260,903	23.1%	62,538,995
ROTORUA DIST	5	10.77	18,705,159	23.1%	4,328,417
SOUTHLAND	1	6.99	6,613,649	34.0%	2,251,941
SOUTHLAND	2	269.20	61,693,402	34.0%	21,006,539
SOUTHLAND	3	83.29	42,031,668	34.0%	14,311,739
SOUTHLAND	4	1220.46	463,094,299	34.0%	157,683,124
SOUTHLAND	5	11.95	15,609,800	34.0%	5,315,121
STH CANTERBURY	1	6.43	7,388,752	12.6%	932,208
STH CANTERBURY	2	117.34	44,246,328	12.6%	5,582,374
STH CANTERBURY	3	57.43	56,227,469	12.6%	7,093,984
STH CANTERBURY	4	960.54	572,208,522	12.6%	72,193,152
STH CANTERBURY	5	1.90	4,796,889	12.6%	605,203
TAURANGA CITY	1	4.85	10,584,793	20.6%	2,177,896
TAURANGA CITY	2	13.63	39,368,012	20.6%	8,100,246
TAURANGA CITY	3	5.96	15,008,974	20.6%	3,088,202
TAURANGA CITY	4	55.55	156,448,534	20.6%	32,190,389
TAURANGA CITY	5	26.97	60,409,655	20.6%	12,429,712
WELLINGTON	1	15.35	29,912,912	19.5%	5,835,486
WELLINGTON	2	114.44	269,795,795	19.5%	52,632,442
WELLINGTON	3	68.85	78,645,348	19.5%	15,342,332
WELLINGTON	4	228.34	571,582,321	19.5%	111,505,717
WELLINGTON	5	205.43	653,746,741	19.5%	127,534,559
WEST COAST	1	20.37	5,900,806	37.6%	2,219,154
WEST COAST	2	514.95	102,164,051	37.6%	38,421,493
WEST COAST	3	69.93	23,296,479	37.6%	8,761,257
WEST COAST	4	1152.89	273,265,440	37.6%	102,768,694
WEST COAST	5	0.84	904,479	37.6%	340,153
WEST WAIKATO	1	6.59	13,901,491	22.4%	3,118,022
WEST WAIKATO	2	91.34	115,587,276	22.4%	25,925,543
WEST WAIKATO	3	42.49	73,141,227	22.4%	16,405,145
WEST WAIKATO	4	413.48	683,211,560	22.4%	153,240,318
WEST WAIKATO	5	80.16	111,581,156	22.4%	25,026,994
WEST WANGANUI	1	10.73	13,293,764	26.9%	3,569,765
WEST WANGANUI	2	458.70	136,539,991	26.9%	36,664,992
WEST WANGANUI	3	118.39	92,098,724	26.9%	24,731,208

network management area	T10 skid site category	km	veh-km/yr	percentage of hours for which (rainfall in NMA > 0)×2	"wet" veh_km/yr
WEST WANGANUI	4	1095.99	655,324,902	26.9%	175,973,955
WEST WANGANUI	5	10.34	25,646,028	26.9%	6,886,711
national SH's	1	159	206,410,810	21.7%	43,604,650
national SH's	2	5,371	2,823,755,418	21.7%	621,561,348
national SH's	3	1,381	1,257,052,634	21.7%	272,386,531
national SH's	4	14,554	10,449,206,088	21.7%	2,260,955,167
national SH's	5	1,151	4,334,869,176	21.7%	931,692,321
national SH's	**all**	**22,615**	**19,071,294,126**	**21.7%**	**4,130,200,017**

Notes:

1. There are 24 NMAs in the NZ SH network.
2. The NMA lengths (km) were calculated from RAMM data via a Simple Query Language (SQL) script.
3. The exposures (veh-km/yr) were also calculated from RAMM data via an SQL. The SQL contained the text: *sum((end_m - start_m)/1000*traffic_adt_est*365)*
4. The RAMM data was extracted in January 2013.
5. Two sets of exposure data were used in this paper. It would have been preferred to use just one set of exposure data, but this was not possible given that the exposure data of Appendices A & B contains SH data which is pigeon-holed by T10 skid site category and Appendix F contains both SH and TLA data.
6. The rainfall in each NMA was calculated from National Institute of Water and Atmospherics (NIWA) hourly rainfall data (mm) for the 207 Automatic Weather Stations (AWSs) for the period 25/11/1999-31/12/2011. (This rainfall data was received from Andrew Tait of NIWA by Opus International Consultants in June 2012. The information recording the NMA each AWS was in used the correspondence table prepared by Murray Forbes, Central Laboratories, Opus International Consultants).
7. A road was assumed to have a "wet" pavement for twice the percentage of hours for which the rainfall was greater than 0 mm.

