# Incorporating Safety Management Modelling into NZ-dTIMS

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Date: May 2016
Reference: 5-29E54.00
Status: Draft 2

# Contents

# Acknowledgements

The considerable contributions of Elke Beca of Westlink Bay of Plenty for supplying all the datasets required for calibrating and validating the safety models, Jim Curtis of Half Leaf Data for coding the models in Python and running the various scenarios of interest and Matt Smith of Opus Christchurch for generating the 2014-16 SAL tables that proved invaluable for confirming the modelling outputs are gratefully acknowledged.

# Abbreviations and acronyms

| | |
|---|---|
| AADT | Average Annual Daily Traffic |
| AF | Adjustment Factor |
| AP | Asset Preservation |
| BCR | Benefit Cost Ratio |
| CAS | The Transport Agency's 'Crash Analysis System' |
| dTIMS | Deighton Total Infrastructure Management System |
| ESC | Equilibrium SCRIM Coefficient |
| HSDC | High Speed Data Collection |
| IL | Investigatory Level for Skid Resistance |
| ILM | Investigatory Level for Macrotexture |
| MPD | Mean Profile Depth i.e. a measure of macrotexture in mm |
| NLTP | National Land Transport Programme |
| NMA | The Transport Agency's 'Network Management Area' |
| NZTA | New Zealand Transport Agency ('The Transport Agency') |
| PSV | Polished Stone Value |
| RAMM | The Transport Agency's 'Road Asset Maintenance Management' database |
| RAPT | The Transport Agency's Review and Prioritisation Team |
| RV | Residual value i.e. difference between the measured SAL skid/texture value and the IL/ILM value applying to the SAL. A negative RV indicates the IL/ILM has been breached. |
| $r^2$ | Coefficient of determination |
| SAL | Skid Assessment Length |
| SC | SCRIM Coefficient |
| SCRIM | Side-way Force Coefficient Routine Investigation Machine |
| SFC | Side-way Force Coefficient i.e. a measure of skid resistance |
| STAG | The Transport Agency's 'Skid Technical Advisory Group' |
| TINT | Time to subsequent intervention |
| TL | Threshold Level for Skid Resistance |
| TLM | Threshold Level for Macrotexture |
| YFI | First Year of Intervention |

# Executive summary

This report details how safety management has been incorporated into NZ-dTIMS, a modelling system used to perform deterioration modelling and life-cycle cost analyses of the New Zealand state highway network. In the context of this report, safety management pertains to surfacing treatments related to maintaining appropriate levels of braking and cornering performance for road users under wet conditions. Therefore, safety management concerns the provision of adequate levels of skid resistance, as this affects the level of wet friction provided, and road surface texture, as this affects the rate wet friction reduces with increasing vehicle speed.

The report also presents the results of modelling three scenarios 20 years into the future covering the period 2015 to 2024. The scenarios considered were:

1. Immediate treatment of breaches of skid resistance and macrotexture values as specified in the Transport Agency's T10 specification for state highway skid resistance management termed network safety need.
2. $100 million per annum asset preservation works programme as generated by dTIMS, termed network asset preservation need.
3. The unlimited safety and $100 million capped asset preservation works programme combined within dTIMS, termed the network combine need.

The key findings are summarised as follows:

- By basing the safety modelling on skid assessment lengths (SAL), which range in length from 10 m to 100m, it was possible to combine established models for estimating the decay of skid resistance and macrotexture due to trafficking with model constants and scalars derived from skid resistance and macrotexture time histories pertaining to a SAL that minimised the difference between the predicted and actual values. Accordingly, each of the 330,000 or so SALs had unique model calibrations. The resulting safety modelling framework gave predicted deterioration rates that closely matched those observed. Also, false positives, i.e. when a condition is not met but the model predicts it is, were kept in check so that the predicted breaches of skid resistance and macrotexture threshold levels resulted in cumulative lengths that were within a factor of 0.7 (flushing) and 1.4 (skid resistance) of that actually observed. It also correctly predicted about 40% of skid resistance and macrotexture breaches at the individual SAL level. The predictive ability of the safety modelling framework can therefore be considered adequate for the purposes of budget forecasting.
- Combining safety and asset preservation programmes generates a number of benefits including:
  - A maintenance cost saving of the order of $5.2 million per annum when compared to managing the programmes separately
  - A redistribution of safety need which sees the peak need occurring in 2022 reduce from 1065 lane-km to 539 lane-km
- Treating SAL's with breached threshold levels was shown to be a very cost effective safety measure, reducing the crash density from 4.51 wet crashes per lane-km to 1.7 wet crashes per lane-km. This corresponds to an estimated social cost saving of $30.2 million per annum. Therefore, the benefit cost ratio for treating SAL's with breached skid resistance/macrotexture values under the safety only scenario is 4 and under the combined scenario it is 5.

# 1 Introduction

This report details how safety management has been incorporated into NZ-dTIMS, a modelling system used to perform deterioration modelling and life-cycle cost analyses of the New Zealand state highway network. In the context of this report, safety management pertains to surfacing treatments related to maintaining appropriate levels of braking and cornering performance for road users under wet conditions. Therefore, safety management concerns the provision of adequate levels of skid resistance, as this affects the level of wet friction provided, and road surface texture, as this affects the rate wet friction reduces with increasing vehicle speed.

Incorporation of safety management into NZ-dTIMS was one of a number of projects undertaken to enhance the coverage and reliability of forecasting work performed to support the NLTP submission for the 2018/21 programme.

## 1.1 Context

NZ-dTIMS has the ability to predict pavement deterioration caused by defects such as cracking, rutting and roughness. However, during its development, modelling of skid resistance and surface texture loss was not attempted as this was considered to be a seal design issue rather than a pavement management issue. A further complicating factor was that both skid resistance and texture loss are addressed as local defects resulting in treatment lengths that vary between 10 m and 100 m. In comparison, the NZ-dTIMS analysis and forecasting framework is based around uniformly performing contiguous sections of state highway, giving treatment lengths for pavement related defects that range from a minimum of 5 m to a maximum of 500 m.

In practice, a substantial amount of resurfacing and rehabilitation works that is undertaken is to address skid resistance and flushing issues, where flushing is an extreme case of texture loss in chipseal surfaces brought about by the bitumen binder rising to the top of the sealing chip. The flushing condition is assumed to represent the normal end of life of a chipseal or a potential asset preservation issue i.e. seal instability. A large proportion of asset preservation related resurfacing work forecast by NZ-dTIMS will, therefore, address skid resistance and texture issues prior to them manifesting themselves as a safety concern. However, there is no way at present for separating out the amount of resurfacing and rehabilitation works forecast by NZ-dTIMS that is safety related from that which is asset preservation related and determining the impact on state highway network skid resistance and texture profiles.

## 1.2 Project Objective

The objective of the model development detailed in this report is to allow the effect of different investment levels on network skid resistance and texture levels and the associated impact on casualty crashes to be quantified. This in turn will enable the portion on the NLTP that is safety works related to be quantified and also the funding level required to achieve a specified safety outcome in terms of percentage change in casualty crashes.

In order to achieve this objective, the following key questions needed to be answered:

- What is the surface driven safety need of the state highway network i.e. how much of the state highway network falls below the skid resistance and texture threshold levels given in the T10:2013 Specification for state highway skid resistance management?
- How much of this safety need is addressed by asset preservation works before becoming a candidate for immediate intervention?

- What is the casualty crash profile on state highway sections where the skid resistance and texture threshold levels have been breached?

## 1.3 Report Scope

This report, in overview, presents the findings of a first attempt to integrate two surfacing issues, namely skid resistance and texture loss, into the NZ-dTIMS modelling system. The layout of the report is as follows.

To provide context to the modelling approaches adopted, section 2 backgrounds the Transport Agency's safety management policy and section 3 presents historical trending of skid assessment lengths SAL's over the three year period 2014 to 2016, and state highway skid resistance and texture values over the 14 year period 2003 to 2016. Section 4 details the approaches adopted for modelling skid resistance and texture loss. Section 5 covers the calibration and validation of the new surfacing related models. Section 6 summarises the results of applying the models over the 20 year period 2015 to 2034. Key conclusions and recommendations for further work are given in section 7.

# 2 Safety Management of State Highways

## 2.1 T10 Specification

One of several critical elements of the Transport Agency's safety management of sealed sections of the state highway network is the T10 Specification: 2013[1]. This specification is concerned with the cost-effective provision of road surfaces that have an appropriate level of wet friction for all road vehicles. Appropriate wet friction is determined by reference to investigatory and threshold levels of both skid resistance, as measured by the sideway-force coefficient routine investigation machine (SCRIM), and macrotexture, which is required to minimise the progressive loss of skid resistance with increasing speed.

The investigatory level for skid resistance (IL) and the investigatory level for macrotexture (ILM) are maintenance priority indicators for programming treatment. These levels have been set with the objective of equalising the personal risk of a wet road skidding crash across the state highway network while maintaining an economic balance between the cost of their provision and the resulting savings in crashes.

Personal risk or crash rate is a measure of the number of crashes that have happened per 100 million vehicle kilometres of travel on the road. Crash rates reduce with increasing skid resistance. However, while the general shape of this relationship is the same for all sites, the actual crash rate may vary significantly between different types of site. For example, approaches to controlled intersections have a higher crash rate than event-free divided carriageways. This differential crash rate is addressed through a different IL value being allocated to each of the 5 site categories adopted in the T10 Specification.

A continuous length of state highway with a single site category description is referred to as a skid site. These sites are normally not less than 50 m long but can be several kilometres in length.

IL and ILM's are set at levels where there is adequate skid resistance and texture respectively. If the skid resistance or texture at a site is found to be at or below the investigatory level, this piece of information is only one of several used in deciding whether or not maintenance of the road surface is required. The other factors to be considered are roughness, rutting, flushing, maintenance cost and recent crash history.

The threshold levels for skid resistance (TL) and the threshold level for macrotexture (TLM) are skid resistance and texture maintenance trigger levels. They are the point at which action is likely to be taken (i.e. the site is given priority for urgent remedial work). The urgency of the remedial work is dependent on the location of the particular site and the extent to which the skid resistance or texture is below the threshold level.

## 2.2 Annual Surveys

An annual survey of the entire state highway network, corresponding to a survey length of about 22,000 lane kilometres is undertaken to measure skid resistance in terms of SCRIM Coefficient (SC) and texture, in terms of mean profile depth (MPD), which has units of millimetres. These measurements are via the Transport Agency's High Speed Data Collection Contract[2]. The SC and texture measurements are made in both wheelpaths and are averaged over a length of 10 m. As part

[1] https://www.nzta.govt.nz/assets/resources/skid-resistance-investigation-treatment-selection/docs/T10-skid-resistance-investigation-treatment-selection-201306.pdf, accessed on 10th May 2016.

[2] https://www.nzta.govt.nz/roads-and-rail/road-composition/pavement-condition-surveys/, accessed on 10th May 2016.

of the annual survey, other high-speed road condition statistics, such as rutting and roughness, and road geometry (gradient, crossfall and horizontal curvature) are also collected.

The annual survey is undertaken in most lanes, though the default lane is the outer lane i.e. the lane furthest from the centreline or median.

As the skid resistance varies with time (primarily due to rainfall and traffic numbers), the data is seasonally corrected for both with-year and between-year variations to produce the equilibrium SCRIM coefficient (ESC). This is then used as a factor for prioritising surface maintenance for skid resistance and texture via the investigatory and threshold values appropriate to the site category or according to the risk of a skidding crash at the site.

## 2.3 Exception Reporting

As the seasonal corrections required to calculate the ESC cannot be generated until the end of the summer period, a skid resistance and texture exception report (referred to as an 'exception report') is produced immediately following the survey of each Transport Agency management area to enable prompt initial assessment and programming of treatment to address 10 m road sections where the SC and/or macrotexture are less than the TL or TLM.

Each 10 m length is assigned to priority A or B for investigation. Priority A sites are those that have had at least two wet skid crashes within 250 m of the site in the previous five years or are flushed or breach the threshold level by a significant margin. All other 10 m lengths are assigned to a priority B.

All 10 m lengths that are in priority A are investigated. This investigation may include adjacent 10 m lengths in the same treatment length to ensure the most appropriate treatment or maintenance will be undertaken. Where treatment is found necessary, it is carried out in the current survey season, where practicable. Otherwise, it is programmed for the following season.

For treatment sites where surfacing is the best option but seasonal constraints prevent this, interim action to ensure the site is safe during winter is considered. This may include removal of excess binder (e.g. waterblasting), rejuvenating the microtexture of the roading aggregate (e.g. scabbling) or signage.

## 2.4 Prioritising Sites for Treatment

In April, shortly after the annual survey is completed, the skid resistance data is seasonally corrected to give ESC values and populated in the Transport Agency's road assessment and maintenance management (RAMM) database. This ESC data is used to confirm sections of lanes to be investigated for treatment or maintenance and their prioritisation as more sites will be included in the exception report than can be investigated as a priority.

When using this ESC data to prioritise sections of lanes, IL's are for the mean ESC value within an appropriate averaging length. This length is referred to as the Skid Assessment Length (SAL). The SAL for each of the 5 skid site categories adopted in the T10 Specification: 2013 is given in Table 1 along with the base IL.

With reference to Table 1, lengths of SAL's vary from a minimum of 10 m to a maximum of 100 m. However, whenever the length of a feature of interest is less than the SAL, the actual length is averaged and considered.

**Table 1:** Skid assessment length by T10 skid category

| Site Category | Skid Site Description | Skid Assessment Length, SAL (m) | Base IL (ESC) |
|---|---|---|---|
| 1 | Approaches to:<br>a. Railway level crossings<br>b. Traffic signals<br>c. Pedestrian crossings<br>d. Stop and Give Way controlled intersections (where state highway traffic is required to stop or give way)<br>e. Roundabouts<br>One lane bridges:<br>a. Approaches and bridge deck | 60 | 0.55 |
| 2 | a. Urban curves < 250 m radius<br>b. Rural curves < 250 m radius<br>c. Rural curves 250 m – 400 m radius<br>d. Down gradients > 10%<br>e. On ramps with ramp metering | 50 | 0.5 |
| 3a | State highway approach to a local road junction | 60 | 0.45 |
| 3b and 3c | Down gradients 5% - 10%<br>Motorway junction area including on/off ramps | 50 | 0.45 |
| 3d | Roaundabouts, circular section only | 10 | 0.45 |
| 4 | Undivided carriageways (even-free) | 100 | 0.4 |
| 5 | Divided carriageways (event-free) | 100 | 0.35 |

The scoring system summarised in Table 2 is used for prioritising sites that are below the IL or ILM. The score for each parameter listed in Table 2 is calculated for each SAL under consideration based on the average ESC and macrotexture for the SAL, and then summed to give the total SAL score. The priority ranking is highest to lowest SAL score.

**Table 2:** Scores for investigating SAL priority

| Parameter | Scores and Criteria |
|---|---|
| Number of wet skid crashes over past 5 years | One crash zero points, two or more crashes 80 points for each crash |
| Difference between SAL ESC and IL i.e. skid residual value (IL_RV) | 0 points if IL_RV ≥ 0<br>4 points for each 0.01 between IL_RV = -0.01 and IL_RV=-0.05<br>10 points for each 0.01 between IL_RV =-0.06 and IL_RV=-0.10<br>15 points for each 0.01 below IL-RV =-0.10 |
| Difference between SAL Texture and ILM i.e. texture residual value (ILM_RV) | 0 points for ILM_RV ≥ 0<br>5 points for each 0.1 between ILM_RV = -0.1 and -0.3<br>10 points for each 0.1 when ILM_RV < -0.3 |
| Annual Average Daily Traffic (AADT) | 1 point for each AADT/1000 |

When calculating the SAL score for texture, rounding to a single decimal place applies so if the 2nd decimal place of ILM_RV is a 1,2,3,or4 round up (i.e. make less negative) . However, if the 2nd decimal place of ILM_RV is a 5,6,7,8,9 round down (i.e. make more negative).

The following two examples illustrate how the scoring regime in Table 2 is applied in practice:

Example 1 Skid Resistance:
If the IL pertaining to the SAL of interest is 0.55 ESC and the measured ESC averaged over the SAL is 0.38 ESC, the residual value (IL_RV) is 0.38-0.55 = -0.17 ESC. Therefore the contribution to the SAL score (sal_esc_rv_score) = $4\times5+10\times5+15\times7 = 175$.

Example 2 Texture:
If the ILM pertaining to the SAL of interest is 1.0 mm MPD and the measured MPD averaged over the SAL is 0.76 mm, the residual value (ILM_RV) is 0.76-1= -0.24, which rounds up to -0.20. Therefore, the contribution to the SAL score (sal_ilm_rv_score) = 10. However, if the measured MPD = 0.74 mm, ILM_RV= 0.74-1=-0.26, which rounds down to -0.3. In this case, the contribution to the SAL score = 15. Say, the ILM_RV= -0.434, rounded up this equals -0.4 so the sal_ilm_rv_score = 40.

These two examples highlight two important points:

1. The SAL score is more sensitive to a deficiency in skid resistance than a deficiency in texture.
2. The SAL texture value has to be at least 0.3 mm MPD below the ILM to have any significant impact on the SAL score.

Currently, the TL has been set at a skid resistance level of 0.1 ESC below the IL or a minimum value of 0.3 ESC, whichever is higher. Therefore, the SAL score of a SAL where only the TL has just breached is 70 for T10 site categories 1 to 4 and 20 for T10 site category 5.

The TLM for chipseal surfaces, which is the predominant surfacing type on the state highway network, is set at a macrotexture level of 0.3 mm MPD below the ILM. Therefore, the SAL score of a SAL where only the TLM has just breached will be 15.

