TRL Limited

PUBLISHED PROJECT REPORT PPR148

Surface texture measurement on local roads

by H Viner, P Abbott, A Dunford, N Dhillon, L Parsley and C Read (TRL Limited)

Prepared for:	**Project Record:**	**Surface Texture Measurement on Local Roads**
	Client:	**Edward Bunting, Traffic Management Division, Department for Transport.**

This report has been prepared for Edward Bunting, Department for Transport, Traffic Management Division. The views expressed are those of the authors and not necessarily those of the Department for Transport .

Published Project Reports are written primarily for the Customer rather than for a general audience and are published with the Customer's approval.

	Approvals
Project Manager	
Quality Reviewed	

This report has been produced by TRL Limited, under/as part of a Contract placed by the Department for Transport. Any views expressed are not necessarily those of the Department for Transport.

CONTENTS

Executive Summary

Project Title: Surface Texture Measurement on Local Roads

Project Officer: Mr E Bunting, Traffic Management Division, DfT

Project Manager: Dr H Viner, Transport Research Laboratory

Objectives of Project

This project was commissioned by the Department for Transport (DfT) as part of a programme of research to support the specification for SCANNER (Surface Condition Assessment of the National NEtwork of Roads) surveys of the local road network from 2007. This project is concerned with the use of surface texture measurements on local roads, with the specific requirements to:

- Identify how texture depth varies along and across typical local road carriageways in England and how texture depth measurements correlate with visible surface defects and overall maintenance condition, including tyre noise generation.
- Identify how texture depth measurements could be combined with other measurements to characterise the maintenance condition of local roads.
- Establish whether there is a sufficiently reliable link between measured surface texture depth and skid resistance, to enable texture depth measurements to be used as an indication of inadequate skid resistance on typical local road surfaces.
- Develop techniques or methods for using texture depth measurements, on their own or in combination with other measurements, to identify and characterise road surface maintenance condition, including the presence of defects and tyre noise generation.
- Develop a method or system to measure and record texture depth or depths automatically, suitable for incorporation in an overall assessment of road condition and maintenance need and to provide workable specifications for the method or system.

Project Outputs

The conclusions and implications for SCANNER surveys from 2007 are as follows:

Texture characteristics of local roads

- On A roads it will generally be appropriate to use the texture depth thresholds established for use on trunk roads to maintain good skid resistance at high speeds.
- On B and C roads this approach is less satisfactory: even with a very low threshold of 0.4mm SMTD an unrealistically high proportion of the road length is identified as being in need of investigation and, even so, not all the lengths that should be investigated are identified.
- Local roads are sufficiently variable across their width and along their length that relying on a single measurement of 100m average nearside texture depth overlooks relevant information in many cases, therefore it is recommended that texture data is averaged at 100m but that 10m lengths with an individual value more than 0.3mm below the mean should be flagged separately.
- On A roads, where the objective is to maintain high-speed skid resistance, consideration should be given to making measurements in the offside wheelpath in addition to the nearside.
- Improved methods for detecting localised variability in texture are needed for B and C roads. An approach to this is described below.

Detection of localised surface texture defects

Conventional systems for the measurement of longitudinal and transverse road profile can provide, at traffic speed, information about localised changes to the surface texture. A method has been

demonstrated that uses texture data collected across the lane width and combines information about the average level of texture depth, the overall variability and the difference between the centre of the lane and the wheel paths to assess the condition of the surface texture that can be used at a network level. This method was shown to be as good as a single measurement of texture depth in the nearside wheel path for identifying sections with deteriorating surface texture on a test dataset that included mainly roads with relatively high levels of surface texture. On roads with low surface texture the new method would be expected to outperform the current nearside measurement, but this needs further testing to confirm this and establish appropriate threshold levels.

For scheme level analysis, the information from all the transverse lasers can be displayed to give a visually detailed map, which may help engineers to assess the type and extent of the local areas of deterioration. However, this would require a substantial increase in the amount of data delivered by the survey contractor and stored by Pavement Management Systems.

It should be noted that the measurement of texture depth from the profiling system is not accurate in all circumstances and the specification is not adequate for MPD requirements; consequently, if adopted, this approach should enhance rather than replace existing additional texture systems.

Skid resistance

Texture depth is related to high speed skid resistance in wet conditions, but not to low speed measurements, such as those made by a SCRIM or Griptester. Current technology is not capable of measuring the fine scale surface microtexture, such as that on the surface of aggregate chips, as part of SCANNER surveys. Consequently, there is no evidence to justify texture depth measurements being used as a surrogate for skid resistance measurement. Accident studies strongly support the need for skid resistance data in addition to texture depth data.

Noise

This report provides background information on assessing noise from road traffic and describes the various noise sources on a vehicle and how they contribute to overall traffic noise levels. Three sources of noise generation need to be considered:

- Propulsion noise can be a major component of the overall noise level where traffic speeds are low and/or heavy vehicles are a high proportion of the traffic. Quieter surfacing materials are unlikely to be effective in reducing noise emissions where the dominant source of noise is propulsion noise.
- Tyre road noise is the dominant form of noise for light vehicles travelling at moderate and high speeds. Vehicle speed and the nature of the surface both have significant effects on the generation of tyre road noise.
- Body rattle noise is low on roads where a high standard of evenness is achieved. On uneven roads, the vertical movements of the body produced when driving over poor profile cause significant levels of body noise. It has been demonstrated that locations with high levels of body rattle noise can be identified using the first derivative component of the CDM (central difference method) parameter that can be calculated from the longitudinal profile. This will require an additional data parameter to be delivered by the survey contractors.

SCANNER specification for the measurement of surface texture depth

As a result of this work it is recommended that the specification for SCANNER surveys includes accurate measurement of texture depth in the nearside wheel path, measurement of transverse texture variability and measurement of the potential for body rattle noise generation.

1 Introduction

This project was let by the Department for Transport (DfT) as part of a programme of research to support the specification for SCANNER (Surface Condition Assessment of the National NEtwork of Roads) surveys of the local road network from 2007. The SCANNER survey methodology and equipment has been derived from the Traffic Speed Condition Surveys (TRACS), originally developed for the Highways Agency. These surveys were designed for implementation on major roads such as Motorways and All-Purpose Trunk Roads, and were subsequently adapted for use on Principal Roads as TRACS-Type Surveys (TTS). Since the TTS operated on the Principal Road network, the survey environment was similar to that for which the original TRACS systems and machines had been designed, in as much as the roads surveyed tended to be reasonably straight, wide and level.

The move to other local roads will involve performing surveys in environments far removed from those for which the survey systems were originally developed. As well as the practical issues associated with ensuring that the survey vehicles can operate in all the conditions they will encounter, there are a range of technical issues related to the change of environment. These include the fact that some of the parameters measured and reported by TTS systems may not be appropriate or relevant on local roads. Additionally, the ways in which local roads deteriorate may differ from the deterioration observed on the principal and trunk roads due to different levels of trafficking and construction techniques. Consequently the data requirements of Local Authority engineers may be different from the data requirements on trunk and principal routes.

This project is concerned with the use of surface texture measurements on local roads, with the specific requirements to:

- Identify how texture depth varies along and across typical local road carriageways in England and how texture depth measurements correlate with visible surface defects and overall maintenance condition, including tyre noise generation.
- Identify how texture depth measurements could be combined with other measurements to characterise the maintenance condition of local roads.
- Establish whether there is a sufficiently reliable link between measured surface texture depth and skid resistance, to enable texture depth measurements to be used as an indication of inadequate skid resistance on typical local road surfaces.
- Develop techniques or methods for using texture depth measurements, on their own or in combination with other measurements, to identify and characterise road surface maintenance condition, including the presence of defects and tyre noise generation.
- Develop a method or system to measure and record texture depth or depths automatically, suitable for incorporation in an overall assessment of road condition and maintenance need and to provide a workable specification for the method and system.

2 Consultation and Review

At the initiation of this project a consultation and review phase was undertaken. Within the consultation, discussions were held with a number of Local Authorities and consultants to assess their views on a range of issues relating to the collection of SCANNER data. The results were presented in an interim report (Parsley et al, 2005) and the key findings in relation to the measurement of surface texture and how this information was used to refine the research are summarised below.

The consultation attempted to determine how maintenance current practices are driven and prioritised. In discussions, it was apparent that maintenance is often carried out primarily for reasons of reducing the BVPI. However, the consultation tried to look beyond the focus on BVPI to establish the physical characteristics of lengths of pavement that would identify them as having a potential maintenance need, and has considered the levels of detail and information that would be required by the engineer to make maintenance decisions.

Prior to the consultation, TRL proposed a list of defect types that it considered may be relevant to the safety, functional level of service and engineering maintenance requirements of local roads. An extract of the list with the defects relevant to this project is given below in Table 2-1. In general it was found that engineers agreed that the defects identified in the list discussed with them were representative of the types of defects found on local roads. There was also general agreement with the allocation of defects to the categories shown.