C APPENDIX: “WET” SH CRASH NUMBERS

Notes:

1. The crash data was extracted from the RAMM database using the following filters: sealed roads, 01/01/2003 <= crash date <= 31/12/2012, pavement “wet”.
2. “L”, “M” and “H” T10 sub-categories were ignored (e.g. if the T10 skid site category = “3H”, “3” was recorded).
3. Where there were multiple lanes on a carriageway, the T10 skid site category of the lane with the lowest T10 skid site category was recorded (e.g. “3” was recorded if the skid site categories on a carriageway at a given RP were 5 (lane L1), 3 (lane L2) and 4 (lane L3)).
4. Crashes were characterized by the worst injury in the crash where: F=fatal injury, S=serious injury, M=minor injury and N=non-injury.

D APPENDIX: SKID RESISTANCE AVERAGES

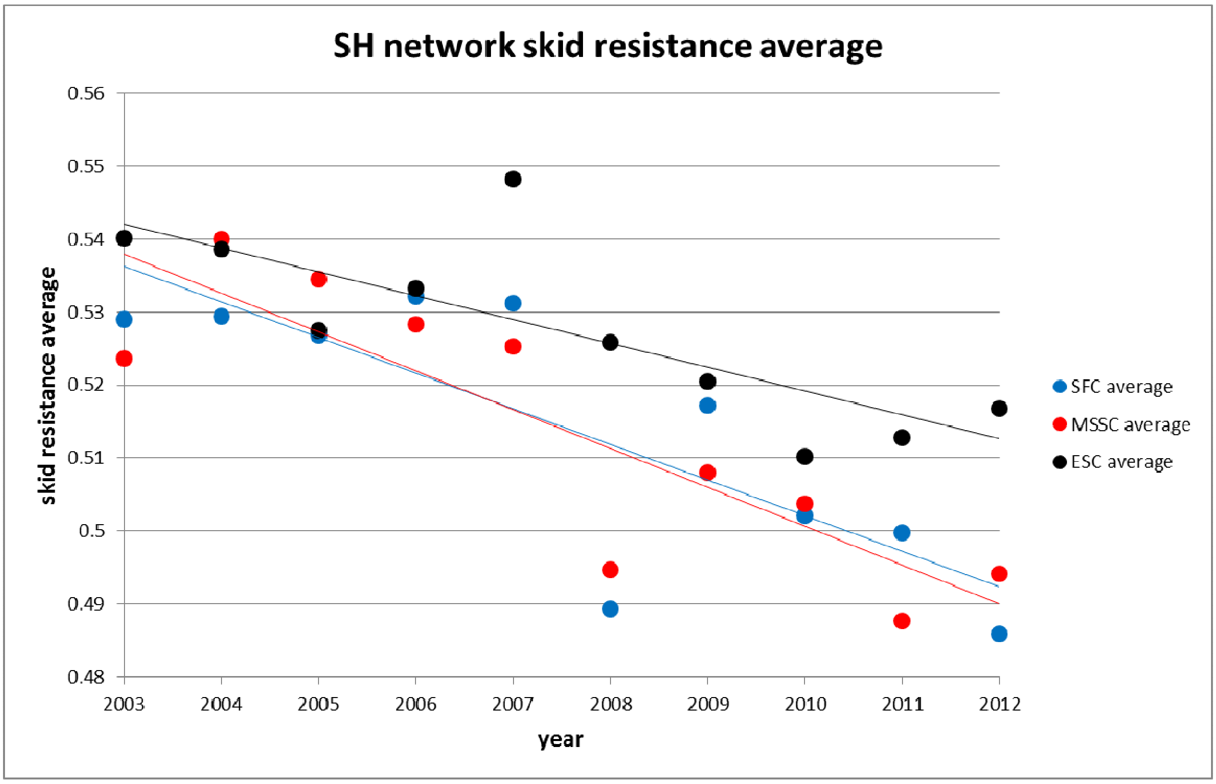

Figure 11: SH skid resistance averages

E APPENDIX: "WET" CRASH RATE TRENDS WITH SKID RESISTANCE AVERAGES

Table 3: Statistics of correlations of crashes with 10-year average skid resistance