A fully flushed section of road is defined when both the skid resistance is ≤ 0.35 ESC and the macrotexture is ≤ 0.7 MPD[3]. Therefore, for an IL=0.55ESC (i.e. T10 site category 1), the presence of flushing will give a SAL score of 235, whereas for an IL=0.5ESC (i.e. T10 site category 2) the SAL score reduces to 160.

For the 2015 SCRIM+ survey (2014/15 summer), the funding made available for treating SAL's that were below the IL or ILM was NZ$13.5 million. This funding allowed SAL's with a SAL score of 140 or greater and an average ESC value that is equal or less than IL-0.05 of to be treated, corresponding to a total length of about 397 lane-km's or 1.8% of the entire sealed state highway network.

The process of generating SAL's and associated SAL scores for each annual survey has been automated since the 2014 SCRIM+ survey. This information is readily accessible via the "Skid Assessment Length" table in RAMM.

In summary, the SAL score process has been formulated to target those lengths of state highway where there is a potential problem with skid resistance rather than lengths that have adequate skid resistance but a history of wet road crashes. Its intent is to identify sites where lower skid

[3] Whitehead,D., Donbavand,J. and Mitchell, J. (2011), Developing an Objective Measure for Flushing, 3rd International Surface Friction Conference, Safer Road Surfaces – Saving Lives, Gold Coast, Australia, 2011

resistance may be contributing to the crash rate that can be addressed by the available SCRIM sealing budget.

The expectation is that as the industry gains more experience with skid resistance management and appropriate maintenance work is undertaken, the number of SAL's requiring investigation will reduce significantly allowing the SAL score threshold of 140 to be lowered, provided funding for SCRIM sealing remains at around current levels.

# 3 Trend analysis

To better understand the impact of historical maintenance funding levels and practices, trending of state highway network skid resistance and texture values over the 14 year period 2003 to 2016 and SAL's over the three year period 2014 to 2016 has been performed. The key findings are presented below.

## 3.1 State Highway Skid Resistance and Texture Trends

Boxplots have been employed to help visualise how the condition of sealed sections of the state highway network has changed between 2003 and 2016, with regard to lane averaged skid resistance and texture (i.e. the average of left and right wheelpaths). For each year, the box shows the upper quartile, the median, and the lower quartile. Therefore, 50% of the 10 m average readings lie within the box. The vertical lines (*the whiskers*) run from the 10 percentile value to the 90 percentile value. Therefore 80% of the 10 m average readings lie between the two short horizontal bars. If the data was normally distributed, the distance between each of these short horizontal bars and the nearest edge of the box should be the same as should the height of the box above and below the median line.

### 3.1.1 Skid Resistance

The skid resistance trending has been based on SCRIM coefficient (SC) values rather than ESC values. This was done to eliminate any possible distortions that may be introduced by the seasonal correction procedure.

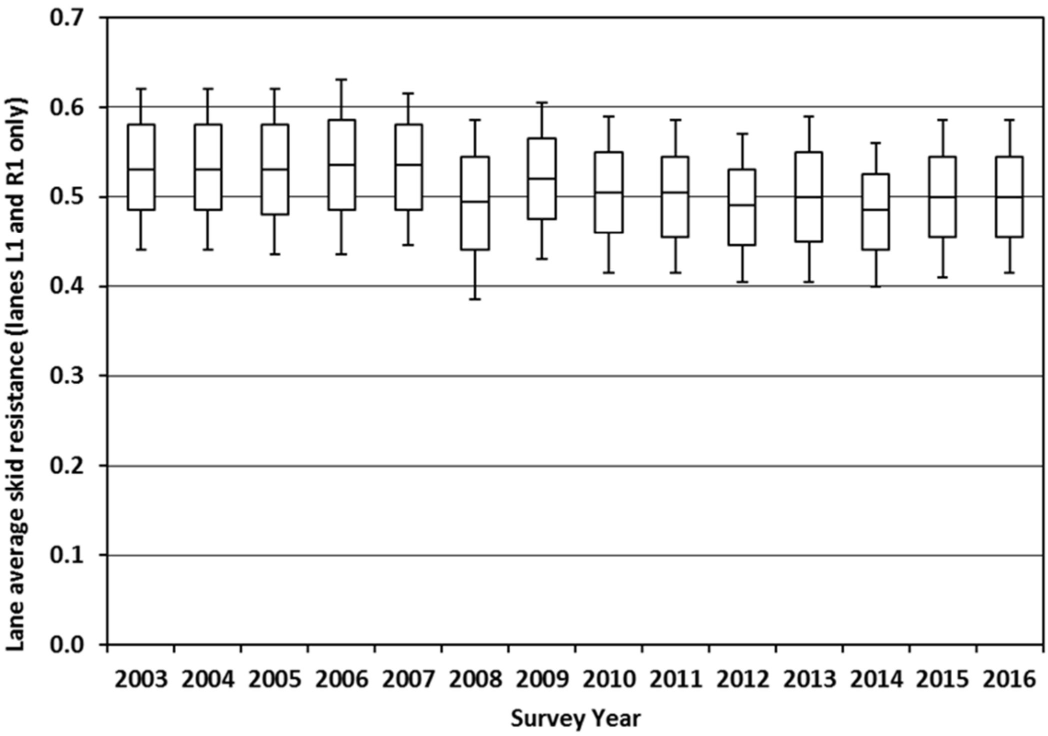



**Figure 1:** Trending of state highway lane skid resistance

With reference to Figure 1, 2008 is clearly an anomaly, possibly caused by the survey taking place later in the season than usual because of delays in getting the SCRIM+ machine from the UK. Therefore if 2008 is discarded, it can be seen that over the period 2003 to 2007, the network skid resistance remained fairly stable, with a median value at about 0.53 SC. From 2009 to 20014, the network skid resistance reduced at a rate of 0.005 SC/year, before stabilising over 2015 and 2016 around a median value of 0.50 SC.

Since the introduction of the revised T10 specification in 2013, there is also an upward trend in the 10 percentile value from 0.40 SC to 0.42 SC, indicating that the SAL score prioritisation and experience gained by the industry are having the desired effect.

### 3.1.2 Macrotexture

The macrotexture trending has been separated into chipseal surfaces and bituminous mix surfaces as they are differentiated in the T10 Specification in terms of minimum macrotexture requirements. Also, texture loss is more of an issue for chipseal surfaces because trafficking causes embedment of the sealing chips into the binder.

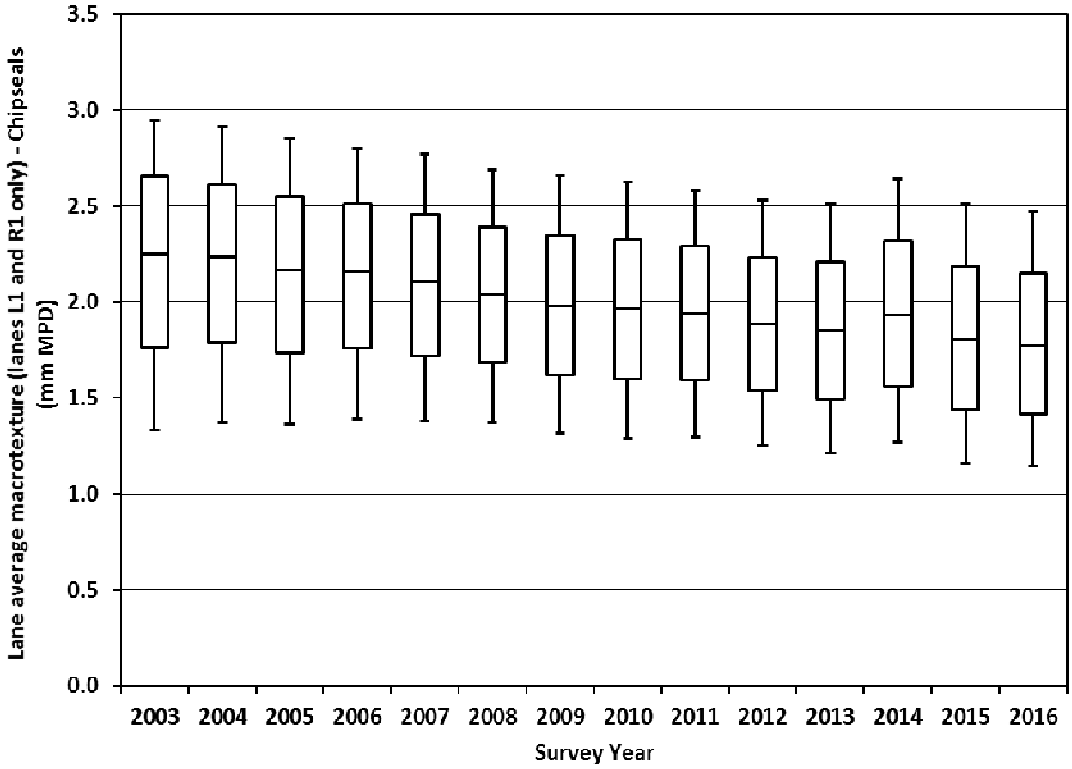



**Figure 2:** Trending of state highway macrotexture – chipseals only

With reference to Figure 2, it can be seen that the texture data is normally distributed. However, the median macrotexture value of chipseal surfaces on the state highway network is reducing at a rate of 0.034 mm MPD per year, whereas the 10 percentile value is reducing at a slower rate of 0.022 mm MPD per year.

Despite this gradual consumption of macrotexture, the 2016 10 percentile value is still 0.015 MPD above the ILM value of 1 mm MPD.

In contrast, Figure 3 shows the median macrotexture value of bitumen to be much more stable over time. Between 2003 and 2007 the median value is about 1.00 mm MPD whereas from 2008 to 2016 the median value averages at about 1.12 mm MPD. Pleasingly, there has been a steady improvement in the 10 percentile value from 0.36 mm MPD in 2003 to 0.59 mm MPD in 2016.

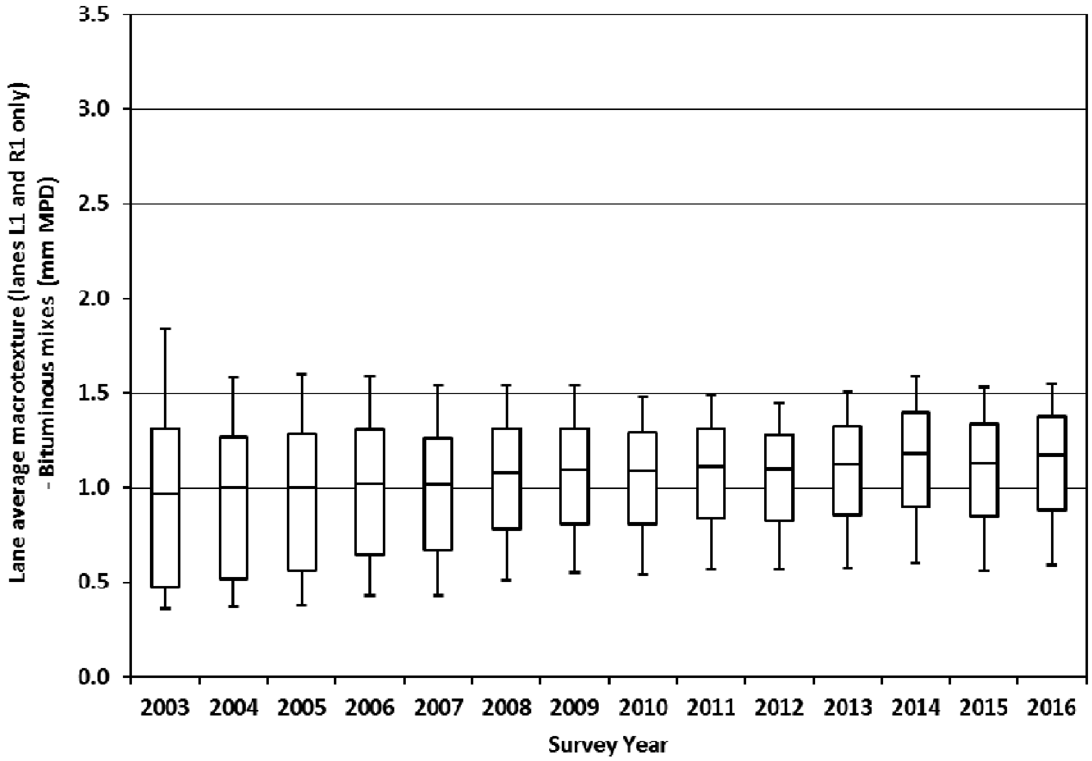



**Figure 3:** Trending of state highway macrotexture – bituminous mixes only

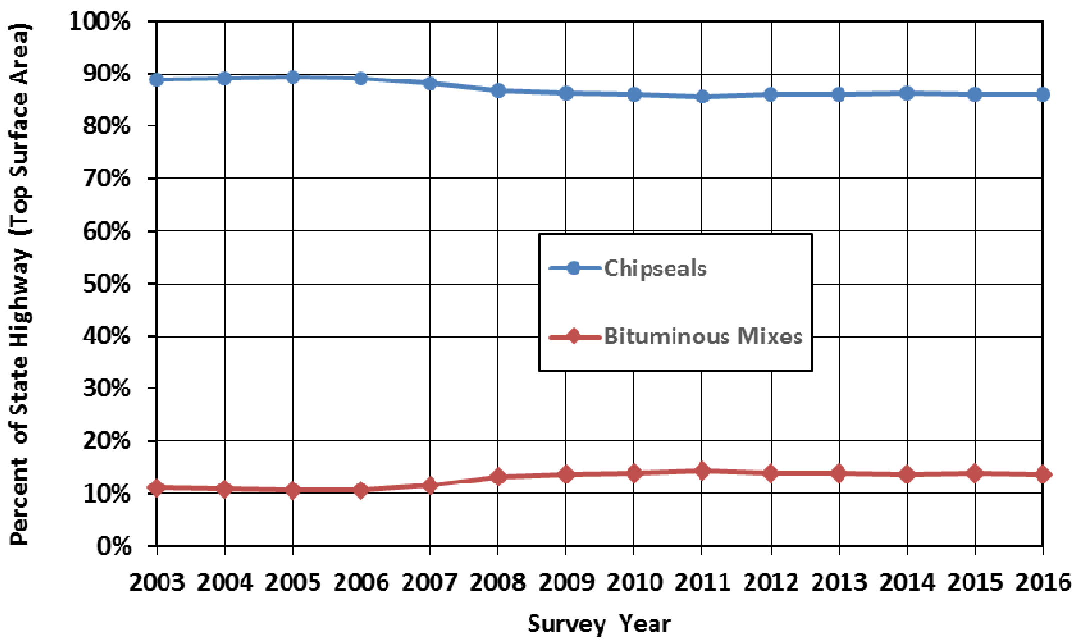



**Figure 4:** Comparative usage of chipseals and bituminous mixes on the state highway network

With reference to Figure 4, the increase in the median value of bituminous mix macrotexture coincides with an increase in the surface area of bituminous mix surfacings on the state highway network from approximately 11% between 2003 and 2006 to approximately 14% between 2010 and 2016. This is the result of newly constructed sections of motorways and expressways being opened, such as the Waikato Expressway, where noise considerations have dictated the use of open graded porous asphalt.

## 3.2 SAL Trends

Table 3 below summaries various length, crash and percentage numerics derived from RAMM's "skid assessment length" table for the 3 year period where SAL scoring has been used to prioritise treatment in response to constrained maintenance funding levels.

**Table 3:** SAL numerics

| | Survey Year | | |
|---|---|---|---|
| | 2014 | 2015 | 2016 |
| **All SAL's** | | | |
| No. of SAL's | 327,302 | 328,006 | 329,900 |
| Cumulative Length (lane-km) | 22,165.577 | 22,182.972 | 22,331.780 |
| % of total length classified as "Urban" | 8.1% | 8.0% | 7.9% |
| Minimum SAL Length (m) | 1 | 2 | 10 |
| Maximum SAL Length (m) | 100 | 100 | 100 |
| Av. No. of wet road SAL crashes per year | 39,714 | 38,155 | 36,539 |
| **SAL's with SAL score ≥ 140 & RV≤ -0.05** | | | |
| No. of SAL's | 9,099 | 8,275 | 8,384 |
| Cumulative Length (lane-km) | 426.148 | 387.815 | 389.070 |
| % of length of entire state highway network | 1.92% | 1.75% | 1.74% |
| Av. No. of wet road SAL crashes per year | 5,351 | 4,856 | 4,377 |
| % of all wet road crashes | 13.5% | 12.7% | 12.0% |
| % classified as "Urban" | 23% | 22% | 22% |
| % with TL breached | 55% | 54% | 55% |
| **SAL's with TL breached** | | | |
| No. of SAL's | 11,431 | 9,880 | 11,289 |
| Cumulative Length (lane-km) | 540.149 | 469.249 | 532.670 |
| % of length of entire state highway network | 2.43% | 2.11% | 2.39% |
| Av. No. of wet road SAL crashes per year | 2,684 | 2.286 | 2,149 |
| % of all wet road crashes | 6.8% | 6.0% | 5.9% |
| % classified as "Urban" | 14.7% | 16.3% | 15.2% |
| **SAL's with TL not breached but TLM breached** | | | |
| No. of SAL's | 3,232 | 4,823 | 4,327 |
| Cumulative Length (lane-km) | 178.325 | 274.984 | 242.120 |
| % of length of entire state highway network | 0.80% | 1.23% | 1.08% |
| Av. No. of wet road crashes per year | 767 | 1,147 | 1,047 |
| % of all wet road SAL crashes | 1.9% | 3.0% | 2.9% |
| % classified as "Urban" | 51.6% | 49.0% | 49.1% |

These numerics have been calculated for all SAL's as well as three subsets of SAL's comprising:

1. SAL's satisfying the SAL treatment criteria of a SAL score of 140 or greater and an average ESC value that is equal or less than IL-0.05;
2. SAL's breaching the threshold level for skid resistance (TL); and
3. SAL's breaching the threshold level for macrotexture (TLM) but not breaching the threshold level for skid resistance (TL).

