Australian Government
Australian Transport Safety Bureau

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ROAD SAFETY RESEARCH REPORT

CR223

A Pilot Study of the Relationship between Macrotexture and Crash Occurrence

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Victoria, Australia

February 2005

Department of Transport and Regional Services

Australian Transport Safety Bureau

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AUSTRALIAN TRANSPORT SAFETY BUREAU
DOCUMENT RETRIEVAL INFORMATION

Report No.	Date	Pages	ISBN	ISSN
CR 223	February 2005	47	0 642 2533 4	1445 4467

Title and Subtitle
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Abstract
Macrotexture refers to variations in the road surface in the range 0.5 mm to 50 mm. It is generally believed to affect braking through the two mechanisms of hysteresis and the prevention of a water film. A literature review concluded that crash risk is greater at sites with low macrotexture, but studies differ as to the macrotexture values at which risk begins to increase. Limited work to date suggests that the relationship cannot be explained simply in terms of traffic flow. A pilot study of the relationship between macrotexture and crashes was undertaken by locating each crash on the macrotexture measurement record. The relationship was compared on the Great Eastern Highway, Western Australia, Princes Highway West, Victoria, and the Duke’s Highway, South Australia. In nearly all cases, there was an association between macrotexture and crashes, the exceptions being rural sites on the Princes Highway West, where the relationship was marginally significant, and urban sections on the Dukes Highway, where there was no association (but note there was very little urban road on this route). There was a significant association between low macrotexture and crashes at all rural intersection sites, but no association between low macrotexture and wet road crashes, nor between macrotexture and young driver cashes, and insufficient data to examine the relationship for heavy vehicles. The data were also examined for associations between low macrotexture and young driver and heavy vehicle involvement. There was no significant association with young driver involvement. There was insufficient data to do formal testing for heavy vehicle involvement, but the pattern of the data suggests that low macrotexture was underrepresented at the sites of crashes involving heavy vehicles. The results agree with previous studies regarding the increase in risk with low macrotexture. The prospects for a surface management process based on macrotexture are therefore good, but further work is required before this is possible.

Keywords
Macrotexture, Crashes, Road pavement, Road surface, Road maintenance

Notes
(1) ATSB reports are disseminated in the interest of information exchange.
(2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government.

Acknowledgements

The authors thank all the staff from the three State Road Authorities who so willingly assisted with this project. Special thanks are due to Geoff Murray (Main Roads Western Australia), Tim Bell, Gary Nisbet and Alistair Colebatch (VicRoads), and Steve Lippett and Amando Reyes (Transport South Australia).

Summary

Background

Macrotexture refers to variations in the road surface in the range 0.5 mm to 50 mm. It is generally believed to affect braking performance by assisting drainage, thereby preventing the formation of a water film over the road surface, and through hysteresis, the deformation of the tyre which converts mechanical energy into heat. Macrotexture is relatively stable, and can be measured by laser profilometers travelling at highway speed in the course of multi-variable highway condition surveys.

Literature review

To date, few studies examining the relationship between macrotexture and crashes have been undertaken. These studies, conducted in the UK, France and Australia, are in agreement that crash risk is greater at sites with low macrotexture, and that crash risk is relatively unaffected over the rest of the usual range of macrotexture. However, it is difficult to determine how close the agreement is about the point at which risk begins to rise, due to different measurement equipment and units of measurement. The UK and Australian studies show that the proportions of crashes on wet road surfaces were approximately the same for low macrotexture and other sites, suggesting that the drainage function may be less important than commonly believed. The UK study also showed that the relationship between macrotexture and crashes could not be explained by both occurring at sites with higher traffic flows in the vicinity of junctions.

There do not appear to be any studies which have investigated the relationship between macrotexture and stopping distance.

Method

Macrotexture and crash data were obtained from the Great Eastern Highway, Western Australia, the Princes Highway West, Victoria, and the Duke’s Highway, South Australia. Analysis proceeded by locating each crash on the running record of macrotexture. The macrotexture of the section where each crash was located was taken as the macrotexture at the crash site. Sites were identified as rural sites (speed limit greater than 80 km/h) or urban sites (speed limit 80 km/h or less). Distributions of macrotexture were prepared across all sites, and across crash sites.

Analysis was carried out separately for rural and urban sites. For each macrotexture category, the percentage of crash sites was compared with the percentage of all sites. The ratio of crash sites to all sites for each macrotexture category was taken as an indication of the crash risk associated with that level of macrotexture. On the basis of the risk data, sites were classified as low macrotexture or high macrotexture for the next stage of the analysis.

The possible relationship of a number of crash variables to macrotexture was investigated by cross-tabulating the number of crashes in each category of interest with macrotexture to create a 2x2 contingency table, except in the case of severity where the contingency table differed for the States according to the number of crash severity categories. The chi square test was used to test for association between the crash variables and macrotexture.

Results

For the Great Eastern Highway, a significant association between crashes and macrotexture was found for both rural and urban sites.

For the Princes Highway West, there was a significant association between macrotexture and crashes for urban sections, and a marginally significant association for rural sections.

For the Dukes Highway, there was a significant association between macrotexture and crashes for rural sections, but no association for urban sections. Note that there were very few urban sections on this road.

There was significant over-representation of low macrotexture at intersection crash sites on rural sections of all three routes (marginally significant in the case of the Duke's Highway), and at intersection crash sites on urban sections of the Great Eastern Highway. There was also significant over–representation of low macrotexture at the sites of crashes on straight sections on the Great Eastern Highway, but no other significant associations with road alignment.

There was no association between low macrotexture and wet road crashes. The data were also examined for associations between low macrotexture and young driver and heavy vehicle involvement. There was no significant association with young driver involvement. There was insufficient data to do formal testing for heavy vehicle involvement, but the pattern of the data suggests that low macrotexture was underrepresented at the sites of crashes involving heavy vehicles.

Implications for surfacing management based on macrotexture monitoring

The results agree with previous studies regarding the increase in risk with low macrotexture, although there is not close agreement about the precise value of macrotexture at which crash risk begins to rise. The prospects for a surface management process based on macrotexture are therefore good.

On the Great Eastern Highway and the Princes Highway West, 30% and 36.5% of crashes occurred at low macrotexture sites, and the crashes which could be saved by treating all low macrotexture sites was estimated to be 13% and 17% respectively. Twenty-one percent and twenty-nine percent of each route would have to be resurfaced to achieve this. However, it may be possible to target improvements more narrowly at high risk sites. Two possible examples are intersections and curves.

Before a surfacing management process based on macrotexture can be developed, a further study is required to examine the relationship between crash risk and macrotexture in more detail, taking into account intersections, road geometry and road surfacing materials and techniques. A study of vehicle braking distance on surfaces with different macrotexture would also be useful in demonstrating the effects and providing practical guidance in situations where increased macrotexture might be required.

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1 Introduction

1.1 Macrotexture defined

Macrotexture, effectively the average depth of the gap between the stones in a road surface, is believed to be an important characteristic of road surfaces which affects stopping distance at high speed. It is generally believed that two mechanisms are involved.

1. Drainage - good texture depth assists drainage, preventing the formation of a water sheet across the surface with the resulting risk of aquaplaning.
2. Mechanical deformation of the tyre (hysteresis) – good texture depth is necessary to enable mechanical deformation to take place, which dissipates energy in the form of heat.

While drainage would be expected to affect stopping distance only under wet conditions, hysteresis should affect stopping distance under all conditions. Macrotexture needs to be understood in relation to two other aspects of texture which also influence the stopping behaviour of vehicles: microtexture and megatexture. The three aspects differ in the size of the surface variations they describe, and in the mechanisms through which they affect stopping performance and roadholding; these are described in Table 1.

Texture Classification	Range of surface variations Φ	Contribution to Skid Resistance	Potential road user disbenefit	Measurement in the field
Micro-texture	less than 0.5 mm	Adhesive Friction	none	SCRIM Pendulum Tester
Macro-texture	0.5mm - 50 mm with amplitudes from 0.1 mm to 20mm	Hysteretic Friction Water escape from beneath the tyre	Vehicle noise and tyre wear	Sand Patch Laser Profiler Laser Texture Meter
Mega-texture	50mm - 500 mm with amplitudes from 0.1 to 50 mm	Low mega-texture reduces the demands on the vehicles suspension during braking and steering, and reduces water ponding/retention when rutting is present	none when minimized (poor ride, and reduced directional control and braking efficiency when excessive)	Laser Profiler Traditional Survey Roughness meter (qualitative)

Table 1: Classification and character of macrotexture in relation to other texture measurements.
(from ISO/CD 1373: Characterisation of pavement texture utilizing surface profiles: Determination of mean profile depth)

Microtexture affects stopping distance from lower speeds or, on high speed roads, the last few metres of a braking manoeuvre. The mechanism involved is mechanical removal of particles from both the road and the tyre surfaces. The effects of microtexture are well understood, with large scale, well-defined studies going back to Sabey's work in the 1950s. Several major studies have been conducted since then, with a high degree of consensus regarding the results (for example, see Cairney 1997 for a review of these studies). In contrast, there appears to be relatively few studies of the relationship between macrotexture and crashes (for example, see Gothie 1993). Only one study appears to have been carried out in Australia, covering only one highway (Tredrea 2001). This study has not been formally published.

So far as road safety is concerned, megatexture is important mainly for its capacity to trap water when rutting has started to appear in the pavement. This has the potential to create situations where aquaplaning can occur in response to extreme manoeuvres, such as heavy braking.

1.2 Monitoring surface condition

Skid resistance surveys carried out in Australia to date have usually been conducted using a Sideways Force Coefficient Routine Investigation Machine (SCRIM), a purpose-built vehicle which pulls a wheel set at a constant angle to the vehicles' path. Strain gauges measure the resistance of the wheel, which is then used to calculate the Sideways Force Coefficient (SFC). The SCRIM surveys measure a combination of microtexture and macrotexture, are expensive to conduct, and produce measurements which may vary considerably with the weather. Macrotexture, on the other hand, can be measured by laser devices in the course of road condition surveys, which are carried out periodically for other purposes and produce results which may be consistent over a number of years. The additional cost of collecting and reporting macrotexture information is very modest. There is therefore a strong case for investigating the full potential of macrotexture as a measure of road surface condition.

Only one Australian jurisdiction (New South Wales) has so far been able to sustain regular SCRIM measurements over the whole of their network for an extended period. There would therefore be considerable benefits for road authorities if surface condition on high-speed roads could be managed by reference to macrotexture only. This would permit the establishment of a systematic risk management program for surfacings, based on periodic assessment of macrotexture. In turn, this has the potential to reduce crashes on rural roads by ensuring that stopping distance is adequate for the conditions. It is not possible to quantify these benefits with present knowledge.

Many jurisdictions now routinely conduct macrotexture surveys, and store results in a format that is accessible via GIS. They also geocode or georeference crash locations. This should make it a relatively simple matter to match up crash locations with macrotexture at the crash site (bearing in mind the limitations on accurate crash location), along with SCRIM (skid resistance) readings if available.

2 Literature review

The Australian Transport Research Index (Australian), Transportation Research Information Service (TRIS - North American) and International Transport Research Database (IRTD - European) were searched for the term 'macrotexture', and the resulting abstracts scanned and papers relevant to the research issue obtained.

2.1 Measurement of macrotexture

Harwood et al (1980) list 17 contact and 11 non-contact methods of measuring macrotexture. However, this review need be concerned with only two of these, the historically standard method and the current standard method. Other methods have not been widely used in Australia (if at all), and are not likely to be used in the future.

Macrotexture has traditionally been measured by the 'sand patch test' which involves spreading a known volume of sand across the road surface in a circular pattern until it all falls between the aggregate, then measuring the diameter of the area covered by the sand. Dividing the volume by the area of the sand patch provides the average depth of the sand, equal to the average depth of the gaps between the aggregate. This method is slow, labour intensive, and unsuitable for extensive measurement.

Current methods are based on laser measuring devices. Infra-red laser pulses are reflected from the road surface onto a diode array. The position of the returned pulses is used to estimate the vertical distance between the sensor and the road. The root-mean-square distance, a measure of the variation in the vertical distance, is used to calculate the average texture depth, referred to as sensor measured texture depth (SMTD).

There are a number of commercially available systems for measuring SMTD, all with broadly similar capabilities. SMTD can be measured at speeds close to normal highway operating speeds, with recording and processing carried out by computer. SMTD records are referenced using road authorities' linear referencing systems and/or GPS references as the survey proceeds. Locating the SMTD data in relation to other information held by road authorities, such as other asset management records or crashes is a relatively straightforward matter. High speed measurement enables networks to be monitored at regular intervals for modest cost, and links to other data elements enable more comprehensive analysis than has been possible in the past.

Wix and Gow (2002) compared SMTD from two laser measuring devices with the sand patch test. The laser devices were Multi Laser Profilers (MLP), an array of laser/sensor combinations mounted on a survey vehicle for the purposes of measuring roughness and rutting as well as texture depth. This calibration work was undertaken in support of a major road survey contract. Eight test sites, each 10 m long were selected so as to represent the full range of texture likely to be encountered on the highway network.