Table 2-1: Allocation of criteria for treatment for different defects (extract from original Table)

	DEFECT TYPE	DEFECT	Safety	Functional level of service	Engineering maintenance
16	Surface texture	Fretting	X	X	X
17		Fatting up	X	X	
18		Poor surface texture / skid resistance	X		
19	Other	Noisy surface		X	

The participants were asked to help in establishing the importance of the individual defects, in terms of the priority that engineers would give to their treatment. This was not straightforward due to the many different types of roads common to the different authorities, and with different rankings possible for urban and rural roads, A, B, C and unclassified roads, and types of road user (e.g. cars and motorcycles). However, when the areas of greatest agreement between authorities were identified it was found that poor surface texture and skid resistance were among the three defects considered to be the highest priority in the safety category.

Knowledge of the skid resistance of pavements was seen as very important in the consultation and engineers considered the use of surface texture information as a proxy measurement for skid resistance desirable, as it could supplement or reduce the need for SCRIM or Griptester surveys. Although past experience suggested that the current measure of texture depth is unlikely to be satisfactory in this respect, it was thought that improvements to the technology for measuring surface texture or alternative measures that could be derived from currently available technology might be more successful. This was investigated as described in Section 4. The development of measures to detect localised deteriorations of the road surface texture, primarily fatting up, is described in Section 5.

Surface texture is known to influence the level of noise generated at the tyre road interface. However, tyre noise was generally not highlighted as a major issue in the consultation. Concerns expressed by engineers in relation to noise were more typically associated with urban areas, and in particular noise generated by heavy goods vehicles travelling on uneven pavements, poor ironwork, and traffic calming. As for the ride quality, concerns about noise were driven by complaints, in this case from residents. Again this may reflect the bias to engineering assessment and not functional/user assessment. However, although noise was not reported to be a high priority, authorities were increasingly using thin surfacings or other low-noise surfacings.

As a result of this consultation, the original approach proposed to address noise issues was modified. A review of the available information about tyre road noise generation was carried out, from which a summary of the influence of factors such as vehicle type, speed and surface type was created to assist engineers in understanding the extent to which quieter surfacings could be effective in reducing noise nuisance. In addition, a short study was carried out to provide additional information about the influence of poor surface profile on noise generation. This work is described in Section 6.

3 Texture characteristics of local roads

3.1 Background

Texture depth measurements made by laser systems (as opposed to volumetric methods) in the UK are currently reported as Sensor Measured Texture Depth (SMTD). SMTD measurements are generally made at 10m intervals in the nearside wheeltrack, although many systems have the capability of also measuring in the centre of the lane and/or in the offside wheeltrack and some highway authorities require this data. Furthermore, alternative means of reporting the texture measurements made by current laser systems are available, including the Mean Profile Depth (MPD) measure, which is widely used in Europe.

This stage of the project aims to determine the texture characteristics of local roads, as measured by these currently available techniques, and to establish the extent to which they can be used to detect and quantify deterioration in the road surface for the purposes of determining maintenance need. Section 5 considers new ways in which more detailed texture depth measurements may be able to give more information about the surface condition and need for maintenance.

3.2 Ways of characterising texture depth - SMTD and MPD

Current laser texture measurement devices work by measuring the distance between the sensor and the road surface. As the sensor moves along the road, changes in this distance, due to the surface texture, are recorded at short intervals (the sampling interval is typically 1mm). A detailed texture profile of the surface is built up but this data requires further processing to give a value useful to highway engineers. Typically, this involves the following steps:

- The data is split into short lengths over which the texture depth will be calculated (the evaluation length, typically 100mm or 300mm).
- The data is filtered to remove features such as the offset (i.e. the height of the sensor above the road surface) and to remove the effect of vehicle bounce (which changes the height of the sensor above the road over longer distances) or to otherwise restrict the content of the signal to the wavelengths associated with features of the surface texture.
- A calculation is performed on the filtered data to give a result that characterises the height of the texture within each evaluation length.
- The results for each evaluation length are aggregated to longer lengths for reporting (the reporting length, typically 10m).

Both SMTD and MPD algorithms can be described in these terms, as shown in Table 3-1. The main difference between these two methods is in the way that the height of the texture is estimated: the SMTD measurement is essentially a root mean square (rms) measure of the texture both above and below the mean level, whereas MPD measures the height of the highest peaks above the mean level.

The measures are correlated, but the relationship between the two measures will depend on the shape of the surface texture and, therefore, on the type of surface. This is illustrated in Figure 3-1, which compares two hypothetical surface shapes with the same SMTD value. For one surface, the MPD value is higher than the SMTD value and for the other surface the MPD value is lower than the SMTD value.

3.3 SMTD vs. MPD on local roads

The relationship between SMTD and MPD measures on local roads was investigated using HARRIS1[1] data collected from a sample of local roads on this project. The SMTD and MPD values at each position for a 6km sample (2km each on A, B and C roads) are plotted in Figure 3-2. It is evident that the two measures are related but that there is a substantial amount of variability,

[1] Highways Agency Road Research Information System 1 – described in Section 5.

particularly at higher texture depths. More detailed investigation showed that there were only minor differences in this relationship for the A, B and C roads when considered separately.

Table 3-1: SMTD and MPD algorithms for reporting texture depth from laser measurements

Calculation step	Sensor Measured Texture Depth (SMTD)	Mean Profile Depth (MPD)
Evaluation length	300mm	100mm
Filtering	The data for each evaluation length are filtered by subtracting a quadratic (parabolic) best fit trend.	The data are filtered using either: i) a digital high-pass filter applied to the continuous texture profile to remove wavelengths above 100mm or ii) removal of the slope and offset for each evaluation length by subtracting a linear least squares fit.
Characterise height of the texture	Calculate standard deviation of the filtered data.	Calculate the height above the mean level of the highest single profile point in each half of the evaluation length; take the average of these two values.
Aggregate to longer lengths	Calculate the average texture height for all evaluation lengths within each 10m length.	Calculate the average texture height for all evaluation lengths within each 10m length.

