Allocating Skid Resistance Investigatory Levels on the basis of Risk Analysis

Chris Kennedy[1], Michael Haydon[2], John Donbavand[1]

[1]*WDM Ltd*
[2]*Works Infrastructure Ltd*

ABSTRACT

It has been acknowledged recently in the UK and New Zealand that setting single investigatory levels (IL's) for each site category may not be the optimum management of risk since each site category is quite broad and individual sites, within a site category, can have very different conditions. Therefore, a range of IL's has been recommended for each site category; the advantage of setting a range is that levels can be more closely aligned with particular risk for each individual site. Also, since the range is set out in the policy it removes the perceived risk to the Site Investigation Engineer, to move the IL away from the tabulated value in the specification. However, fundamental to this new approach is the correct assessment of risk through the use of a site investigation process.

In this paper, a risk assessment has been carried out on 35 category 2 or 3 sites situated in the Northland region. The assessment includes the results from the SCRIM survey, the effect of rain fall on the skid resistance, the results of a curve deficiency procedure, a full site investigation for each site and the wet crash data for the sites. Using all this information a comparative analysis of risk for each of the sites has been determined.

The risk assessment has been used to assign individual investigatory levels and, using information from previous studies, an estimate in the benefits arising from crash reduction has been made. Using the cost associated with the crash reduction a benefit-cost analysis has been carried out taking into account the benefits obtained by crash reduction on one hand and the cost of achieving the recommended IL on the other.

Finally, the implications to local key performance measures have been discussed, along with the implications if the approach was adopted on a national basis.

1. INTRODUCTION

The current Transit T/10 policy defines a single Investigatory Level, IL, and a single Threshold Level, (TL) for different site characteristics on the New Zealand network. The site characteristics, such as gradient, horizontal radius and proximity to roads joining the main carriageway are used to define five types of site.

The risk of skidding crashes is then used to set the IL, such that sites that require the highest friction demands have the highest IL. These Investigatory levels are used to identify lengths of road that require further investigation and the priority that should be given for treatment selection. The system works well, but there are some weaknesses as there is only one investigatory level for each of the five types of site and, therefore, no scope for varying the potential skid risk within the broad site type. The T/10 policy thus assumes all sites across a category type, have the same risk level.

Research in the United Kingdom has suggested that a better approach is to have a range of ILs for each category type. The advantage of this approach is that sites investigated because they are currently below the IL, and found not to justify treatment, can have the IL modified or reduced. They may then comply with the revised skid resistance IL requirements.

This means that these investigated sites can then be removed from the pool of sites identified for investigation each year, allowing effort to be concentrated on those sites where improvements are required. Alternatively, certain sites presenting a greater risk of skidding accident than would be expected for the particular site would justify a higher IL.

A similar study for Transit using State Highway data has recommended that a similar approach might be beneficial for use in New Zealand[1]. The use of TLs in the New Zealand skid policy does not affect the use of varying ILs, because the TL is set at a constant 0.1 below the IL. This would continue if the IL for a site were changed (up or down from the standard level).

2.0 AIMS AND METHODOLOGY OF THE PROJECT

2.1 AIMS OF THE PROJECT

The aim of this project was to apply the concepts of variable IL on a sample of site categories 2 and 3 in the Northland study area, to assess the impact of introducing such an approach on the current policy and, in particular, on the benefits and cost of delivering the policy.

In carrying out an overall risk assessment, crash data, a spreadsheet defining curve deficiency and information on rainfall records, together with a model relating rainfall to changes in SCRIM measurements have been used.

The curve deficiency and rainfall models described below are still undergoing validation and are not endorsed by this paper, rather the methodology presented here endeavours to show how information and models of this sort could be adopted to apply a risk management approach to network level management. Papers presented by others at this conference discuss these other investigations[2]

2.2 METHODOLOGY

The methods used to complete the project included:

2.2.1 Selecting a sample network

In collaboration with Works Infrastructure Ltd, a number of sites covering the five sub-networks in the Northland study area were selected. Data from these sites was extracted from RAMM to develop a working database that was associated with existing software to allow network videos to be viewed, accident data to be interrogated and SCRIM results to be incorporated.

2.2.2 Validating the site category definition

The latest SCRIM video of the selected sub-network, together with the alignment data from the latest SCRIM survey, were viewed and interrogated to check and confirm the current site category. This stage was to ensure that lengths of road falling below the IL were defined correctly. This produced a database containing 89 validated sites. The number of sites was culled further if they met one or more of the following criteria:

- were less than a year old, since the sites may not reach their ultimate stage of polishing, therefore could not be expected to follow a relationship between the ESC and PSV;
- there were no PSV details for the aggregate; or
- the last maintenance treatment was a void fill. A void fill chip is designed to fit into the interstices of the surface chip so it is uncertain what influence the void fill aggregate would have on the skid resistance.

The final number of sites that were considered in this project was 35.

2.2.3 Incorporate the latest network SCRIM survey data and evaluate

The 2003/04 ESC results from RAMM were added to the database. After validating the data, the database was then used to define those lengths of network where the ESC was below the IL and the TL

2.2.4 Site Visits

Each of the 35 validated sites was then visited and inspected and a hazard and risk assessment carried out by completing a proforma questionnaire developed for this project. The form used is shown in Figure 1. The completed forms are in Appendix 1.

Figure 1 Site Assessment Form

Risk Assessment Site Investigation Form

Site Number/Code …………………

StateHighway …………………

Reference Station ………………….