The two laser devices differed in the size of the laser spot projected, the version with the smaller spot being able to generate a more detailed profile leading to higher SMTD values, although the differences in SMTD are very small. The performance of one MLP at the eight test sites was compared over a number of years by conducting a regression of each year against a reference year (2002). In all cases the coefficient of determination was greater than 0.94, indicating a high level of agreement. Data from the other MLP for one year only was compared with the reference year data, and a coefficient of determination (r^2) of 0.986 was obtained.

Correlation with manual sandpatch texture depth (SPTD) was also very good, with r^2 ranging between 0.889 and 0.982 for different years. However, the SMTD and SPTD values are quite different, although they bear a reliable linear relation to one another. The averaged calibration for the two most recent years has been adopted for converting the Western Australian and Victorian SMTD to SPTD in Section 5 of the present report.

2.2 Relation of SMTD to SCRIM measurements.

The other commonly used measurement of road surface condition is sideways-force coefficient (SFC), measured by the sideways-force coefficient measurement machine (SCRIM). The SCRIM apparatus consists of a wheel mounted at an angle of 20 degrees to the direction of travel. The sideways force developed by this wheel, dragged over a road surface at a constant speed, is a measure of the skid resistance of the road, which is a complex interplay of macrotexture and microtexture which varies according to operating speed. Delanne (1993) puts forward two models to describe this interaction, one based on empirical findings, the other based on theoretical analysis. Translation of this work from French is beyond the scope of the present review.

The relationship between SMTD and SCRIM appears to be non-existent, or very weak. Roe et al. (1991) studied the relationship between macrotexture, SCRIM and crashes on three road networks in the UK, each of which included sections of motorway, major roads and minor roads. Sites were arranged into macrotexture classes covering a wide range. For each macrotexture class, there was essentially the same distribution of SCRIM values which corresponded closely to a normal distribution. Roe et al. concluded that the distributions of macrotexture and SCRIM measurements were unrelated, allowing the relative contributions of both variables to be assessed. Studying the relationship between mean texture depth and SCRIM measurements on Japanese motorways, Shimeno (1996) found only a low correlation between them which varied according to measuring speed, being lowest at a measurement speed of 60 km/h. It may be the case that the extent to which there is a relationship between macrotexture and SCRIM depends upon construction techniques and maintenance practices in relation to traffic flow. The important point for the present review is that there is no necessary connection between them, and that they do not seem to be closely related in practice.

2.3 Surface condition and stopping distance

Bullen and Ruller (1997) report a study on emergency braking stopping distances on asphaltic concrete for six Australian vehicle types. It demonstrates that vehicle size and loading (mass) may have a considerable effect on emergency braking stopping distances. It was also noted that macrotexture had an important role in regard to the coefficient of friction and aquaplaning. The paper notes that the aquaplaning threshold is related to a range of factors such as tyre pressure, tyre footprint, tread depth, water depth and texture depth.

The paper recognises that macrotexture needs to be studied in relation to its effect on 'instantaneous' skid function. The report also recognises that the in situ testing undertaken as part of the study does not give enough information on the instantaneous friction (Bullen and Ruller 1997).

It is possible to estimate the effects of improved skid resistance in terms of the reduction in operating speed which would be required to achieve the equivalent reduction in braking distance. The critical value for skid resistance is the Sideways Force Coefficient (SFC), a value derived from direct measurement of the pavement. Vehicle braking distance may be expressed as:

$$S = V2/255*f \text{ (metres)},$$

where f (friction factor) is approximately equal to the SFC.

At a travelling speed of 40 km/h, raising SFC from 0.40 to 0.60, which is within the range of what would be expected from a resurfacing treatment, is equivalent to reducing operating speed by seven kilometres per hour. At 60 km/h, it is equivalent to reducing speeds by eleven km/h. Special treatments formulated to give even higher levels of skid resistance could be expected to produce even greater equivalent speed reductions (Oliver 2003).

There does not appear to be any equivalent data available on the relationship of macrotexture to stopping distance.

2.4 Relationship of macrotexture to crashes

In view of the important contribution of macrotexture to friction, the ease with which it has been possible to collect macrotexture data for the last ten years or so, and the sophistication of the crash analyses which are now possible, it is surprising that there appear to be only two published studies of the relationship between macrotexture and crashes. This review includes a third study which has not yet been formally published. This contrasts with the voluminous literature on the relationship between crashes and pavement friction, measured by a range of devices, mostly pre-dating SCRIM. A comprehensive review of this work is available in Cairney (1997).

The study by Roe et al (1991) referred to in Section 2.2 contains a detailed examination of the relation between macrotexture and crashes. The study compared SMTD at crash sites with SMTD for the route as a whole. There was a higher percentage of crash sites than of all sites when SMTD was less than 0.8 on one route, less than 0.7 on a second route, and less than 0.6 on a third route, indicating increased risk of crashing with low macrotexture. For the lower macrotexture categories, the excess of crash sites compared to all sites increases, and is approximately double for SMTD values below 0.4.

Two further aspects of the Roe et al study are important. First, crashes were classified into skidding crashes with a wet pavement, skidding crashes with a dry pavement, non-skidding crashes with a wet pavement, and non-skidding crashes with a dry pavement. The relationship of all categories of crash to macrotexture was similar, suggesting that the drainage aspect of macrotexture is of little importance. Second, the authors were concerned that the relation between macrotexture and crashes they observed might be the result of crashes occurring where macrotexture was low anyway and that the relationship was caused, as they elegantly describe it 'by association rather than a direct contribution' (Roe et al, p.13). In order to test this possibility, crashes were divided between those which occurred near junctions and those which occurred elsewhere. Sites across the network as a whole were divided into sites near junctions and others. The four macrotexture distributions were found to be very similar, and the relationship between low macrotexture and crashes identified in the initial analysis was again found. For sites as a whole, the distribution of macrotexture close to junctions was similar to the distribution at other sites. Thus the results cannot be explained by low macrotexture and large numbers of crashes both being related to different patterns of traffic movements at junctions.

These findings have been confirmed by two further studies.

Gothie (1993) reports a study relating wet-road crashes to macrotexture. The study covered 215 km of national roads in the Rhone-Alpes region of France carrying approximately 10,000 vehicles per day. The study included 201 wet-road crashes over a 4.5 year period. The relationship between crashes and macrotexture is shown in Figure 1. The top line on the graph represents the maximum wet road crash rate for each macrotexture category, the middle line the mean wet road crash rate and the bottom line the lowest wet road crash rate. It can be seen that crash rate varies little for higher levels of macrotexture, but rises steeply when macrotexture falls below 0.5 mm.

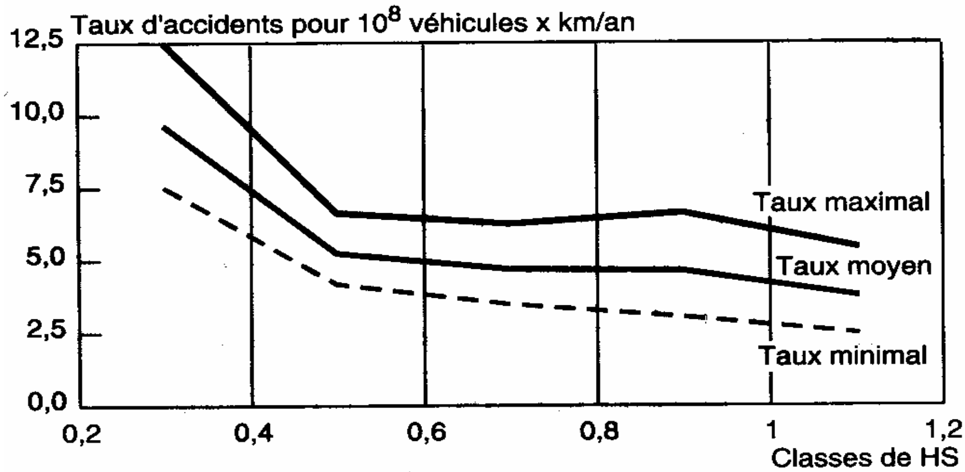

Figure 1: Relation between macrotexture and wet road crash rate (from Gothie 1993).
The x-axis represents macrotexture, and the y-axis the wet road crash rate per 10^8 vehicle/km/year.

Tredrea (2001) examined the relationship between macrotexture and crashes on four urban routes and four rural routes in Victoria. Macrotexture data was available as SMTD from MLP surveys and was converted to its SPTD for analysis. The VicRoads CRASHSTATS system was used to identify locations for crashes on the routes. The locations were identified on the macrotexture records, and the average macrotexture for the 100m leading up to the crash calculated. Distributions of macrotexture over the whole road (reference data) were then compared with distributions of macrotexture at crash sites (accident data), and inferences about the over-representation of crashes at low macrotexture sites were made on the comparison of the distributions. There was no over-representation of the accident data at low macrotexture sites for urban roads, but a clear over-representation for rural roads (see Figure 2).

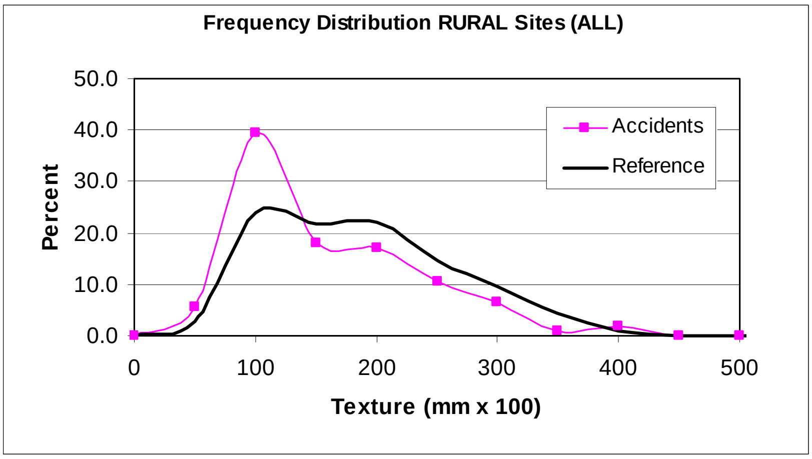

Figure 2: Distributions of macrotexture at accident sites and reference sites on selected Victorian rural roads (from Tredrea, 2001).

2.5 Towards a surface management regime based on macrotexture

The three studies examined are in agreement regarding the increase in risk associated with low macrotexture, although there is some variation in the threshold value at which risk increases. It is not clear to what extent these differences are due to differences in the road and traffic systems in the different countries, or are due to differences in the calibration or data handling associated with macrotexture measurement. The essential point is that there is a clear relationship between crashes and macrotexture.

The two further findings reported by Roe et al (1991) discussed above reinforce the viability of macrotexture as an indicator of safety performance. The finding that wet and dry pavement crashes have the same relation to macrotexture indicates that it is an indicator of the risk which applies to nearly all crashes[1] rather than a limited subset. The finding that the relationship between crashes and macrotexture was not the result of both being associated with intersections allays misgivings that the relationship may be an artefact of both being associated with higher levels of conflicting traffic movements.

[1] Crashes in some unusual circumstances may be an exception, for example where a driver has fallen asleep at the wheel.

3 METHOD

3.1 Macrotexture data

The road authorities in three States made available macrotexture data collected by contractors as part of the routine monitoring of network condition. In all three cases, a laser profilometer was used to measure Sensor Measured Texture Depth following similar procedures. However, there were some differences among the data available from the three States, summarised in Table 2.

	Measure	**Directions**	**Length of Sections in Analysis**
Western Australia	SMTD	2	20m
Victoria	SMTD	1	10m
South Australia	SMTD.	1	100m

Table 2: Comparison of macrotexture data from each State.

In the case of the Western Australian and Victorian data, the research team was able to choose the length over which macrotexture data was aggregated, and 20 metres was chosen as a suitable value. The South Australian data was available only in 100 metre sections, the format in which contractors reported the data to Transport SA.

The SMTD categories had 0.1 mm increments.

3.2 Crash data

While both Western Australia and South Australia require property damage only crashes to be reported down to a low monetary value, Victoria only requires that property damage only crashes are reported under some unusual circumstances (eg if the driver of one vehicle is not present), and makes available only casualty crashes in the crash data base.

The differences among the crash data for the three States are summarised in Table 3.

	Severity categories	Crashes	Casualty Crashes	Crashes/km	Casualty Crashes/km
Western Australia	Fatal, hospital admission, medical treatment, major property damage, minor property damage	1167	375	3.9	1.3
Victoria	Fatal, hospital admission, other injury	354	354	1.3	1.3
South Australia	Fatal, injury, property damage.	254	121	1.3	0.6

Table 3: Summary of crash data categories available.