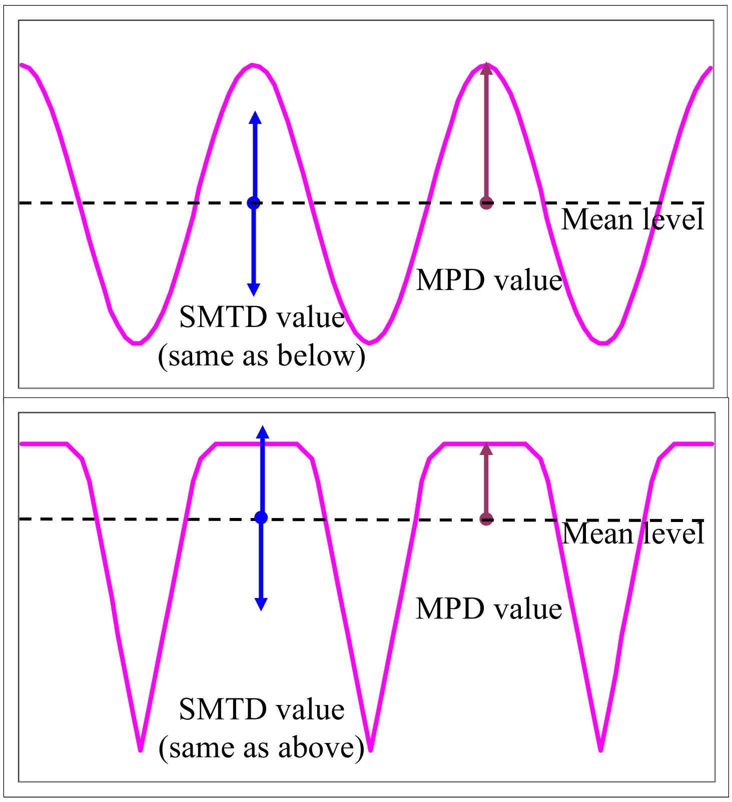


Figure 3-1 Comparison of SMTD and MPD values for surfaces with different shapes

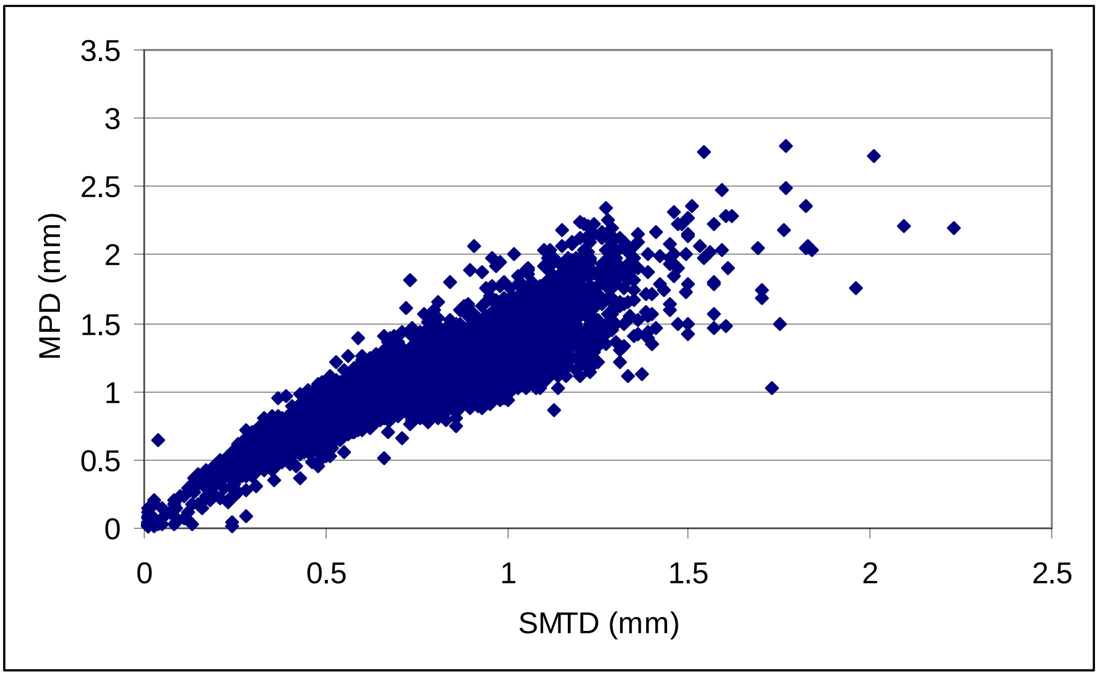


Figure 3-2 Relationship between SMTD and MPD measures on a sample of local roads

Similar data for a larger sample of roads (42km) is given in Figure 3-3. Here, the data have been grouped into bands with a width of 0.1mm SMTD and the average SMTD and MPD values for each band have been plotted. The range of MPD values in each band has been indicated by error bars extending to twice the standard deviation of the MPD values, i.e. encompassing approximately 95% of the values in the band.

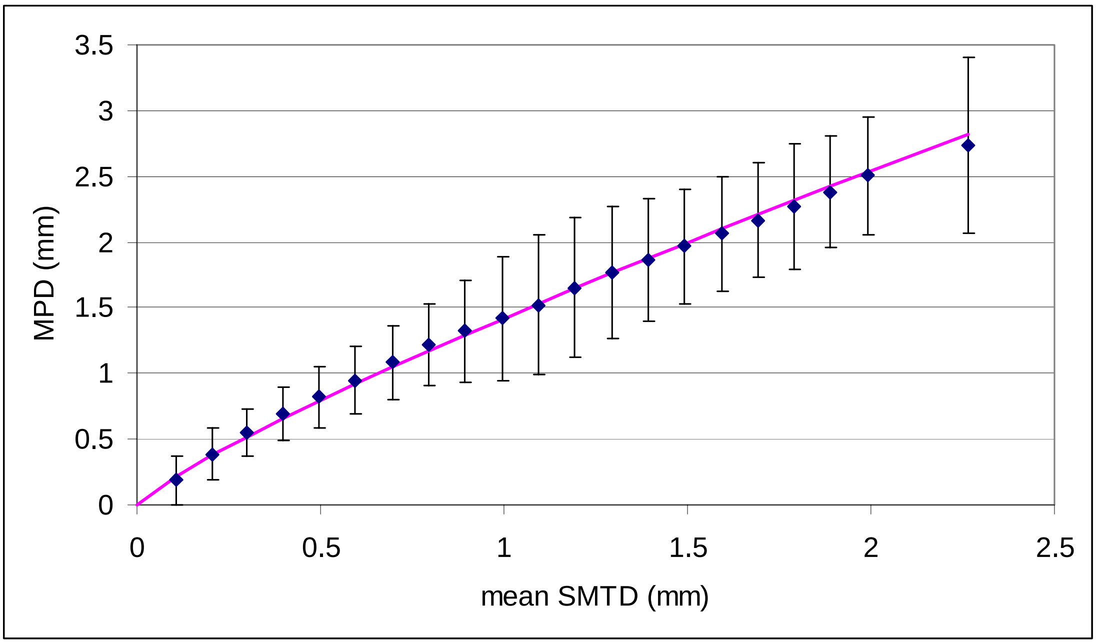


Figure 3-3 Relationship between SMTD and MPD measures on a larger sample of local roads

It is apparent from Figure 3-3 that the relationship between SMTD and MPD is only approximately linear: at higher texture depths, increases in SMTD produce smaller increases in MPD and the overall trend flattens off. The trend can be represented by the equation:

$$MPD = 1.42 \text{ x } SMTD^{0.840} \qquad [1]$$

This is also plotted in Figure 3-3, as a solid line. If MPD were to be adopted in preference to SMTD as the measure of texture for local roads then this relationship could be used to convert existing thresholds for SMTD into new thresholds for MPD.

The arguments for and against a change to MPD are finely balanced:

Arguments for a change to MPD

- Compared with SMTD, it is equally well related to high-speed friction on wet roads.
- It is widely used in Europe. It is the basis of the texture measurement that is needed to implement the European Friction Index as a harmonised scale of friction measurement and is likely to form the basis for texture measurement within European Performance Indicators for road pavements.
- As the accepted European standard for texture depth measurement by a laser profiling device, public bodies are required to encompass this measure when the level of texture depth is specified when procuring goods and services, for example if specifying the texture depth to be achieved for a new surfacing material.

Arguments for remaining with SMTD

- Continuity with previous texture depth data, engineering practice and research is maintained.
- The implication of the variability observed above is that the lengths of road triggering a threshold set in terms of SMTD will not always be the same lengths of the road that trigger the corresponding threshold set in terms of MPD. In general, the roads with low MPD values will be those with flatter surface profiles, i.e. as seen in the bottom half of Figure 3-1. This may mean that a MPD threshold would pick up more negatively textured surfacing materials than a SMTD threshold set at an equivalent level.
- There is limited evidence that the repeatability of MPD measurements on newly surfaced roads is worse than in-service roads. SMTD measurements appear to be more robust in this respect, possibly because the SMTD value will be less dependent on the results of single outlying profile points, which might occur due to unusual reflections from the new surface.
- There will be costs associated with making a conversion to MPD. These will be associated with appropriate software modifications to the surveying systems and pavement management systems that currently process SMTD data. However, modifications would not be required to current hardware.
- MPD requires a sampling interval of 1mm. Current systems can achieve this but the new measurements reported in Section 5 can not be reported as MPD without substantial additional investment in equipment.

Overall, it is recommended that the benefits of moving to MPD do not outweigh the disadvantages at present. However, this remains finely balanced and should be reviewed in the light of future developments and desire to report on a common scale with other European highway administrations.

3.4 Characteristics of surface texture (SMTD) on local roads

This section examines the characteristics of surface texture on local roads, specifically how texture varies for different types of road and how the texture varies along and across the road. The objective was to determine the best way to use texture data to determine the need for maintenance, where texture is measured using a similar approach to the current SCANNER specification, i.e. reported as a single measure (in this case SMTD) at intervals of 10m or longer over a restricted number of measurement lines. As noted above, Section 5 considers new ways in which more detailed texture depth measurements may be able to give more information about the surface condition and need for maintenance.

3.4.1 Data

Two sources of data have been used for the analysis, both are analysed at 10m intervals unless otherwise indicated:

SMTD data has been obtained from roads in two counties (Oxfordshire and Somerset). The data was recorded at 10m intervals and comprised a total of 3554 km of data (2337km of A class roads, 421km of B class roads and 796km of C class roads). Where extreme texture measurements were found, outside the range 0.01mm to 3.0mm, these were considered to be possible measurement errors and the data were not used in the analysis. These represented less than half a percent of the data.

Secondly, texture data was collected using the Highways Agency Road Research Information System (HARRIS) from a number of local authority roads, along routes that were constructed to link sections that local authority engineers had identified as being in poor condition or to measure specific identified defects for the later stages of this project.

3.4.2 Texture on different road classes

Taking the nearside wheelpath, the distribution of texture depth recorded on local roads in Oxfordshire and Somerset is shown for each road class in Table 3-2. As expected, B and C class roads tend to have surfaces with lower texture depth than A class roads, as seen from the higher percentage of the road length falling below each of the threshold values.