Route position …………………..

Direction …………………….

Site Category ……………………

Event(s) ……………………

Treatment ………………………..

Treatment Date …………………………

Quarry supplier for Surfacing Aggregates

PSV of Surfacing aggregate …………………..

General condition of the road at the site. (Subjective)

Is the Macrotexture Adequate
…………………..

Are there Rut depths that could make ponding of water likely
…………………..

Are there high levels of roughness that could affect vehicle handling
…………………….

Volume and type of traffic including vulnerable road users.

Observed traffic speeds to determine if they are appropriate to the nature of the site
………………

What are the types of manoeuvring made at the site and the consequences of not completing them successfully e.g. potential for head-on or side impact at speed.
………………..

The impact of an accident occurring

Would an accident occurring at this site be critical, catastrophic normal impact etc
…………………………

Road layout.

Does the road layout deviate significantly from the current standards for geometric design; negative cambers, very narrow lanes etc
……………………..

Visibility

Is the event visible from a distance of 100m
…………………

Is the event a surprise ie a single curve on a long straight fast road
………………..

Comments …………………………

Preliminary Risk Rating ………………………

2.2.5 Incorporating crash data into the study database

A copy of the crash database, containing the last three years data, was used to incorporate crash data into the analysis. The hazard and risk assessment made from the site visits were carried out prior to incorporating the crash data, to avoid bias.

2.2.6 Investigating the overall risk associated with the validated Sites

The site assessment, the crash data, the curve deficiency and information on rainfall records at the time of the SCRIM survey have been incorporated into to the overall assessment to develop and apply a risk strategy for each of the 35 sites.

Each site is given a Preliminary risk rating at the conclusion of the assessment. This combined with the crash information, traffic volumes, the curve deficiency rating and the ESC measurement, and the rainfall data provides the information required to assess the overall risk.

2.2.7 Determining the Benefits and Costs of changing from the current policy to a risk management based approach to setting ILs

The benefit-cost ratio of making a change to the current policy was estimated and the implications in relation to the KPM for Northland region are discussed below.

3.0 RESULTS

The information for the 35 sites has been documented on a spreadsheet. The information includes Site number, State highway, Reference Station, Route position, Site category, Lane direction, Date of maintenance treatment, Treatment type, Aggregate source, PSV, Traffic volume, HCV volume, % HCV growth, ESC, Required PSV, Required ESC, Deficiency in ESC, Deficiency in PSV, wet crashes per year, total crashes with current surface, rainfall data, crashes per year, crash rate, risk assessment from Site Visit and curve deficiency risk assessment.

The complete spreadsheet is shown in Appendix 1.

3.1 THE EFFECT OF RAINFALL ON THE ESC VALUES

An investigation carried out by Works Infrastructure[3] and Opus[4] has indicated that the ESC value will increase to a maximum after at least 10mm of rainfall, although this does depend on the volume and type of traffic.

Also, if there is no rain, the skid resistance sfc will be reduce by 0.01 each day, to a minimum of 0.1 below the maximum value. Therefore, if the rainfall before the SCRIM survey is known, it is argued by Works Infrastructure Ltd that the maximum and minimum ESC can be calculated, as shown below.

Steps

Step 1: Identify Survey Result (ESC value from High Speed Data Survey) Example = 0.53
Step 2: Identify how many dry days have occurred prior to the survey
Step 3: identify how much rain has fallen; say 10mm has fallen and there was one dry day prior to the survey. Therefore, the skid resistance will be 0.01 below the maximum.
Step 4: Calculate maximum skid resistance of surface
Example = 0.53 + 0.01 = 0.54
Step 5: Calculate minimum skid resistance of surface
Example = 0.54 – 0.1 = 0.44
Rainfall data has been collected and supplied for all the sites considered in this paper. A value of zero indicates that at least 10mm of rain fell prior to the survey. A value of -0.01 indicates that 9mm of rain fell, a value of -0.04 indicates there has been four dry days prior to the survey etc.

The minimum and maximum skid resistance for the sites has been calculated and is shown in Table 1

Table 1 Minimum and Maximum ESC Values

Site Number	Survey ESC	Req ESC	Rainfall	Minimum ESC	Maximum ESC
1	0.50	0.5	-0.01	0.41	0.51
4	0.46	0.5	-0.01	0.37	0.47
6	0.46	0.5	-0.015	0.38	0.48
9	0.49	0.5	-0.01	0.40	0.50
10	0.57	0.5	-0.01	0.48	0.58
13	0.42	0.5	-0.04	0.36	0.46
14	0.55	0.5	-0.04	0.49	0.59
16	0.49	0.5	0	0.39	0.49
17	0.47	0.5	-0.015	0.39	0.49
23	0.52	0.45	-0.04	0.46	0.56
24	0.45	0.5	-0.01	0.36	0.46
25	0.58	0.45	-0.07	0.55	0.65
27	0.50	0.5	-0.01	0.41	0.51
29	0.47	0.5	-0.01	0.38	0.48
32	0.53	0.45	-0.07	0.50	0.60
34	0.54	0.5	-0.01	0.45	0.55
40	0.62	0.5	-0.01	0.53	0.63
41	0.47	0.5	-0.04	0.41	0.51
44	0.45	0.5	0	0.35	0.45
45	0.49	0.5	-0.01	0.40	0.50
46	0.53	0.5	-0.01	0.44	0.54
48	0.55	0.5	0	0.45	0.55
53	0.54	0.5	-0.04	0.48	0.58
54	0.48	0.5	-0.01	0.39	0.49
55	0.51	0.45	-0.04	0.45	0.55
57	0.48	0.5	-0.005	0.38	0.48
60	0.38	0.5	0	0.28	0.38