3.3 Analysis

Analysis proceeded by locating each crash on the running record of macrotexture. The macrotexture of the section where each crash was located was taken as the macrotexture at the crash site. Sites were identified as rural sites (speed limit greater than 80 km/h) or urban sites (speed limit 80 km/h or less). Distributions of macrotexture were prepared across all sites, and across crash sites.

Analysis was carried out separately for rural and urban sites. For each macrotexture category, the percentage of crash sites was compared with the percentage of all sites. The ratio of crash sites to all sites for each macrotexture category was taken as an indication of the crash risk associated with that level of macrotexture. On the basis of the risk data, sites were classified as low macrotexture or high macrotexture for the next stage of the analysis.

The possible relation of a number of crash variables to macrotexture was investigated by cross-tabulating the number of crashes in each category of interest with macrotexture to create a 2x2 contingency table, except in the case of severity where the contingency table differed for the States according to the number of severity categories. The chi square test was used to test for association between the crash variables and macrotexture.

4 Results

4.1 Western Australia

4.1.1 The route – Great Eastern Highway

The route selected for study was the Great Eastern Highway, between Perth and Coolgardie. The route was 296.79 kilometres in length. Sections where the speed limit was 80 km/h or less were treated as urban, the remainder rural. The route comprised 250.13 kilometres of rural road and 46.66 kilometres of urban road. Data was available from a survey carried out in both directions, and was analysed in 20 metre sections.

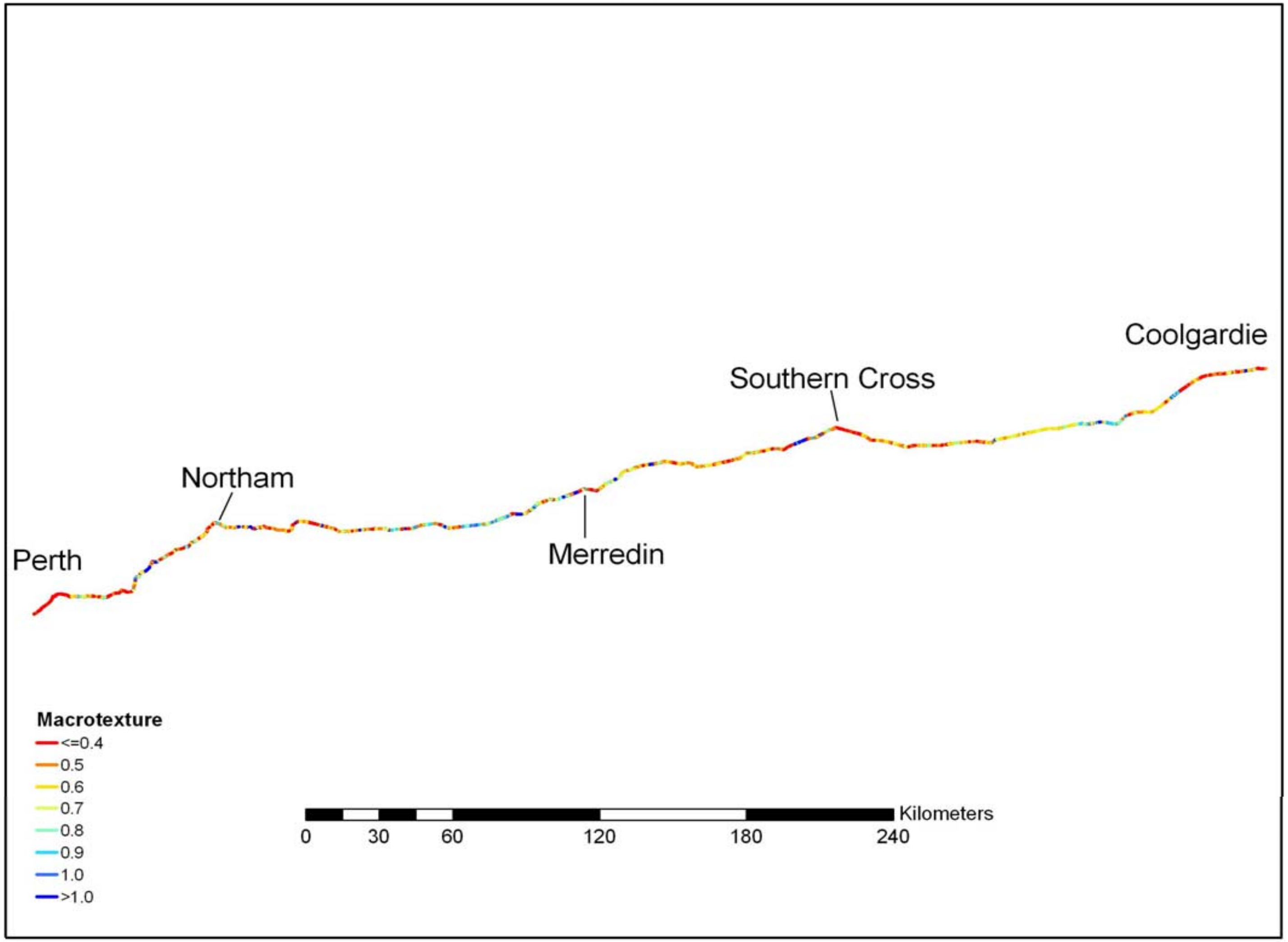

Figure 3: Map of the Great Eastern Highway

4.1.2 Macrotexture

Distributions of macrotexture for rural and urban sections of the Great Eastern Highway for each direction of travel are shown in Figures 4 and 5. Inspection of the distributions shows that they are closely matched. The distributions have therefore been combined for the purposes of analysis.

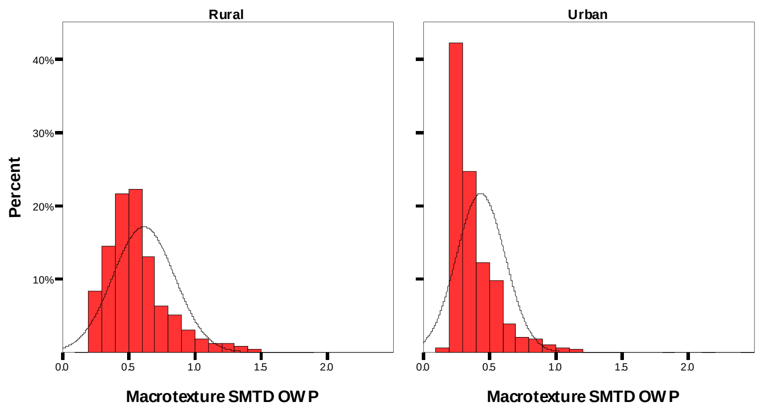

Figure 4: Macrotexture for rural and urban sections of the Great Eastern Highway, Direction 1.

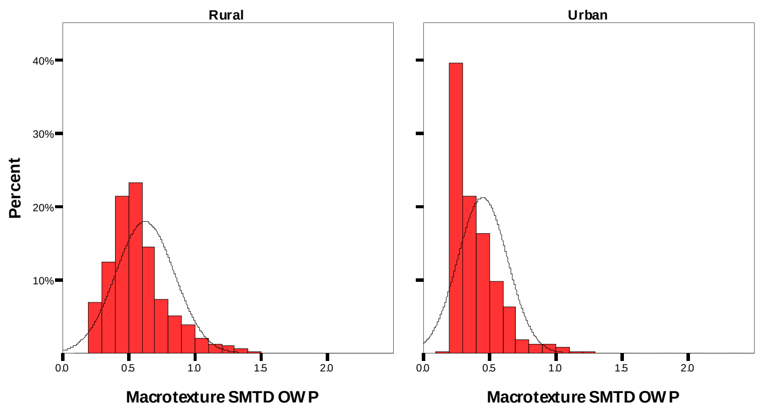

Figure 5: Macrotexture for rural and urban sections of the Great Eastern Highway, Direction 2.

The combined distributions for travel in each direction are shown in Figure 6, separately for the rural and urban sections. The distribution for the urban sections has a much higher proportion of sections with low macrotexture than does the distribution for the rural sections.

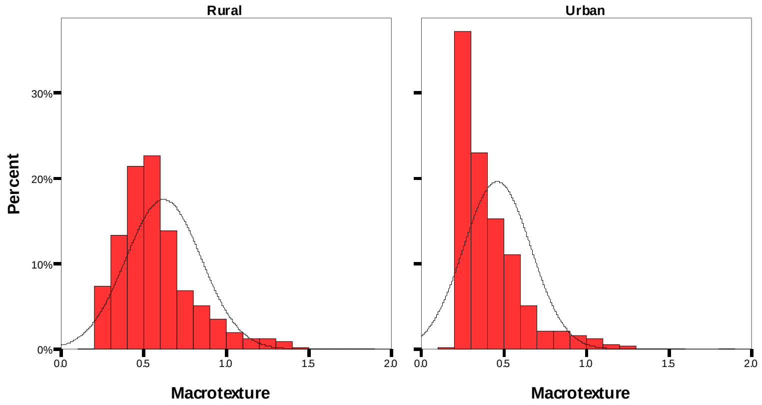

Figure 6: Distribution of macrotexture on rural and urban sections, Great Eastern Highway.

4.1.3 Macrotexture on sections where crashes occurred

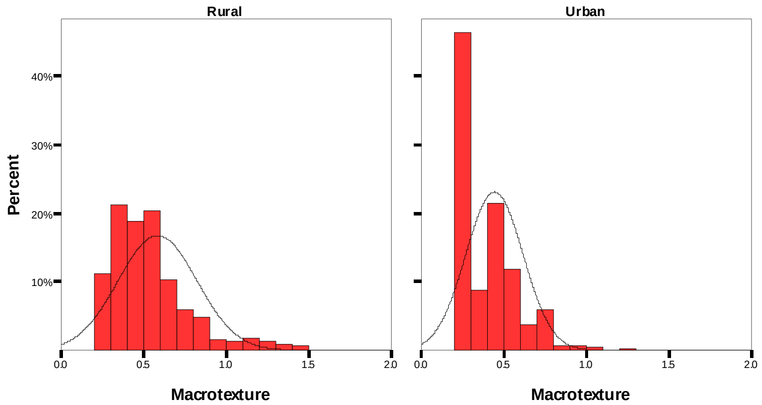

Figure 7: Distribution of macrotexture on rural and urban sections, Great Eastern Highway.

The distributions of macrotexture on the sections where crashes occurred are shown in Figure 7, separately for rural and urban parts of the route. Many more of the urban sections had low macrotexture than was the case for the rural sections.

4.1.4 Crash risk in relation to macrotexture

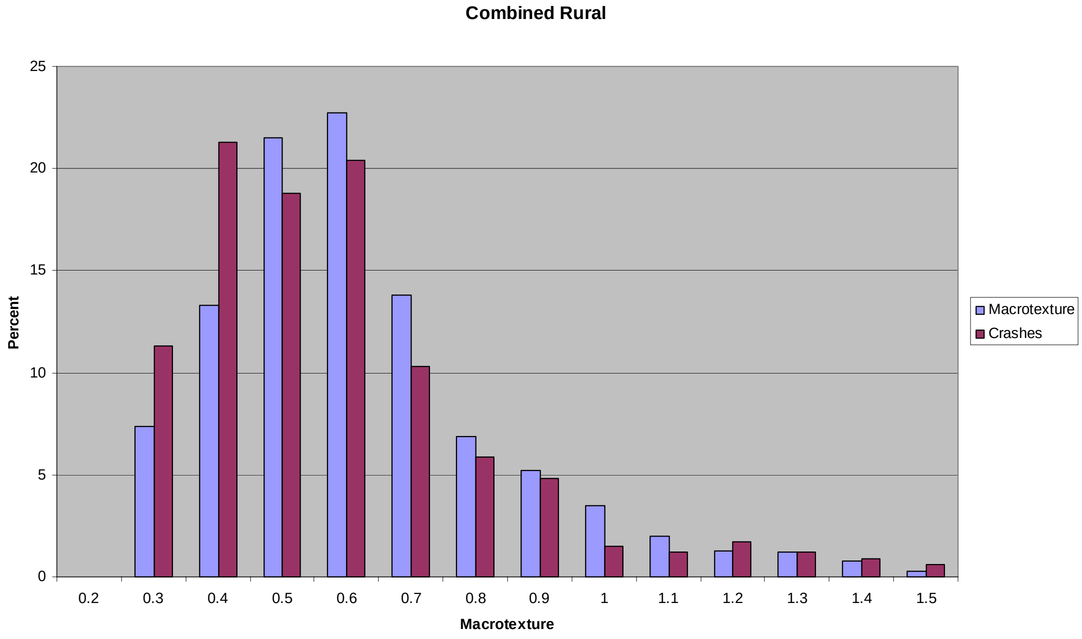

Figure 8: Comparison of distributions of macrotexture on all sites and at crash sites, Great Eastern Highway, rural.