Table 3-2 Distribution of texture depth for local roads in Oxfordshire and Somerset

Road Class	Length (km)	Mean (mm)	Percentage of length having SMTD less than value indicated				
			0.4mm	0.5mm	0.6mm	0.8mm	1.1mm
A	2337	0.98	3.4	7.5	14.3	31.2	64.1
B	421	0.89	5.5	11.0	20.2	41.8	73.6
C	796	0.75	14.7	25.0	38.1	60.5	84.1
All	3554	0.92	6.2	11.9	20.4	39.0	69.8

The threshold values[2] of 0.4mm, 0.8mm and 1.1mm form the boundaries between condition categories in the current advice for interpreting texture depth values on trunk roads, as indicated in Table 3-3 (IAN42/05).

For trunk roads it is also recommended that the Investigatory Level for skid resistance is increased for surfaces known to have a texture depth below 0.8mm in order to avoid the combination of low skid resistance and low texture depth (DMRB 7.3.1).

[2] Not applicable to high friction surfacing materials

Table 3-3: Thresholds for texture depth applicable to English trunk roads

Texture depth (mm SMTD)	Category	Description
>1.1mm	1	Sound
0.8 - 1.1mm	2	Some deterioration
0.4-0.8mm	3	Warning level of concern
<0.4mm	4	Severe deterioration requiring urgent investigation and possible remedial action.

These thresholds were established to maintain adequate levels of high speed skid resistance on trunk roads and for this reason they will generally be appropriate to A-roads, which carry high volumes of traffic, generally at high speeds. Table 3-2 shows that, judging by the Somerset and Oxfordshire data, just over 30% of A-roads will trigger at least a warning level of concern, but less than 5% of road length would require urgent investigation. It therefore appears feasible to apply the same threshold levels for condition assessment to most A-roads. There may be exceptions where these requirements are not appropriate, e.g. to roads where speed restrictions apply or the volume of traffic is low, which could be identified and addressed on an individual basis.

Table 3-2 shows that applying the same threshold levels to B and C class roads would result in identifying an unrealistically high proportion of the local road network for investigation: the higher percentage of roads with low texture depth will be compounded by the higher total length of these roads. In any case, for B and C roads it is not appropriate to apply texture depth criteria in the same way as A roads, as they are not designed to provide the same high speed, high volume function as the A-roads.

An alternative approach on B and C roads would be to use a lower texture depth threshold to identify areas needing investigation. However, this would be a crude approach, since more than 40% of C roads fall below 0.6mm texture depth and, even at a low texture depth of 0.4mm SMTD, 15% of C roads would still require investigation, which represents a large amount of effort and may not prove to be strongly correlated to actual maintenance requirements.

3.4.3 Texture on rural and urban roads

The road environment, i.e. whether rural or urban, was not available for the Somerset and Oxfordshire data as provided and so data from the HARRIS survey in Leicestershire was examined. The sample was of 30km of A-roads, where the roads had been identified as being rural or urban based on the speed limit[3]; of which 75% were rural roads. For this sample, the rural roads had higher texture than the urban roads with less than 1% of roads falling below the 0.4mm threshold and 17% below the 0.8mm threshold, as seen in Table 3-4. This supports the argument for applying the texture depth thresholds in Table 3-3 to rural, high-speed A-roads.

[3] Rural taken as 50mph and above; Urban as 40mph and below

Table 3-4 Texture values for rural and urban classified A roads in Leicestershire

Road Type	Length (km)	Mean (mm)	Percentage of length having SMTD less than value indicated	
			0.4mm	0.8mm
Rural	22.8	1.09	0.8	17
Urban	7.8	0.93	1.7	31
All	30.6	1.05	1.0	20

3.4.4 Transverse variability of surface texture

In the current SCANNER specification, surface texture measurements are limited to the nearside wheelpath (SCANNER specification, volume 2). However, it would be straightforward to conduct additional measurements in the offside wheel path or midway between the two wheel tracks, approximately in the centre of the lane. This is done in Scotland, where the survey contractor delivers texture depth measurement in both wheelpaths, and the centre path, and was also available from surveys carried out in Oxfordshire and Somerset, on which the following analysis is based. The analysis has considered what additional information is provided by extending the measurement to two or three measurement lines in order to determine whether there is a significant benefits in doing this.

The overall average texture for the different classes of road, in the different transverse measurement lines, was as follows in Table 3-5.

Table 3-5 Texture depth recorded in different transverse positions

Road class	Mean texture depth (mm SMTD)			Mean differences (mm SMTD)*	
	Nearside wheelpath	Centre	Offside wheelpath	Nearside - centre	Nearside - offside
A	0.98	1.01	1.06	-0.02	-0.07
B	0.89	1.07	0.91	-0.18	-0.02
C	0.74	0.84	0.71	-0.10	-0.03

*Negative values indicate the nearside value to be the lower; apparent errors are due to the effect of rounding

For A and B road classes, slightly higher texture measurements were recorded in the offside than the nearside wheelpath, vindicating the normal choice of the nearside wheelpath as generally being in worse condition. For B and C-roads, the central texture measure is generally higher than the wheelpaths, possibly indicating wear, but this is not apparent for A-roads. However, while this is true on average, there are many individual cases where the offside or central texture depth is lower than the nearside texture depth, i.e. the nearside measurement on its own could fail to identify a length that requires investigation.

That this is indeed the case is clear from Figure 3-4 and Figure 3-5. These graphs show the differences, for each 10m length, between the texture depth recorded in nearside wheeltrack and that recorded in the offside wheelpath or the centre of the lane. In these graphs, positive values correspond to 10m lengths where the nearside value is higher, and therefore gives an optimistic view of the surface condition compared with the offside or central measurement. Comparing the nearside and offside measurements (Figure 3-4), it can be seen that the distribution is symmetrical, but that it is relatively common for the nearside measurement to be 0.2mm or even 0.4mm higher (or lower) than the offside measurement. This is also the case when considering the nearside and central measurements (Figure 3-5), although the distributions are more skewed, particularly for B-roads.

The frequency with which the nearside texture measurement potentially fails to identify 10m lengths with low texture are investigated in Table 3-6. This table shows the percentage of the overall road length in each class where the nearside measurement overestimates the texture in the offside or centre of the lane by at least 0.2mm or, worse, by at least 0.4mm. Both of these differences are large enough for them to be unlikely to have arisen as a result of measurement error.

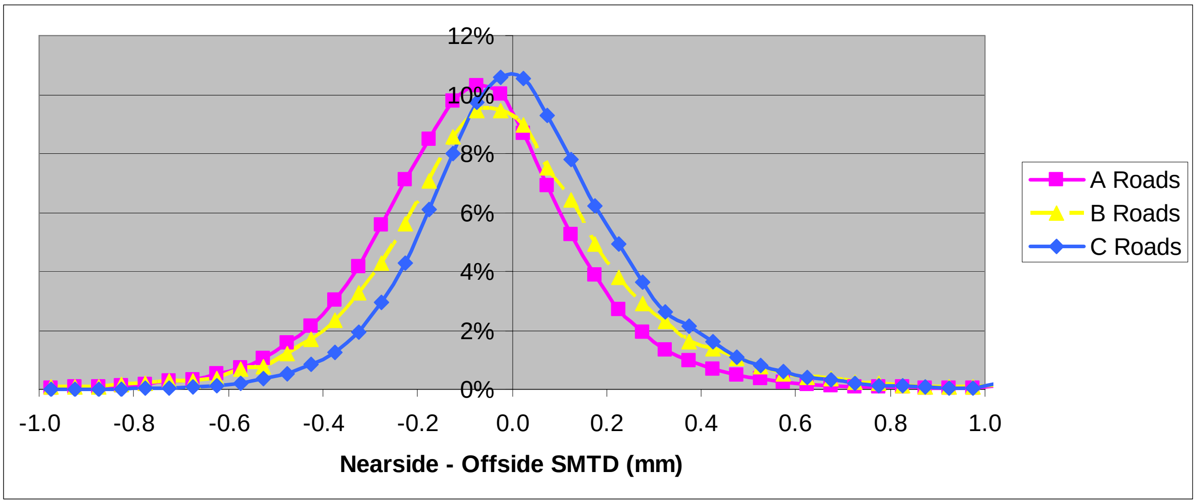


Figure 3-4 Differences between nearside and offside wheelpath texture measurements