63	0.41	0.5	-0.015	0.33	0.43
71	0.42	0.5	-0.01	0.33	0.43
72	0.43	0.5	-0.01	0.34	0.44
76	0.44	0.5	0	0.34	0.44
77	0.4	0.5	0	0.30	0.40
79	0.43	0.5	0	0.33	0.43
82	0.42	0.5	0	0.32	0.42
88	0.43	0.5	0	0.33	0.43

To set standards for the worst case scenario the minimum ESC as calculated by the rainfall data should not drop below the required IL.

As can be seen this is not the case for any of the sites. To set the skid resistance for the worst case scenario is probably not the most cost-effective approach. However, it would be reasonable to set the mean between the minimum and maximum levels as a requirement, particularly in view of the above average rainfall in the study area.

3.2 Comparison of the ESC and the Polished Stone Value

The Polished Stone Value (PSV) is a value which indicates the propensity of a stone to polish in service. A relationship between the PSV and the skid resistance of a road and the number of vehicles that weigh 1.5 kN or greater was established by Szatkowski and Hosking[5], namely:

PSV = sfc*100 + (0.00663*CV) - 2.4

Where:
sfc = sideway force coefficient
CV= Commercial vehicles ie any vehicle greater than 1.5 kN.

This relationship was modified in the New Zealand T/10 specification by classifying commercial vehicles as 3.5tonnes or greater (a value that was available in the Transit NZ database). The additional polishing produced by the lighter vehicles was taken into account by increasing the PSV requirement by five units, viz.

PSV = sfc*100 + (0.00663*CV) + 2.6

Where:
sfc = sideway force coefficient
CV= Commercial vehicles ie any vehicle greater than 3.5 tonne

Table 2 shows the measured ESC, the required IL, the measured PSV and the PSV required to achieve the IL ESC as calculated by the T/10 equation. The final two columns list the ESC and the PSV deficiencies. A positive number indicates a value above that required and a negative number indicates value below that required.

Table 2 Required PSV

Site Number	Measured ESC	Required IL	Measured PSV	Required PSV	ESC Deficiency	PSV Deficiency
1	0.50	0.5	55	54	0.00	1
4	0.46	0.5	53	56	-0.04	-3
6	0.46	0.5	53	53	-0.04	0
9	0.49	0.5	53	56	-0.01	-3
10	0.57	0.5	53	53	0.07	0
13	0.42	0.5	53	58	-0.08	-5
14	0.55	0.5	53	57	0.05	-4
16	0.49	0.5	53	53	-0.01	0
17	0.47	0.5	53	53	-0.03	0
23	0.52	0.45	55	52	0.07	3
24	0.45	0.5	53	56	-0.05	-3
25	0.58	0.45	53	54	0.13	-1
27	0.50	0.5	65	56	0.00	9
29	0.47	0.5	53	56	-0.03	-3
32	0.53	0.45	53	57	0.08	-4
34	0.54	0.5	58	53	0.04	5
40	0.62	0.5	53	53	0.12	0
41	0.47	0.5	55	58	-0.03	-3
44	0.45	0.5	53	55	-0.05	-2
45	0.49	0.5	53	54	-0.01	-1
46	0.53	0.5	55	54	0.03	1
48	0.55	0.5	53	53	0.05	0
53	0.54	0.5	55	57	0.04	-2
54	0.48	0.5	58	54	-0.02	4
55	0.51	0.45	53	53	0.06	0
57	0.48	0.5	53	56	-0.02	-3
60	0.38	0.5	53	53	-0.12	0
63	0.41	0.5	53	54	-0.09	-1
71	0.42	0.5	53	56	-0.08	-3
72	0.43	0.5	53	56	-0.07	-3
76	0.44	0.5	53	53	-0.06	0
77	0.4	0.5	53	53	-0.10	0
79	0.43	0.5	53	53	-0.07	0
82	0.42	0.5	53	53	-0.08	0
88	0.43	0.5	53	53	-0.07	0

A summary of the results, in terms of the PSV and the ESC requirements, are shown in Table 3

Table 3 Number of Sites Meeting Requirements

Condition	Number
Sites meeting the PSV and ESC requirements	7
Sites meeting the PSV requirements but not meeting the required ESC	4
Sites not meeting the PSV but meeting the required ESC	12
Sites not meeting the PSV and not meeting the ESC Requirements	12

Above, it is assumed that, if the deficiency in the PSV is zero or greater, then it met the requirements. If the ESC is zero or less, it did not meet the requirements.

As can be seen, 12 of the 35 sites met the PSV requirements and of these, seven met the ESC requirements also. There are 12 sites that did not meet the PSV or the ESC requirements and there are 12 sites that did not meet the PSV requirements but did meet the ESC requirements. The details are more easily seen by referring to Figure 2, below.

For the sites that comply with both the PSV and the ESC (top right hand segment), four of the sites just meet the PSV requirement, with a deficiency of zero. The bottom right hand corner shows sites where the PSV failed but the ESC met the requirement. There were only four these occurrences but one of these is notable, where the PSV deficiency is -1 but the ESC is 0.13 greater than requirement. The site is a category 3 site so the required ESC is 0.45 and the actual ESC is 0.58 which is the highest ESC measured.