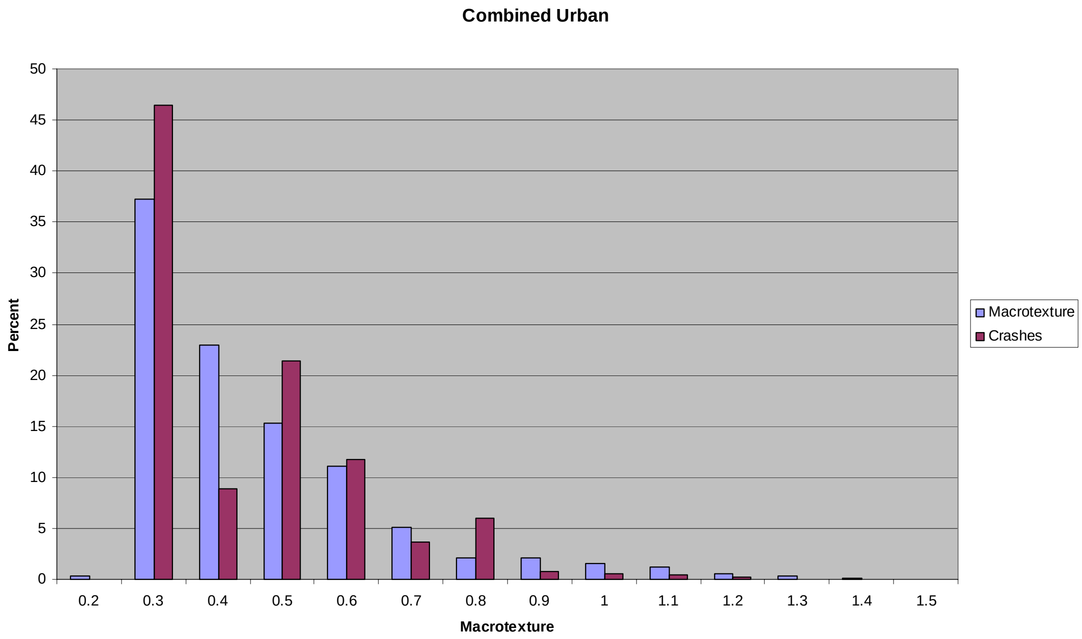

Figure 9: Comparison of distributions of macrotexture on all sites and at crash sites, Great Eastern Highway, urban.

Figure 8 indicates that for rural sections, there is a considerably higher proportion of crash sites than of all sites in the lower macrotexture categories, especially in the 0.3 and 0.4 categories.

Figure 9 indicates a different pattern for urban sites, with a higher percentage of crashes sites than all sites for the 0.3 and 0.5 categories, but fewer crash sites than all sites for the 0.4 category. Numbers of all sites and crash sites with macrotexture greater than 0.7 are small and may not be reliable.

To enable statistical testing, a cut off value of 0.4 was adopted for rural sites. Sites with an SMTD of 0.4 and below were categorised as low macrotexture, and those with an SMTD of 0.5 and above were categorised as high macrotexture. For urban sites, in view of the low crash numbers in the 0.4 category, a cut-off of 0.3 was adopted. The number and percentage of sites in each category is presented in Table 4, separately for rural and urban sections.

	Rural		Urban	
	Crash sites	**Non-crash sites**	**Crash sites**	**Non-crash sites**
Low macrotexture	211 (30.2)	10340 (20.8)	241 (46.4)	2182 (37.5)
High macrotexture	487 (69.8)	39344 (79.2)	278 (53.6)	3649 (62.5)

Table 4: Crash sites and non-crash sites by macrotexture, rural and urban sections, Great Eastern Highway.

The chi square test was used to test for an association between crashes and macrotexture. In the case of the rural sites, the chi square test indicates a highly significant association (chi square = 36.87, df = 1, p <0.00001). Compared to the non-crash sites, the crash sites are over-represented among the low macrotexture sites (30.2% compared to 20.8%). The association is also highly significant for the urban sections of the route (chi square = 16.19, df = 1, p <0.0001), with crash sites over-represented amongst the low macrotexture sites compared to non-crash sites (46.4% compared to 37.5%).

4.1.5 Further analyses

Relation of crash severity to macrotexture

	Fatal	Hospital admission	Medical treatment	Major property damage	Minor property damage
Rural					
Low macrotexture	7 (33.0)	26 (24.5)	47 (40.5)	104 (32.7)	27 (31.0)
High macrotexture	14 (67.0)	80 (75.5)	69 (59.5)	214 (67.3)	60 (69.0)
Urban					
Low macrotexture	0 (0.0)	10 (24.4)	47 (52.8)	150 (49.5)	34 (40.0)
High macrotexture	2 (100.0)	31 (75.6)	42 (47.2)	153 (50.5)	50 (60.0)

Table 5: Crash severity by macrotexture, rural and urban sections, Great Eastern Highway.

Table 5 shows the number of crashes in each severity category, broken down by macrotexture at the crash site. In view of the small numbers of fatal crashes, and to maximise the statistical power of the comparisons, all casualty categories were combined, and both property damage categories were combined to produce Table 6.

Rural		
	Fatal, hospital and medical	**Major and minor property damage**
Low macrotexture	80 (32.9)	131 (32.4)
High macrotexture	163 (67.1)	274 (67.6)
Urban		
	Fatal, hospital and medical	**Major and minor property damage**
Low macrotexture	57 (43.2)	184 (47.6)
High macrotexture	75 (56.8)	203 (52.4)

Table 6: Combined crash severity by macrotexture, rural and urban sections, Great Eastern Highway.

The chi square test was applied to the combined data, separately for urban and rural sites. In neither case was there any association between crash severity and macrotexture (chi square = 0.04, df= 1, p = 0.8449, chi square = 0.75, df = 1, p = 0.3854 respectively).

Crashes by surface moisture

	Rural		**Urban**	
	Wet	**Dry**	**Wet**	**Dry**
Low macrotexture	33 (37.5)	175 (31.7)	42 (42.9)	198 (47.6)
High macrotexture	55 (62.5)	377 (68.3)	56 (57.1)	218 (52.4)

Table 7: Crashes on wet and dry roads by macrotexture, rural and urban sections, Great Eastern Highway.

Crashes on wet and dry roads, broken down by macrotexture, are shown in Table 7. In neither the case of rural or urban sites was there any association between surface moisture and macrotexture (chi square = 0.1.16, df = 1, p = 0.2804, chi square = 0.72, df = 1, p = 0.3976 respectively).

Crashes by location type

	Rural		Urban	
	Intersection	**Non-intersection**	**Intersection**	**Non-intersection**
Low macrotexture	63 (51.6)	146 (27.8)	128 (59.5)	113 (37.2)
High macrotexture	59 (48.4)	380 (72.2)	87 (40.5)	191 (62.8)

Table 8: Crashes at intersection and non-intersection sites by macrotexture, rural and urban sections, Great Eastern Highway.

The numbers of crashes at intersection sites and at non-intersection sites for different macrotexture categories are shown in Table 8. There was a significant association between location type and macrotexture for both the rural and the urban sites (chi square = 25.85, 25.32 respectively, df = 1, and p <0.00001 in both cases). For both the urban and rural sites, a much higher proportion of intersection crashes occurred at low macrotexture sites. In both cases over 50% of the intersection crashes occurred at low macrotexture sites.

Crashes by alignment

	Rural		Urban	
	Curve	**Straight**	**Curve**	**Straight**
Low macrotexture	55 (29.6)	152 (33.5)	40 (30.3)	245 (64.5)
High macrotexture	131 (70.4)	302 (66.5)	92 (69.7)	135 (35.5)

Table 9: Crashes on curved and straight sections by macrotexture, urban and rural sections, Great Eastern Highway.

Macrotexture at crash sites on curved and straight sections is shown separately for urban and rural sections in Table 9. In the case of rural sites, similar percentages of curved and straight sections were in the low macrotexture category, and there was no association between macrotexture and crashes (chi square = 0.92, df = 1, p = 0.3369). For the urban sections, there was a much higher proportion of low macrotexture sections among the straight sections than among the curves, and the association was highly significant (chi square = 46.35, df = 1, p <0.00001)

Crashes by heavy vehicle involvement

	Rural		Urban	
	Heavy vehicle involved	**No heavy vehicle involved**	**Heavy vehicle involved**	**No heavy vehicle involved**
Low macrotexture	17 (13.7)	172 (40.6)	22 (33.0)	219 (48.4)
High macrotexture	107 (86.3)	252 (59.4)	44 (67.0)	234 (51.6)

Table 10: Crashes involving heavy vehicles by macrotexture, rural and urban sections, Great Eastern Highway.

Crashes were classified according to whether or not a heavy vehicle was involved, and these are shown in Table 10, broken down by macrotexture category, separately for urban and rural crashes. Analysis by the chi square test showed that the association between macrotexture and heavy vehicle involvement was significant for both the rural and urban sites (chi square = 30.63, df = 1, p <0.00001, chi square = 5.22, df = 1, p = 0.0223 respectively). In both cases, the percentage of low macrotexture sites was lower for crashes involving heavy vehicles than for other crashes.

4.2 Victoria

4.2.1 The Route – Princes Highway West

The route selected for study was the Princes Highway West, between Geelong and Portland. The route was 280.94 kilometres in length, of which 244.58 kilometres were rural and 36.36 kilometres were urban, using the same definition of rural and urban as was used for the Great Eastern Highway, ie sections where the speed limit was 80 km/h or less were defined as urban, and other sites were defined as rural. Macrotexture data was available from a survey in one direction only, and was analysed in 20 metre sections.

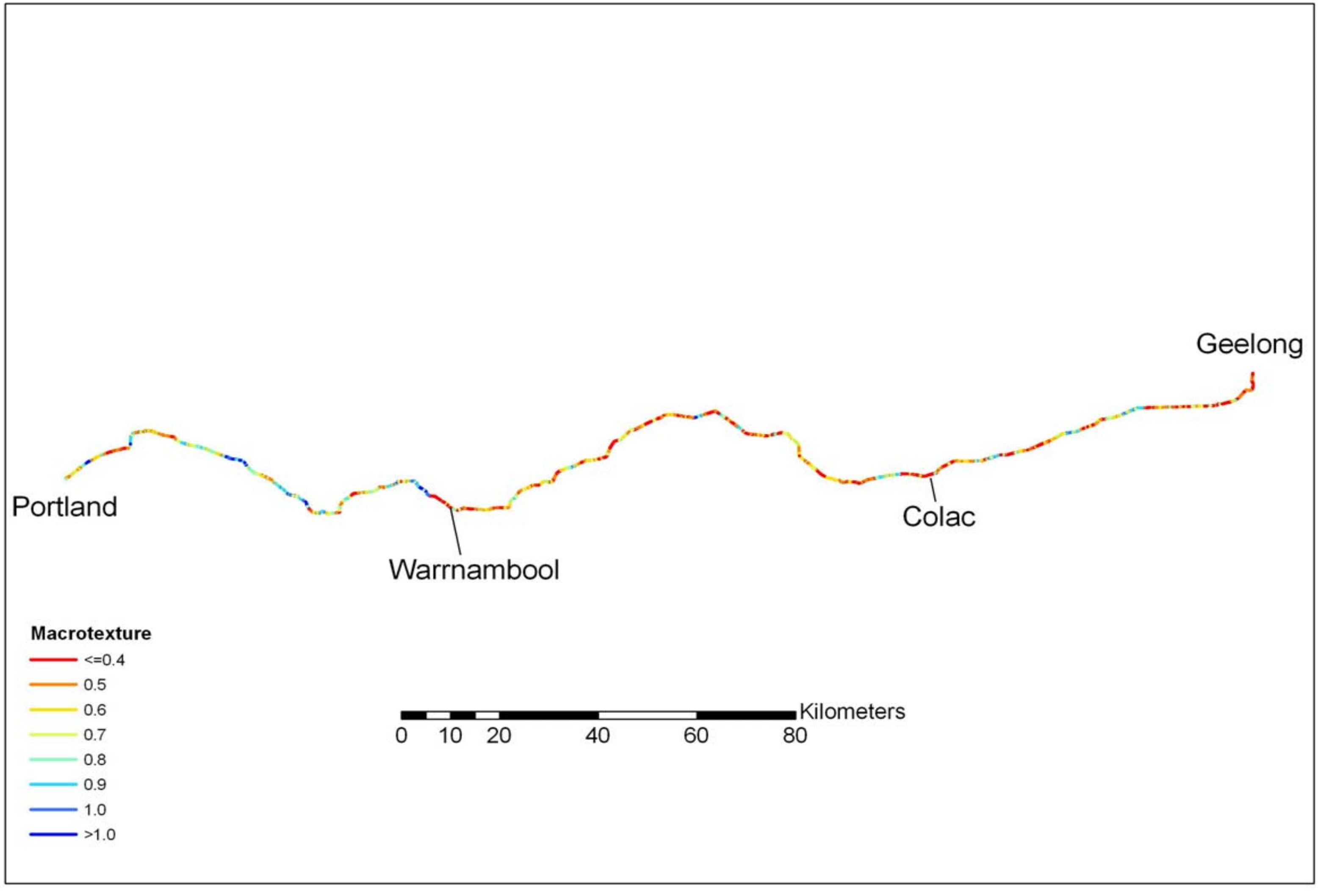

Figure 10: Map of the Princes Highway West.

