Managing road surfaces for safety at the network level: is macrotexture enough?

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ABSTRACT

This paper reports an analysis of the relationship between road surface characteristics and crashes on undivided two-way roads in the state of Victoria, Australia. Surface condition data from multi-laser profilometer surveys was linked to geometry, traffic and crash data using GIS and the resulting tables analysed to investigate the relationships. The three road surface characteristics were either uncorrelated or showed small enough correlations to disregard possible interactions among the variables. Crash rate was higher for road sections with low macrotexture; a power relationship provided a good fit to the data. Crash rate was also higher for roads where roughness was extreme, with a polynomial relationship providing a good fit to the data. No clear relationship emerged between rutting and crash rate. An economic analysis suggests that resurfacing sites with macrotexture of 1 mm SPTD or less would produce crash savings which would provide a very good return on the investment.

1. INTRODUCTION

There is at present little information on how road surface characteristics relate to crashes under Australian conditions. All Australian jurisdictions currently commission regular surveys of surface condition using multi-laser profilometers (MLPs), but there has been little attempt so far to relate the measurements taken by these devices to safety outcomes.

The work reported in this paper is part of a project for Austroads, the peak body for road authorities in Australia and New Zealand, to examine the relationship between surface characteristics and crashes. The work covered is an examination of the relationship between surface characteristics on rural roads in the state of Victoria.

There is body of work relating macrotexture to crash occurrence (Roe, Webster and West 1991, Gothie 1993), with crash rate increasing rapidly when macrotexture falls below a sand patch texture depth of approximately 1.00 mm. The same general pattern has been found on rural roads in Australia (Tredrea 2001, Cairney and Styles 2005) but this is based on a limited sample of roads and requires confirmation.

Swedish work (Ihs 2004) shows that the crash rate is higher when rutting is present. The one Australian study which examined this issue is consistent with this picture, but the length of road and number of crashes is too small to have confidence in the finding (Cairney, Styles and Bennett. 2005)

Ihs (2004) also demonstrated that crash rates increased with roughness. Although an early Australian study (Nelson English, Loxton and Andrews Pty. Ltd. 1988) found no relationship, between crash rates and roughness, a more recent study found that crash risk increased for moderate levels of roughness (Cairney, Styles and Bennett 2005).

2. METHOD

A number of declared roads in Victoria, both urban and rural, were included in the study.. This paper presents the results from two-way undivided carriageway roads where the speed limit was 100 km/h. The roads included in the study are shown in Figure 1. These roads are part of a light duty network, constructed of granular materials with a sprayed seal surface, with few excepetions.