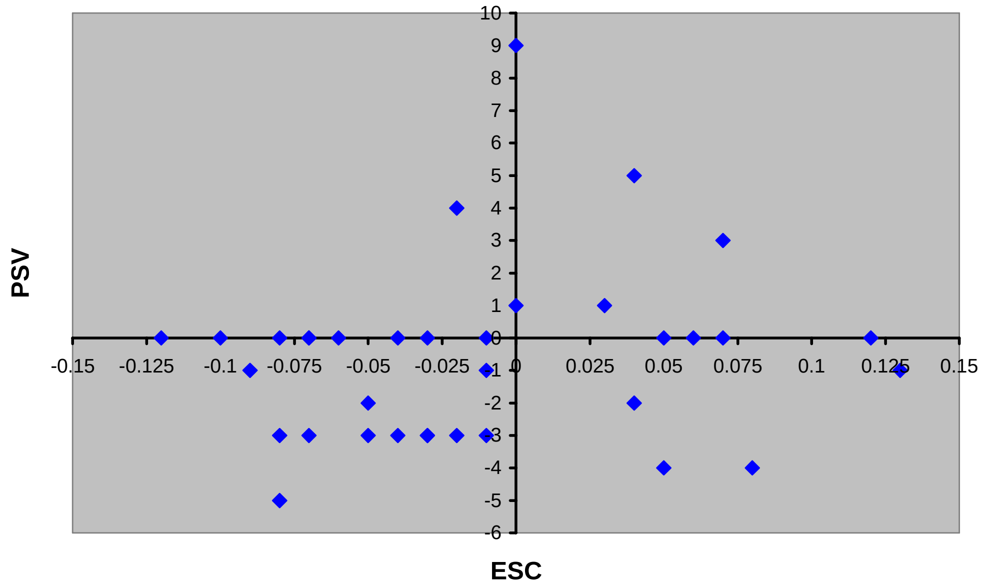
There are 2 possible reasons for the above results: the commercial traffic volume is 1007 per lane per day, which is comparatively high for the Northland area. The lower this value, the greater the chance of the PSV complying.

The site was last surfaced in 1999 so it is possible that the PSV of the stone quarried in 1999 was higher than the current PSV since there can be a reasonable amount of variability within a quarry. It is also possible that the assumed relationship between PSV and sfc given above is incorrect so the resulting sfc is underestimated.

There were 12 occurrences of the PSV and the ESC being deficient. This indicates that 75 percent of the sites that have not met the PSV requirement also do not meet the ESC requirements.

There were 12 occurrences where the PSV met the requirements but the ESC did not; of these, eight sites only just met the required PSV. It is again possible that the assumed relationship between PSV and sfc is invalid but, in this case, the resulting sfc is overestimated or the effect of polishing resulting from high contact stress has not been adequately accounted for in the estimate of PSV.

Figure 2 Plot of PSV versus ESC



From these results, there is no clear correlation between the PSV and the ESC and it can be concluded that the skid resistance of the road surface is dependent on a number of variables that have not been fully taken into account in the T/10 equation.

3.3 RELATIONSHIP BETWEEN DEFICIENT CURVES AND CRASHES

A study has been carried out by Works Infrastructure Ltd and MWH New Zealand Ltd[2] to identify sites in the region that may be expected to have high crash risks and to develop a maintenance strategy which uses a risk based criteria. This strategy was based on assessing the approach speed of a curve and comparing it with the design speed of the curve. A ranking system was assigned that set the risk as:

High - if the approach speed is greater than 15km/h more than the design speed of the curve;

Medium – if the approach speed is between 10km/h and 15 km/h greater than the design speed of the curve;

Low – if the approach speed is greater than 10 km/h than the design speed but has adequate (>10%) super elevation.

It was found that 855 curves are deficient, which constitutes 49 percent of all curves in the study area. Only one percent of these fall in the low risk category, 36 percent and 63 percent are in the medium and high deficiency level respectively.

The study concluded there was not a firm relationship established between curve deficiency and crash rate but that there was an upward trend in crash rate with increased curve deficiency.

3.4 IDENTIFYING THE OVERALL HAZARD LEVEL AND RISK OF THE SITES AND SELECTING THE INVESTIGATORY LEVEL

3.4.1 Completing the Proforma

A preliminary hazard and risk assessment for each site was carried out by performing a site investigation and completing the proforma. The information assessed at this stage was the surface features of the site, such as texture, rutting and road roughness. These features may influence crash rates on the sites as well as the traffic speed and the type of vehicle movement on the sites.

As indicated above, Section 3.3, speed can have an effect on the crash rate so adequate skid resistance is required, depending on the manoeuvre being undertaken. The impact of a crash is also considered in the overall assessments.

If a crash is likely to lead to a head-on crash, or the vehicle leaving the road on top of a hill etc., then the impact of a crash could be high and the risk rating would be increased accordingly. The general road layout was considered, to determine if it meets the design standards. Visibility was also assessed because, if, for example, an event is a surprise, then the risk of a crash is higher.

After taking all the information into account a hazard-consequence rating was assigned, where 1 = very low risk for the type of site and 10 = very high risk. If the risk rating is 4 or lower then there could be good reason to consider lowering the IL providing there have been no crashes for the previous three years. Alternatively, if the risk rating is 6 or greater there could be good reason for increasing the IL particularly if there have been any wet crashes over the previous three years.