4.2.2 Macrotexture

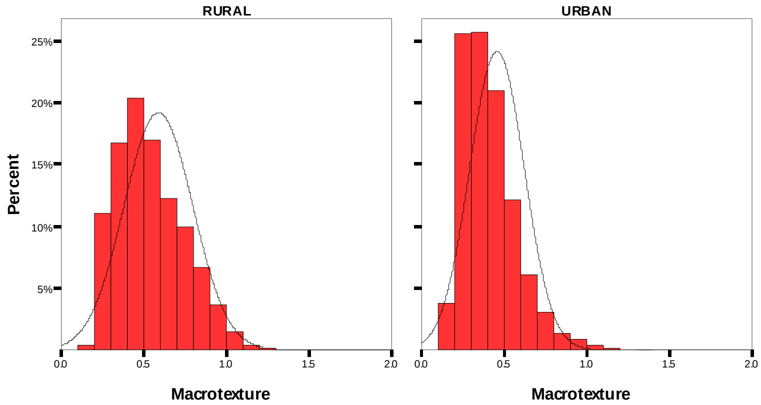

Figure 11: Distribution of macrotexture on rural and urban sections, Princes Highway West.

The distributions of macrotexture on the rural and urban sections of the Princes Highway West are shown separately in Fig 11. The distribution for the urban sections has a much higher proportion of sections with low macrotexture than does the distribution for the rural sections.

4.2.3 Macrotexture on sections where crashes occurred

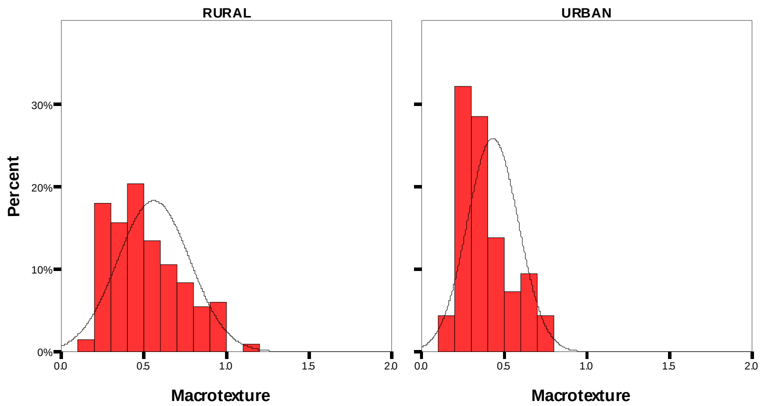

Figure 12: Distribution of macrotexture on rural and urban sections where crashes occurred, Princes Highway West.

The distributions of macrotexture on the sections where crashes occurred are shown in Figure 12, separately for rural and urban parts of the route. Many more of the urban sections had low macrotexture than was the case for the rural sections.

4.2.4 Crash risk in relation to macrotexture

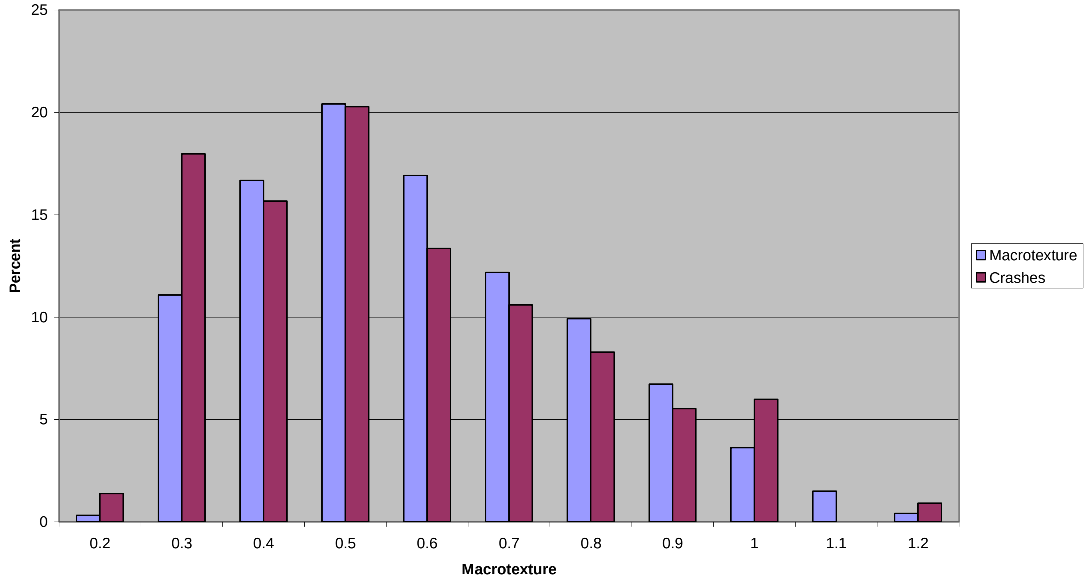

Figure 13: Comparison of distributions of macrotexture on all sites and at crash sites, Princes Highway West, rural.

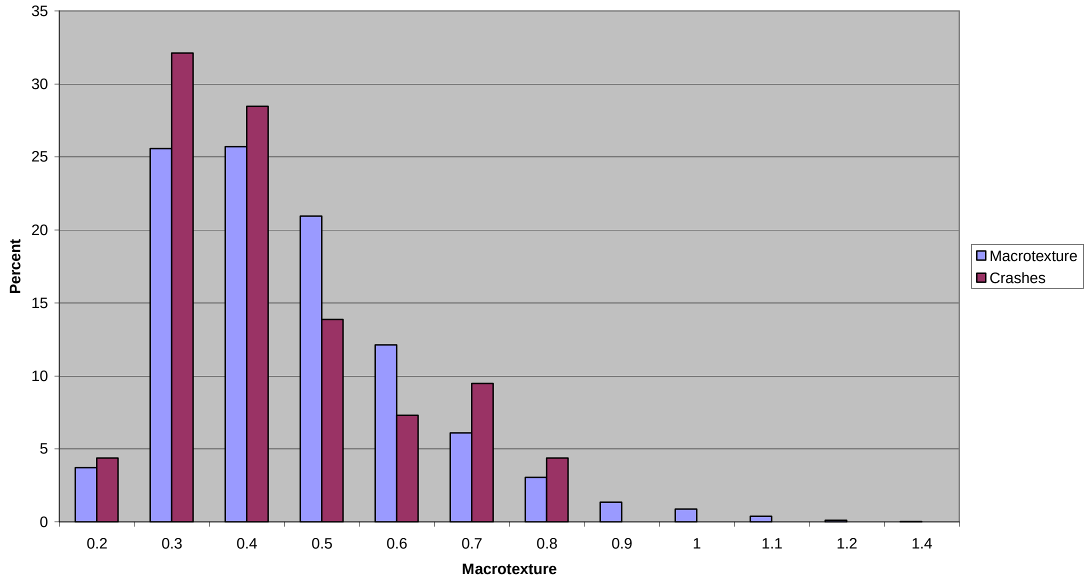

Figure 14: Comparison of distributions of macrotexture on all sites and at crash sites, Princes Highway West, urban.

Figure 13 indicates that for rural sections, there is a considerably higher proportion of crash sites than of all sites in the lower macrotexture categories, especially in the 0.3 category. Figure 14 indicates a similar pattern for urban sites, although the excess of crash sites over all sites is less pronounced for the 0.3 macrotexture category, and extends to the 0.4 category.

To enable statistical testing, a cut off value of 0.3 was adopted, sites with an SMTD of 0.3 and below being categorised as low macrotexture, and those with an SMTD of 0.4 and above being categorised as high macrotexture. The number and percentage of sites in each category is presented in Table 11, separately for rural and urban sections.

	Rural		Urban	
	Crash sites	**Non-crash sites**	**Crash sites**	**Non-crash sites**
Low macrotexture	50 (36.5)	1010 (28.9)	42 (19.4)	2791 (11.5)
High macrotexture	87 (63.5)	2489 (71.1)	175 (80.6)	21492 (88.5)

Table 11: Crash sites and non-crash sites by macrotexture, rural and urban sections, Princes Highway West.

The chi square test was used to test for an association between crashes and macrotexture. In the case of the rural sites, the chi square test just failed to reach the conventional level for significance of 0.05 (chi square = 3.72, df = 1, p = 0.0539), but was significant at the 0.10 level. Compared to the non-crash sites, the crash sites are slightly over-represented among the low macrotexture sites (36.5% compared to 28.9%). The association is significant for the urban sections of the route (chi square = 13.00, df = 1, p = 0.0003), and there is almost twice the percentage of crash sites amongst the low macrotexture category (19.4% compared to 11.5%).

4.2.5 Further analyses

Relation of crash severity to macrotexture

Rural			
	Fatal	**Serious injury**	**Other injury**
Low macrotexture	2 (20.0)	12 (16.0)	28 (21.2)
High macrotexture	8 (80.0)	63 (84.0)	104 (78.8)
Urban			
	Fatal	**Serious injury**	**Other injury**
Low macrotexture	0 (0.0)	12 (30.0)	38 (40.4)
High macrotexture	3 100.0)	28 (70.0)	56 (59.6)

Table 12: Crash severity by macrotexture, rural and urban sections, Princes Highway West.

As property damage only crashes are required to be reported only in a few defined circumstances, the analysis is confined to casualty crashes only. Table 12 shows the number of crashes in each severity category, broken down by macrotexture at the crash site. For the purposes of analysis, the fatal and serious injury categories were combined (see Table 13).

Rural		
	Fatal and serious injury	**Other injury**
Low macrotexture	14 (16.5)	28 (21.2)
High macrotexture	71 (83.5)	104 (78.8)

Urban		
	Fatal and serious injury	**Other injury**
Low macrotexture	12 (27.9)	38 (40.4)
High macrotexture	31 (72.1)	56 (59.6)

Table 13: Combined crash severity by macrotexture, rural and urban sections, Princes Highway West.

The chi square test was applied to the combined data, separately for urban and rural sites. In neither case was there any association between crash severity and macrotexture (chi square = 0.18, df = 1, p = 0.6705, chi square = 1.99, df = 1, p = 0.1578 respectively).

Crashes by Surface Moisture

	Rural		**Urban**	
	Wet	**Dry**	**Wet**	**Dry**
Low macrotexture	6 (14.3)	34 (20.4)	8 (38.1)	42 (36.2)
High macrotexture	36 (85.7)	133 (79.6)	13 (61.9)	74 (63.8)

Table 14: Crashes on wet and dry roads by macrotexture, rural and urban sections, Princes Highway West.

Crashes on wet and dry roads, broken down by macrotexture, are shown in Table 14. In neither the case of rural or urban sites was there any association between surface moisture and macrotexture (chi square = 0.80, df = 1, p = 0.3711, chi square = 0.03, df = 1, p = 0.8686 respectively).

Crashes by Location Type

	Rural		**Urban**	
	Intersection	**Non-intersection**	**Intersection**	**Non-intersection**
Low macrotexture	23 (31.1)	19 (13.3)	35 (38.5)	15 (32.6)
High macrotexture	51 (68.9)	124 (86.7)	56 (61.5)	31 (67.4)

Table 15: Crashes at intersection and non-intersection sites by macrotexture, rural and urban sections, Princes Highway West.

The numbers of crashes at intersection sites and at non-intersection sites for different macrotexture categories are shown in Table 15. There was no association between crash location and macrotexture at urban sites (chi square = 0.45, df = 1, p = 0.5015), but the association at rural sites was significant (chi square = 9.98, df = 1, p = 0.0017). At low macrotexture sites, there was a much higher percentage of intersection crashes (31%) than of non-intersection crashes (13%).

Crashes by Heavy Vehicle Involvement

	Rural		**Urban**	
	Heavy vehicle involved	**No heavy vehicle involved**	**Heavy vehicle involved**	**No heavy vehicle involved**
Low macrotexture	0 (0.0)	42 (23.3)	1 (16.7)	49 (37.4)
High macrotexture	27 (100.0)	138 (76.7)	5 (83.3)	82 (62.6)

Table 16: Crashes involving heavy vehicles by macrotexture, rural and urban sections, Princes Highway West.

Crashes were classified according to whether or not a heavy vehicle was involved, and these are shown in Table 16, broken down by macrotexture category, separately for urban and rural crashes. No crashes involving heavy vehicles occurred on low macrotexture rural sections, and only one such crash occurred on low macrotexture urban sections. Analysis by the chi square test was not appropriate as there must be at least five entries in each cell of the contingency table. However, it is clear from the very low percentages of crashes involving heavy vehicles on low macrotexture sections (0% and 17% respectively for rural and urban sections) compared with the higher percentages of other crashes occurring on low macrotexture sections (24% and 37% respectively) that sites with low macrotexture do not have a disproportionate number of heavy vehicle crashes.