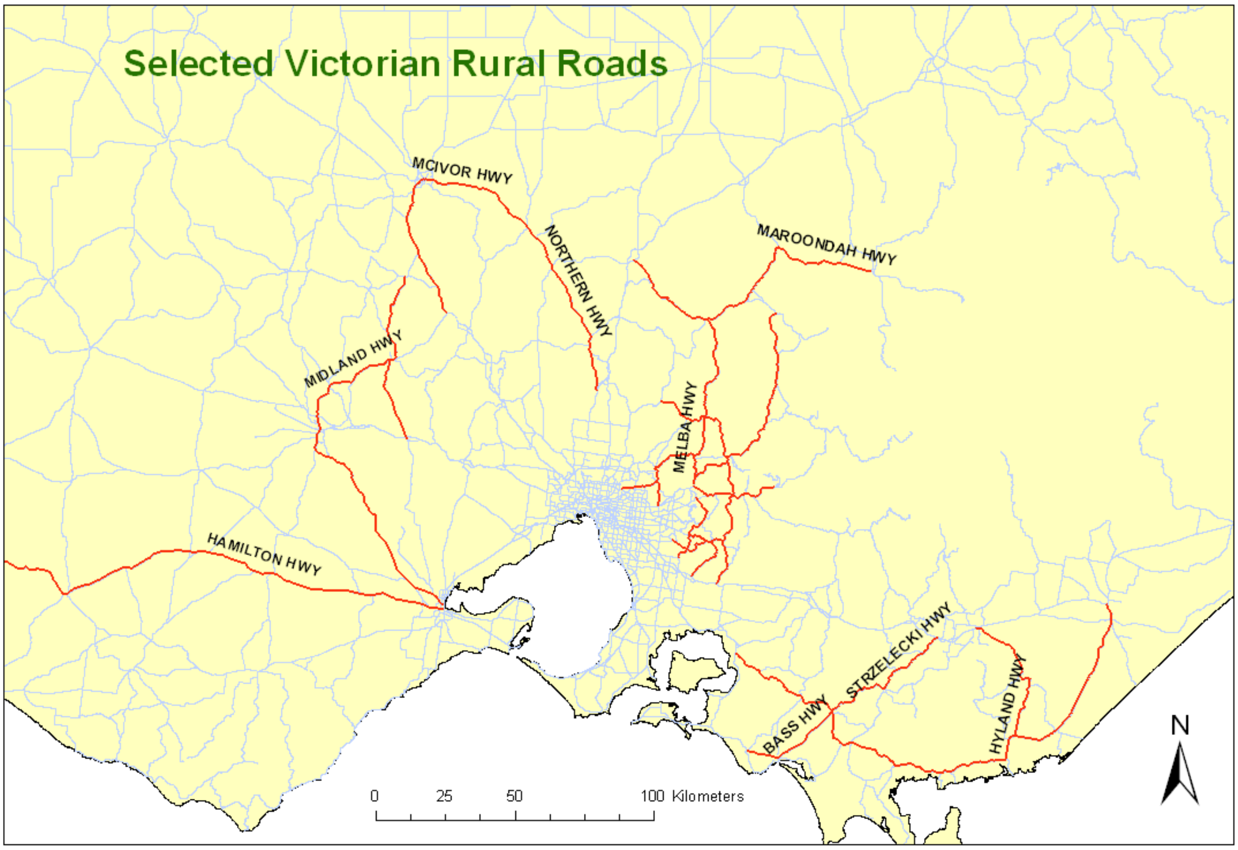

Figure 1: Roads included in the study

Survey data from these roads was accessed, together with traffic data and crash data. The roads were split into 50m sections, and measures of roughness, rutting and surface texture were joined spatially in ArcMap to these sections. In the case of surface texture, the data was only available in as an average over 100m lengths, so these were split into 50m segments to match the other variables. In some cases, the roughness and rutting data had to be rounded to the nearest 50m segments as the chainage at the start and finish sections did not match the geometry. Locations of crashes from the VicRoads crash database were joined spatially to the closest 50m segment of road. Average daily traffic volumes were also joined to the dataset to enable crash rates to be calculated.

This dataset was exported from ArcMap into Excel, where crash rates per 100 million vehicle kilometres travelled over 5 years were calculated. Texture, rutting and roughness, and the geometry variables were allocated to broad ordinal categories to simplify the analysis. Two forms of analysis were performed:

Pivot tables were used to analyse the distribution of crashes among the categories for texture, roughness and rutting, and VKT used to derive an overall crash rate for each category. No attempt was made to differentiate intersection from non-intersection crashes at this stage. The results were graphed (crash rate vs one of the three surface variables) and a correlation co-efficient were calculated. This was repeated using a cross-tabulation of two surface variables, and graphed using simultaneous line graphs. Intersections were identified by the presence of intersection-type crashes (using DCA codes) and the same analysis was performed for just these road segments.

Analysis by site was done by aggregating all 50m segments of road, and classifying by the presence of an intersection crash type (by DCA), midblock crash type or no crash. Proportions of each texture, roughness and rutting category falling into each crash site type were tabulated and graphed.

The study included 1,386 km of road and 1,344 crashes.

3. DATA SOURCES

Road surface characteristics were obtained from MLP surveys carried out in the middle of the study period. The surface characteristics available for analysis were macrotexture (expressed in sand patch texture depth units (SPTD)), rutting (mm), and roughness (Austroads roughness counts).

The traffic volumes used were obtained from the HTVN database (Homogeneous Traffic Volume Network). This is a database of traffic volume estimates for major road links for the whole of Victoria. Links are defined as lengths of road between intersections of major roads with major roads; or are terminated at country town boundaries. The links have been chosen so that the traffic volumes along them are as homogeneous as possible. All traffic volumes derived from the HTVN are estimates, based on actual point location counts. Multiple counts are averaged for that link. Where a link has no actual traffic count done in the study period then the volume is estimated algorithmically from other counts along the same route.