3.4.2 Crash Rate

Ideally, there should be a uniform level of risk of a skidding crash across the state highway regardless of the site category and the IL should be varied to incorporate the risks.

However, from recent work performed on data from Wales, Scotland and in New Zealand it has been found that some sites have a greater risk of skidding crashes than others and also that it is not always possible to provide sufficient skid resistance on all sites to reduce levels of risk to those of other less demanding sites. Thus, when assessing the crash rate it must be compared to similar sites to determine if it is higher than average for the type of site considered.

The crash rate is very influential in setting the IL, but this must be balanced against the current ESC of the site. For example, if the crash rate is high and the ESC is deficient, then bringing the ESC up to the required value may reduce the crash rate adequately. In that case there would be no reason to increase the IL.

To determine what the average crash rates would be for the sites, information from a study[1] carried out in NZ was used. In that study, regression equations of crash rate versus skid resistance were obtained for a number of site categories. The equations for site 2 curves and site 3 gradients are

$Y = -62.021x + 45.698$ site cat 2 Curves
$Y = -15.601x + 13.843$ site cat 3 Gradients

Where:
Y is the crash rate and
x is the ESC

Using these regression equations, the crash rate for any ESC can be obtained.

The mid point between the maximum and the minimum skid resistance, as calculated using the rainfall data from the sites, was used in the equation to estimate the average crash rate at that particular skid resistance and at that site location, Table 4. The calculated average crash rates can be compared with the actual crash rates at the ESC to determine if the crash rate at any site is higher than average.

The crash rate at each site was determined using the following equation:

$$\text{Crash Rate} = \frac{\text{Total average number of Injury Crashes per site}}{\text{Total average daily number of vehicles entering the site} \times 365/10^8}$$

The crash rate can be very influenced by a freak occurrence, especially if the commercial vehicle volume is low.

3.4.3 Crash Density

The crash density is the number of crashes per year for each kilometre and has been calculated for each of the sites. This factor does not rely on the volume of traffic so, when used together, the crash rate and crash density can be very useful.

Equations for the crash densities for curves and gradients have been developed from the work that established the crash rates above. The calculated crash densities for the curves and the gradients on a national basis are all less than 0.1 crashes/km/yr. In this study, it has been found that the crash densities in Northland are much higher.

For example if one crash occurs over a three year period, on a site that is 500m long, the crash density will 0.67. This indicates that crash densities should be only used with large samples. Nevertheless, the crash rates and densities do indicate that, in general, the 35 sites have a poor crash record.

3.5 SETTING THE INVESTIGATORY LEVEL

The IL was set for each site using the information from the site risk investigation, the wet crash records, the curve deficiency study and the Works Infrastructure predicted minimum and maximum skid resistance levels and is shown in Table 4 below.

Of the 35 sites investigated, it is recommended that the IL of 9 sites is increased (I) 2 sites are decreased (D), 2 sites undergo another review (R) and 22 sites stay the same (S). These sites are discussed in more detail in the next section

Table 4 Site Details and Overall Assessment

Site	Crash rate	Crash Density	Average crash rate from Eq	Site Investigation Risk rating	MWH Deficiency Rating	Min SCRIM Rainfall	Max SCRIM Rainfall	Req ESC	Overall Assessment
1	17.4	2.8	17.1	5	H	0.41	0.51	0.5	S
4	24.3	2.6	19.6	5		0.37	0.47	0.5	S
6	0.0	0	19.3	5	M	0.38	0.48	0.5	S
9	0.0	0	18.0	5	M	0.40	0.50	0.5	S
10	129.4	1.5	12.8	5	H	0.48	0.58	0.5	S
13	15.8	8	20.3	8	H	0.36	0.46	0.5	I
14	32.1	2.9	12.5	8	M	0.49	0.59	0.5	I
16	80.7	4.4	18.3	4	M	0.39	0.49	0.5	Review
17	135.5	2.6	18.7	6	H	0.39	0.49	0.5	I
23	19.2	2.5	6.0	5		0.46	0.56	0.45	Review
24	0.0	0	20.3	5		0.36	0.46	0.5	S
25	13.1	3.1	4.5	5		0.55	0.65	0.45	S
27	24.3	5.7	17.3	6	H	0.41	0.51	0.5	I
29	48.6	9.8	19.1	5	M	0.38	0.48	0.5	I
32	3.1	6.7	5.3	4		0.50	0.60	0.45	S
34	42.9	3.4	14.7	6		0.45	0.55	0.5	I
40	86.2	1.6	9.8	5	M	0.53	0.63	0.5	S
41	5.3	1.2	17.2	5	M	0.41	0.51	0.5	S
44	0.0	0	21.2	5	H	0.35	0.45	0.5	S
45	34.8	2.6	17.9	6	H	0.40	0.50	0.5	I
46	22.2	1.0	15.1	5	M	0.44	0.54	0.5	S
48	21.9	2.6	15.0	3*	H	0.45	0.55	0.5	I see *
53	38.5	8.6	12.6	6	M	0.48	0.58	0.5	I
54	0.0	0	18.4	5	M	0.39	0.49	0.5	S
55	10.6	7.4	6.1	5		0.45	0.55	0.45	S
57	182.2	5.9	18.9	7	M	0.38	0.48	0.5	I
60	0.0	0	25.0	4	M	0.28	0.38	0.5	D
63	0.0	0	22.4	6	H	0.33	0.43	0.5	S
71	0.0	0	22.1	5		0.33	0.43	0.5	S
72	0.0	0	21.5	5		0.34	0.44	0.5	S
76	0.0	0	21.5	3	H **	0.34	0.44	0.5	S
77	0.0	0	24.0	4	M	0.30	0.40	0.5	D
79	0.0	0	22.1	5	H	0.33	0.43	0.5	S
82	0.0	0	22.8	5		0.32	0.42	0.5	S
88	0.0	0	22.1	5		0.33	0.43	0.5	S