Combining subsets 2 and 3 provides numerics on all the SAL's requiring treatment to restore either skid resistance or macrotexture or both to an acceptable level.

It should be noted that due to the uncertainty in the location of crashes, the T10 Specification stipulates that wet crashes within 250 m of a SAL are to be considered. This can lead a crash to be assigned to multiple sites. To put this in context, the total number of wet road crashes from the Transport Agency's CAS database was 2,526 in 2013 corresponding to survey year 2014, 2,392 in 2014 corresponding to survey year 2015 and 2,391 in 2015 corresponding to survey year 2016. With reference to the crash numbers tabulated in Table 3, it can be seen that this crash assignment process inflates annual wet road SAL crash numbers by a factor of about 15. Therefore, the wet road SAL crash numbers given in Table 3 should be better considered as a "wet crash index." However, as there is little change in individual SAL lengths and the algorithm for assignment of crashes to a SAL is constant, it is reasonable to compare the wet road SAL crash numbers on a year-on-year basis to identify trends.

With reference to Table 3, the following key trends are observed.

*All SAL's:*

- An increasing trend in the number of SAL's. This is a consequence of more inner lanes of multi-lane sections of the state highway being surveyed each year.
- The number of wet road SAL crashes is decreasing at about 4% a year.
- The wet road SAL crash density has reduced from 1.79 crashes per lane-km in 2013 to 1.64 crashes per lane-km in 2016

*SAL's satisfying the SAL treatment criteria:*

- The number of these SAL's is decreasing. In 2014, the cumulative length of these SAL's corresponded to 1.92% of the entire sealed state highway network, whereas in 2016 it has reduced to 1.74%.
- A little more than half (55%) of these SAL's have an average skid resistance value that is at or below the TL.
- Approximately 22% of these SAL's are classified urban.
- The wet road SAL crash density associated with these SAL's is reducing (i.e. 12.6 crashes per lane-km in 2014 compared to 11.3 crashes per lane-km in 2016). This indicates that the SAL scoring is correctly identifying SAL's where lower skid resistance is contributing to the wet road crash numbers.

*SAL's breaching the skid resistance threshold value, TL*

- The number of these SAL's is reasonably constant over the three years, fluctuating about a cumulative length that is around 2.3% of the entire state highway network.
- About 15% of these SAL's are classified urban.

- The crash density of these SAL's is fairly consistent over the three years of interest, having a value of about 4.6 wet road SAL crashes per lane-km.

*SAL's breaching the threshold level for macrotexture (TLM) but not breaching the threshold level for skid resistance (TL)*

- The number of these SAL's is reasonably constant over the three years, fluctuating about a cumulative length that is around 1% of the entire state highway network.
- About 50% of these SAL's are classified urban.
- The crash density of these SAL's is fairly consistent over the three years of interest, having a value of about 4.3 wet road SAL crashes per lane-km. This is similar to that of SAL's breaching TL.

In summary, this analysis of SAL's indicates that the scheme for prioritising SAL's for treatment is very effective in targeting where lower skid resistance is contributing to wet road crashes. However, each year about 1.7% to 2.2% of the length of the state highway network remains below TL or TLM.

## 3.3 Short Length SAL's

With reference to Section 2.4, the minimum expected length of a SAL is 10 m if the T10 Specification requirements are satisfied, and this short length applies only to roundabouts. However, Table 3 shows minimum SAL lengths of 1 m in 2014 and 2 m in 2015.

All SAL's < 10 m were therefore investigated. This showed that in 2014, there were 51 SAL's that satisfied this condition, giving a cumulative length of 0.26 lane-km, with 8 of the 51 meeting the SAL treatment condition. In 2015, this reduced to 32, giving a cumulative length of 0.16 lane-km, with 4 of the 32 SAL's meeting the SAL treatment condition. In 2016, there were no SAL's < 10 m. Therefore, any issues with the automated process for generating SAL's appear to have been rectified for the 2016 survey.

Given the small number of SAL's < 10 m, it was decided to exclude them from any subsequent analysis involving 2014 and 2015 SAL datasets.

## 3.4 Concluding Comments

The trend analysis shows that current expenditures on rehabilitation and resurfacing works are insufficient to arrest the annual loss of skid resistance and macrotexture of chipseal surfaces due to trafficking action. This is not of particular concern because, in the case of macrotexture, the 10 percentile value is still above the investigatory value. For skid resistance, the 10 percentile value is well above the skid resistance value of 0.35 ESC, which is considered the minimum that can be tolerated on high friction demand sections of the state highway network (i.e. T10 specification site categories 1 and 2). In addition, improvements in the selection of aggregates has seen the state highway network averaged median skid resistance value stabilising over the past two years. However, the most telling factor is that the number of wet road crashes on the state highway network has continued to decrease by about 5% from 2,526 in 2013 to 2,391 in 2015 suggesting that safety hasn't been compromised by the observed changes in skid resistance and chipseal macrotexture median values.

The trend analysis has also shown that targeting where lower skid resistance and texture is contributing to wet road crashes to be a very cost effective safety intervention. For example, $13.5

million was spent on SCRIM sealing in 2015. The associated saving in the social cost of crashes is calculated to be $60.4 million (see Appendix A) giving a benefit cost ratio (BCR) of 4.5.

# 4 Modelling Details

## 4.1 Overview

Traditional pavement deterioration models used for predicting how pavement condition varies over time in response to climate and traffic, such as incorporated in the World Bank's "The Highway Design and Maintenance Standards Model (HDM)," have been derived from data pertaining to road lengths 300 m or greater as this is representative of a typical pavement treatment length. In contrast, modelling of skid resistance and macrotexture is driven by the need to determine to within a year when the surfacing of a short section of road between 10 m and 100 m length breaches the T10 threshold value. In other words, for skid resistance and macrotexture modelling, emphasis is on predicting "end of life" rather than "whole of life." This is made more difficult by the fact that, on average, no more than 3.5% by length per year of the state highway network has either skid resistance or macrotexture that is equal to or below the TL value. Therefore, the amount of relevant data available to develop and validate the skid resistance and macrotexture "end-of-life" models is miniscule compared to "whole-of-life" pavement condition models.

Furthermore, in order to be of use for budget forecasting purposes and for identifying where asset preservation and safety related works overlap, the prediction of TL and TLM breaches needed to be as accurate as possible, with the number of "false" positives kept to a minimum. As a consequence, the skid resistance and macrotexture models need to offer the best compromise between length of state highway network where the threshold value is breached, as this defines the quantity of safety works required, and the individual SAL's requiring treatment, as this defines where on the state highway network safety works is to be carried out. This requirement guided the way the modelling was approached.

The approach adopted was to apply at the SAL level well established models for estimating the decay of skid resistance and macrotexture due to trafficking action over time so that SAL specific calibration and scalar factors could be derived for minimising the difference between observed and predicted values. Also, for the constant term of the models, new seal values of skid resistance and macrotexture achieved at the SAL for the existing surface was utilised rather than generic values derived for a particular aggregate type for skid resistance or for a particular seal type for macrotexture. This significantly improved the predictive accuracy of the model when investigating the effect of traffic volume on the time interval for TL or TLM to be breached.

The models used for predicting skid resistance and macrotexture are detailed below, along with how outputs from these models were used to identify the condition of flushing and utilised within the NZ-dTIMS treatment optimisation framework.

## 4.2 Skid Resistance Model

The skid resistance model used was a simplified form of the skid resistance model presented in the 2012 Transport Agency Research Report 470 "Selection of Aggregates for Skid Resistance."[4]

The model form is:

$$ESC = ESC_{Year2} + fn(AGE \times AADT) \quad ...(4.1)$$

where:

[4] https://www.nzta.govt.nz/resources/research/reports/470/, accessed on 25th May 2016

$ESC_{Year2}$ = The year 2 ($Yr_2$) skid resistance SAL value. This is the second skid resistance reading post reseal, which may be less than 24 months post reseal depending on time of reseal and HSDC[5] survey.

fn(AGE×AADT) = 66.24 +

-4396.06/ln(AGE×AADT) +

114403.94/ln(AGE×AADT)$^2$ +

-1466054.60/ln(AGE×AADT)$^3$ +

9273525.00/ln(AGE×AADT)$^4$ +

-23194384.21/ln(AGE×AADT )$^5$

and:

AGE = surfacing age in months

AADT = lane average annual daily traffic

*N.B.* fn(AGE×AADT) is only applicable for the range 20900≤ AGE×AADT≤1260000

It should be noted AADT in this case is the lane AADT not the carriageway AADT as SAL's are lane based. Also if the AGE×AADT value is less than 20,900 it is increased to 20,900, the minimum allowable value, and if greater than 1,260,000 it is reduced to 1,260,000, the maximum allowable value.

Figure 5 provides a graphical representation of the AGE×ADT function, which was derived by fitting a curve to a "look-up" table contained in the spreadsheet, which accompanies Transport Agency Research Report 470.

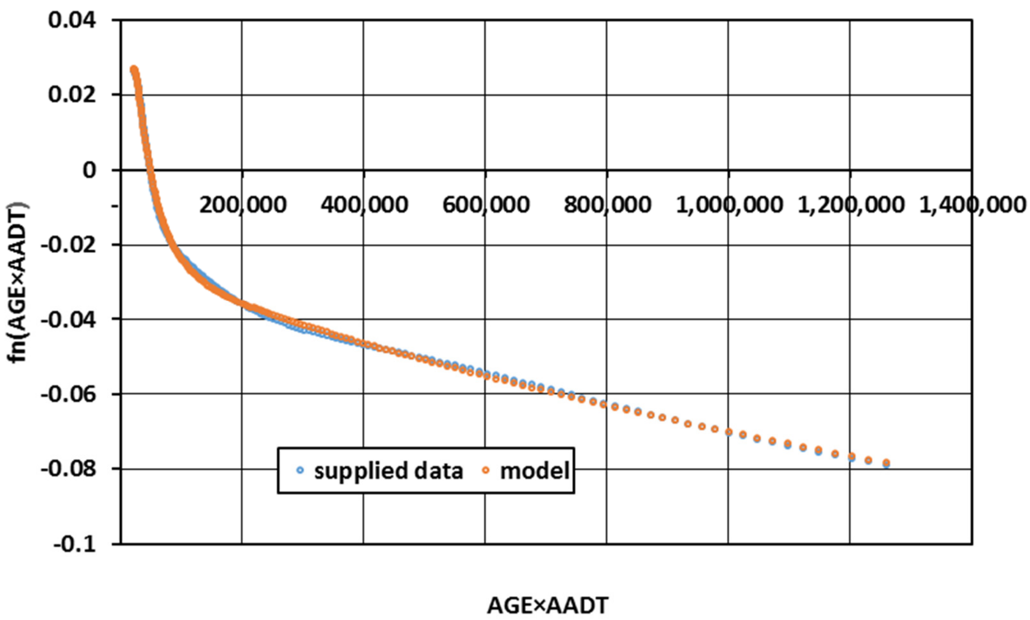



**Figure 5:** Reduction in Year 2 Skid Resistance as a function of cumulative traffic

[5] https://www.nzta.govt.nz/roads-and-rail/road-composition/pavement-condition-surveys/, accesed on 25th May 2016

With reference to Figure 5, it will be seen that there is a rapid loss of skid resistance with cumulative traffic but this tapers off after about 200,000 vehicle passes.

The year 2 value of ESC is used as this allows sufficient time for bitumen to wear off the sealing aggregate and for SAL specific polishing stresses due to accelerating, braking or cornering to take effect. This eliminates the need for the model to include terms that account for the polishing effect of road geometry, such as the curvature, gradient and T10 skid site category terms incorporated in the Transport Agency Research Report 470 skid resistance model.

For modelling purposes, the year 2 value is assumed to apply to year 0 and year 1 as well.

In applying the model, if no year 2 ESC value was available, than the ESC values measured up to 8 months post the sealing date were substituted as the year 2 ESC value in equation 4.1. SAL's were excluded from the analysis if the only available ESC value for the current surfacing was measured when the surfacing was less than 8 months. This 8 months threshold was derived from skid resistance versus age time histories given in Transport Agency Research Report 470, which showed skid resistance values to rise over the first few months, peaking at 8 months before declining in the manner shown in Figure 5.

## 4.3 Macrotexture Model

Two model forms for macrotexture were investigated, these being the HDM4 model in annual incremental form, which employs logarithmic deterioration, and a simple linear deterioration model. When applied to a Transport Agency management area, Bay of Plenty West, the HDM4 model was shown to be more accurate between 0-5 years with the linear model more accurate when the surface age reaches 5+ years.

For the HDM4 model, the average absolute texture error is below 0.1 mm when the surface age is less than 6 years. When the surface age is less than 3 years old, the HDM4 model has only 10% of the SAL's with a texture error greater than 0.5, while the linear model has 20%. When the surface age is greater than 10 years, the HDM4 model becomes more inaccurate than the linear model. At this point the HDM4 model has 20% of SAL's with an error greater than 1.0 mm while the linear model only has 9%. This is expected due to the logarithmic form of the HDM4 model.

Overall, the HDM4 model is slightly more accurate and so was adopted for predicting macrotexture. Based on all model observations for Bay of Plenty West, 50% show an absolute error greater than 0.3 mm and only 10% show an absolute error of greater than 0.8 mm.

Application of the HDM4 model involves the following steps:

1. Macrotexture (MPD) data is extracted from RAMM and averaged by lane and summarised by SAL. One record per SAL for each year since the date of last reseal. This results in a lane average MPD per year per SAL.
2. The year zero ($Yr_0$) macrotexture value per SAL is determined. This is the first record post reseal, which may be up to 12 months post reseal depending on time of reseal and HSDC survey.
3. The HDM4 texture deterioration model (annual incremental form) is applied to calculate MPD texture as follows:

$$MPD_{Yr\,n+1} = MPD_{Yr\,n} - (a_0 * LOG10((Yr\ n + 1.0) / Yr\ n)) \quad ...(4.2)$$

where:

- $MPD_{Yr\,n}$ starts at Yr 0
- $a_0$ =Texture Slope = value based on surface type (chipseal or AC) and chipsize as follows:

| Chip Grade | 2 | 3 | 4 | 5 | 6 | AC |
|---|---|---|---|---|---|---|
| $a_0$ | 0.85 | 0.85 | 0.8 | 0.5 | 0.5 | 0.1 |

4. MPD macrotexture is calculated using equation 4.2 from Yr0 through to the current year. The ratio of observed to predicted MPD macrotexture is determined for each year. Note that the $Yr0_{ratio}$ will always be = 1.
5. The average ratio (excluding Yr0) is calculated for each SAL. This becomes the SAL scaling factor to improve fit of the HDM4 texture model. Where no data is available, the scaling factor = 1.

## 4.4 Model Adjustment Factors

The Bay of Plenty data subset was again employed to determine if improved agreement between predicted and actual values of ESC and MPD could be achieved by applying a simple additive adjustment factor (AF).

For ESC, the AF was determined to be -0.01 ESC i.e. equation 4.1 gave predictions of ESC that were 0.01 ESC too high on average. In this case, the correction factor is applied at the time the TL is breached.

For MPD, the AF was determined to be +0.02 mm MPD i.e. equation 4.2 gave predictions of MPD that were 0.02 mm MPD too low on average. In this case, the correction factor is applied on a yearly basis.

Although the value of the skid resistance and macrotexture adjustment factors were small, their impact was significant. Therefore, any subsequent calculations of ESC and MPD using equations 4.1 and 4.2 included the addition of a -0.01 ESC constant and +0.02 mm MPD constant respectively.

## 4.5 Flushing

As chipseals age in service they lose macrotexture and can reach a condition described as flushed. Flushing can lead to a dramatic lowering of the skid resistance available to vehicles because the tyre rubber is supported on the low skid resistant bitumen. Figure 6 shows how a flushed section of state highway looks.

Flushing is currently one of the primary drivers of both resurfacing to address safety concerns and rehabilitation where build-up of multiple seal layers over time can cause the surface to become unstable and so prone to flushing over shorter and shorter time periods post resurfacing. At this stage the main consideration is whether another resurfacing layer will last more than 4 to 4.5 years, which is the minimum life of a chipseal that is considered to be economic. If the expected life is less than this economic life, the only option is to recycle the entire surface layer.

**Figure 6:** Example of a flushed chipseal surface

An objective measure for flushing that utilises skid resistance and macrotexture thresholds developed by Whitehead et al[6] has been adopted by the Transport Agency to identify the extent the state highway network is flushed. Therefore these thresholds were applied to the model estimates of SAL skid resistance and macrotexture to identify when a SAL is starting to flush so that they can be flagged to assist the optimisation of asset rehabilitation works.

The following skid resistance (ESC) and macrotexture (MPD) conditions, which are related to chipseal type, were used in the modelling to signify the onset of flushing:

- ESC = 0.4 and MPD = 1.0 mm for grade 2, 3, 2/4 and 3/5 chipseal i.e. coarser textured chipseals
- ESC = 0.4 and MPD = 0.7mm for grade 4,5, and 6 chipseal i.e. finer textured chipseals

## 4.6 dTIMS Modelling Interactions

The skid resistance and macrotexture modelling is based on SAL's, not treatment lengths on which the dTIMS modelling is based. Because the mismatch of lengths between SAL's and treatment lengths can be significant, mapping of SAL's onto treatment lengths is not a straightforward process as it can result in SAL's overlapping treatment lengths. Therefore, running the skid resistance and macrotexture models within dTIMS was not considered an option because of the considerable work required in converting input data from a SAL basis to a treatment length basis.