Crash data was obtained from the VicRoads Crashstats system, which contains details of all fatal and injury crashes in Victoria. A crash report has to be filed before persons injured in traffic crashes are eligible for injury insurance benefits, so coverage of injury cases is believed to be fairly complete. It does not include non-injury crashes. Geocodes were available for all crashes included in the study, facilitating the process of matching crashes to location and surface characteristics.

4. RESULTS

Relationship among road surface characteristics

Pearson correlation coefficients were calculated for each pair of characteristics. The results are shown in Table 1.

Table 1 Correlations among surface characteristics

Comparison	Pearson r	r^2
Macrotexture vs Roughness	-0.0857	0.0073
Macrotexture vs Rutting	0.0134	0.0002
Roughness vs Rutting	0.2464	0.0607

There is no correlation between macrotexture and roughness or macrotexture and rutting. There is only a slight correlation between roughness and rutting. These findings mean that it is not necessary to consider the interaction of the different surface characteristics.

Relationship between road surface characteristics and crash occurrence

Figure 2 shows the relationship between crash rate and texture. Crash rate is fairly constant over most of the texture range, but increases when for texture in the 1.2 to less than 1.8 mm category, and continues to increase as texture decreases. The crash rate for the lowest texture category is more than double the crash rate for most of the range.

Exploratory fits of different possible functions were made to the relationship between macrotexture and crash rate. A good fit was found by power function, expressed in the following equation:

$\text{Crash rate} = 43.44\ x^{-0.4924}$

where x = macrotexture in SPTD units.

The r^2 value associated with this equation was 0.74, indicating a reasonably good fit.

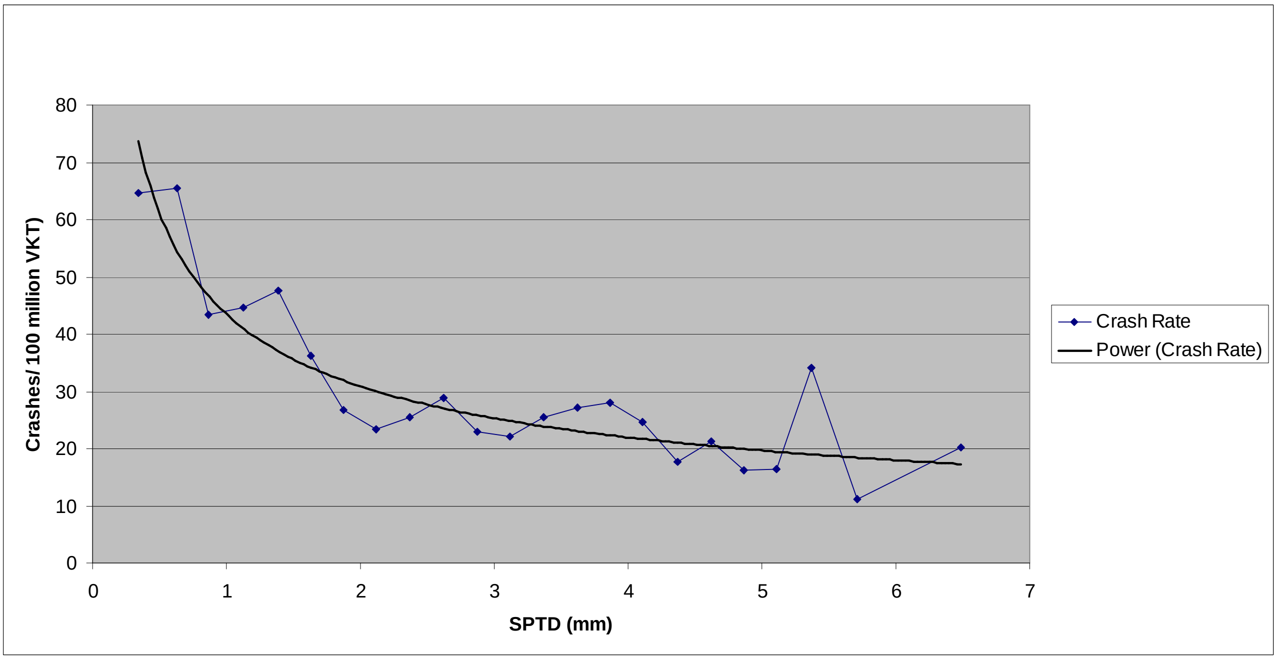

Figure 2: Relationship between macrotexture and crash rate for rural high speed roads.