T10 skid site category	Statistics of least-squares linear trend line of rate of "wet" F, S, M & N crashes with 10-year average raw skid resistance		
	correlation coefficient (R^2)	slope	intercept
1	0.0608	-1,909.80	1,404.70
2	0.4318	-1,058.20	667.23
3	0.0487	-562.56	455.10
4	0.2500	-169.52	121.00
5	0.0252	536.47	-170.03
T10 skid site category	Statistics of least-squares linear trend line of rate of "wet" F, S, M & N crashes with 10-year average MSSC skid resistance		
	correlation coefficient (R^2)	slope	intercept
1	0.0757	-2,115.10	1,507.00
2	0.4923	-1,193.40	732.95
3	0.0532	-619.06	483.50
4	0.2041	-160.75	116.45
5	0.0192	524.44	-163.27
T10 skid site category	Statistics of least-squares linear trend line of rate of "wet" F, S, M & N crashes with 10-year average ESC skid resistance		
	correlation coefficient (R^2)	slope	intercept
1	0.0640	-1,843.30	1,393.10
2	0.5143	-1,180.20	744.27
3	0.0460	-542.55	451.34
4	0.1985	-149.57	112.62
5	0.0224	537.31	-176.56

F APPENDIX: SH & TLA EXPOSURES

Table 4: Exposures (units = 10^8 veh-km/yr)

year (01 January - 31 December)	SH		TLA	
	rural	urban	rural	urban
1995	123.3	22.8	54.6	118.4
1996	128.1	23.6	56.0	121.2
1997	132.8	24.5	57.3	124.1
1998	137.5	25.4	58.6	127.0
1999	143.1	26.4	60.9	131.9
2000	146.1	26.9	61.3	132.8
2001	151.7	27.9	62.0	134.4
2002	156.5	28.8	63.4	137.3
2003	161.0	29.6	64.8	140.3
2004	166.4	30.6	66.4	143.9
2005	170.7	31.4	69.0	149.5
2006	175.5	32.2	69.3	150.1
2007	177.7	32.6	70.3	152.2
2008	179.8	33.0	71.1	154.0
2009	181.1	33.2	72.4	156.9
2010	181.2	33.2	72.4	156.9
2011	181.9	33.4	72.3	156.7
2012	181.0	33.2	72.1	156.2

Notes:

1. 1995-2010 national veh-km/yr exposure figures were transcribed from the earlier report of Henderson and Cenek (2011).
2. 2011 and 2012 national veh-km/yr urban + rural exposure sums were based on the download of NZTA (2013b).
3. Urban/rural splits in the above sums were based on linear extrapolation of the urban:rural exposure ratios of the 1995-2010 exposure data reported in Henderson and Cenek (2011). Separate ratios were used for SH and TLA calculations.
4. To eliminate any spurious step-changes in exposures and the consequential calculated crash rates, the 2011 and 2012 exposure figures found in item 2 above were scaled so that the SH and TLA exposures were consistent with those of the report of Henderson and Cenek (2011). Separate scale-factors were used for SH and TLA exposures. (This need to scale exposure data is undesirable. However, it was necessary given the data available and the objective of extending the findings of the report of Henderson and Cenek (2011) to 2012.)

G APPENDIX: SH & TLA CRASH NUMBERS

Table 5: F, S & M crash numbers

year (01 January - 31 December)	SH				TLA			
	rural		urban		Rural		urban	
	"all"	"wet"	"all"	"wet"	"all"	"wet"	"all"	"wet"
1995	2,858	976	1,073	285	1,617	461	6,703	1,856
1996	2,605	957	955	270	1,371	401	5,645	1,485
1997	2,293	696	864	196	1,278	318	5,098	1,190
1998	2,207	751	736	163	1,312	361	4,584	995
1999	2,292	772	708	158	1,236	314	4,318	937
2000	2,113	689	640	131	1,165	308	3,982	838
2001	2,409	848	750	195	1,330	379	4,451	1,063
2002	2,535	835	931	209	1,565	407	5,231	1,240
2003	2,707	807	911	207	1,740	470	5,371	1,222
2004	2,723	907	852	198	1,676	491	5,252	1,224
2005	2,822	841	851	169	1,765	446	5,494	1,066
2006	2,866	835	922	185	1,848	488	5,808	1,181
2007	3,090	872	954	189	1,934	504	6,184	1,236
2008	2,749	737	956	182	1,925	478	6,145	1,360
2009	2,654	778	882	166	1,767	462	5,929	1,271
2010	2,516	736	886	186	1,850	499	5,705	1,215
2011	2,301	692	841	184	1,629	450	5,114	1,148
2012	2,262	615	833	155	1,529	390	5,049	1,035

Notes:

1. The crash numbers were extracted by Tiffany Lester of Opus Central Laboratories on 12/12/2013 from the CAS database.
2. Crashes designated as “all” occurred on pavements with any CAS “ROAD WET” field entry.
3. Crashes designated as “wet” occurred on pavements with a CAS “ROAD WET” field entry of “W” (wet).