The solution adopted was to apply the skid resistance and macrotexture models to each SAL entry in the 2015 RAMM "Skid Assessment Length" table outside of dTIMS and to use a 'lookup' table within dTIMS to relate the resulting SAL outputs to treatment length. This 'lookup' table:

- specifies the year that each SAL requires the next safety treatment (output from safety modelling) i.e. year of first intervention (YFI);
- whether this safety treatment is flushing related (output from safety modelling);
- the fixed interval between safety interventions (output from safety modelling) i.e. time to subsequent intervention (TINT);
- the treatment length that the SAL belongs to;

[6] Whitehead,D., Donbavand,J. and Mitchell, J.(2011) Developing an Objective Measure for Flushing, 3rd International Surface Friction Conference, Safer Road Surfaces – saving Lives, Gold Coast, Australia, 2011.

- percent of the treatment length covered by the SAL (calculated outside of safety modelling); and
- percent of the treatment length that has a safety treatment planned in the 'same' year where 'same' year is defined as ± 1 year (calculated outside of safety modelling).

The 'lookup' table structure is as follows:

| SAL-ID (system_id) | Treatment Length ID (TL-id) | road_id | start_m of treatment length | end_m of treatment length | Year of First Intervention (ESC or MPD below TL/TLM) | Flushing (Y/N) | Number of Years between subsequent TL/TLM breaches | % of Treatment Length | % of Treatment Length that is safety treated within ± 1 year |
|---|---|---|---|---|---|---|---|---|---|
| Fixed | Fixed | Fixed | Fixed | Fixed | Model | Model | Model | Calculated | Calculated |

As generation of the 'lookup' table was found to require extensive data mining and data manipulation, it was decided to have a single aggregate source per SAL, this being the aggregate source of the current surfacing as this permitted reliable estimation of the year 2 skid resistance value (i.e. $ESC_{Year2}$ in equation 4.1).

Once input into dTIMS, the safety programme, as defined by YFI and TINT values in the 'lookup' table, is treated as a committed programme. Depending on the percentage of the treatment length that requires treatment, one of two treatment options are triggered as follows:

- Whenever less than 50% of the treatment length requires safety related treatment (i.e. either TL or TLM breached over a small length) routine maintenance treatment is triggered. Such treatment incurs cost (assigned to the safety budget) but there is no condition reset. A flag is carried which reduces the next asset preservation treatment (area and cost) by the treated SAL area – so effectively it is recognised that the treated SAL area is not resealed again as a result of the asset preservation treatment. The SAL will be treated at a fixed interval i.e. TINT as defined by the 'lookup' table regardless of the asset preservation treatments. It should be noted that with safety maintenance treatment, the cost is captured but length is not. It is also a proxy for all types of minor safety treatments including scabbling, waterblasting or small reseal.

- Whenever 50% or more of the treatment length requires safety related treatment (i.e. either TL or TLM breached over a significant length), a safety reseal of the entire treatment length is triggered. In this case, a test is carried out to determine which occurs first post 2015 – the first safety treatment (i.e. YFI) or the first asset preservation treatment. If safety treatment is the first, it is locked in for the year specified in the 'lookup' table. The full treatment length is treated from the safety budget and condition fully reset as per a normal reseal. If asset preservation treatment occurs prior to the safety treatment, the next safety treatment will be reset according to the fixed interval i.e. TINT as defined by the 'lookup' table. Put another way, when an asset preservation treatment occurs on a treatment length, all safety work planned after the asset preservation treatment increases by TINT. With safety reseals, both cost and length are captured, with the cost of the treatment length treated for safety assigned to the safety budget and cost of treating the remainder of the treatment length assigned to the resealing budget.

There is one other thing to note. Treatment lengths that don't comprise SAL's that breach either the TL or TLM will never be eligible for safety renewal. They will only ever receive safety maintenance or asset preservation renewal and vice-versa.

The asset preservation dTIMS model is then run to generate strategies including 'large safety section options.' The intervention dates of the optimised asset preservation treatment programme that result are then combined with the safety maintenance treatment intervention dates to allow annual ESC and MPD profiles to be generated outside of dTIMS for safety and asset preservation treatments combined for comparison with the profiles generated by considering treatment of TL/TLM breaches only i.e. safety treatment only.

In generating these annual ESC and MPD profiles, simplified deterioration functions were employed to reduce the computations required. For skid resistance it was assumed that between year 0 and year 2, the ESC value remained constant at the year 2 value, then decaying linearly to the TL value applying to the SAL of interest over the period $TINT_{ESC}$-2. However, the minimum value of $TINT_{ESC}$-2 has been set at 7 years to reflect the Transport Agency's expectation that as the industry gains more experience with skid resistance management, aggregates which are prone to polishing prematurely will be identified and replaced with aggregates proven to last a minimum of 7 years. This is shown schematically in Figure 7. For macrotexture, MPD was assumed to decay linearly from MPD at year 0 to TLM at year $TINT_{MPD}$.

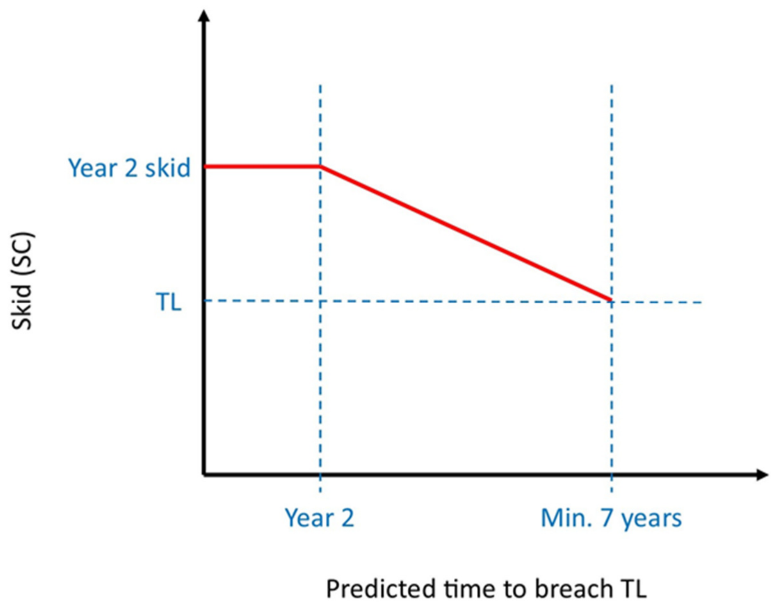



**Figure 7:** Modelled SAL skid resistance time history

The code for performing the safety modelling and annual skid resistance and macrotexture profiling outside of dTIMS was written in Python[7], an open source programming language.

Python is a widely used, high-level, general-purpose programming language. Its design philosophy emphasizes code readability, and its syntax allows programmers to express concepts in fewer lines of code than established programming languages such as C++ or Java.

The main reason for using Python was that Python code can be packaged into stand-alone executable programs for some of the most popular operating systems, so Python-based software can be distributed to, and used on, those environments with no need to install a Python interpreter.

[7] https://en.wikipedia.org/wiki/Python_(programming_language), accessed on 30th May 2016

The time the Python based safety model software takes to complete a run involving New Zealand's entire state highway network varies between 1 hour and 3 hours, depending on the extent of pre-processing required.

Included in the safety model software is the ability to duplicate the T10 Specification SAL scoring system. This permits the impact of changes in funding level to be readily investigated simply by changing the score that must be reached before safety treatment is considered.

Because of the random nature of crashes, it is not feasible to predict with any certainty what the crash numbers of a SAL are likely to be 10 to 20 years in the future, let alone 1 to 2 years into the future. Therefore, it is envisaged when SAL scoring is applied to model predictions of skid resistance and texture, the crash score will be defaulted to zero. This gives for the TL breached condition, a SAL score which can lie anywhere between 70 and 178 depending on AADT i.e. a base value of 70 plus 1 point for each AADT/1000, with the minimum SAL AADT being 30 and the maximum SAL AADT being 107774, both in the Auckland Alliance. For the TLM breached condition only, the SAL scoring results in a score range from 15 to 123, 15 being the base value.

As a consequence, SAL's with a predicted high skid deficiency coupled with a high AADT will be prioritised if the T10 Specification SAL scoring is applied to the modelled outputs.

Appendix 2 of this report provides a schematic that shows the various interactions between the safety modelling performed by the Python code and dTIMS asset preservation modelling.

## 4.7 Modelling Limitations

Running the safety models outside of dTIMS modelling framework results in the following two limitations when it comes to budget forecasting:

- There is no ability to consider "what-if scenarios" regarding the use of more expensive polishing resistant aggregates such as calcined bauxite or "melter" aggregate and bituminous mixes instead of chipseals as this results in too many options to deal with.
- Safety treatments can only be prioritised via SAL scoring NOT optimised.

# 5 Validation of Safety Modelling Output

The validity of the modelling approach adopted was investigated on two levels:

1. Its ability to replicate historical trending of state highway condition with respect to skid resistance and macrotexture over the 5 year period 2011 to 2015;
2. The degree to which predicted SAL TL and TLM breaches for the year 2015 agreed with those that actually occurred.

## 5.1 Historical Trending

The analysis period of 2011 to 2015 was selected as it did not include neither the 2006-7 state highway data used to derive the skid resistance model nor the 2001-2 state highway data used to derive the macrotexture model.

The skid resistance model was applied to SAL's with a surfacing that was more than 2 years old whereas the macrotexture was applied to all SAL's that had a year 0 MPD value and were untreated over the entire 5 year analysis period.

The differences between actual and predicted trending for the 10 percentile and 50 percentile SAL values are shown graphically in Figures 8 and 9 for skid resistance and macrotexture respectively.

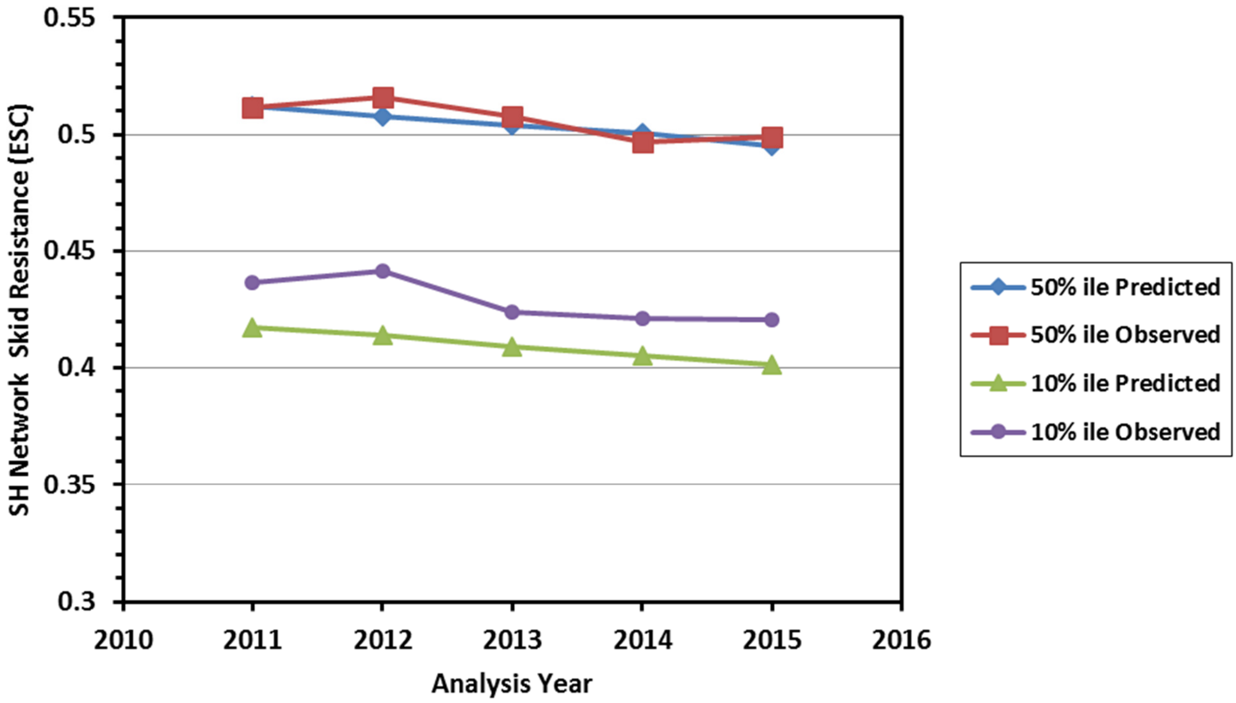



**Figure 8:** Observed versus Predicted Trending of State Highway Skid Resistance

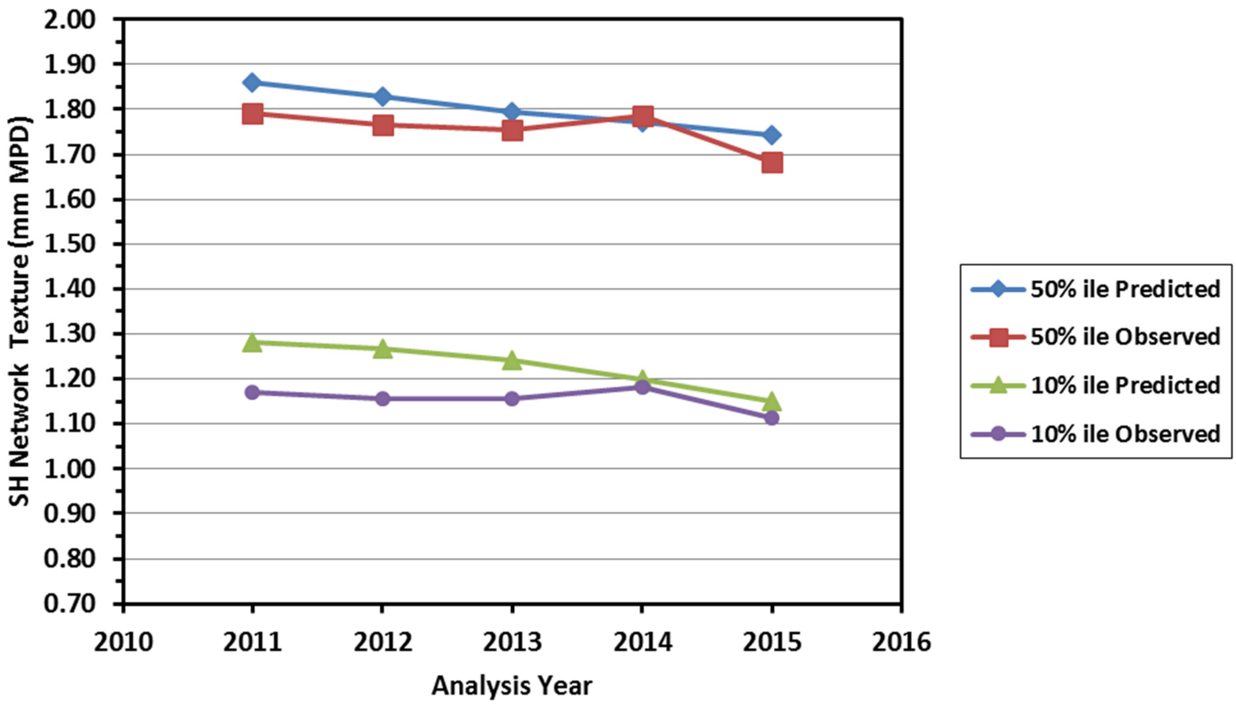



**Figure 9:** Observed versus Predicted Trending of State Highway Macrotexture

Figures 8 and 9 show that the agreement between predicted and observed median (50 percentile) is very close, being better than 0.008 ESC (1.6%) for skid resistance and 0.07 mm MPD (3.9%) for macrotexture. In contrast, the level of agreement between predicted and observed 10 percentile values, which is more of interest because they relate better to breaches of TL and TLM, was not as good being at worse 0.03 ESC (6%) for skid resistance and 0.11 MPD (9%) for macrotexture.

The two key points to arise from this trending analysis are:

1. The skid resistance model slightly underestimates the true value of SAL ESC whereas the macrotexture model slightly overestimates the true value of SAL MPD. This is a desired outcome, as from the perspective of provision of safe driving surfaces for road users, skid resistance is considered to be more important than macrotexture, as evidenced from the SAL scoring adopted by the Transport Agency to prioritise SAL's for treatment (refer section 2.4).
2. Despite being derived from the application of the skid resistance and macrotexture to the 2015 dataset, the model adjustment factors of -0.01 ESC and +0.02 MPD appear to be generally applicable given the level of agreement achieved for the four other years retrospectively investigated. Therefore, their continued use when making future projections of skid resistance and macrotexture appears warranted.

## 5.2 Breaches of TL and TLM

The skid resistance and texture models detailed in section 4 were validated by their retrospective application to the entire state highway network, starting from the year the current surface was laid, to predict what the values for each SAL would be in 2015. This enabled direct comparison with SAL values measured during the 2015 HSDC survey.

SAL's forming treatment lengths identified by the Transport Agency's Review and Prioritisation Team (RAPT) for asset preservation treatment in 2015 were excluded from the retrospective analysis. This was done because their condition must be reset as a result of them being resealed in 2015, post the HSDC survey.

The total number of SAL's analysed amounted to 318,447, corresponding to 21,569.368 lane-km of state highway. With reference to Table 3, the total number of SAL's in 2015 was 328,006, corresponding to a length of 22,182.972. Therefore, 9559 SAL's were affected by asset preservation treatment in 2015, amounting to 613.604 lane-km's of state highway.