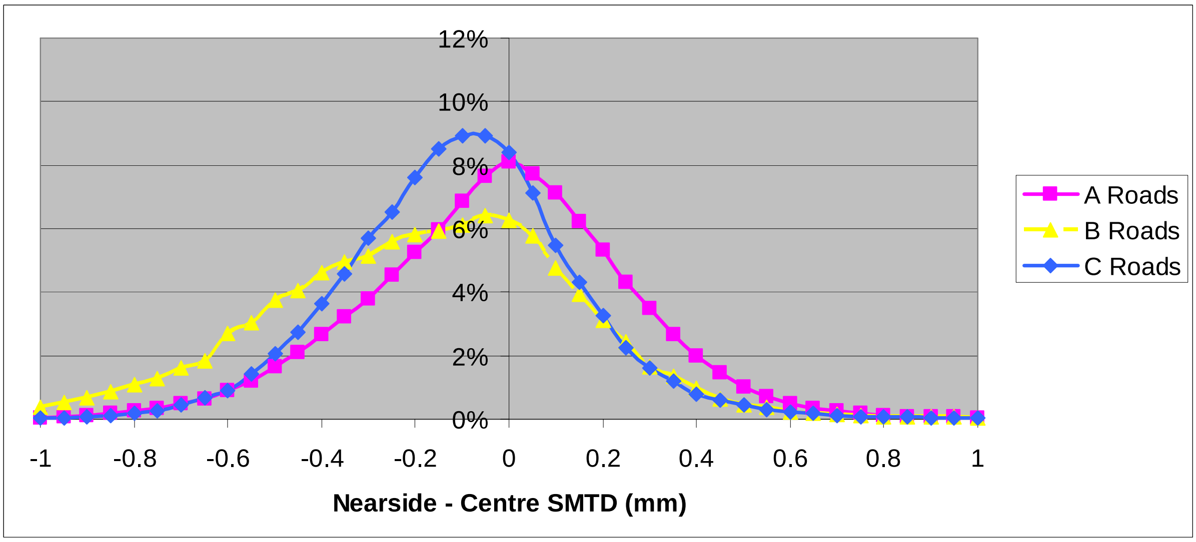


Figure 3-5 Differences between nearside and centre-line wheelpath texture measurements

Table 3-6 Percentage of roads where the nearside texture is more optimistic than the offside texture or the texture in the centre of the lane, to the extent shown

Road Class	Offside wheelpath		Lane centre	
	0.2mm	0.4mm	0.2mm	0.4mm
A	9.5	2.5	19.4	5.7
B	16.0	5.4	10.2	3.0
C	19.0	5.6	9.3	2.5

The values indicate a reasonable proportion of A-roads, around 10-20%, where the offside or middle of the lane has been measured at least 0.2mm lower than the nearside wheelpath, and a measurable proportion where the offside or middle of the lane was measured more than 0.4mm lower. On the other road classes, the percentages are higher. These data suggest that there is enough variability in the texture across the width of the lane that it is important to measure the texture depth in more than one measurement line.

3.4.5 Longitudinal variability of surface texture

The standard length of section for recording texture data is 10 metres, but the data can be averaged over longer lengths, e.g. 100m, for further analysis. Averaging the data has the advantage of increasing the confidence in the value, since the measurement uncertainty is reduced (by a factor of the square root of the number of measurements, i.e. by a factor of 3.2 if ten 10m values are averaged to give a 100m texture depth value). This gives greater confidence in the result, which is important when data are assessed against threshold levels because, where the condition is close to the threshold level, measurement error can result in sections erroneously triggering (or not triggering) the threshold level. In general, it would be advantageous to report network condition using 100m averages and take advantage of the improved measurement precision. However, if the texture within the longer length is not uniform then averaging the 10m data will smooth over real changes in condition and potentially obscure short lengths in poor condition if the adjacent lengths are better.

The following analysis has considered lengths of 50 metres and 100 metres to determine the loss of information that might occur when averaging over these distances. This was assessed by calculating the difference between the mean value and the lowest individual 10m value for each 50m or 100m length. Table 3-7 shows the percentage of all 50m or 100m lengths where the difference between the lowest value and the mean value is at least the value indicated. Differences of at least 0.2mm, are unlikely to result from measurement error and, for these lengths of road, the average result does not adequately indicate the condition of that length.

It is apparent that averaging the 10m data over longer lengths does remove relevant information in a reasonable number of cases – probably up to between 15 and 25% of cases for 50m lengths and between 35% and 50% of cases for 100m lengths. In the remaining cases, which is still the majority of cases, the lowest individual 10m length is still within the range expected for measurement uncertainty. In these cases, averaging over longer lengths improves the confidence in the result.

Table 3-7 Percentage of 50m or 100m average values where the lowest individual 10m length is lower than the average value by at least the amount indicated

Road Class	Averaging over 50m			Averaging over 100m		
	0.2 mm	0.3 mm	0.4 mm	0.2 mm	0.3 mm	0.4 mm
A	15.6	5.1	1.8	34.5	13.3	5.6
B	23.2	7.9	3.1	47.8	20.8	8.8
C	15.7	4.7	1.6	34.7	11.7	4.0
All	16.6	5.3	1.9	36.2	13.9	5.6

It is therefore recommended that the 10m data are averaged to 100m for the purpose of reporting network condition, but that 100m averages are not used on their own to identify areas of low texture requiring investigation and possible maintenance because of the risk of missing isolated low sections in critical locations, for example on bends, or on high-speed roads, particularly if the skid resistance is low. Therefore, either the 10m data should be used as the basis for identifying sections for further investigation, or the lowest value in each 100m section needs to be examined in addition to the average value.

3.4.6 Characteristics of sections with poor surface texture

During the consultation process, engineers in selected local authorities were asked to identify sections within their network with specific defects. Each authority identified a number of sections and indicated the main types of deterioration for each. For sections where poor condition was related to surface deterioration, as determined by the presence of the type of defects listed in Table 2-1, the texture data was examined to see if these sections also had higher proportions of low texture values. The defaults were ranked by the local engineers with severity levels of 1 to 3, with 3 being the worst level. The results of the examination of texture values for these sections are shown in Table 3-8.

It is apparent that more severe deterioration can be associated with low levels of measured surface texture although, in some cases, the low texture may be apparent only over a low percentage of the overall length in poor condition. Furthermore, some sections with less severe deterioration do not exhibit particularly low texture depths, even over localised areas, as shown by the fact that none of the length was below 0.4mm for three of the sections. It is interesting that a high texture depth is recorded for one of the Shropshire sites where fretting was noted, since fretting may increase the texture depth if the gaps left by the lost aggregate form a higher overall texture than with the stones present. However, this does not appear to be replicated for the other cases of fretting.

Table 3-8 Defects and texture values for "poor" sections

County	Road Class	Defect and relative severity recorded	Mean texture (mm)	Percentage of length less than 0.4mm
Hampshire	B	Fatting level 2 Poor texture level 2	1.14	3.1
Hampshire	B	Poor texture level 2	0.65	17.4
Hampshire	C	Fretting level 1 Fatting level 1 Poor texture level 2	0.70	22.3
Leicestershire	B	Fatting level 1	1.03	1.2
Leicestershire	C	Fretting level 1 Fatting level 1	0.94	0
Leicestershire	U	Fatting level 2	0.46	31.7
Shropshire	A Built-up	Fretting level 1 Fatting level 1	1.07	0
Shropshire	A Non built-up	Fretting level 1	1.56	0
Shropshire	B	Fretting level 2 Fatting level 2	0.70	1.82

Although limited, this analysis confirms that it will be difficult to identify sections with defects using a single threshold level based on the measurement of texture depth in the nearside wheel track. Clearly, an alternative approach to assessing surface texture characteristics on local roads are needed to improve engineers' ability to identify sections exhibiting deterioration. This is considered further in Section 5.

3.4.7 Correspondence with Coarse Visual Inspection data

Coarse Visual Inspection (CVI) data was obtained from the local authorities for those sections identified by them as having surface deterioration and for roads in their vicinity. In this way, a comparison could be made between laser based texture depth measurements and an engineering assessment of the condition of the surface. Figure 3-6 shows the results of a CVI survey, specifically looking at "surface deterioration" (recorded by the surveying engineer using the code "BSDE") for a 10km sample of roads in Hampshire. Figure 3-7 shows the corresponding texture depth data from laser measurements of the nearside wheeltrack of the vehicle for the same length of road, which has been allocated categories 1 to 4 using threshold levels in Table 3-3.