***** This site was categorised incorrectly it should be site category 2

** From the information on this site, the IL would have been reduced but the curve study judged this site as High Risk.

3.5.1 Sites Recommended for Change

3.5.1.1 .Sites Recommended for an Increase in the Investigatory Level

Site 13

This site is currently a site category 2 with a required ESC of 0.5. The site has a curve which is less than 250m radius and it also has a 10% gradient. The impact of a crash on this site is considered critical, because there is a potential for head-on crashes if overcompensating the curve. The rating from the investigation is 8, the deficiency rating is high and the crash rate is above average for the site and the crash density is high. Taking all factors into account it is recommended that the IL for this site be increased to 0.55.

Site 14

This site is multi-event, a curve on a gradient, with low texture and a second curve a 'surprise'. The deficiency rating is medium and the crash rate is way above average and the crash density is high. It is recommended the IL for this site be increased to 0.55.

Site 16

This site has a high crash rate and crash density but the site hazard risk investigation suggests that it is below the average risk rating and the curve deficiency is medium risk. It is suggested that a review of the site is carried out to determine if anything was missed from the last site inspection and also to determine if the crashes are caused by skidding.

Site 17

The risk rating from the site inspection is slightly above average, due to the curve leading to a one way bridge. There are also intersections along the route leading to minor accesses. The crash rate is very high and the crash density is not insignificant. The IL should be increased to 0.55.

Site 23

The site is considered average risk and the current skid resistance is above the IL. However, the crash rate is high and parts of the site are flushed. A review is recommended to determine the likely cause of crashes.

Site 27

The hazard risk rating on this site is 6, which is just above average. The impact of a crash at this location could be critical and the crash rate and crash density is high so it is recommended that the IL be increased to 0.55.

Site 29

The hazard risk rating from the site inspection was average but the crash rate and crash density is high. It is recommended that the IL be increased to 0.55.

Site 34

The site has a bend and is on a gradient with dips in the middle of the curve. There is a negative camber on parts of the site, the lanes are narrow and there is a bridge at the end of the curve. The crash rate and density is high so it is recommended that the IL be increased to 0.55.

Site 45

This site is a curve at the end of a fast straight road. The curve is a surprise since it is not signed and the crossfall is flat. The hazard risk rating on site was 6, the curve deficiency value was high and the crash rate and density is high. It is recommended that the IL for this site be increased to 0.55.

Site 53

The hazard risk rating for this site is above average, because the safe approach speed on the curve is lower than visually indicated which may be responsible for the high crash rate and crash density. It is recommended that the IL be increased to 0.55.

Site 57

This site is the first in a series of curves. The approach speed is 100km/h there are no advisory signs recommending a speed reduction . The hazard risk rating is 7, the crash rate is very high and the crash density is significantly above average. It is recommended that the IL for this site be increased to 0.55.

3.5.2.2 Sites Recommended for a Decrease in the Investigatory Level

Site 60

The hazard risk rating is below average and there have been no crashes for the previous 3 years, even though the maximum skid resistance of the site is 0.38. It is therefore recommended that the IL of the site be reduced to 0.45.

Site 77

The hazard risk rating is below average and there have been no crashes, even though the maximum skid resistance is 0.40. It is recommended that the IL for the site be reduced to 0.45.

4.0 BENEFIT COST RATIOS FOR CHANGES MADE TO THE IL FOR THE SITES

The benefit cost analysis is based on resurfacing sites as soon as is practicable. The following assumptions have been used in the calculations

- Surfacing will last for 8 years;
- The discount rate is 10%;
- Treatment costs occur in year 1 and the crash savings occur in every year for the 8 year life of the treatment.
- Calcined Bauxite will achieve an ESC of 0.6.

4.1 CRASH SAVINGS

For large studies involving 1000's of sites, the crash saving accomplished by increasing the IL could be calculated using the equation of the lines from the graphs of crash density for the curves and the gradients developed in a previous study[1].

It is then a simple matter to determine the crashes saved by increasing the IL. However, these equations were developed for all the curves and gradients for the entire state highway system whereas, in this study, the increases are only being applied to a relatively small number of sites that are considered to be higher risk than the average event and/or have a higher than average crash rate and crash density.

Therefore, the equations developed for all curves and gradients are not applicable, since it is believed the crash saving will be much higher on the high risk sites. It is suggested that the crash savings are estimated using the results from studies carried out by Transit New Zealand[6], Young[7] and Hosking[8].

Young found that, for an increase of SC from 0.4 to 0.5, there was a 45 percent or more reduction in wet-road skidding rates, while Hosking found, more generally, that an increase of 0.1 SC would reduce the number of wet-road skidding accidents in Great Britain by about 37 percent.