Crashes by young driver involvement

	Rural		Urban	
	No young drivers involved	**Young driver involved**	**No young drivers involved**	**Young driver involved**
Low macrotexture	20 (23.8)	22 (16.5)	19 (29.7)	31 (42.4)
High macrotexture	64 (76.2)	111 (83.5)	45 (70.3)	42 (57.6)

Table 17: Crashes involving young drivers by macrotexture, rural and urban sections, Princes Highway West.

Crashes were classified according to whether or not they involved a young driver (ie a driver aged 25 or younger), and the results are shown in Table 17, broken down by macrotexture category and separately for rural and urban crashes. There was no significant association between young driver involvement and macrotexture (chi square = 1.74, df = 1, p = 0.1868; chi square = 2.40, df = 1, p = 0.1211 respectively for rural and urban sections).

As an aside, one surprising feature of these data is the fact that considerably more of the crashes involved young drivers than did not. Even allowing for the higher crash rate of young drivers, this seems to indicate an extraordinary degree of over-representation.

4.3 South Australia

4.3.1 The Route – Duke's Highway

The proportion of the Duke's Highway covered in the study is shown in Figure 15. The route is 191.5 kilometres long, with 179.8 kilometres of rural road and 11.7 kilometres of urban road.

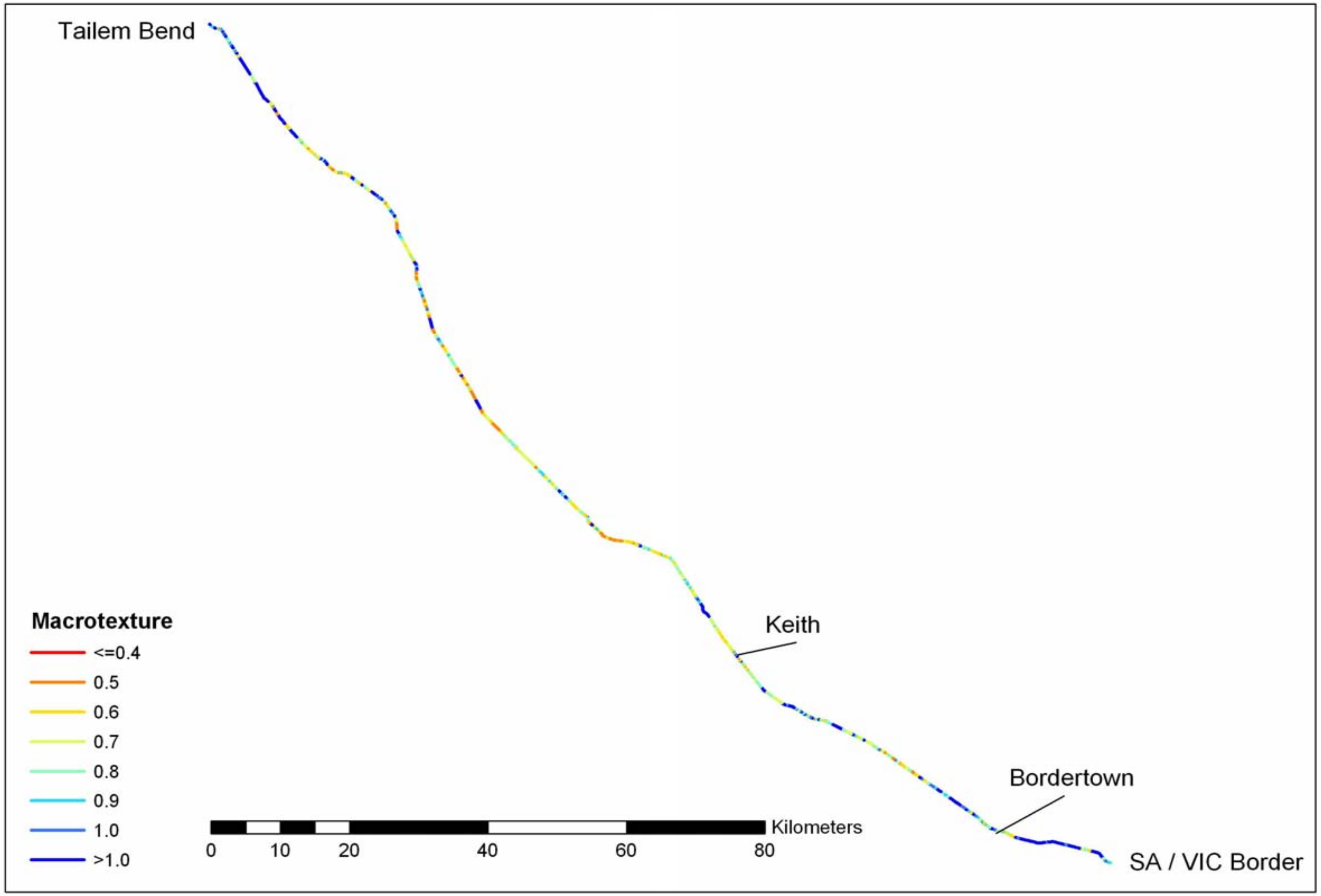

Figure 15: Map of the Duke's Highway.

4.3.2 Macrotexture

The distributions of macrotexture on the rural and urban sections are shown in Figure 16. In contrast to the results from the Great Eastern Highway and the Princes Highway West, only a few sections with a macrotexture of 0.4 were recorded, and none was recorded with a macrotexture value lower than that.

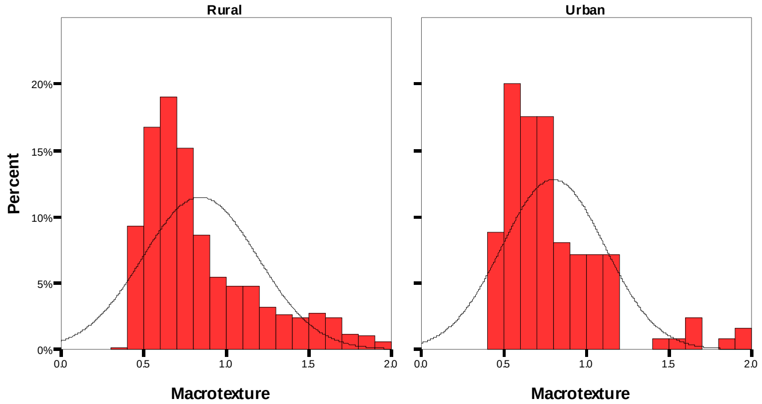

Figure 16: Distribution of macrotexture on rural and urban sections, Duke's Highway.

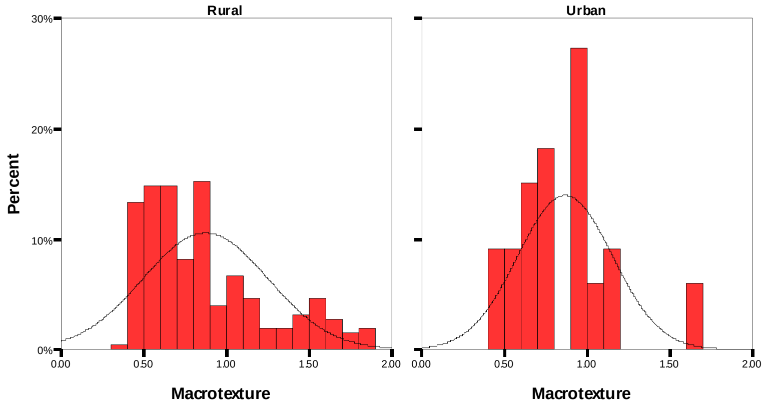

Figure 17: Distribution of macrotexture on rural and urban sections where crashes occurred, Duke's Highway.

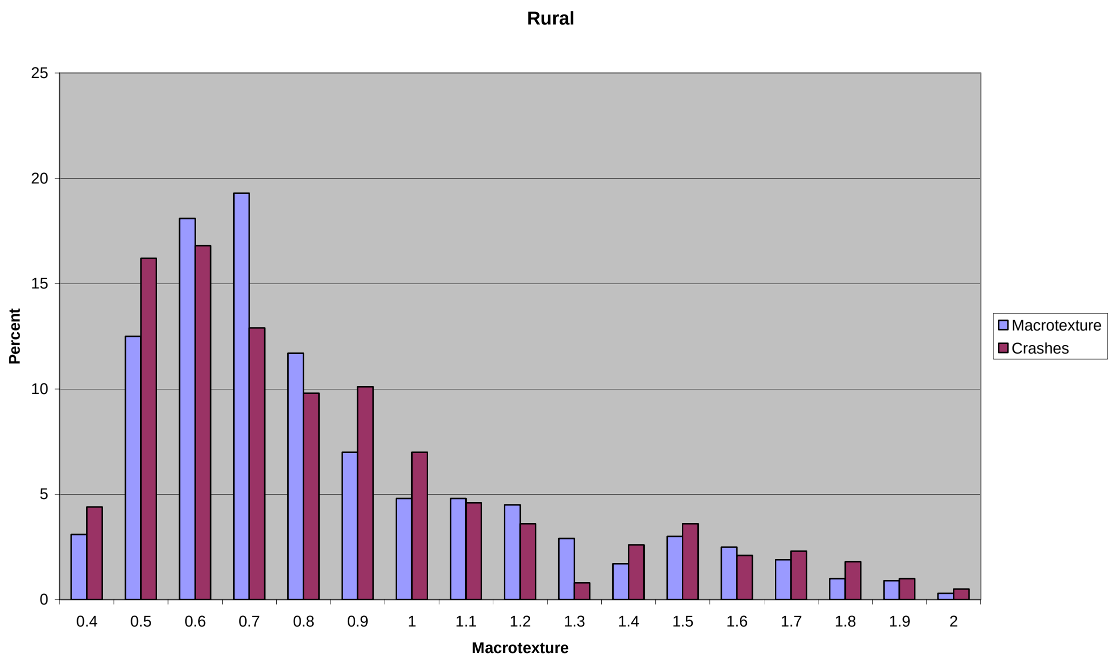

Figure 18: Relative risk on rural sections, Duke's Highway.

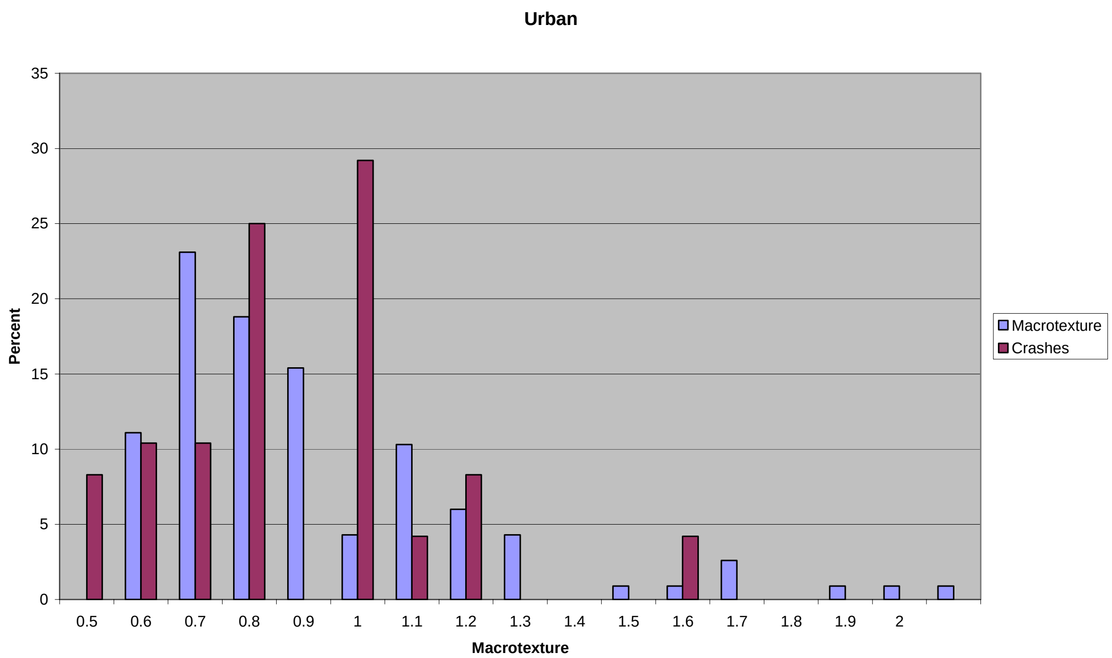

Figure 19: Relative risk on urban sections, Duke's Highway.

	Rural		Urban	
	Crash sites	**Non-crash sites**	**Crash sites**	**Non-crash sites**
Low macrotexture	80 (20.6)	281 (15.6)	4 (8.3)	13 (11.1)
High macrotexture	308 (79.4)	1517 (84.4)	44 (91.7)	104 (88.9)

Table 18: Crash sites and non-crash sites by macrotexture, rural and urban sections, Dukes Highway.