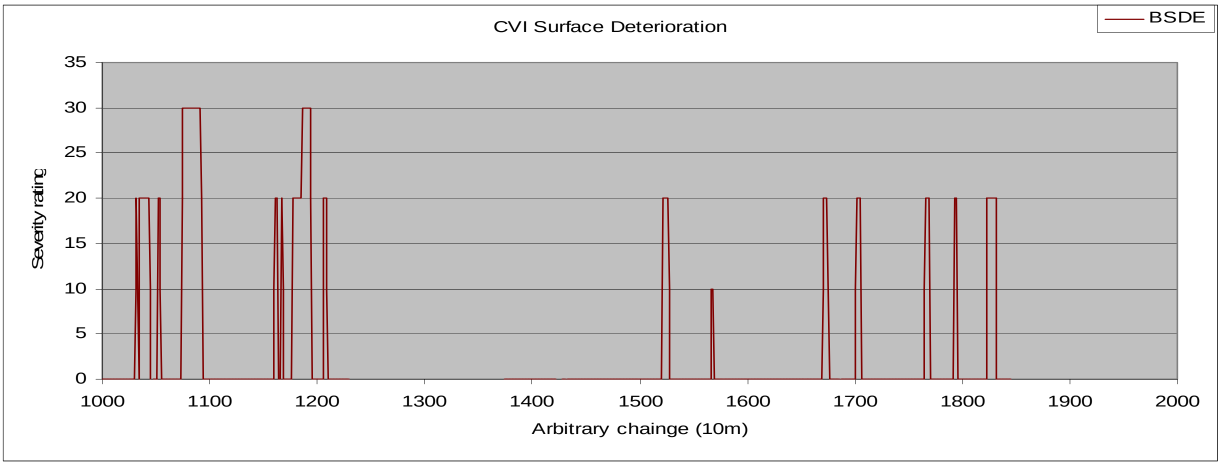


Figure 3-6 CVI data

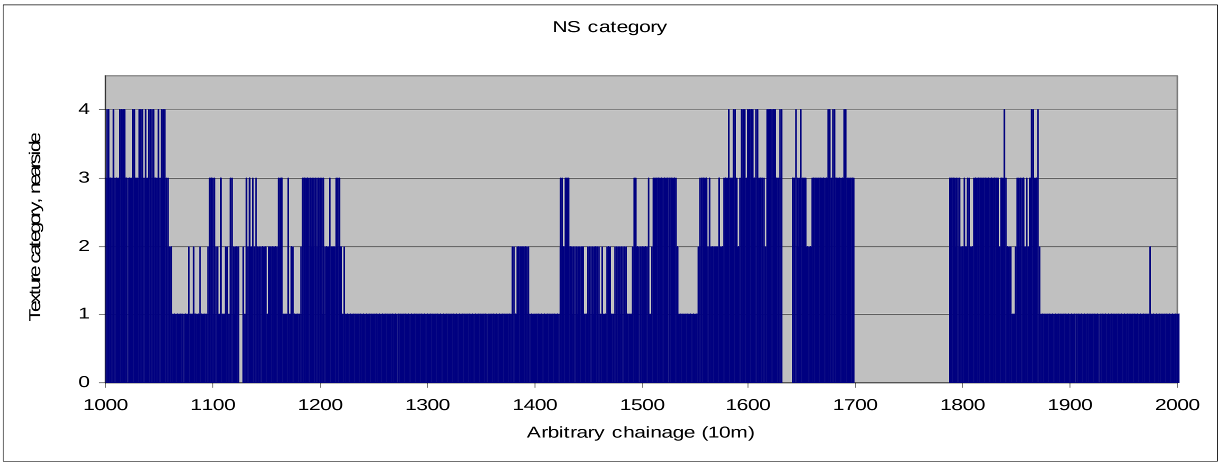


Figure 3-7 Texture depth condition category from nearside SMTD measurement

There is some correspondence between the two sets of data: at several points the severe surface deterioration reported by the CVI matches points where texture data places the condition in the higher categories (i.e. worse condition). The number of incidents of severe deterioration recorded by the CVI survey is low compared to the number of points with category 4 texture depth, but in most cases where there is a CVI flag, there is also a section of low texture. However, the level of severity does not necessarily agree, insofar as there are only a few cases where the highest CVI severity (30) corresponds to the highest texture category (4) but several cases where texture category 4 corresponds only to medium CVI severity.

There are a number of reasons why this may be the case, including the fact that only the nearside wheelpath is measured by the laser system but this again suggests that low texture depth, on its own, does not provide a precise indication of the places suffering surface deterioration.

3.5 Summary

This section has reviewed the use of texture data in a similar format to that required by the current SCANNER specification, i.e. measured at 10m intervals in one or a limited number of transverse positions, recorded as SMTD or MPD and possibly averaged to longer lengths for further analysis. The key points from this work are:

- The arguments for adopting MPD as opposed to SMTD for characterising the height of the surface texture are finely balanced but, on balance, it is recommended that the benefits of making this change do not outweigh the disadvantages at present. However, this situation may change in future if there is a greater need to compare data with other European countries or to make use of reporting mechanisms developed in Europe, such as performance indicators for road pavements or the European Friction Index.

- The threshold levels established for assessing texture depth on English trunk roads will generally be appropriate to rural A-roads that carry high volumes of traffic at high speeds. The data suggests that the condition of A-roads is such that applying these thresholds is realistic.
- This approach is unlikely to be satisfactory for B and C-roads because, even setting thresholds at a low level identifies an unrealistic proportion of the network as requiring further investigation. The relatively weak correspondence between low texture and engineers' assessment of condition and with CVI data also suggest that this will not be a sufficiently precise way of identifying areas suffering from deterioration of the surface texture.
- Local roads are sufficiently variable across their width that measuring in more than a single transverse position is necessary to obtain a reliable view of the condition of the road.
- For reporting at network level, better measurement precision will be obtained by averaging over 50m or 100m lengths. However, on its own, this will not provide a reliable way of identifying sections needing investigation for low texture depth because, in many cases, the lowest individual 10m reading is significantly below the average value. Therefore, either the 10m data should be used as the basis for identifying sections for further investigation, or the lowest value in each 100m section needs to be examined in addition to the average value.

4 Texture as a surrogate for risk of skidding accidents

4.1 Background

Specifications and thresholds for achieving and maintaining texture depth on roads carrying high-speed traffic have been set in the UK for many years in order to maintain skid resistance performance in wet conditions. In this context, “skid resistance” refers to the skid resistance at high slip speed, i.e. where the tyre is skidding over the surface texture at speeds up to that of actual traffic speed, and such measurements are known to be related to the surface texture. In contrast “skid resistance” measurement by devices such as the SCRIM or GripTester is made at low slip speeds, typically less than 20km/h, because the test wheel is only slipping over the surface at a fraction of the vehicle speed during the test.

As a result, there can be confusion over whether texture depth measurements, such as SMTD, can be used instead of (low slip speed) skid resistance measurements. Furthermore, the skid resistance at low slip speeds is believed to be related to fine scale surface texture and the relative simplicity of a non-contact, laser measurement of texture depth makes it an attractive alternative to conventional skid resistance measurements. Therefore, part of the project brief was to determine whether a reliable surrogate for (low slip speed) skid resistance based on a non-contact survey method could be found within the timetable for implementation of SCANNER surveys. In practice, this proved largely unsuccessful but is reported in Sections 4.2 and 4.3.

Section 4.4 considers the evidence in the literature relating to the role of texture depth in limiting the risk of skidding accidents and reports an analysis of Scottish data carried out for this project.

4.2 Relationship between SMTD and skid resistance

The relationship between (low speed) skid resistance and texture depth was investigated using Mean Summer SCRIM Coefficient (MSSC) values of skid resistance and corresponding texture data obtained from the counties of Oxfordshire and Somerset. For analysis, this dataset was grouped by site category (non-event sections, bends, gradients and junction approaches) and by road class (A, B and C class roads), although the majority of the available data was from A roads. The length of data analysed where both skid resistance and texture depth data were available is summarised in Table 4-1.

Table 4-1 Length (km) of Oxfordshire and Somerset data analysed

Road Class	Site category				Total
	Non-event	Junction approaches	Gradients	Bends	
A	812	73	184	117	1186
B	6.3	1.1	0.9	2.4	10.7
C	6.9	1.2	1.3	1.0	10.4

No evidence of a relationship between skid resistance and texture depth was found for any of these combinations. Sample analyses demonstrating this lack are shown below in Figure 4-1 to Figure 4-4.