Fortunately, the exclusion of these 9559 SAL's was not problematic because only 56.222 lane-km out of the 613.604 lane-km (i.e. 9%) had breached TL or TLM.

The key results of the validation are summarised in Table 4 below.

**Table 4:** Agreement of Predicted and Observed TL and TLM Breaches and Instances of Flushing

| Condition | Length of State Highway TL/TLM Breached or Flushed (lane-km) in 2015 | | |
|---|---|---|---|
| | **Predicted** | **Actual** | **Matched** |
| Skid | 467.601 (2.17%)[1] | 335.188 (1.55%)[1] | 127.922 (27.4%)[2] |
| Macrotexture | 189.979 (0.88%)[1] | 190.240 (0.88%)[1] | 84.253 (44.3%)[2] |
| Flushed | 104.214 (0.48%)[1] | 148.690 (0.69%)[1] | 33.020 (31.7%)[2] |

[1] Percentage of entire sealed length of state highway network i.e. 21,579.885 lane-km

[2] Percentage of predicted length

As expected from the 10 percentile historical trending analysis, Table 4 shows that the skid resistance model is slightly over-predicting the length of state highway with TL breached whereas the macrotexture is only slightly under-predicting the length of TLM breached. The length of state highway flushed is also under-predicted. Overall, the level of agreement in cumulative SAL lengths between predicted and actual is better than 132 lane-km confirming that the proposed modelling will be appropriate for setting maintenance budgets.

The level of agreement at an individual SAL basis is not so close, with only 27.4% of SAL's predicted to have a mean ESC value at or below TL matching observed. Flushing is only slightly better at 31.7% whereas macrotexture shows the best level of matching at 44.3%.

This analysis confirms that a reasonable compromise between maximising matching and minimising false positives has been achieved. A more comprehensive analysis of the predictive ability of each of the three models is provided in Appendix A3.

## 5.3 Issues with Model Input File

In order to run the skid resistance and texture models, the following information is required at the individual SAL level:

- Details of the existing surfacing i.e. surfacing date, surfacing type, aggregate source, and location and extent within the SAL;
- Skid resistance and macrotexture time histories from the surfacing dates;
- IL and ILM levels that apply; and
- Traffic characteristics.

This information is extracted from the SAL, surfacing, skid resistance and macrotexture tables in RAMM and combined to generate input files for the skid resistance and macrotexture models.

Table 5 shows a few rows from the skid resistance input file to illustrate key aspects of the file structure. This has been abbreviated to allow fitting onto the page, with the columns "Surface Function" pertaining to the purpose of the surfacing e.g. second coat, reseal, void fill etc. and "PSV" pertaining to the polished stone value of the surfacing aggregate, which is a measure of the aggregate's resistance to polishing from traffic, being excluded.

**Table 5:** Extract from Skid Resistance Input File

| system_id | road_id | start_m | end_m | start_m_1 | end_m_1 | lane | RD | survey_no | ESC LnAvg | surface_date | surf_material | chip_size | pave_source | scrim_il | aadt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2474127 | 2 | 11090 | 11140 | 11048 | 11100 | L1 | 18/12/2001 | 6 | 0.719 | 12/02/1999 | 1CHIP | 2 | BELLINGHAM | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11048 | 11100 | L1 | 9/12/2004 | 9 | 0.539 | 12/02/1999 | 1CHIP | 2 | BELLINGHAM | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11048 | 11100 | L1 | 4/02/2008 | 13 | 0.581 | 12/02/1999 | 1CHIP | 2 | BELLINGHAM | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11048 | 11100 | L1 | 3/12/2009 | 15 | 0.538 | 12/02/1999 | 1CHIP | 2 | BELLINGHAM | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11048 | 11100 | L1 | 7/12/2014 | 20 | 0.486 | 12/02/1999 | 1CHIP | 2 | BELLINGHAM | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11100 | 11260 | L1 | 9/12/2004 | 9 | 0.539 | 10/11/2003 | 1CHIP | 3 | LARMERS ROAD | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11100 | 11260 | L1 | 28/11/2006 | 11 | 0.595 | 10/11/2003 | 1CHIP | 3 | LARMERS ROAD | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11100 | 11260 | L1 | 3/12/2009 | 15 | 0.538 | 10/11/2003 | 1CHIP | 3 | LARMERS ROAD | 0.5 | 2808 |
| 2474127 | 2 | 11090 | 11140 | 11100 | 11260 | L1 | 2/12/2013 | 19 | 0.494 | 10/11/2003 | 1CHIP | 3 | LARMERS ROAD | 0.5 | 2808 |

With reference to Table 5, data for SAL ID 2474127 is given. It can be seen that this SAL is 50 m long. However, there are two different surfaces over its length, a 10 m section of grade 2 chip between 11090 m and 11100 m, with a surfacing date of 12/02/1999, and a 40 m section of grade 3 chip between 11100 m and 11140 m, with a surfacing date of 10/11/2003.

For situations like this where a SAL comprises more than one surface type, the rule adopted for simplicity was to assign the surface properties of the longest section to the SAL. For SAL 2774127, this is the grade 3, chipseal surface constructed in 2003 with aggregate sourced from Lamers Road quarry.

The effect of this surface assignment process was to reduce the number of SAL's breaching TL and TLM. This is illustrated in Table 6, where actual state highway ESC skid resistance distributions derived from the skid resistance file and the 2015 SAL dataset used to generate it are compared.

With reference to Table 6, the key points to note are:

1. The 10.517 km discrepancy in total state highway length is due to repeat entries caused by the macrotexture survey date not being the same as the skid resistance survey date. This occurs because the laser based macrotexture measurements cannot be made if the road surface is damp/wet whereas the skid resistance measurements can be made under any road condition.

2. Despite 613.604 lane-km's of state highway being removed, corresponding to the SAL's scheduled to undergo asset preservation treatment in 2015, the cumulative length of SAL's with ESC equal or less than TL at 2% of the state highway (i.e. 432.277 lane-km) is very close to the 2.11% (i.e. 468.061 lane-km) calculated for the complete 2015 SAL dataset (refer Table 3)
3. The surface assignment process reduces the percentage by length of state highway with an ESC value at or below the TL value by about 0.45% (corresponding to 97.089 lane-km) and ESC values between TL and IL by about 1.8% (corresponding to 377.983 lane-km). This will cause the model to underestimate the extent of TL breaches when it is used to predict state highway condition into the future. This underestimation, whilst not desirable, was not seen as a major impediment to incorporating safety modelling in dTIMS because it resulted in state highway safety treatment lengths that were comparable to those presently being generated using a SAL score of 140.

**Table 6:** Effect of SAL Surface Assignment Process on State Highway Skid Resistance Distribution

| Condition | Length of State Highway Meeting Condition | |
|---|---|---|
| | Skid Resistance Input File | Originating SAL Dataset |
| $ESC_{actual}$ >IL | 18,537.337 lane-km (85.9%) | 18,051.748 lane-km (83.7%) |
| TL<$ESC_{actual}$≤IL | 2,707.360 lane-km (12.5%) | 3,085.343 lane-km (14.3%) |
| $ESC_{actual}$≤TL | 335.188 lane-km (1.55%) | 432.277 lane-km (2.0%) |
| Total Length | 21,579.885 lane-km | 21,569.368 lane-km |

## 5.4 Concluding Remarks

The validation exercise highlighted that the non-alignment of surfacing lengths, skid assessment lengths and treatment lengths is problematic, as it makes it difficult to assign surfacing details to a SAL without causing a distributional change in skid resistance and texture values from that actually observed. Therefore, it is recommended that the Transport Agency consider locking in skid assessment lengths so that they cannot change on a yearly basis as at present, and wherever possible, surfacing lengths, treatment lengths and SALs should be aligned so that no overlapping occurs.

However, despite this alignment issue, the validation exercises undertaken showed that the skid resistance and macrotexture models perform sufficiently well, giving deterioration rates that match closely those observed. Also false positives are in kept in check resulting in estimates of TL and TLM breaches that result in cumulative lengths that are consistent with historical safety works and so are reasonable for the purpose of budget forecasting.

# 6 Application of Safety Modelling

The safety modelling framework described in section 4 was used to predict skid resistance, macrotexture and flushing occurrence for each 2015 SAL over the 20 year period 2015 to 2034[8]. From this, annual safety need was derived from the predicted length of network breaching the T10 Specification:2013 threshold levels. As highlighted in section 4.6, the modelling assumed a reseal to address skid resistance (i.e. TL breach) will have a life of 7 years or more, to reflect improvements in recent years to how skid resistance is managed on the state highway network. The consequence of this was that any SAL's with a historical resealing interval of less than 7 years due to loss of skid resistance had their resealing interval increased to 7 years.

The results of the modelling are summarised below in terms of maintenance need and impacts on state highway condition and crash numbers.

## 6.1 Maintenance Need

Three scenarios over the 10 year period 2015 to 2024 were considered:

- Network safety need as determined outside dTIMS using the Python software.
- Network asset preservation need as determined by dTIMS modelling.
- Network asset preservation and safety needs combined as determined by dTIMS with the safety works programme loaded as input.

Although all the models were run over a 20 year period, the maintenance need analysis focussed on the first 10 years because the 11 plus year forecasts were considered less reliable due to uncertainties associated with traffic composition and growth.

The dTIMS modelling established an investment of $100million per annum was required to preserve the state highway network at an acceptable condition. The predicted treatment type and length profile corresponding to this level of investment scenario, as generated by dTIMS, was termed the asset preservation need.

The combined need was a scenario run in dTIMS, which included the safety need loaded as an additional input. In this case dTIMS generates treatment options in the same way as a straight asset preservation model. However, where a safety treatment was required, it was included in all treatment options on the road segment being analysed (either before or after the asset preservation treatment depending on condition and timing). Optimisation was performed with safety treatments allowed an unlimited budget and asset preservation capped at $100 million per annum. Having an unlimited safety budget assured that all safety treatments will be funded.

The results in terms of length of state highway treated on an annual basis are summarised in Table 7.

With reference to Table 7, the forecast length of safety need over the 10 year analysis period amounts to 292 lane-km per annum, which corresponds to 1.2% of the length of the state highway network. This is comparable to the 388 lane-km safety sealing performed in 2015 to address SAL's with a score of 140 or more.

[8] The years 2015 to 2034 in this case refer to the actual calendar year and not the survey year, with year 0 of the analysis corresponding to 2015.

By comparison, the asset preservation need is about 6 times more at 1,890 lane-km per annum, which corresponds to 8.1% of the length of the state highway network.

**Table 7:** Forecast Surfacing Need for Period 2015-2024

| Scenario | Forecast Surfacing Need | |
|---|---|---|
| | Annual Average Length (lane-km) | % Network |
| Safety Only | 292 | 1.2% |
| Asset Preservation Only | 1,890 | 8.1% |
| Combined Safety | 178 | 0.8% |
| Combined Asset Preservation | 1,793 | 7.7% |

When safety treatment needs are combined with asset preservation treatment needs, the amount of resurfacing required under both work streams reduce.

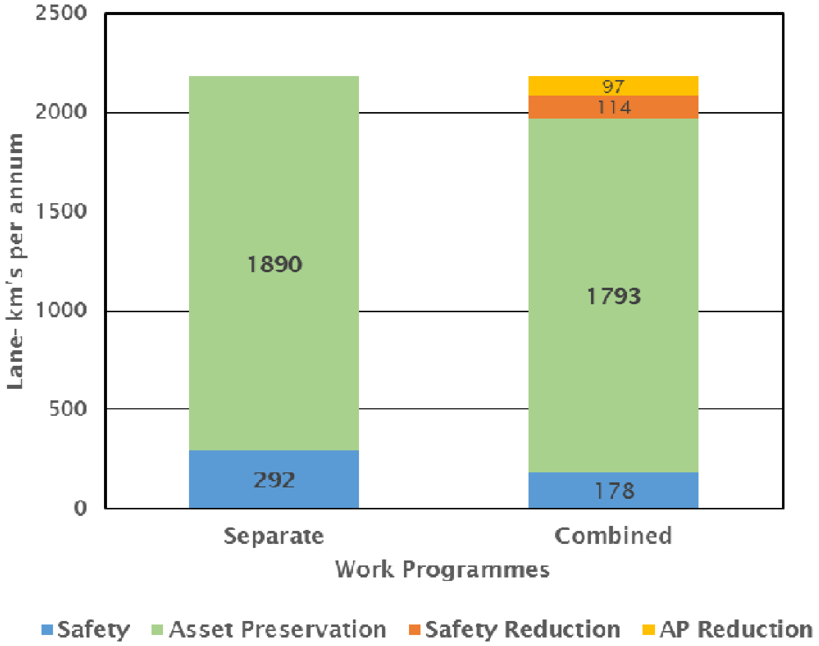



**Figure 10:** Forecast annual work quantities

With reference to Figure 10, the modelling forecasts that over the 10 year analysis period, the safety treatment need is reduced by some 39% on account that resurfacing under asset preservation addresses some of the length of state highway that breaches skid resistance and texture. On a per annum basis, this corresponds to 114 lane-km.

Conversely, as a result of safety addressing some of the surfacing required under asset preservation, more funding can be diverted to pavement related work. This results in a 97 lane-km reduction in the forecast annual asset preservation resurfacing need from 1,890 lane-km to 1,793 lane-km, which corresponds to a 5.1% reduction.

An analysis of historical safety needs showed that over the past 3 years about 3,370 lane-km per year or about 15% of the state highway network lies between the skid resistance investigatory and threshold levels. With reference to Figure 11 below, about a third of this length i.e. 1,106 lane-km is very close to breaching the threshold level. Maintenance treatment of this 1,106 lane-km is shown to be on average fiscally neutral with every $1 spent on resurfacing yielding $1 in crash cost saving (refer Appendix 5). However, by identifying lengths of state highway where lower skid resistance and texture are contributing to wet road crashes, treatment can be very cost effective resulting in benefit cost ratio's in excess of 4.

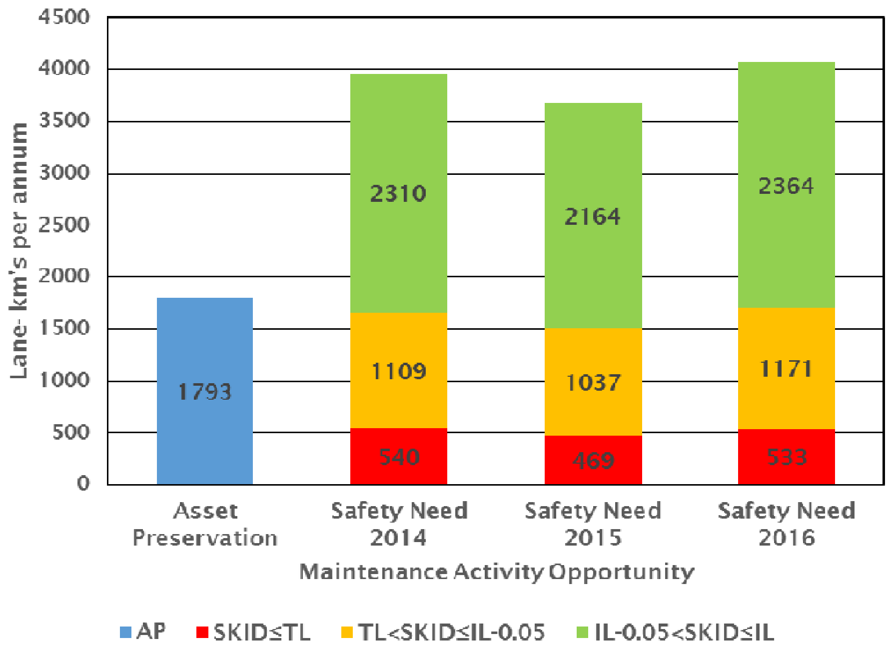



**Figure 11:** Historical distribution of safety need and how it relates to forecast asset preservation need

With reference to Figure 12, it can be seen that the majority of the safety need comprises low skid resistance levels in high wet crash risk locations such as intersections, tight curves and steep downhill grades.

Figures 11 and 12 show that there is considerable opportunity for asset preservation surfacing to contribute to safety by:

1. Impacting on the amount of state highway that is close to breaching skid resistance and texture thresholds, thereby allowing safety works to remain at manageable levels.

2. Reducing crashes wherever asset preservation surfacing coincides with sections of state highway with a history of surfacing related crashes.