In New Zealand, it was found that there was an increase of 0.05 MSSC from 1995 to 1998 at deficient sites and that there was <u>also</u> a drop in wet-road skid injury crashes from 717 to 495. It was concluded that this was consistent with findings from the other studies and that an increase of 0.1 MSSC, will reduce wet-road skidding crashes by 40 percent.

The crashes reported in this study are wet-road crashes not wet-road <u>skidding</u> crashes since it has been found that skidding crashes are significantly under reported. Therefore, if it assumed that 50 percent of the wet-road crashes are due to skidding, then it would be appropriate to suggest that there would be a 20 percent reduction in wet-road crashes for the sites in this study, for every 0.1 SC increase in the skid resistance.

4.2 COSTS

4.2.1 Cost of Crashes

The cost of injury crashes, in 2003 monetary values, for rural and urban sites, is given in Transfund's Project Evaluation Manual, reproduced below, Table 5

Table 5. Cost of Injury Crashes for Rural and Urban Sites (2003)

Speed Limit and/or Site	Cost for All Vehicles ($)		
	Railway Crossings	Rural Bridges	All Other Sites
50 km/h	330,000	N/A	220,000
60 km/h	390,000	N/A	290,000
70 km/h	445,000	N/A	370,000
80 km/h	505,000	505,000	440,000
100 km/h Rural	620,000	620,000	590,000
100 km/h Remote Rural	935,000	935,000	890,000
Motorway	N/A	N/A	250,000

4.2.2 Cost of Materials

The recommendation is to replace the surfacing immediately, or as soon as is practicable. Therefore, the cost to increase the IL's to the recommended level will be the full cost of the surfacing. Natural aggregates with a high PSV are not available in Northland area, so haulage costs will need to be incorporated. Naturally occurring aggregates available in the region have a PSV ranging from 51 to 58, while those from other parts of NZ can provide PSV's of up to 65. If PSV levels of greater than 65 are required, then specialist artificial aggregates such as calcined bauxite will be required.

It has been assumed that:

- Average carriageway width = 7m
- The additional cost of higher PSV natural aggregate will be $1.50 per m^2 including any haulage costs
- The cost of High Friction Surfacing(Calcined Bauxite) is estimated to be $50/m^2.

4.3 PSV TO ACHIEVE THE RECOMMENDED IL

The calculated PSV necessary to achieve the recommended IL skid resistance can be calculated using the T/10 equation. However, as now seen from the reported work, an aggregate does not always behave in service as predicted.

The PSV equation can be rearranged, to make sfc the dependent variable

sfc = [PSV – (CV* 0.00663 + 2.6)]/100

Thus, by putting the PSV of the stone and the commercial vehicles in the equation the calculated sfc can be obtained and compared with the measured sfc to determine if the aggregate is producing the skid resistance as predicted .

This has been done for all of the sites above, where an increase in the IL is recommended and the results are shown in Table 6.

Table 6 In-Service Behaviour of the Aggregate on Sites Recommended for an Increased IL

Site Number	PSV of Stone Used	Mid Skid Resistance	Calculated Skid Resistance	Difference between in-service sfc and Calculated sfc
13	53	0.41	0.45	-0.04
14	53	0.54	0.46	0.08
17	53	0.44	0.5	-0.06
27	65	0.46	0.59	-0.13
29	53	0.43	0.47	-0.04
34	58	0.5	0.55	-0.05
45	53	0.45	0.49	-0.04
53	55	0.53	0.48	0.05
57	53	0.43	0.47	-0.04

As can be seen the aggregates on seven of the nine sites are performing below predicted expectations.

In cases where the PSV equation indicated that the stone should have given the appropriate SFC and has fallen short there could be additional stresses at the site. These additional stresses can be compensated for by adding another constant in the PSV equation as a stress factor. Hence, the PSV equation now becomes:

PSV = 100*SFC + CV 0.00663 + 2.6 + stress factor

It is reasonable to set the stress factor as the difference between the expected sfc and the actual sfc multiplied by 100. The required PSV to achieve the recommended IL skid resistance, taking the stress factor into account, is now shown in Table 7.

Table 7 Required PSV to Meet the sfc Requirements

Sites Number	Required PSV
13	67
14	62
17	64
27	74
29	65
34	63
45	62
53	62
57	65

According to Transit's PSV list the aggregate with currently the highest PSV in New Zealand comes from Moutohora and has a PSV of 65, followed by Linton Quarry with a PSV of 61.

Table 7 indicates all sites would require a stone with a PSV above 61 and two sites require a PSV above 65. However, as the Moutohora chip was used on site 27 and it gave an ESC of 0.13 below that predicted by the T/10 equation, there is no reason to suspect it would perform any better at other high stress sites.

This means that each of the sites would require to be treated with calcined bauxite to achieve the recommended skid resistance levels which will considerably increase the cost for treating the sites, however, it would also increase the crash reduction benefits.

The benefit cost ratios of using calcined bauxite on the sites is shown in Table 8. As can be seen, the lowest benefit cost ratio is 3 and the highest 30, indicating that there are significant benefits in crash reduction savings. These benefits far outweigh the costs of applying a calcined bauxite treatment to the recommended sites.

5.0 IMPLICATIONS

5.1 IMPLICATIONS FOR THE KEY PERFORMANCE MEASURES

The key performance measures (KPMs) are currently set against the IL's in the T/10 specification. Therefore, if changes were made to the KPMs, to incorporate risk management techniques, there would be implications to be considered, both regionally and nationally.