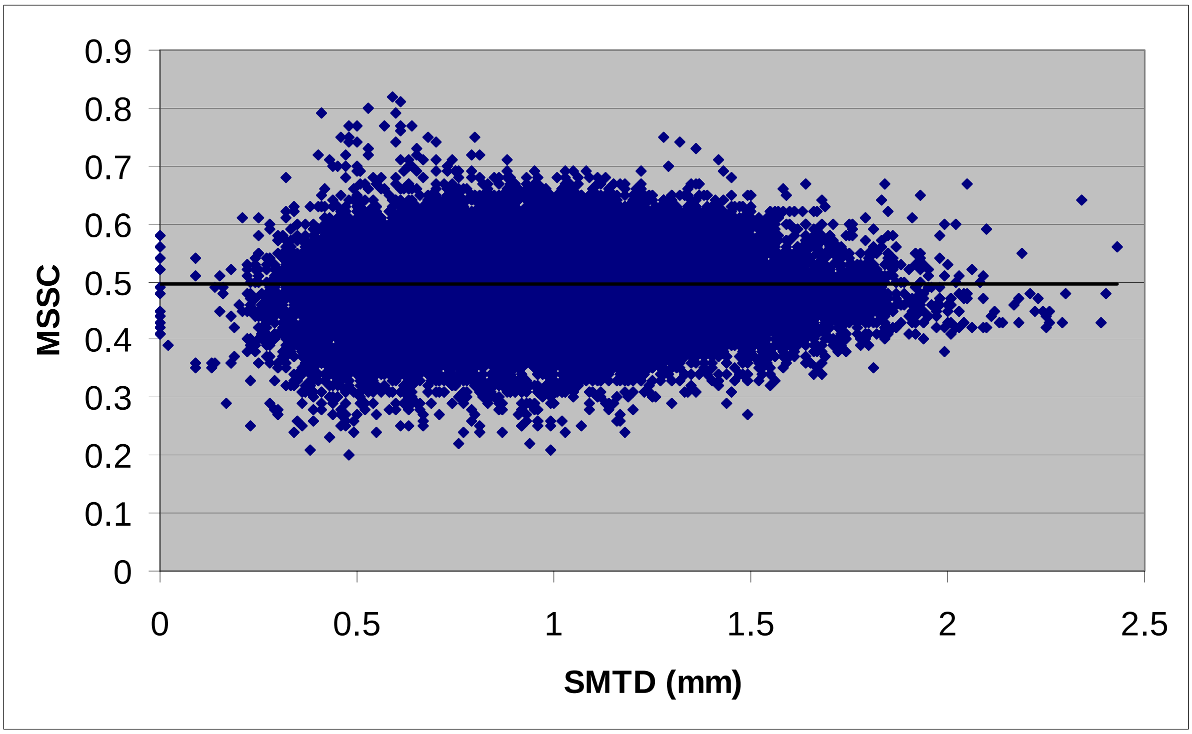


Figure 4-1 Relationship between skid resistance and texture depth – non-event lengths

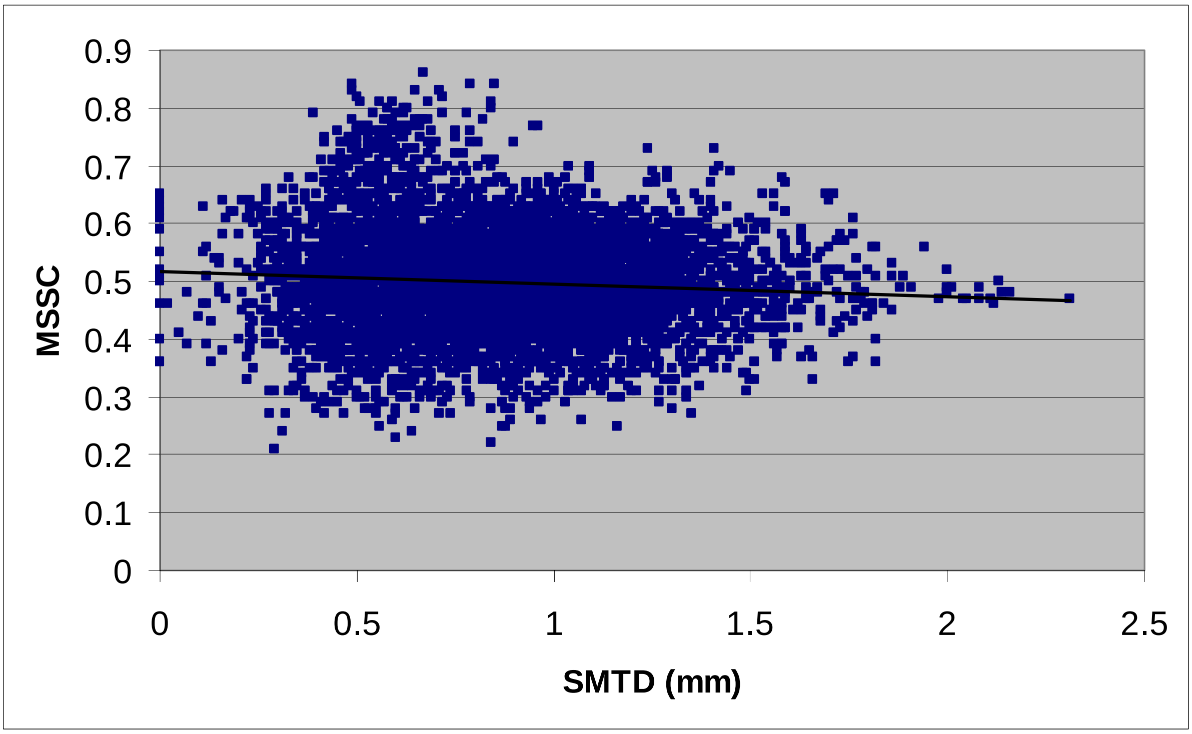


Figure 4-2 Relationship between skid resistance and texture depth – junction approaches