The chi square test was used to test for an association between crashes and macrotexture. In the case of the rural sites, the chi square test was significant (chi square = 5.76, df = 1, p = 0.0164). Compared to the non-crash sites, the crash sites are over-represented among the low macrotexture sites (20.6% compared to 15.6%). However, the association is not significant for the urban sections of the route (chi square = 0.28, df = 1, p = 0.5940), and there is little difference in the percentage of crash sites and non-crash sites in the low macrotexture category (8.3% compared to 11.1%).

4.3.3 Further analyses

Since a significant association was found between crash occurrence and macrotexture only for the rural sections, and there are very few urban sections available for analysis, the remaining analysis is carried out on the rural sections only.

Relation of crash severity to macrotexture

Rural			
	Fatal	**Injury**	**Property damage**
Low macrotexture	3 (18.8)	20 (19.0)	29 (21.8)
High macrotexture	13 (81.2)	85 (81.0)	104 (78.2)

Table 19: Crash severity by macrotexture, rural sections, Duke's Highway.

Rural		
	Fatal and injury	**Property damage**
Low macrotexture	23 (19.0)	29 (21.8)
High macrotexture	98 (81.0)	104 (78.2)

Table 20: Combined crash severity by macrotexture, rural sections, Duke's Highway.

The chi square test was applied to the combined data. There was no association between crash severity and macrotexture (chi square = 0.30, df= 1, p = 0.5812).

Crashes by surface moisture

	Rural	
	Wet	**Dry**
Low macrotexture	12 (25.0)	40 (19.4)
High macrotexture	36 (75.0)	166 (80.6)

Table 21: Crashes on wet and dry roads by macrotexture, rural sections, Duke's Highway.

Crashes on wet and dry roads, broken down by macrotexture, are shown in Table 21. No association between surface moisture and macrotexture was evident (chi square = 0.75, df = 1, p = 0.3880).

Crashes by location type

	Rural	
	Intersection	**Non-intersection**
Low macrotexture	49 (22.2)	3 (9.1)
High macrotexture	172 (77.8)	30 (90.9)

Table 22: Crashes at intersection and non-intersection sites by macrotexture, rural sections, Duke's Highway.

The numbers of crashes at intersection sites and at non-intersection sites for different macrotexture categories are shown in Table 22. At low macrotexture sites, there was a higher percentage of intersection crashes (22.2%) than of non-intersection crashes (9.1%). This difference was significant only at the 0.1 level (chi square = 3.02, df = 1, p = 0.0824). However, note the small number of non-intersection crashes available for analysis.

Crashes by alignment

	Rural	
	Curve	**Straight**
Low macrotexture	12 (24.5)	43 (19.1)
High macrotexture	37 (75.5)	182 (80.9)

Table 23: Crashes on curved and straight sections by macrotexture, rural sections, Duke's Highway.

Macrotexture at crash sites on curves and straights sections are shown in Table 23. There was no association between alignment and macrotexture (chi square = 0.73, df = 1, p = 0.3943).

Crashes by heavy vehicle involvement

	Rural	
	Heavy vehicle involved	**No heavy vehicle involved**
Low macrotexture	7 (15.2)	45 (21.7)
High macrotexture	39 (84.8)	162 (78.3)

Table 24: Crashes involving heavy vehicles by macrotexture, rural and urban sections, Duke's Highway.

Crashes were classified according to whether or not a heavy vehicle was involved, and these are shown in Table 24, broken down by macrotexture category. No significant association between heavy vehicle involvement and macrotexture was found (chi square = 0.98, df = 1, p = 0.3221).

4.4 Comparison of relative risk across routes

Relative risk scores for each macrotexture category on each route were derived by dividing the number of crash sites in that category by the number of all sites in the same category, separately for each route. The results for rural sections of the routes is shown in Figure 20, which is a consolidation of the results for each individual route presented in Figures 8, 13 and 18.

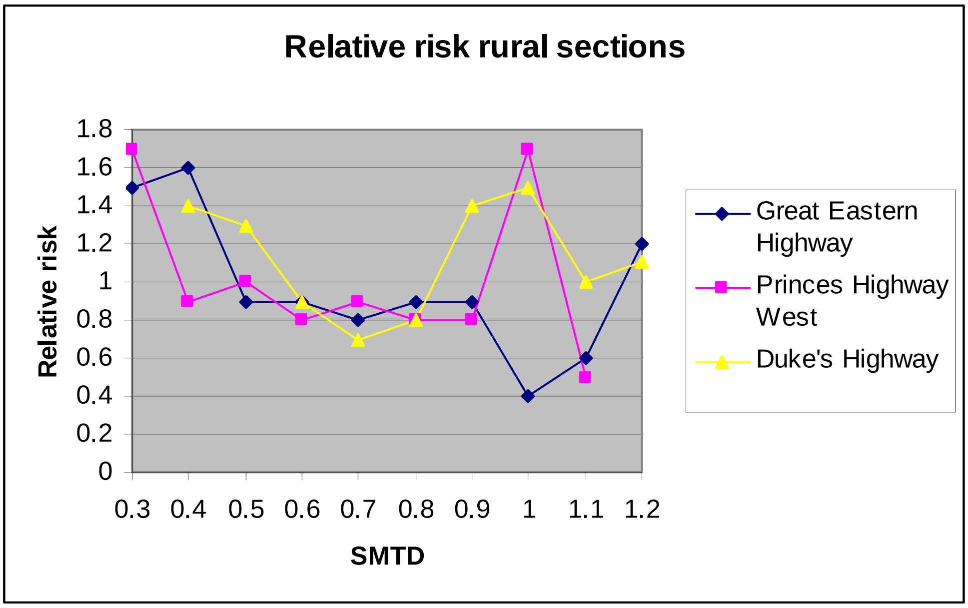

Figure 20: Relative risk on rural sections for all three routes.

Figure 21 shows the relative risk for urban sections on the three routes, and which consolidates the data presented in Figures 9, 14 and 19.

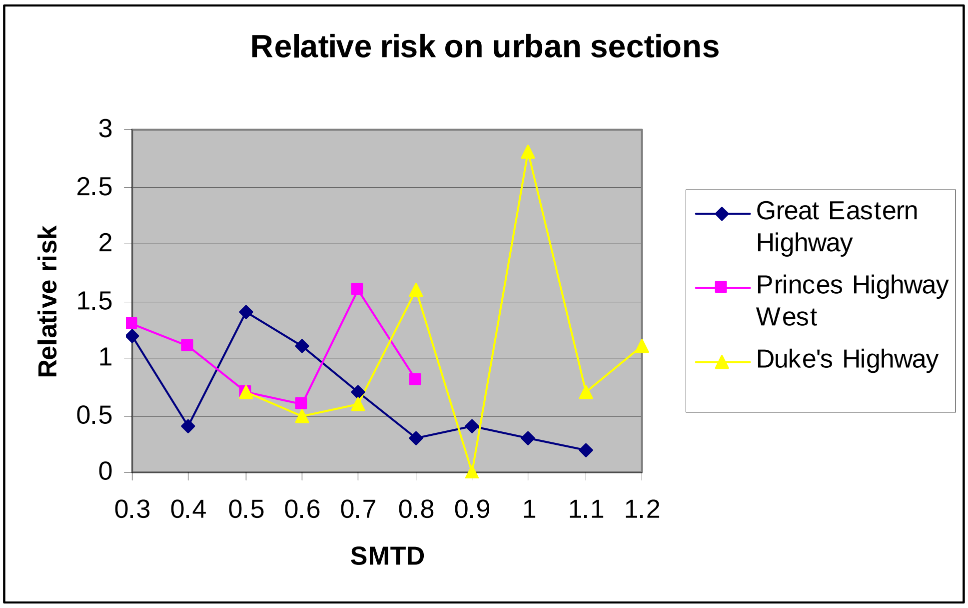

Figure 21: Relative risk on urban sections for all three routes.

The pattern of results for the rural sections in Figure 20 is clear. Relative risk is greater than 1 for the lowest macrotexture values, and is less than 1 for all but one instance for all values up to 0.8, where the patterns diverge widely. However, the relative risk estimates for the higher macrotexture values are based on small numbers and may be expected to fluctuate. For the Princes Highway West, only the 0.3 category at the lower end of the range has a relative risk greater than 1, while for the Great Eastern Highway, both the 0.4 and 0.3 categories exceed 1.

In the case of the Duke's Highway, it is the 0.4 and 0.5 categories for which relative risk exceeds 1.

No systematic relationship between relative risk and macrotexture is evident for the urban sections in Figure 21.

4.5 Effects of section length on macrotexture measurements

Macrotexture measurements from South Australia differed in that there were no sections recorded with a macrotexture lower than 0.4, while Western Australia and Victoria had a small number of sites with macrotexture as low as 0.2, and large numbers of sites with a macrotexture of 0.3. South Australian macrotexture as supplied was only available to the study in 100 metre sections. The Western Australian data was analysed as 20 metre sections, and the Victorian data as 10 metre sections. It is possible that short sections of lower macrotexture are lost when data are averaged over 100 metres, so that no sections have average macrotexture in these lower categories.

To test this possibility, sections from the Great Eastern Highway and the Princes Highway West were aggregated over 100 m sections, and compared with the data used in the analysis in Figures 22 and 23.

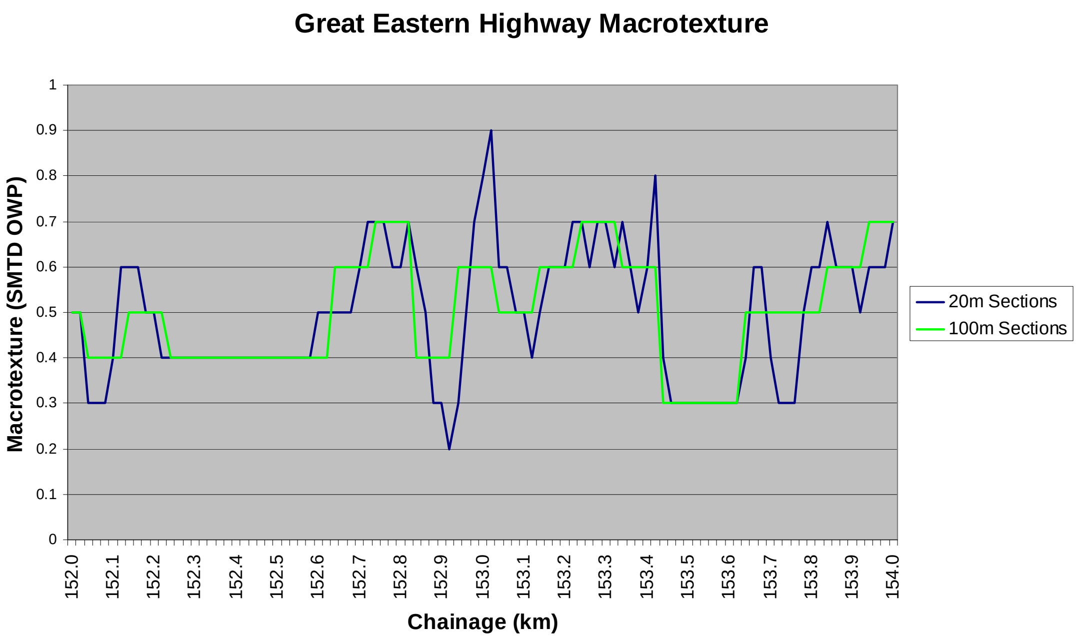

Figure 22: Macrotexture averaged over 20 m and 100 m sections, Great Eastern Highway.

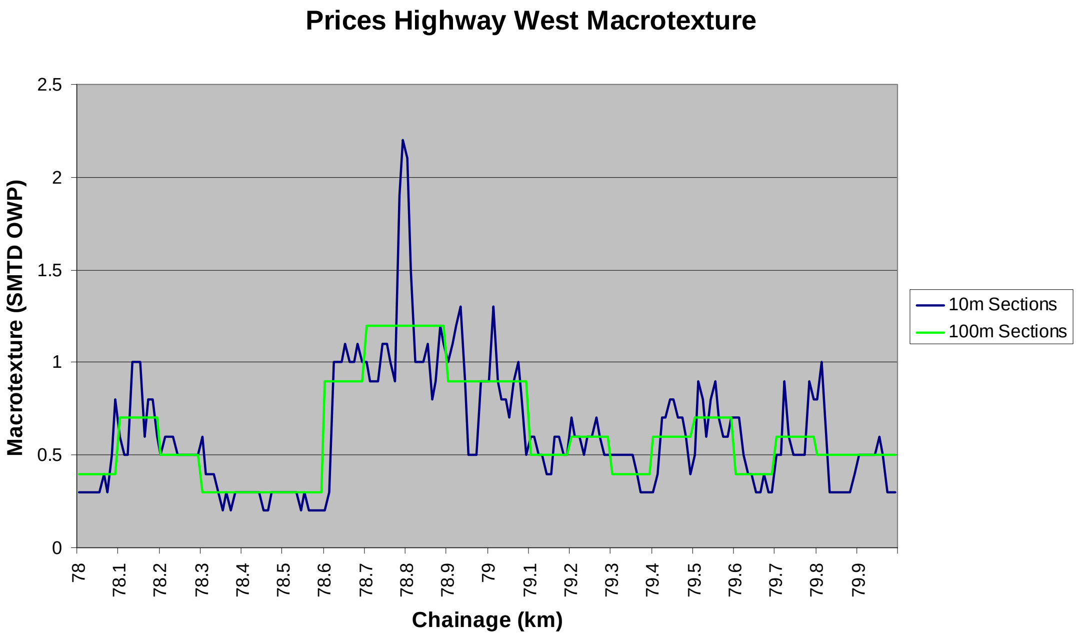

Figure 23: Macrotexture averaged over 10 m and 100 m sections, Princes Highway West.