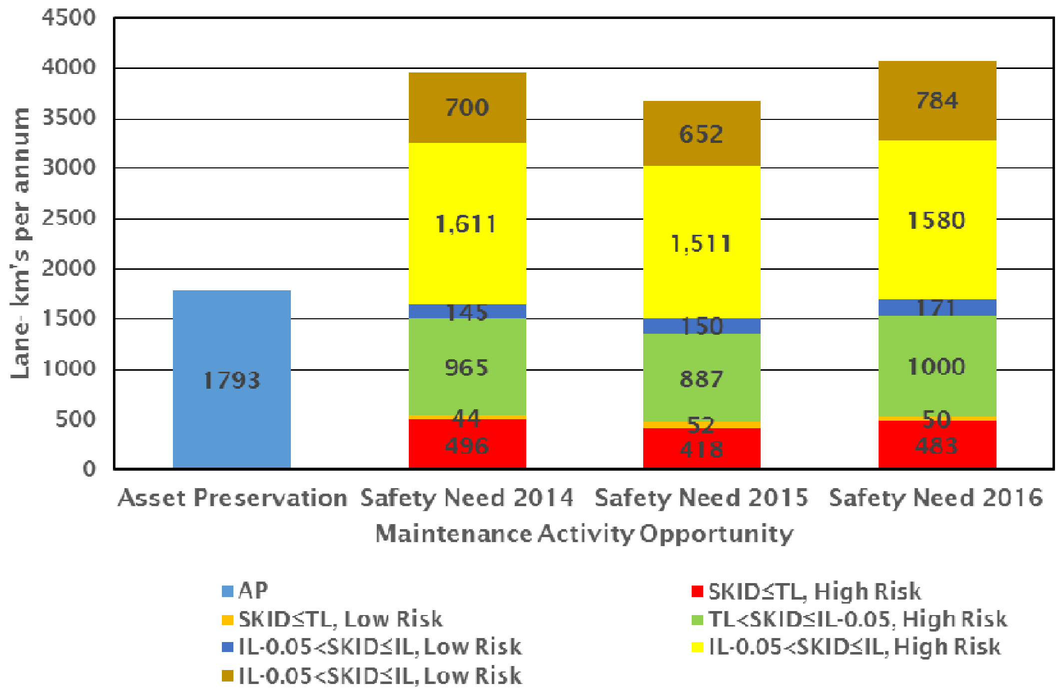



**Figure 12:** Historical make-up of safety need

Figure 13 shows the safety model forecast annual predicted lengths (black bars) for the 20 year period 2015 to 2034 matched with the combined safety/asset preservation forecast (red bars).

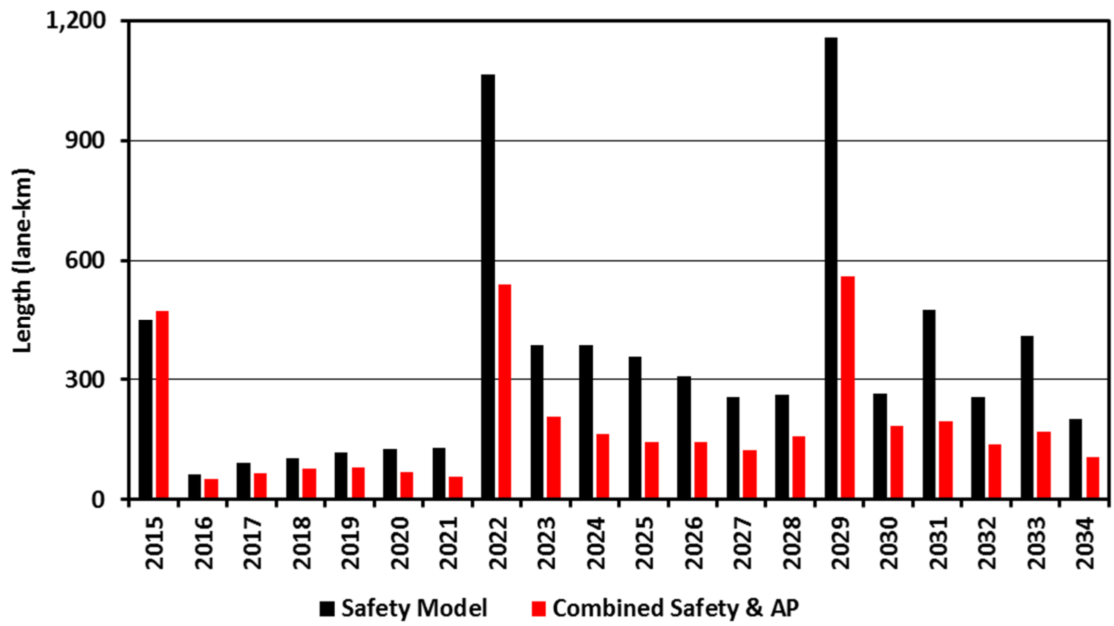



**Figure 13:** Forecast Annual Length of Safety Need

The points to note are as follows:

- From 2016 to 2021, the safety only model forecasts increasing surfacing lengths i.e. 63 lane-km in 2016 to 129 lane-km in 2021, whereas combined safety/asset preservation model forecasts the surfacing length to be reasonably stable at about 66 lane-km per annum. These annual surfacing rates appear to be too low to deal with the large number of SAL's that have ESC and MPD values that fall between the investigatory and threshold values of skid resistance and macrotexture (refer Appendix A4). In 2015, the cumulative length of SAL's that fell in this category was 1,534 lane-km's.
- In 2022, it appears that a large number of SALs' that had ESC and MPD values that fell between investigatory and threshold breach threshold. For the safety model, the surfacing length jumps to 1,064 lane-km, which seems plausible i.e. if we take 1,534 lane-km's and subtract the previous 6 years surfacing lengths, the result is 901 lane-km. As expected, the surfacing length forecast by the combined safety/asset preservation model is about half at 540 lane-km. This clearly highlights the effect of asset preservation works on safety.
- From 2023 to 2028, the safety only model forecasts decreasing surfacing lengths i.e. decreasing from 388 lane-km in 2023 to 262 lane-km in 2028. In contrast, the combined safety/asset preservation model forecasts the surfacing length to be reasonably stable at about 157 lane-km per annum.
- From 2029 to 2034, the SAL length distribution largely replicates that of 2022 to 2027.
- The surfacing length distribution shown in Figure 10 can be made much more uniform simply by applying a SAL score threshold to allow SAL's to be prioritised for surfacing treatment. However, the non-prioritised distribution was preferred as it highlighted when a large demand for surfacing treatment is forecast to occur. These are years 2022 and 2029. It also better highlighted differences between the safety only and combined safety/asset preservation modelling. Inclusion of asset preservation surfacing has the effect of both reducing and smoothing the annual surfacing lengths related to safety.

## 6.2 State Highway Condition Forecasts

Boxplots again have been employed to visualise how the skid resistance and macrotexture condition of the state highway network is forecast to change over the 20 year period 2015 to 2034 under safety only and combined safety/asset preservation modelling scenarios. For each year, the box shows the upper quartile, the median, and the lower quartile. The vertical lines (*the whiskers*) run from the 10 percentile value to the 90 percentile value. The percentile values pertain to lane ESC and MPD averaged over the length of the SAL, unlike section 3.1, where 10 metre averaged values have been used to generate the boxplots of state highway condition.

### 6.2.1 Skid Resistance

With reference to Figures 14 and 15, state highway skid resistance level continues to decline over the 20 year analysis period for both scenarios modelled. The rate of decay in the median value is0.0024 ESC per annum for the safety scenario. The impact of including $100 million per annum asset preservation works in addition to the safety works is to very slightly reduce the decay rate to 0.00235 ESC per annum.

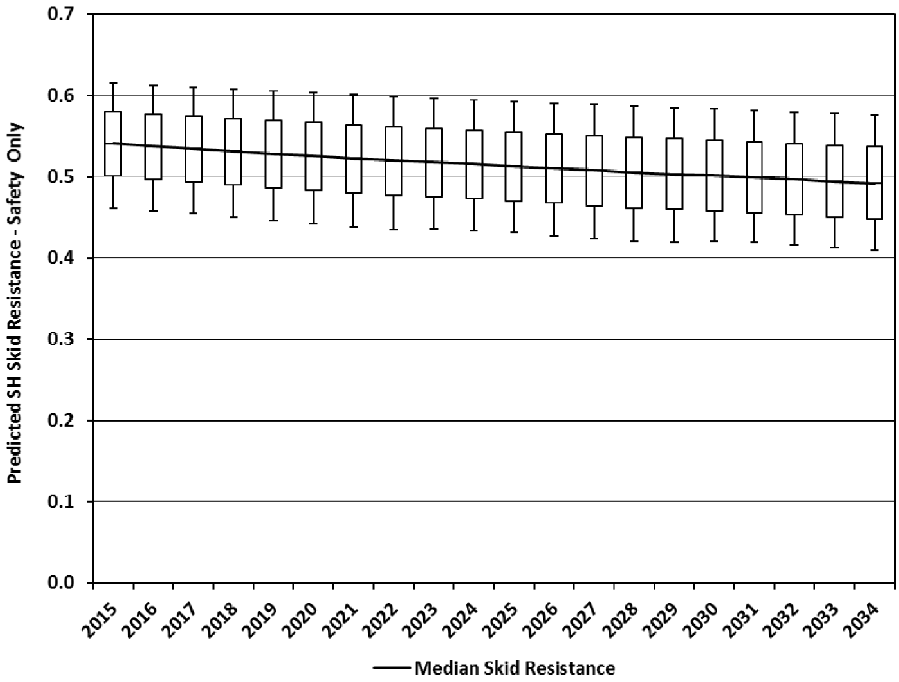



**Figure 14:** Forecast Skid Resistance Condition of State Highway – Safety Scenario

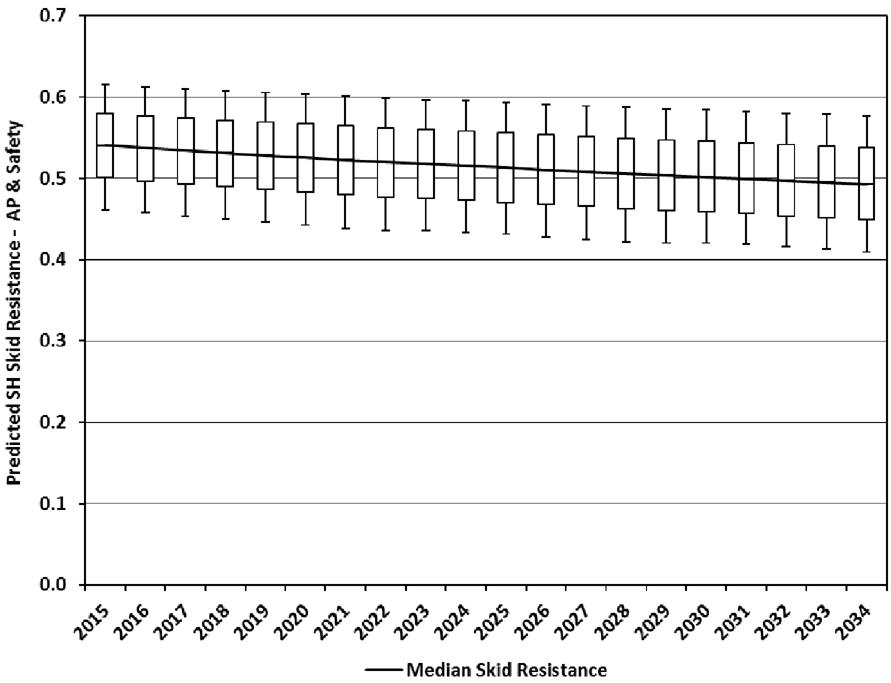



**Figure 15:** Forecast Skid Resistance Condition of State Highway – Combined Safety and Asset Preservation Scenario

To better understand this surprising outcome of the modelling, the following relationship was used to investigate how the inter-relationship between reset value of skid resistance following resurfacing and the percentage of network resurfaced impact on the network median ESC value.

$$ESC_{Yn+1} = (1 - x) \times (ESC_{Yn} - 0.0026) + (x \times ESC_{Y2}) \ldots eq\ 6.1$$

| | | |
|---|---|---|
| where: | $ESC_{Yn}$ | = state highway median value in year n |
| | x | = proportion of state highway network resurfaced |
| | 0.0026 | = observed average annual decay in SH skid resistance |
| | $ESC_{Y2}$ | = average year2 skid resistance value |

For the safety scenario, x = 0.012 and for the combined safety/asset preservation scenario x = 0.085 (refer Table 7). Assuming $ESC_{Yn}$ = 0.538 i.e. the 2015 state highway median ESC value, and $ESC_{Y2}$ = 0.54 this gives a year 10 (2024 value) of 0.516 ESC for the safety scenario and 0.524 ESC for the combined safety/asset preservation scenario, which is consistent with Figures 11 and 12.

However, if $ESC_{Y2}$ = 0.58, the year 10 (2024 value) for the safety scenario increases only to 0.520 ESC but for the combined safety/asset preservation scenario it increases to 0.546 ESC, which represents a significant improvement over the 2015 median value.

This highlights that the modelled rate of decay over the 20 year analysis period is very sensitive to the $ESC_{Y2}$ value assigned to the resurfacing.

With the existing modelling setup, any resurfacing treatment that occurs on a SAL must have the same $ESC_{Y2}$ and time till TL is breached (i.e. TINT) as derived for the SAL from the performance of the SAL's existing surfacing. An analysis of $ESC_{Y2}$ values for Western Bay of Plenty network management area, gave a mean $ESC_{Y2}$ value of 0.525, median $ESC_{Y2}$ value of 0.52 and a 90$^{th}$ percentile $ESC_{Y2}$ value of 0.56 ESC. Therefore, the similarity in forecast skid resistance time histories between safety only and combined safety/asset preservation scenarios is attributed to a low mean $ESC_{Y2}$ value i.e. 0.54 ESC or less.

Equation 6.1 can be used to estimate for different $ESC_{Y2}$ values what proportion of the state highway network needs to be resurfaced on an annual basis to retain the state highway median ESC value to the 2015 value of 0.538 ESC. For example, if the $ESC_{Y2}$ equals 0.54, then 56.5% of the state highway would need to be resurfaced on an annual basis but if the $ESC_{Y2}$ equals 0.58 then only 5.8% would need to be resurfaced on an annual basis.

Conversely, for a given percentage of network resurfaced, equation 6.1 can be used to determine what the $ESC_{Y2}$ value needs to be to retain the state highway median ESC value to the 2015 value of 0.538 ESC. For the combined safety/asset preservation scenario, the percentage resurfaced is 8.5%, so the required minimum $ESC_{Y2}$ needs to be 0.566 or greater.

### 6.2.2 Macrotexture

With reference to Figures 16 and 17, state highway macrotexture level declines over the first six years of the analysis period i.e.2015 to 2020 before stabilising for the remaining 14 years from 2021 to 2034 for both scenarios modelled. The rate of decay in the median value is -0.037 MPD per annum for the safety scenario and -0.029 MPD per annum for the combined safety/asset

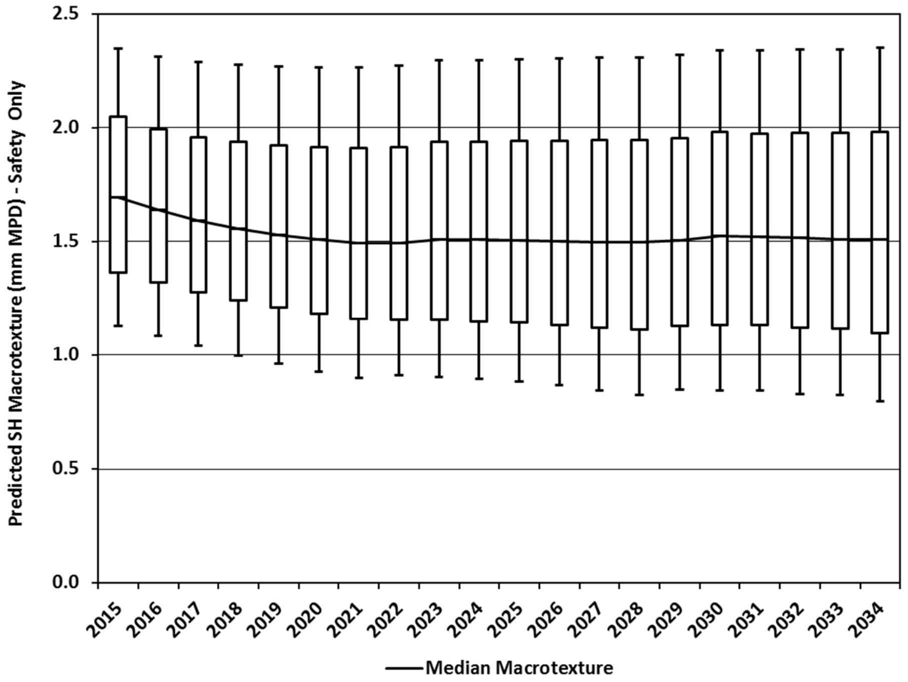



**Figure 16:** Forecast Macrotexture Condition of State Highway – Safety Scenario

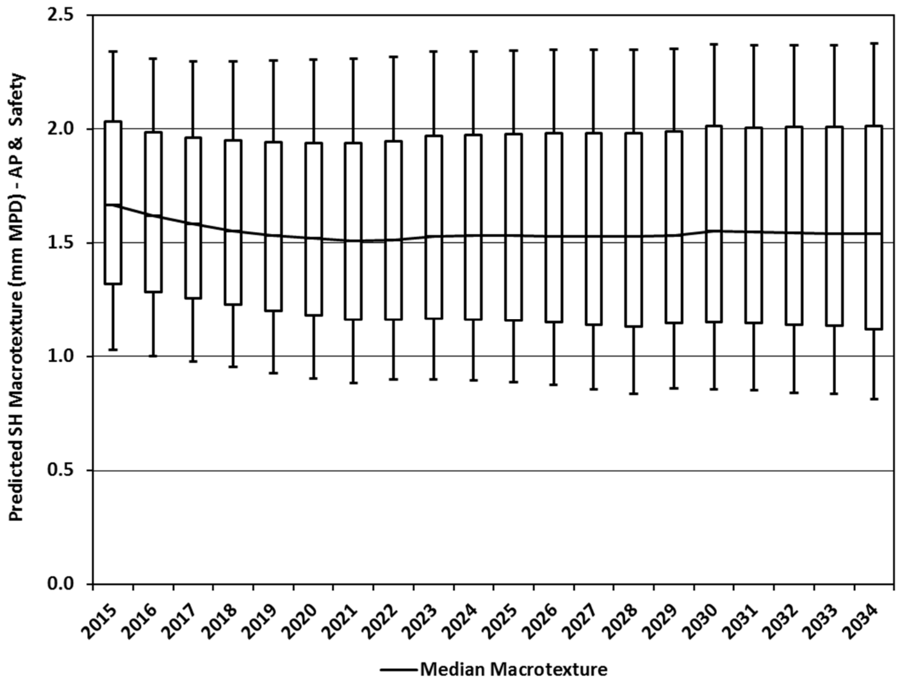



**Figure 17:** Forecast Macrotexture Condition of State Highway – Combined Safety and Asset Preservation Scenario

preservation scenario. Similarly, there is a slight difference in the constant value over the period 2021 and 2034, this being approximately 1.51 mm MPD for the safety scenario and 1.53 mm MPD for the combined safety and asset preservation scenario.