Crash rate is plotted against rutting in Figure 3. Crash rate appears to vary around a constant trend over most of the range of rut depth, with a large decrease on crash rate for the category with the deepest ruts. This decrease in crash rate with high levels of rutting is the opposite of what would be expected, but is based on only 0.5 % of the road length and 0.37% of crashes and may not be a reliable finding.

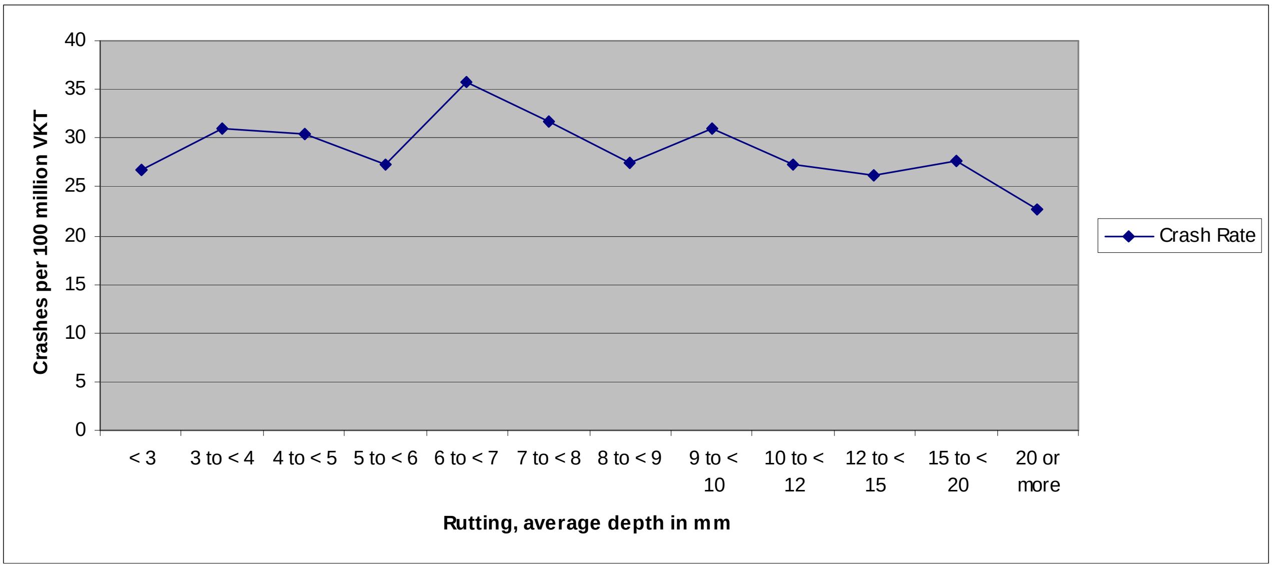

Figure 3: Relationship between rutting and crash rate

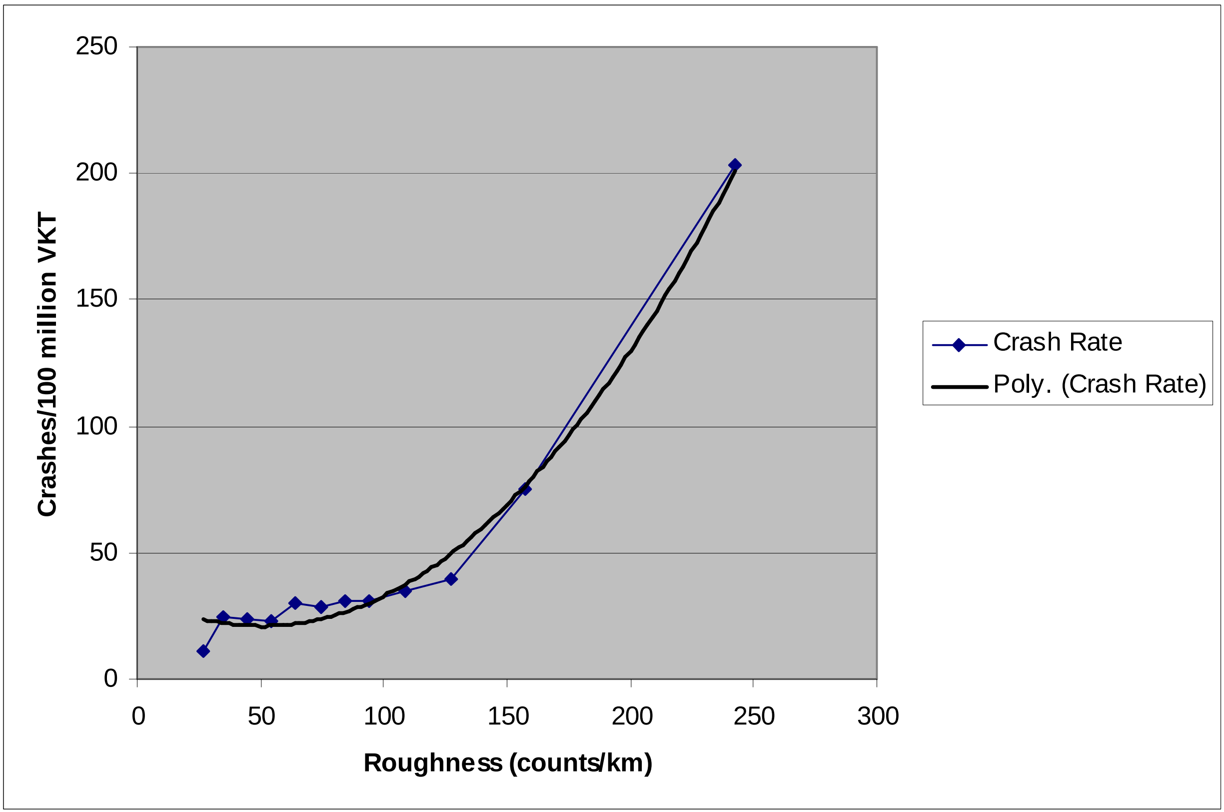

Figure 4: Relationship between roughness and crash rate

The relationship between crash rate and roughness is shown in Figure 4. A small increase in crash rate with increasing roughness is evident over most of the range, with a definite increase beyond 150 counts/km. This increase is particularly severe for the 200+ counts/km category. However, this is based on a small percentage of the road travel (3.6%) and crashes (10.0%), and may not be reliable. Extreme roughness may also be related to particular features which may limit the options for remedial treatment, e.g. railway level crossings.

Exploratory fits of possible functions to the relationship between roughness and crash rate showed that a polynomial function best described the relationship. The equation describing the function was:

Crash rate = $0.0049x^2 - 0.4948 = 33.468$

where R = Roughness in NAASRA roughness counts/km.

The r^2 value in this case was 0.99, indicating an excellent fit to the data. However, higher level of roughness where an elevated crash rate occurred made up only 2.6% of the road length and accounted for less than 4% of the travel. This relationship must be regarded as tentative until it can be confirmed from other studies.