In both cases, it is evident that lower macrotexture sites are missed in the process of averaging over 100 metres.

5 DISCUSSION

5.1 Macrotexture measurements and relation to crashes

There are clear differences in macrotexture between the rural sections and the urban sections of the routes studied, with the urban sections having lower macrotexture. To what extent this is due to the use of asphalt (which has lower macrotexture) and to what extent it is due to greater traffic wear cannot be determined from this investigation. Data for rural and urban sections were analysed separately.

The overall pattern of results clearly suggests that crash risk increases once macrotexture falls below a critical value. The specific findings for each route are:

- For the Great Eastern Highway, there was a significant association between crashes and macrotexture for both rural and urban sites.
- For the Princes Highway West, there was a significant association between macrotexture and crashes for urban sections, and a marginally significant association for rural sections.
- For the Dukes Highway, there was a significant association between macrotexture and crashes for rural sections, but no association for urban sections. Note that there were very few urban sections on this route.

5.2 Critical values for macrotexture

Rural sections from all three routes show increased risk for sections with low macrotexture (see Figure 20). There are differences in the macrotexture categories over which there is increased risk, for 0.3 on the Princes Highway West, 0.3 and 0.4 on the Great Eastern Highway, and 0.4 and 0.5 on the Dukes Highway.

The different laser equipment used in the surveys relates differently to the original sand patch measure of texture (SPTD). To ensure equivalence amongst the measures, the different laser measures have been converted to SPTD equivalents.

According to Wix and Gow (2002), the conversion equation for the equipment used to collect texture data on the Great Eastern Highway and Princes' Highway West is:

$$SPTD = 2.768\ SMTD - 0.13.$$

For the equipment used to collect data from the Duke's Highway (Amando Reyes, personal communication, 27th October 2004), the conversion equation is:

$$SPTD = 0.2 + 0.8\ SMTD$$

Applying the appropriate conversion equation results in critical values of 1.0 mm for the Great Eastern Highway, 0.7 mm for the Princes Highway West and 0.5 mm for the Duke's Highway.

The relative risk of crashing at low macrotexture sites is quite high. For the lowest category, the risk on the Princes Highway West is 1.7 times the average risk (and 1.9 times the risk associated with the next macrotexture category). For the lowest category on the Great Eastern Highway it is 1.6 times the average risk (and 1.8 times the risk associated with highest category with a risk lower than 1), while for the Duke's Highway the risk associated with a macrotexture of 0.4 is 1.4 times the average (and 1.6 times the risk associated with a macrotexture of 0.6).

There is a large spread of critical macrotexture values, expressed as SPTD, across the three different routes. However, the different form of the conversion equation to arrive at SPTD for the South Australian data suggests that this may be more an issue of calibration between the different devices than a real difference.

5.3 Other variables

From the cross-tabulations of the macrotexture data from crash sites by pavement moisture, it is apparent that there is no relationship between wet weather crashes and low macrotexture. Tredrea (2002) was similarly unable to demonstrate any increase in risk at low macrotexture sites associated with wet pavements. This reinforces the point that both macrotexture and microtexture need to be considered when interpreting the safety performance of pavements.

Low macrotexture sites were under-represented at the sites of crashes involving heavy vehicles, significantly so for both rural and urban sites on the Great Eastern Highway. On the other routes, there were insufficient crash sites to conduct statistical tests, but the trend of the results was the same as for the Great Eastern Highway. This suggests that low macrotexture is not a factor in most crashes involving heavy vehicles. This may be due to a variety of reasons. For example, better visibility and better defensive driving by professional drivers may reduce the frequency with which heavy vehicles make emergency stops compared to other vehicles. On the other hand, it is possible that differences in tyre materials and pressures mean that large vehicles are less able to benefit from macrotexture than smaller vehicles.

No association was found between low macrotexture and crashes involving young drivers.

There was an association between low macrotexture and crashes which occurred at intersections. However, this result needs to be interpreted cautiously. Intersections are likely to have lower macrotexture than midblock sites for reasons similar to those explaining why urban sections have lower macrotexture. Asphalt may be used at intersections in preference to the chip seal construction usual for rural roads in order to better withstand traffic wear imposed by turning vehicles and by braking and accelerating. These same traffic movements may impose dynamic forces which result in lower macrotexture at intersections.

This reflects one of the limitations of the study, in that it was beyond the scope of this pilot study to identify the sites as intersection or mid-block, or curve or straight. It would be possible to identify intersection sites from macrotexture records, as intersections are generally recorded on survey data, or can readily be located on the survey record from road reference or GIS sources. Curvature is likely to be more difficult to relate to road-reference-based records and would probably best be done using GIS-based road survey data. Although this poses some challenges, exploratory studies in the past have shown that this is possible (eg Cenek et al 1997, Cairney 1998).

5.4 Relation to other studies

There are number of points of agreement with other studies. In terms of the critical value for macrotexture, the results for the Great Eastern Highway coincide exactly with the critical value found by Tredrea (2001), and the results for the Princes Highway West are reasonably close. These results appear to be lower than the critical values cited by Gothie (1993), and considerably lower than those found by Roe et al (1991). However, we cannot be certain about the calibration of the laser measuring devices used in these surveys compared to the devices used on the Great Eastern Highway and Princes Highway West.

In the present study, no association was found between wet pavement crashes and low macrotexture. Tredrea and Roe et al similarly found no relationship.

The present study found that low macrotexture sites were over-represented amongst intersection crash sites compared to other crash sites. This does seem to be different from Roe at al’s results, as they found almost identical macrotexture distributions for intersection crash sites and non-intersection crash sites.

5.5 Limitations of the present study

The main limitation of the present study is that it is only able to demonstrate an association between crash risk and macrotexture. While this is a useful finding, it does not preclude the possibility that a higher crash rate and low macrotexture are themselves a reflection of other conditions, eg a greater number of traffic movements over certain parts of the route, resulting in more crashes and greater pavement wear, the latter factor resulting in lower macrotexture.

Similar limitations apply to the analysis of the intersection/mid-block and straight/curve variables. In the case of intersections, it was not possible to specify the relative risk associated with intersections with low macrotexture compared to intersections as a whole. It was possible only to compare crash sites at intersections with crash sites not at intersections, whereas calculation of the relative risk would require comparison of the crash sites at intersections with intersection sites with no crashes. This would have required a breakdown of the complete route into intersection and midblock sites.

In the case of curves, an estimate of the relative risk at curves with low macrotexture requires a comparison of macrotexture at crash sites on curves with macrotexture at curve sites with no crashes. This requires a breakdown of the complete route into curve and straight sections.

There are two possible ways in which these limitations could be overcome. The simplest would be to incorporate other data sources to identify intersection and mid-block sites, and curve and straight sites, and carry the analysis used in the present study one step further. Another possible way would be to carry out an analysis based on crash rates (eg crashes per million vehicle kilometres). However, it is unlikely that traffic data on Australian rural roads would be suitable for such a study as the distance between counting stations is likely to lead to significant inaccuracies when estimating crash rates for particular sites.

A further limitation is of course the accuracy with which the crash locations are recorded on the crash data base. It is generally accepted that there are errors in location, especially with crashes which are not attended by police. However, there is no data on how many crashes are wrongly located, or on the distance by which crashes are mislocated.

5.6 Surface management based on macrotexture

For the purposes of this analysis, the macrotexture value at which percentage of all sites exceeds the percentage of crash sites will be taken as representing the lower limit for satisfactory macrotexture. This equates to a SMTD of 0.5 mm for the Great Eastern Highway and 0.4 for the Princes Highway West (refer to Figures 8 and 13 respectively). The present study indicates that the crash risk associated with low macrotexture is 1.8 times greater than that associated with satisfactory macrotexture for the Great Eastern Highway, and 1.9 times greater for the Princes Highway West. Reference to Tables 4 and 11 indicates that the proportion of crashes occurring on low macrotexture sections, as defined in each case, is 30% and 36.5% respectively. For the purposes of this analysis, it is assumed that by increasing macrotexture from low levels to satisfactory levels, crash risk will be returned to the average for satisfactory macrotexture.

In the case of the Great Eastern Highway, restoring macrotexture where required would be expected to reduce crashes to 1/1.8 of their former level. The expected reduction for total crashes would therefore be 30 x (1-1/1.8)%, ie 13%.

For the Princes Highway West, increasing macrotexture where required would reduce crashes to 1/1.9 of their formal level, and the expected reduction in total crashes would therefore be 36.5 x (1-1/1.9)%, i.e. 17%.

Tables 4 and 11 indicate that 21% and 29% of the route respectively would have to be resurfaced to achieve this. This represents a considerable investment in resurfacing.

However, it may be possible to target improvements more narrowly at high risk sites. Two possible examples are intersections and curves. The analyses showed that low macrotexture sites were over-represented in crashes at intersections and curves, so that focussing on ensuring satisfactory macrotexture at intersections and curves may result in greater crash reductions at these sites than the 17-19% implied by the overall results. This process can be further refined by considering factors such as the sharpness of curves, gradient and superelevation, not available in the present study.

The credibility of a surfacing management strategy based on macrotexture would be greatly enhanced if data were available on the effects of macrotexture on braking distance. Not only would this give credibility to macrotexture as a valid index, but it may also be of analytical value in identifying situations where improved macrotexture is likely to be of benefit.

5.7 Next steps

Two further studies are proposed. The first study would explore the relationship between macrotexture and crashes in more detail than possible in the present exploratory study, taking into account relative risk associated with low macrotexture at curves, gradients and intersections. It would also investigate the possible roles of different road stones and construction techniques. The second study would identify the relationship between braking distance and macrotexture over a range of operating speeds.

The method adopted in the first study would follow the general method developed in the present study, i.e. using GIS to superimpose crash location on macrotexture survey records. The method will be expanded by:

1. Relating macrotexture and crash data to road geometry survey data, which allows identification of straight and curved sections, and classification of the curve sections by curve radius. It will also allow gradient and superelevation information to be related to macrotexture and crash data. Although not all crashes are accurately located, experience with the present study and with previous studies relating crashes to road

geometry (e.g. Cenek et al 1997, Cairney 1998) suggests that enough crashes are located with sufficient accuracy to identify relationships among the variables.

2. Identifying intersections from GIS maps or road referencing systems, whichever is more convenient.

3. Identifying surfacing type at intersections. Some rural intersections are surfaced with asphaltic concrete, which has greater resistance to the forces generated by braking or turning vehicles. Compared to the chip seal construction which is the normal form of surfacing on rural roads in Australia, asphaltic concrete has low macrotexture. It is not presently known whether this has safety implications. The type of stone used and its wearing qualities will also be investigated.

4. Cross-tabulating crashes by crash type (eg RUM or DCA codes or their equivalents). Although good macrotexture should in theory have a role in preventing or reducing the severity of all crashes where one of the road users attempts to brake, cross-tabulation by crash type may indicate whether there are any types of crash that are particularly affected by low macrotexture.

The outputs from such a study would include:

1. Estimates of the relative risk associated with low macrotexture, based on a larger data set.

2. Estimates of the relative risk of low macrotexture at intersections, and in relation to curvature and gradient.

3. An indication whether the use of asphalt surfacing at rural intersections results in adverse safety outcomes.

These outputs would be a significant step in creating the knowledge base necessary for a surface management process based on macrotexture.

The second study would involve using an instrumented vehicle to measure stopping distance on surfaces with different macrotextures. The car would be taken to a steady specified speed as it approaches the start of a section where the macrotexture is known, and the brakes applied in a manner approximating an emergency stop. Braking distance and a deceleration profile will be generated using output from an on-board GPS system and from an accelerometer. Tests would be carried out at several sites with different macrotexture on the road system. At each test site, the test would be carried out at speeds ranging between 50 km and 100 km/h (or 110 if the speed limit permits), repeated five times at each speed. Traffic control arrangements would have to be budgeted for. The results would be particularly useful if braking performance on wet and dry roads could be compared.

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A Pilot Study of the Relationship between Macrotexture and Crash Occurrence CR223

ISBN 0 642 2533 4

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