The impact of including $100 million per annum asset preservation works in addition to the safety works is less than would be expected from a simple comparison of the percentages of the network resurfaced under both scenarios i.e. 1.2% c.f. 8.5%. This is because under the combined safety and asset preservation scenario about 215 lane-km out of the 1793 lane-km forecast annual surfacing need is for bituminous surfaces. Compared to chipseals, bituminous surfaces display little or no deterioration in macrotexture under cumulative traffic. Therefore, resurfacing a bituminous surface with another bituminous surface will have no impact on how the state highway macrotexture median value is trending. Furthermore, resurfacing a chipseal surface with a bituminous surface could have no or even a detrimental effect on this trending as the year 0 MPD value of a bituminous surface at about 1 mm is half to a third that of a new chipseal surface and comparable to the end-of-life macrotexture value of a chipseal surface.

## 6.3 Reduction in Social Cost of Crashes

The procedure as detailed in Appendix 1 was used to calculate the reduction in the social cost of crashes through treating all SAL's that breach TL or TLM.

As the percent of the state highway with breached TL/TLM was shown in Table 3 to be relatively stable over 2014, 2015 and 2016, it was decided to average all inputs required to calculate the reduction in social cost of crashes over these three years. The calculation steps are as follows:

- The average crash density on sections of state highway with either TL or TLM breached is 4.51 wet crashes per lane-km. The average crash density over the entire state highway network is 1.71 wet crashes per lane-km. Assuming resurfacing of state highway sections with breached TL/TLM reduces their crash density from 4.51 to 1.71, this represents a reduction of 62%.
- From Table3 in section 3.2 of this report, the percentage of all wet crashes occurring on SAL's with either TL or TLM breached is 8.8% corresponding to 3,367 wet crashes.
- In absence of any other information, it has to be assumed this 8.8% applies equally to wet injury crashes, which average 769 per year (refer Table A1). Therefore, 8.8% of 769 amounts to 67.9 injury crashes per year.
- A reduction in wet injury crashes of 62% corresponds to $0.62\times 67.90 = 42$ wet injury crashes. This corresponds to a social cost of $\$717{,}500\times 42 = \$30.2$ million per annum.

For the safety only scenario, the cost of resurfacing 1.2% of the state highway network is estimated to be $7.43 million. For the combined safety and asset preservation scenario, this reduces to $5.95 million (see Table 8 below). These costs have been derived assuming that for chipsealing the cost is $4.75 per $m^2$ and typical lane width is 3.5 m whereas for bituminous mix the cost is $28.28 per $m^2$ and the typical lane width is 4 m.

Therefore the benefit cost ratios for the two scenarios are:

- For safety only scenario, the BCR = $30.2 m/$7.43 m = 4.06
- For combined safety and asset preservation, the BCR = $30.2 m/$5.95 m = 5.08

## 6.4 Maintenance Cost Savings

Costs were generated from the dTIMS analysis of 10 year surfacing needs analysis for the following three scenarios:

- Treat Separately Asset Preservation ($100M fixed 20 year investment) Surfacing cost over 10 years = $646.4 million
- Treat Separately Safety (Unlimited 20 year investment)
  The surfacing cost over 10 years = $74.3 million
- Treat Combined ($100 million fixed 20 year investment and unlimited safety investment)

The costs have been derived assuming that for chipsealing the cost is $4.75 per $m^2$ and typical lane width is 3.5 m whereas for bituminous mix the cost is $28.28 per $m^2$ and the typical lane width is 4 m.

The cost savings that accrue as a result of combining safety with asset preservation are summarised in Table 8 below.

As can be seen, the benefit of combining safety and asset preservation works rather than treating separately is estimated to be $5.2 million per annum.

**Table 8:** Forecast Surfacing Costs for 10 Year Period 2015-2024

| Scenario | 10 Year Surface Costs ($ million) | | |
|---|---|---|---|
| | Asset Preservation Surface | Safety Surface | Total |
| Treated Separately | $ 646.4 | $ 74.3 | $ 720.7 |
| Treated Combined | $ 609.1 | $ 59.5 | $ 668.6 |
| Total Savings over 10 years | $ 37.3 | $ 14.8 | $ 52.1 |
| Annual Savings | $ 3.7 | $ 1.5 | $ 5.2 |

# 7 Conclusions and Recommendations

Within the scope and limitations of the modelling undertaken the following key conclusions and recommendations are made.

## 7.1 Conclusions

1. The reliable modelling of safety related maintenance works proved to be a very challenging exercise as the conditions being modelled, breaches of skid resistance and macrotexture threshold levels and occurrence of flushing, represent only between 0.3% (flushing) and 2.1% (skid resistance breaches) of the length of the state highway network.
2. By basing the safety modelling on skid assessment lengths (SAL), which range in length from 10 m to 100m, it was possible to combine established models for estimating the decay of skid resistance and macrotexture due to trafficking with model constants and scalars derived from skid resistance and macrotexture time histories pertaining to a SAL that minimised the difference between the predicted and actual values. Accordingly, each of the 330,000 or so SALs had unique model calibrations.
3. The resulting safety modelling framework gave predicted deterioration rates that closely matched those observed. Also, false positives, i.e. when a condition is not met but the model predicts it is, were kept in check so that the predicted breaches of skid resistance and macrotexture threshold levels resulted in cumulative lengths that were within a factor of 0.7 (flushing) and 1.4 (skid resistance) of that actually observed. It also correctly predicted about 40% of skid resistance and macrotexture breaches at the individual SAL level. The predictive ability of the safety modelling framework can therefore be considered adequate for the purposes of budget forecasting.
4. Combined application of the safety modelling framework and the dTIMS asset preservation modelling framework generated the following surfacing need forecasts for the 10 year period 2015-2024:

| Scenario | Forecast Surfacing Need | |
|---|---|---|
| | Annual Average Length (lane-km) | % Network |
| Safety Only | 292 | 1.2% |
| Asset Preservation Only | 1,890 | 8.1% |
| Combined Safety | 178 | 0.8% |
| Combined Asset Preservation | 1,793 | 7.7% |

5. By considering both safety and asset preservation needs together, a number of benefits have been identified as follows:
   - The safety treatment need is reduced by some 39% on account that resurfacing under asset preservation addresses some of the length of state highway that breaches skid resistance and texture. On a per annum basis, this corresponds to 114 lane-km.
   - As a result of safety addressing some of the surfacing need required under asset preservation, the asset preservation need is reduced by 5.1% from 1,890 to 1,793 lane-

km per annum due to more pavement work being possible due to the reallocation of available funding from surfacing to pavement works.

- The total reduction in resurfacing achieved by considering safety and asset preservation together, rather than in isolation amounts to 211 lane-km per annum. This equates to a 9.7% reduction in resurfacing length from 2182 lane-km to 1971 lane-km per annum,
- The forecast annual length of safety need shows an increased need occurring from 2022 onwards on account of the 3500 lane-km's previously having skid resistance between investigatory and threshold levels starting to breach the threshold level. This results in peaks of 1065 lane-km and 11561 lane-km occurring in 2022 and 2029. However, these peaks reduce substantially to 539 and 558 lane-km respectively when forecast asset preservation surfacing is accounted for.
- A key impact of surfacing works performed under asset preservation is to even out the annual amount of surfacing required under safety as it erodes the length of state highway that has values of skid resistance and macrotexture that fall between the investigatory and threshold values.

6. Application of the safety modelling showed that the ability to arrest the observed downward trend in the median levels of skid resistance and macrotexture provided on the state highway network is very much dependent on the proportion of state highway resurfaced and the effectiveness of the resurfacing in restoring skid resistance and macrotexture. For example, under the recommended investment scenario for the 10 year period 2015 to 2024, comprising a fixed annual renewal budget of $100 million and $30 million routine maintenance with unlimited safety budget, the targeted year 2 skid resistance value after resurfacing would have to be 0.57 ESC or greater. By comparison the median year 2 skid resistance value on the state highway network is only 0.52 ESC.
7. Treating SAL's with breached threshold levels was shown to be a very cost effective safety measure, reducing the crash density from 4.51 wet crashes per lane-km to 1.7 wet crashes per lane-km. This corresponds to an estimated social cost saving of $30.2 million per annum. Therefore, the benefit cost ratio for treating SAL's with breached skid resistance/macrotexture values under the safety only scenario is 4 and under recommended investment scenario it is 5.
8. The modelling highlighted that the maintenance cost savings that result from combining safety and preservation works rather than treating them separately is of the order of $5.2 million per annum.

## 7.2 Recommendations

1. The "Skid Assessment Length" table in RAMM should be expanded to include wet fatal, wet serious injury and wet minor injury crashes in addition to the presently recorded all wet crashes, which is a combination of both injury and non-injury crashes. Having details on the injury crashes will allow more robust estimation of crash costs.
2. The existing non-alignment of surfacing lengths, skid assessment lengths and treatment lengths is problematic, as it makes it difficult to assign surfacing details to a skid assessment length without causing a distributional change in skid resistance and texture values from that actually observed. This in turn impacts on the model's ability to reliably forecast the condition of the state highway network into the future, particularly in relation to skid resistance. This could be remedied if treatment length and forward works were recorded by lane rather than the Transport Agency's current practice of by centreline.
3. The requirements for the Python based code for performing the safety modelling and annual skid resistance and profiling outside of dTIMS evolved as the modelling work progressed. As a

consequence, the code is not well structured and efficient as it could be for repeated use and for error checking. Therefore, it is recommended that the code be rewritten to address these shortcomings and to make it more user friendly.

# Appendix 1: Costing Crashes

## A1.1 Cost per Reported Injury Crash

The Transport Agency's Economic evaluation manual (EEM)[9] is the industry's standard for the economic evaluation of land transport activities for New Zealand. The EEM sets out economic evaluation procedures and values used in calculating benefits and costs, necessary for applications seeking investment where a benefit cost appraisal from the Transport Agency is mandatory.

Guidance on reported injury crash costs are given in Appendix A6 of the EEM. In particular, Table A6.5 provides reported injury crash cost in May 2015 dollars by crash site/type and speed limit area.

In this report, a social cost of $717,500 has been assumed for all injury crashes. This has been derived from the average of 100 km/h near rural and 100 km/h remote rural mid- block crash values given in Table A6.5 of the EEM, as these are the most common type of wet road crash.

Table A1 summarises state highway crashes over the 5 year period 2011-2015 by injury crash type. The annual average number of wet injury crashes is 769. This corresponds to an annual social cost of $551.8 million.

**Table A1:** State Highway Wet Road Injury Crashes over the Period 2011-2015

| Year | Wet Crash Type | | | |
|---|---|---|---|---|
| | Minor | Serious | Fatal | Injury |
| 2011 | 683 | 151 | 40 | 874 |
| 2012 | 623 | 116 | 26 | 765 |
| 2013 | 611 | 128 | 30 | 769 |
| 2014 | 590 | 121 | 22 | 733 |
| 2015 | 561 | 127 | 18 | 706 |
| Average | 614 | 129 | 27 | 769 |

## A1.2 SAL Table Crash Data

The crash data in RAMM's "Skid Assessment Length" table pertains to all (injury and non-injury) wet crashes. Despite potential issues with under-reporting, non-injury crashes have been included as they provide an indication of potential wet friction issues with the road surface.

However, because the EEM doesn't value non-injury crashes, it is necessary when valuing a change in SAL "all wet" crash numbers to assume that injury crashes change by the same percentage. This approach will yield to a conservative valuing of crash costs provided that the actual ratio of non-injury crashes to injury crashes is greater than or equal to one.

[9] https://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual-2016.pdf accessed 22/5/2016

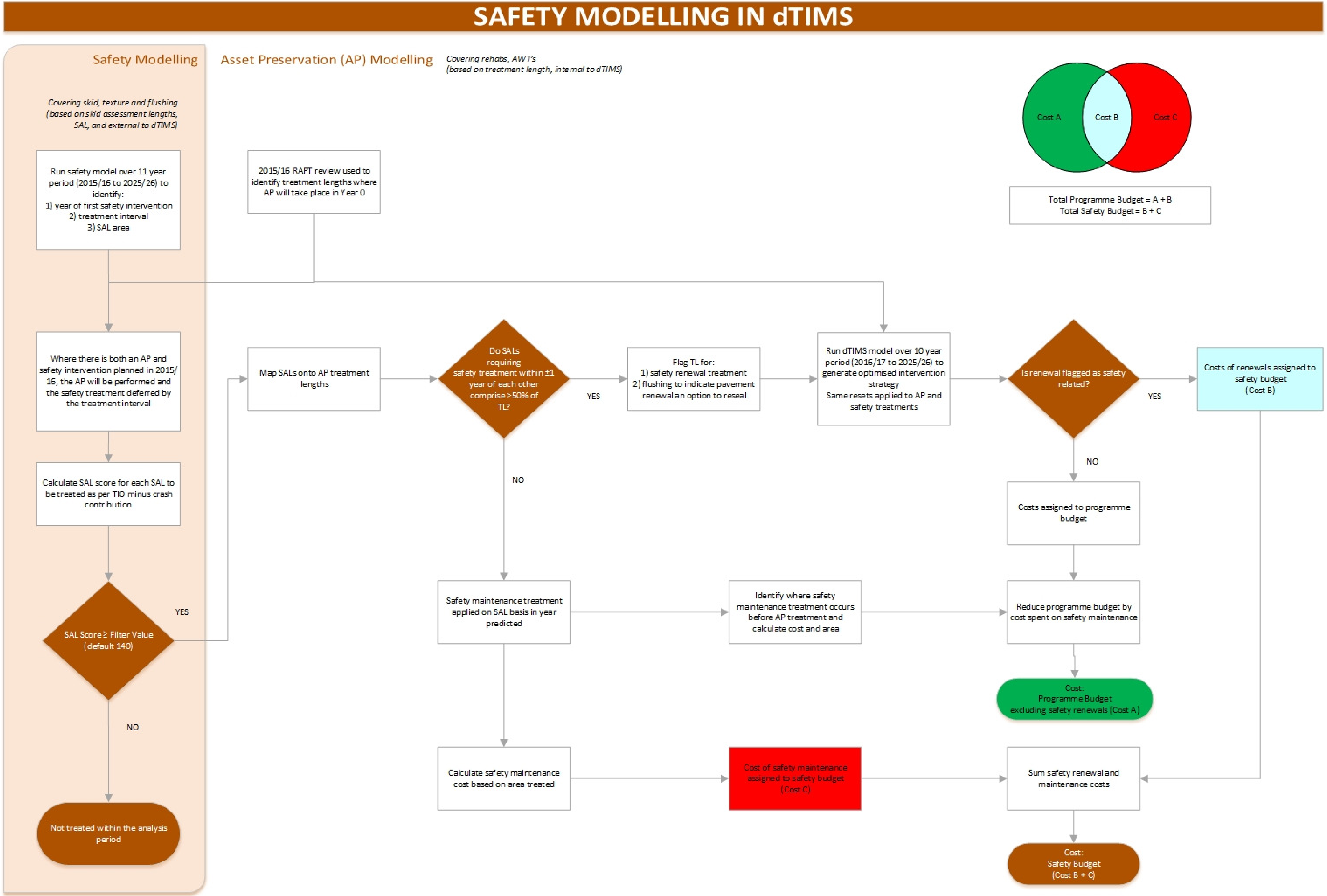
## A1.3 Illustrative Example

Let us assume that the $13.5 million spent on SCRIM sealing in 2015 was effective in reducing the crash density of SAL's satisfying the SAL treatment criteria from 12.49 wet crashes per lane-km to the network average crash density of 1.72 wet crashes per lane-km.