Influence of wet conditions

The percentage of crashes which occurred in wet conditions was compared for sites with a macrotexure of 1.00 mm SPTD or less, and those with higher microtexture (Table 2). As discussed elsewhere in the report, crash risk increases low macrotexture. However, Table 2 indicates that low macrotexture did not result in a higher proportion of wet weather crashes. The lack of difference was confirmed by a chi-square test (chi square = 013, df = 1, p = 0.7224).

Table 2 Crashes in wet and dry conditions for different macrotexture categories

Macrotexture Category	Wet Crashes	Dry Crashes	All Crashes
1.00 or less	74 (31.1%)	164 (68.9%)	238 (100%)
1.01 or more	331 (29.9%)	775 (70.1%)	1106(100%)
Total	405(30.1%)	939(69.9%)	1344(100%)

Economic analysis

If it is assumed that resurfacing a rural road using the usual spray seal techniques results in a macrotexture of at least 3.00 mm SPTD, then from Figure 2 and the associated equation, it can be assumed that the crash rate on the resealed section will be 25 per 10^9 VKT.

Sections of road with a macrotexture of less than 1.00 mm SPTD extend for 80 km. They currently experience approximately 45 injury crashes per year, and accommodate approximately 0.832 x 10^9VKT/year. After resurfacing, this would be expected to be reduced to approximately 23 crashes per year. The most recent work to look at the cost of crashes in Australia estimates the average cost of a casualty crash on rural roads on Victoria at approximately $A 297,000 (Thorolf Thoresen, personal communication on 11th January 2008). The anticipated annual savings would therefore be approximately $A 6.5 million.