H APPENDIX: SH & TLA CRASH RATES

Table 6: Per 10^8 v-km/yr rates of F, S and M crashes

year (01 January - 31 December)	SH				TLA			
	rural		urban		rural		urban	
	"all"	"wet"	"all"	"wet"	"all"	"wet"	"all"	"wet"
1995	23.2	31.7	47.1	50.1	29.6	33.7	56.6	62.7
1996	20.3	29.9	40.4	45.7	24.5	28.7	46.6	49.0
1997	17.3	21.0	35.3	32.0	22.3	22.2	41.1	38.3
1998	16.0	21.8	29.0	25.7	22.4	24.6	36.1	31.3
1999	16.0	21.6	26.8	23.9	20.3	20.6	32.7	28.4
2000	14.5	18.9	23.8	19.5	19.0	20.1	30.0	25.2
2001	15.9	22.4	26.9	28.0	21.5	24.5	33.1	31.6
2002	16.2	21.3	32.3	29.0	24.7	25.7	38.1	36.1
2003	16.8	20.0	30.8	28.0	26.9	29.0	38.3	34.8
2004	16.4	21.8	27.8	25.9	25.2	29.6	36.5	34.0
2005	16.5	19.7	27.1	21.5	25.6	25.9	36.7	28.5
2006	16.3	19.0	28.6	23.0	26.7	28.2	38.7	31.5
2007	17.4	19.6	29.2	23.2	27.5	28.7	40.6	32.5
2008	15.3	16.4	29.0	22.1	27.1	26.9	39.9	35.3
2009	14.7	17.2	26.5	20.0	24.4	25.5	37.8	32.4
2010	13.9	16.3	26.7	22.4	25.6	27.6	36.4	31.0
2011	12.6	15.2	25.2	22.1	22.5	24.9	32.6	29.3
2012	12.5	13.6	25.1	18.7	21.2	21.6	32.3	26.5

Notes:

1. In calculating the “wet” exposures, the assumed "wet" road time was taken as 25% as per Henderson and Cenek (2011). (I.e. the “wet” exposure was calculated by multiplying the exposures in Appendix F by 0.25.)
2. The crash rates were calculated as the crash numbers in Appendix G divided by the exposures in Appendix F.

Author Biographies

Mark Owen

Mark is currently the New Zealand Transport Agency's (NZTA), Regional Performance Manager for the Central Region of New Zealand. In this role, Mark is has responsibility for the operations and maintenance of the highways in the Wellington and Nelson/Tasman regions and has oversight of the maintenance performance of the wider Wellington Business Unit, covering the Central and Lower North Island and top of the South Island. Mark has held this role for over 8 years.

Mark originally joined Transit NZ in 1996, having migrated from Local Authority. His roles have included technical policy development, national asset management and annual planning; and more recently maintenance management and highway operations. Mark was instrumental in the development of the original skid resistance specifications for Transit NZ {now NZTA] and has been a representative on the steering group of the 4 International Surface Friction and SaferRoads conferences.

Mark is a Technical Member of IPENZ and has completed a Master of Technology (Pavements) through the Deakin University in Geelong, Victoria, Australia.

John Donbavand

John arrived in NZ in 1983 and stayed for 18 years during this time he has held a number of positions including Bitumen Chemist, Surfacing Scientist and Engineering Policy Manager for Transit New Zealand.

John returned to the UK in 2001 to take up the position as Project Development Manager at W.D.M. Limited. In this position, John has been involved with a wide range of projects, including, developing procedures to estimate the national maintenance budgets for the Highway Agencies, asset valuation for local roads, providing scheme prioritisation techniques for Highway Authorities and providing skid policies for numerous Highway authorities, including London and Scotland.

John returned to New Zealand in March 2012 and started work with the New Zealand Transport Agency as the National Pavements Manager. In this role his principal responsibility is to maintain and develop the technical standards, specifications and guidelines for State Highway pavements.