The resulting BCR of 4.5 given is section 3.4 of this report is calculated as follows:

- The reduction in crash density from 12.49 wet crashes per lane-km to 1.72 wet crashes per lane-km corresponds to a reduction of 86.23%.
- From Table 3, the percentage of all wet crashes occurring on SAL's satisfying the SAL treatment criteria is 12.7%, corresponding to 4,846 wet crashes.
- In absence of any other information, we assume this percentage also applies to wet injury crashes. From Table A1, the average number of wet injury crashes per year is 769. Therefore, 12.7% of 769 amounts to 97.66 injury crashes.
- A reduction in wet injury crashes of 86.23% corresponds to 0.8623×97.66 = 84.21 wet injury crashes. This corresponds to a social cost of $717,500×84.21 = $60.4 million.
- The BCR therefore is $60.4 m/$13.5 m = 4.5

# Appendix 2: Safety Modelling Schematic


SAFETY MODELLING IN dTIMS
Safety Modelling
Asset Preservation (AP) Modelling
Covering rehabs, AWT's (based on treatment length, internal to dTIMS)
Covering skid, texture and flushing (based on skid assessment lengths, SAL, and external to dTIMS)
Cost A
Cost B
Cost C
Total Programme Budget = A + B
Total Safety Budget = B + C
Run safety model over 11 year period (2015/16 to 2025/26) to identify: 1) year of first safety intervention 2) treatment interval 3) SAL area
2015/16 RAPT review used to identify treatment lengths where AP will take place in Year 0
Where there is both an AP and safety intervention planned in 2015/16, the AP will be performed and the safety treatment deferred by the treatment interval
Map SALs onto AP treatment lengths
Do SALs requiring safety treatment within ±1 year of each other comprise >50% of TL?
YES
Flag TL for: 1) safety renewal treatment 2) flushing to indicate pavement renewal an option to reseal
Run dTIMS model over 10 year period (2016/17 to 2025/26) to generate optimised intervention strategy
Same resets applied to AP and safety treatments
Is renewal flagged as safety related?
YES
Costs of renewals assigned to safety budget (Cost B)
NO
NO
Costs assigned to programme budget
Calculate SAL score for each SAL to be treated as per T10 minus crash contribution
YES
SAL Score ≥ Filter Value (default 140)
Safety maintenance treatment applied on SAL basis in year predicted
Identify where safety maintenance treatment occurs before AP treatment and calculate cost and area
Reduce programme budget by cost spent on safety maintenance
Cost: Programme Budget excluding safety renewals (Cost A)
NO
Calculate safety maintenance cost based on area treated
Cost of safety maintenance assigned to safety budget (Cost C)
Sum safety renewal and maintenance costs
Not treated within the analysis period
Cost: Safety Budget (Cost B + C)

# Appendix 3: Performance of Models

## A3.1 Introduction

The performance of the models in predicting “true positives” i.e. do the models correctly predict that a SAL has breached TL or TLM or is flushed is of more interest than the coefficient of determination ($r^2$) between predicted and actual values of skid resistance (ESC) and macrotexture (MPD). Therefore confusion matrices were employed to assess the proposed models.

A confusion matrix is a table that is often used to describe the performance of a model on a set of test data for which the true values are known. The general form of the confusion matrix is as shown below:

| | **Predicted:** Condition Met NO | **Predicted:** Condition Met YES | |
|---|---|---|---|
| **Actual:** Condition Met **NO** | TN = w | FP = x | Sub Total: w+x |
| **Actual:** Condition Met **YES** | FN=y | TP=z | Sub Total: y+z |
| | Sub Total: w+y | Sub Total: x+z | Total: w+x+y+z |

where:

- True positives (TP): These are the cases in which we predict yes, the SAL has breached TL/TLM and they have actually breached.
- True negatives (TN): We predict no, the SAL has not breached TL/TLM and they have actually not breached.
- False positives (FP): We predict yes, the SAL has breached TL/TLM, but they have actually not breached.
- False negatives (FN): We predict no, the SAL has not breached TL/TLM, but they have actually breached.
- w,x,y,z are the number of observations satisfying the condition.

The model performance measures that are computed from the confusion matrix are:

- ***Accuracy.*** How often is the model correct i.e. (TP+TN)/total
- ***Misclassification rate.*** Overall, how often is the model wrong i.e. (FP+FN)/total
- ***True Positive Rate.*** When it’s actually yes, how often does the model predict yes i.e. TP/Actual Yes
- ***False Positive Rate.*** When it’s actually no, how often does the model predict yes i.e. FP/Actual No
- ***Specifity.*** When it’s actually no, how often does the model predict no i.e. TN/Actual No
- ***Precision.*** When the model predicts yes, how often is it correct i.e. TP/Predicted Yes
- ***Prevalence.*** How often does the yes condition actually occur in our sample i.e. actual yes/total

## A3.2 Confusion Matrices

The following confusion matrices result when the models are applied to the 2015 state highway input dataset. Sub totals and totals are in terms of lane-km's.

The performance values provided pertain only to TL and TLM breaches and occurrence of flushing.

### A3.2.1 Skid Resistance Model

| | Predicted x>IL | Predicted TL<x≤IL | Predicted x≤TL | Actual Totals |
|---|---|---|---|---|
| Actual x>IL | 17,274.234 | 1,163.551 | 99.552 | 18,537.337 |
| Actual TL<x≤IL | 1,343.913 | 1,123.320 | 240.127 | 2,707.360 |
| Actual x≤TL | 104.602 | 102,664 | 127.922 | 335.188 |
| Predicted totals | 18,722.749 | 2,389.535 | 467.601 | 21,579.885 |

Accuracy: 0.858
Misclassification Rate: 0.142
True Positive Rate: 0.382 (x≤TL)
Precision: 0.274 (x≤TL)
Prevalence: 0.015 (x≤TL)

### A3.2.2 Macrotexture Model

| | Predicted x>IL | Predicted TLM<x≤ILM | Predicted x≤TLM | Actual Totals |
|---|---|---|---|---|
| Actual x>IL | 20,293.981 | 311.890 | 50.800 | 20,656.671 |
| Actual TLM<x≤ILM | 380.701 | 297.347 | 54.926 | 732.974 |
| Actual x≤TLM | 55.785 | 50.202 | 84.253 | 190.240 |
| Predicted totals | 20,730.467 | 659.439 | 189.979 | 21,579.885 |

Accuracy: 0.958
Misclassification Rate: 0.042
True Positive Rate: 0.442 (x≤TLM)
Precision: 0.443 (x≤TLM)
Prevalence: 0.009 (x≤TLM)

### A3.2.3 Flushing Model

| | Predicted No Flushing | Predicted Flushing | Actual Totals |
|---|---|---|---|
| Actual No Flushing | 21,360.001 | 71.194 | 21,431.195 |
| Actual Flushing | 115.670 | 33.020 | 148.690 |
| Predicted totals | 21,475.671 | 104.214 | 21,579.885 |

Accuracy: 0.991
Misclassification Rate: 0.009
True Positive Rate: 0.222
False Positive Rate: 0.003

| | |
|---|---|
| Specifity: | 0.997 |
| Precision: | 0.317 |
| Prevalence: | 0.007 |

## A3.3 Discussion

From the performance measures, it can be seen that the conditions we are trying to model accurately, represent a very small portion of the network, resulting in very low prevalence values ranging from 0.003 to 015.

The true positive rate and the precision of all three models are comparable, with the macrotexture and flushing models having a true positive rate that is lower than the precision, whereas for skid resistance it is the other way around.

In summary, when the model predicts that a SAL has breached TL or TLM or is flushed, there is only one chance in about three that it will be correct. However, considering the percentage of the network by length that satisfies the condition of interest, the models are much better, getting at best within 0.13% of the true value (i.e. macrotexture) and at worse within 39.5% of the true value (i.e. skid resistance).

# Appendix 4: Distribution of SALS

Histogram plots of SAL's exceeding investigatory level, between investigatory and threshold levels for survey years 2015 and 2016 are given in Figures A4.1 and A4.2 for skid resistance (ESC) and Figures A4.3 and A4.4 for macrotexture (MPD). The plots are in terms of both lane-km and as a percentage of state highway by length.

As SALs falling between investigatory and threshold levels are of most interest as they will impact on future maintenance need, this classification has been subdivided in two, with the lower subdivision indicating likely demand in the very near future. In all cases, the length of state highway in the lower subdivision is about half of that in the upper division.

Key points to note are as follows:

- The distributions remain reasonably static between 2015 and 2016 survey years.
- For skid resistance, the length of state highway between TL and IL is almost 6 to 7 times more than that at or below TL. The length of state highway between TL and IL-0.05 is more than twice that at or below TL.
- For macrotexture, the length of state highway between TLM and ILM is almost 5 to 6 times more than that at or below TL. The length of state highway between TLM and ILM-0.15 is about twice that at or below TL.

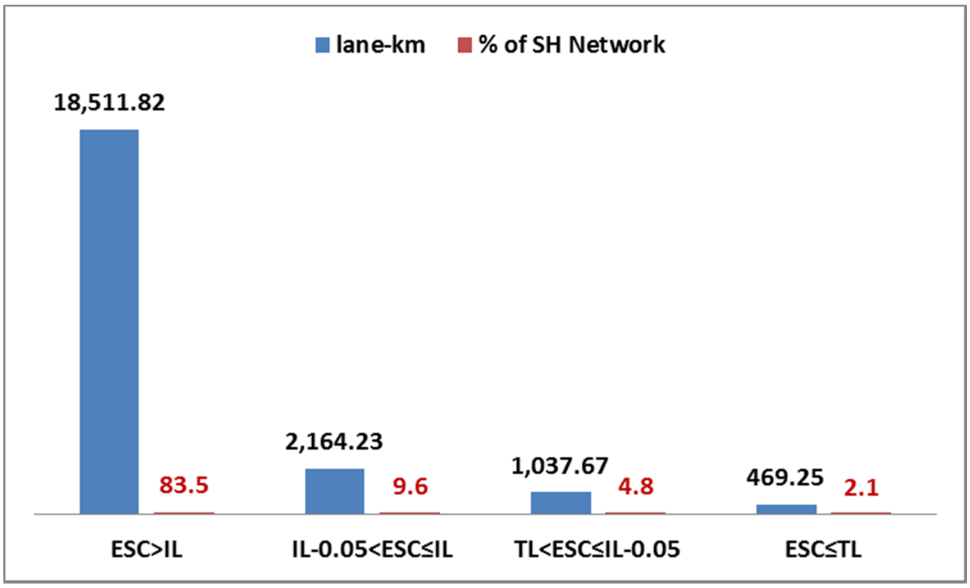



**Figure A4.1:** Distribution of SAL Skid Resistance Values - 2015

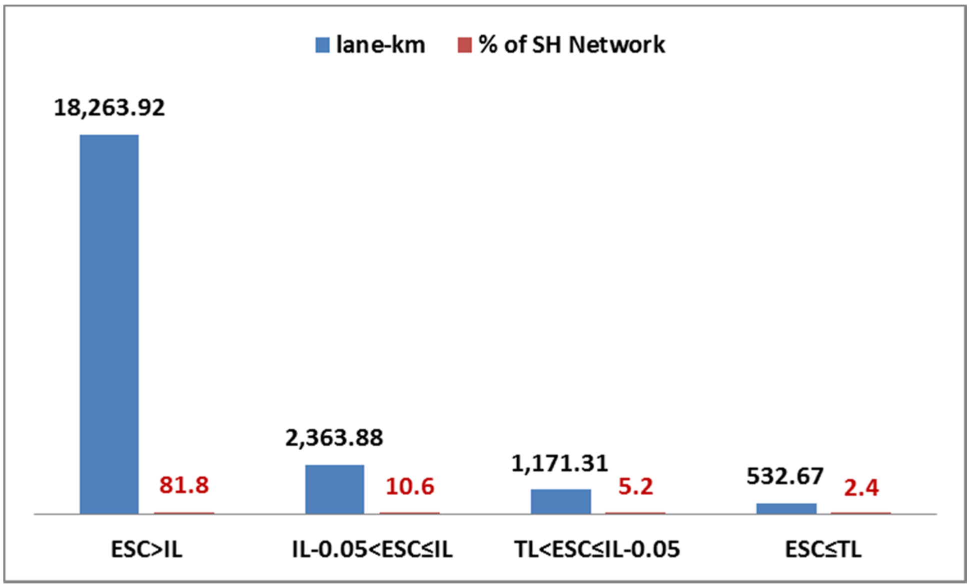



**Figure A4.2:** Distribution of SAL Skid Resistance Values - 2016

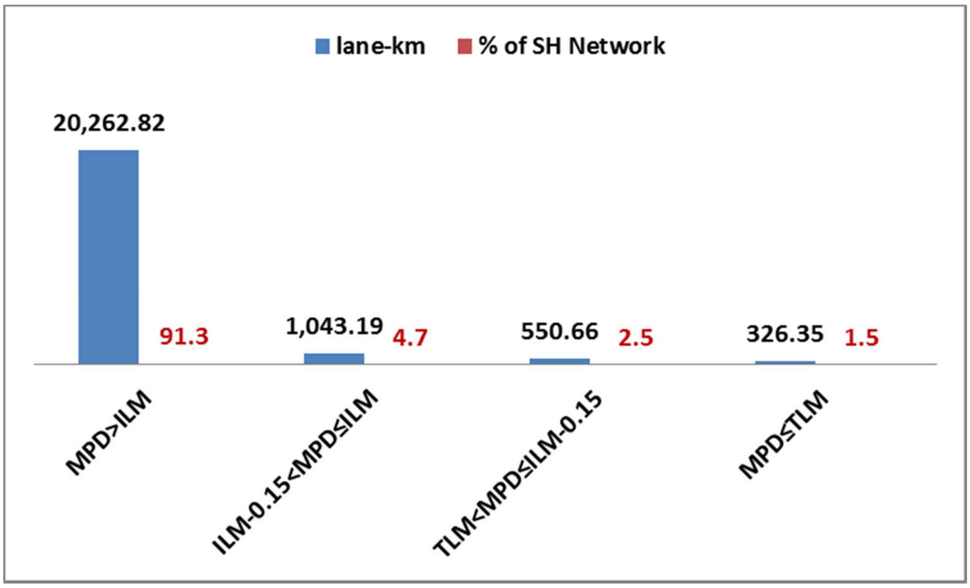



**Figure A4.3:** Distribution of SAL Macrotexture Values - 2015

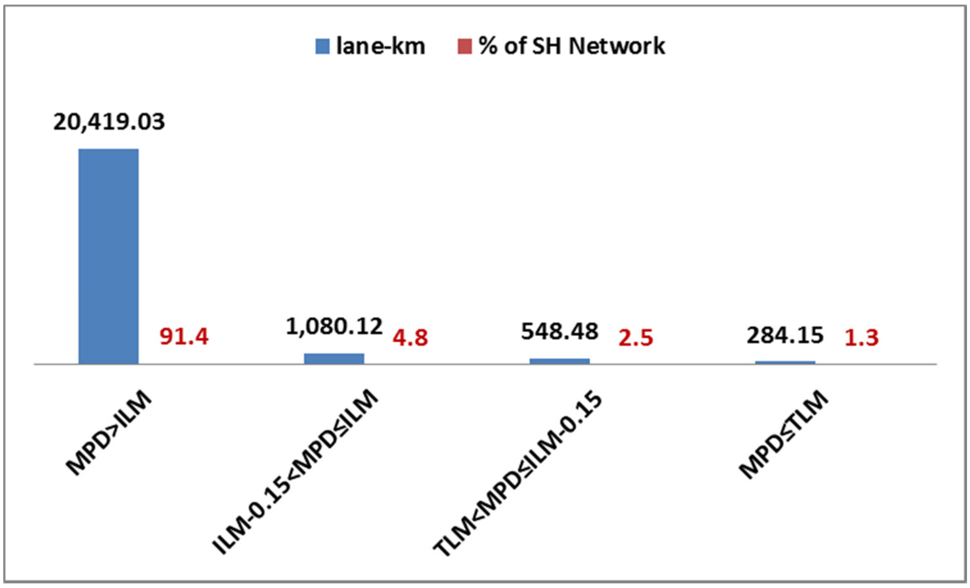



**Figure A4.4:** Distribution of SAL Macrotexture Values - 2016

# Appendix 5: Effect of a 10% Change in the Safety Works Budget

## A5.1 Overview

With reference to Section 6 of Opus Report "Incorporating Safety Management Modelling into NZ-dTIMS," the forecast length of safety need over the 10 year analysis period amounts to 292 lane-km per annum, corresponding to 1.2% of the length of the state highway network.

This amount of resurfacing is estimated to cause wet injury crashes numbers to reduce from 769 to 727 per annum, a reduction of 42 wet injury crashes per annum. From the Transport Agency Economic Evaluation Manual, the social cost of an injury crash is $717,500. Therefore, the total social cost is $30.2 million per annum.

For the safety only scenario, the dTIMS analysis calculates a cost of $7.43 million per annum to resurface this length of state highway, assuming a chipsealing cost of $4.75 per $m^2$ and bituminous mix cost of $28.28 per $m^2$.Therefore, the benefit cost ratio is 4.06.

For the combined safety and asset preservation scenario, the resurfacing cost reduces by $1.48 million to $5.95 million per annum, resulting in a benefit cost ratio of 5.08.

## A5.2 Effect of Reducing the Safety Budget by 10%

The effect of reducing the safety budget from $7.43 million to $6.69 million is to reduce the length of the state highway with breached threshold levels of skid resistance and texture that can be resurfaced by 10% from 292 lane-km to 263 lane-km. This amount of resurfacing is estimated to cause wet injury crash numbers to reduce from 769 to 731 per annum, a reduction of 38 wet injury crashes per annum.

Therefore an agency cost saving of $0.74m results in 4.2 additional wet injury crashes per annum, amounting to a $3 million increase in social cost. In other words for every $1 saved on the recommended safety budget of $7.43 million per annum, there is a $ 4 increase in social cost.

## A5.3 Effect of Increasing the Safety Budget by 10%

The effect of increasing the safety budget from $7.43 million to $8.17 million is to allow an additional 29 lane- km of state highway to be resurfaced. As $7.43 million per annum is considered sufficient to treat all sections of state highway with breached threshold levels of skid resistance and texture, the additional $0.74 million will be allocated to treating sections of state highway about to breach the skid resistance threshold level i.e. their skid resistance lies within 0.05 ESC of the threshold level. These road sections are calculated to have a crash density that is about 23% less than road sections with breached threshold levels.

About 1,100 lane-km, corresponding to about 5% of the state highway, falls in the category of almost breaching the skid resistance threshold level. The number of wet injury crashes on these roads is 77 per annum.

The expenditure of an additional $0.74 million to resurface 29 lane-km of these roads is estimated to result in a reduction of 1 wet injury crash per year, resulting in a social cost saving of $0.72 million.

This corresponds to an almost cost neutral situation i.e. every additional dollar over the $7.43 million spent on safety related resurfacing will result in a $1 reduction in the social cost of crashes.

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