Macrotexture was less than 1.00 mm SPTD on approximately 80 km of the roads studied, equivalent to 5.7% of the road network. Current costs of resealing are generally in the range of $A4 - $A6 per square metre (Ian Cossens, VicRoads , personal communication on 11th January 2008). Two-lane two way roads on the Vicroads rural network generally have a sealed width of 7 metres. The cost of resealing would therefore be $A 28,000 – 42,000 per kilometre. The cost of resealing all sections considered in the study with a macrotexture of 1.0 mm or less would therefore probably be in the range of $A2.24 million to $A 3.36. This is approximately half the estimated benefits which accrue in the first year following resealing.

There are two ways of looking at the long-term benefits. On the one hand, the reseal might be expected to last for 8-10 years, so that the benefits over this period would be several times the cost of the investment. On the other hand, if a suitable maintenance program is in place, then the macrotexture in no section of the network should ever fall below an SPTD of 1mm again, and the benefits from this one-off investment in resurfacing should remain for the life of the road.

5. DISCUSSION

This paper summarises a number of points to emerge from the investigation.

The lack of correlation between the different surface characteristics is an important finding, particularly the lack of correlation between macrotexture and rutting. It would be expected that the processes which cause rutting also result in low macrotexture. However, this turned out not to be the case. The possibility of the effects of macrotexture on crash rate explicable in terms of the effect of rutting may be discounted, as may the possibility of explaining rutting effects in terms of macrotexture.

The relationship between macrotexture and crash rate followed a power function, indicating a steep rise in crash rates with low macrotexture. There was a moderately good correlation between the power function and the data points.

The relationship between roughness and crashes followed a polynomial function. The fit between the polynomial function and the data points was excellent. However, the extreme roughness which resulted in noticeably higher crash rate applied over only a small proportion of the road network, and these extreme roughnesses may be associated with local factors which could possibly make effective remediation difficult. This relationship requires confirmation from other studies before it can be regarded as reliable.

Low macrotexture was not associated with an increase in the proportion of wet weather crashes.

From the economic analysis, it would appear that resurfacing sections where the macrotexture is 1.0 mm SPTD or less, there would be substantial benefits in terms of crash reductions. This estimate is based on a robust cross-sectional study (i.e. one which compares crash rates on different sections of road over the same period). More confidence could be placed in these results if they were backed by a body of before-after studies, i.e. studies which examined crash rate on different sections of road before they were resealed and after they were resealed. It should also be recognised that these estimates constitute a very broad brush approach, and a more detailed appraisal of both a road's crash history and the actual costs of resealing should be undertaken before engaging in such an enterprise. Nevertheless, the results of this preliminary estimate are sufficiently promising to justify this detailed appraisal.

In one respect, these results are unsurprising in that they confirm the pioneering results of Roe et al (1991), something that had already been achieved in the context of Australian rural roads by more limited exploratory studies. However, this study incorporates a sufficient body of data that confidence can be placed in these relationships, at least in the south-east corner of the Australian continent, and they can now be used to inform practice.

The surprising aspects of these results are the power relationship that emerged between crash rate and macrotexture, and the polynomial relationship that emerged between crash rate and macrotexture. These relationships might provide a framework for future empirical research on the relationship between crash rate and road surface characteristics and, if they stand up to scrutiny, may provide a basis for theoretical developments.

The question posed in the title was, is macrotexture enough to manage road surfaces for safety at the network level? The evidence put forward in this paper suggests that even if resurfacing decisions were to be based on macrotexture alone, considerable crash reductions could be achieved if the resources were available to eliminate all road sections with texture 1.00 mm SPTD or less, and that these benefits would greatly outweigh the costs of this resurfacing. It must be remembered that the data reported here was for a high speed rural network, and may not be applicable to lower speed networks. Whether macrotexture alone is sufficient to manage safety on this type of surface depends whether additional or different measurements that take into account microtexture e.g. output from one of the many types of skid resistance measurement devices currently available would result in better identification of sections in need of treatment, and whether the net benefits which resulted from acting on this information would be greater than the cost of obtaining and processing the additional information.

It is worth noting that VicRoads, the authority responsible for managing the roads in this study, has for some years relied on macrotexture as the basis for its rural skid resistance monitoring program, and adopts a minimum SPTD of 1.2 mm in its Maintenance Guidelines.

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6. References

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