5.2 NATIONAL IMPLICATIONS

There is no reason that the benefit costs indicated in this study could not be achieved in other areas of New Zealand with consequent crash reduction savings. This implies that other areas in New Zealand would also benefit from using risk management techniques to determine the Investigatory Level. However, the implications need to be managed carefully to facilitate changes to national policy.

Also, as indicated here, there is doubt regarding the correlation of PSV and the skid resistance achieved in-service.

It is untenable to try to achieve a level of skid resistance using a trial and error process, to identify a surface aggregate with the appropriate in-service characteristics. Therefore, the validity of the PSV and its relationship to the skid resistance on the New Zealand road network needs to be further investigated as a priority.

In the interim, the findings in this study should not be used as evidence to disregard the PSV approach when selecting surfacing aggregate, since it has been found that there is more chance of achieving the required skid resistance if the PSV meets the requirement than if it does not. It is suggested that consideration should be given to the use of a stress factor in the PSV equation where justified.

6.0 CONCLUSIONS

A risk management approach has been investigated and developed to set the optimum investigatory level for individual sites, in line with the risk of a skidding crash. A hazard and risk assessment has been performed using a site investigation process and a proforma developed for this study.

Also used are the results from alternative studies carried out on the same sites. These included a process for evaluating the deficiency of a curve and a process that provides a prediction of the maximum and minimum skid resistance levels for each of the sites according to rain-fall data. Information from the crash database has also been used in the assessment.

It has been found that this approach can be used objectively to assign appropriate investigatory levels and that, by using the results of previous studies, the saving in the number of crashes could be estimated.

It has been found that, at a number of sites, the PSV equation does not adequately represent the behaviour of the surfacing aggregate in-service. This poses problems for selecting the appropriate aggregate for particular sites.

A stress factor has been included in the PSV equation to try and take account of the additional stress of the sites but this has led to relatively high PSV material being required to achieve the recommended skid resistance IL. In fact, it has been recommended that to achieve the desired levels of skid resistance, calcined bauxite should be used in a number of cases.

The benefit cost analysis indicated that even using calcined bauxite the benefits due to crash savings outweighed the cost of surfacing

The local implications are quite broad, since the relatively small changes recommended to the IL in the study area lead to significant changes in the cost of surfacing, however, these changes can be justified using a benefit cost approach.

The national implications are wide-reaching, since it is likely that similar changes will be justified throughout New Zealand. This is beneficial, because of the potential for large crash reduction savings, but the associated costs must also be taken into account when developing and implementing a national policy.

The lack of correlation between PSV and the skid resistance in-service causes a major problem, since the current policy specifies the use of the PSV equation to select aggregates. The validity of the polished stone test, and its relevance to the skid resistance of aggregates in-service on the road, should be investigated as a matter of priority.

Table 8 The Benefit Cost Ratios for Applying a Calcined Bauxite Surfacing to the Sites

Site	Crash Density/km/yr	Length of Site (m)	Crashes/site/yr	Current Mid skid	Increase in Skid resistance	Crash Savings	savings($/yr)	Treatment cost($)	PV	BCR
13	8	250	2	0.41	0.19	0.760	448400	87500	2389972	27
14	2.9	520	1.508	0.54	0.06	0.181	106766	182000	569065	3
17	2.6	510	1.326	0.44	0.16	0.424	250349	178500	1334359	8
27	5.7	350	1.995	0.46	0.14	0.559	329574	122500	1756629	14
29	9.8	410	4.018	0.43	0.17	1.366	806011	143500	4296038	30
34	3.4	290	0.986	0.5	0.10	0.197	116348	101500	620135	6
45	2.6	290	0.754	0.45	0.15	0.226	133458	101500	711331	7.0
53	8.6	230	1.978	0.53	0.07	0.277	163383	80500	870830	11
57	5.9	500	2.95	0.43	0.17	1.003	591770	175000	3154134	18

7.0 REFERENCES

1. Cook, D; Donbavand, J; Kennedy, C. A Review of Skid Resistance Investigatory Levels for New Zealand, Towards Sustainable Land Transport Conference, Wellington New Zealand 21 – 24 November 2004

2. Theron A.J; Houba P; Tate F.N; and Henning T.F.P. Establishment of a Curve Deficiency Classification System in Determining a Risk Management Approach for Addressing Skid Resistance on the Network Level, International Conference on Surface Friction, Christchurch New Zealand 1 – 4 May 2005

3. Kirk, G and Houba, P SCRIM Risk Management Report. Unpublished internal Works Infrastructure Report to PSMC 002 Management Board 2004

4 Cenek, P.D; Alabaster, D.J; Davies, R.B. Seasonal and Weather Normalisation of Skid Resistance Measurements. Transfund New Zealand Report No 139. 1999

5 Szatkowski, W.S and Hosking The effect of Traffic and Aggregate on the Skidding Resistance of Bituminous Surfacings. TRRL Report No LR504 1972.

6 Transit New Zealand Submission No CS/00/9/3746 2000.

7 Young, A E, 1985. The Potential for accident reduction by improving urban skid resistance levels. Queen Mary College, University of London.

8 Hosking, J R. Relationship between skidding resistance and accident frequency: estimates based on seasonal variation. TRRL Report RR 76. Crowthorne 1986

ACKNOWLEDGEMENT

The authors would like to acknowledge the assistance of Mr Glen Kirk who was responsible for collecting the majority of the data used in this study.