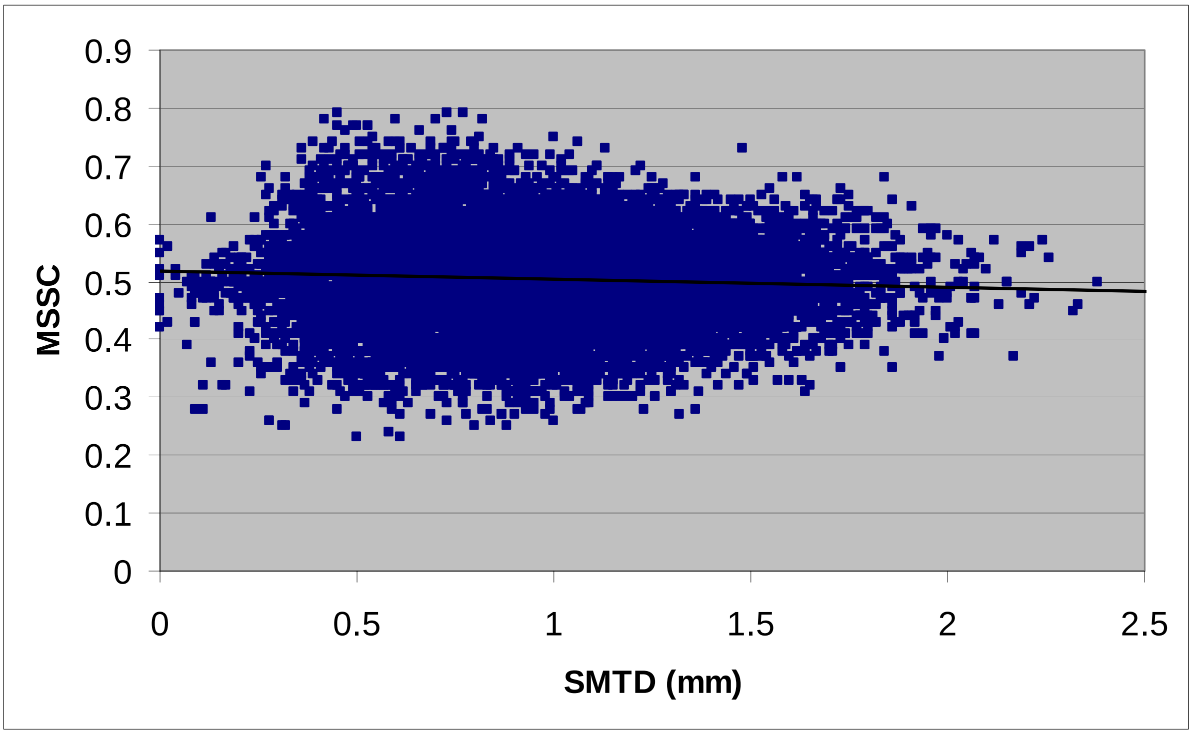


Figure 4-3 Relationship between skid resistance and texture depth – gradients

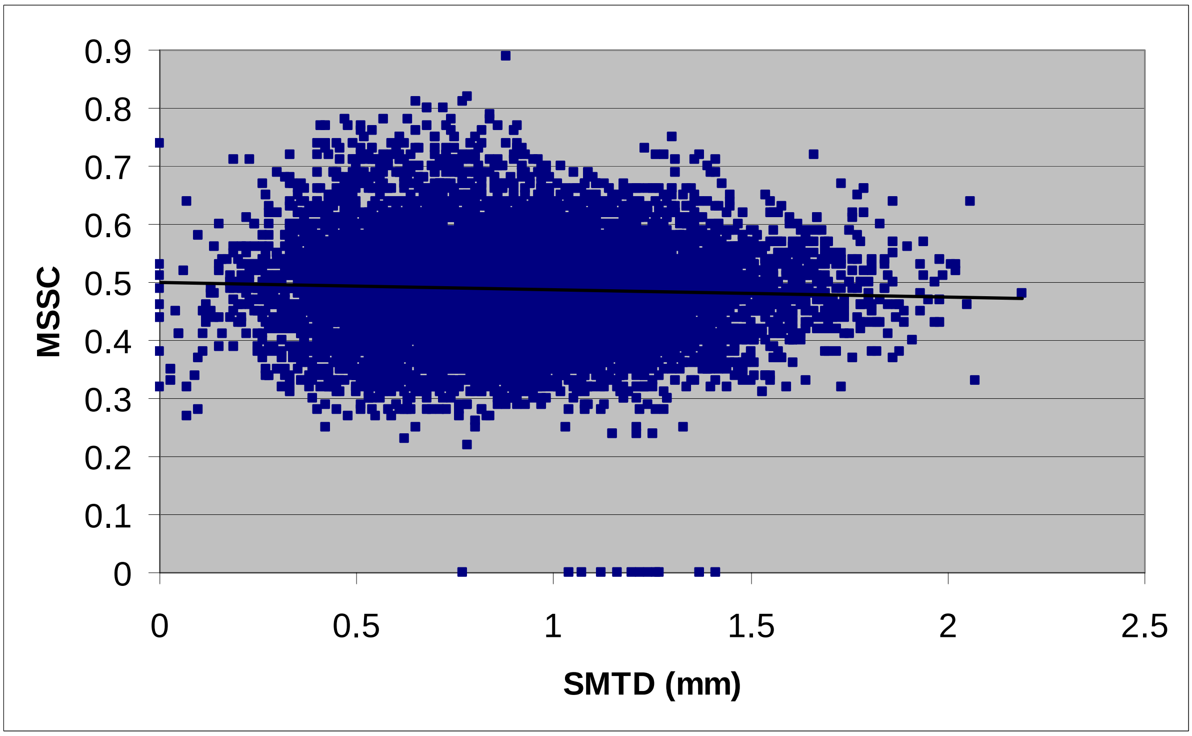


Figure 4-4 Relationship between skid resistance and texture depth – bends

The roads in Somerset and Oxfordshire are predominantly rural and so the data in the above analysis will primarily be influenced by the characteristics of rural roads. However, a study by Birmingham City Council has also indicated that the correlation between surface texture measurements and SCRIM results is not high. Figure 4-5 shows that there is little overlap between roads exhibiting low skid resistance and low texture depth.

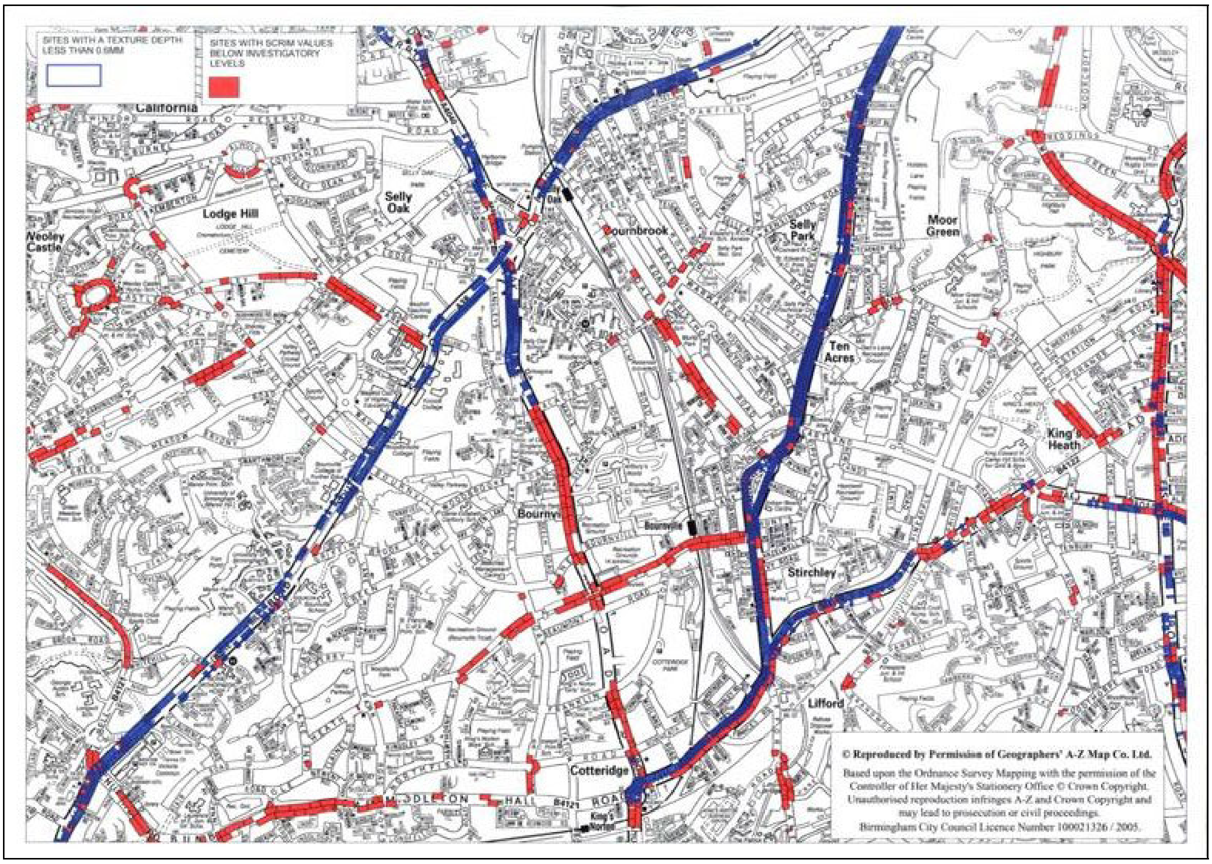


Figure 4-5 Street map of Birmingham showing roads with texture depth less than 0.6mm (Blue) and skid resistance below the investigatory level (Red)

It is therefore concluded that texture depth, as measured by SMTD, cannot be used as a reliable indication of the (low-speed) skid resistance as measured by SCRIM or GripTester.

4.3 Measurement of texture with short wavelengths

Skid resistance is believed to be related to the presence of microtexture, the fine scale texture present on the surface of aggregate chips (Figure 4-6), whereas measures such as SMTD and MPD characterise the level of macrotexture and are dominated by the influence of texture at longer wavelengths, up to 600mm (SMTD) or 100mm (MPD). This section assesses whether a better correlation with skid resistance could be obtained using a measure of surface texture that was more targeted at surface microtexture.

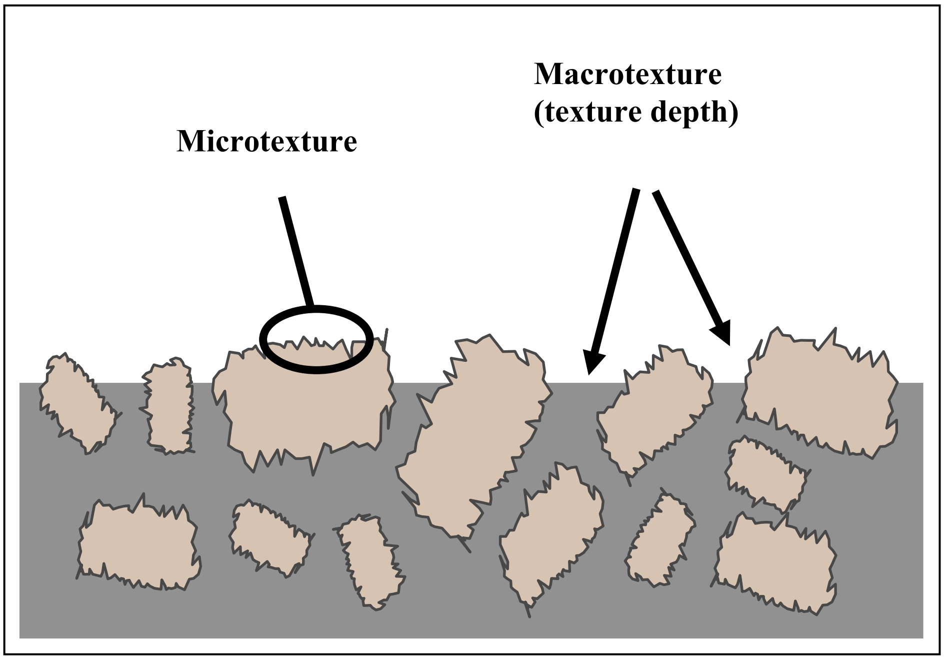


Figure 4-6 Surface micro- and macro-texture

4.3.1 Measurements based on current technology

Texture profile and skid resistance data were collected in targeted HARRIS and SCRIM surveys on a 17km route of local roads in the Bracknell area. Standard texture profile measurements for TTS surveys are made with 1mm spacing between profile points. However, the maximum resolution of the HARRIS texture lasers is 0.2mm spacing, which was used for these surveys. The higher resolution enabled the texture profile to be analysed at smaller wavelengths, more representative of a surfaces microtexture.

The process used to align the data from the different surveys was to use operator push button events for location referencing, and then to carry out fine tuning by adjusting the position of the data based on a comparison of the standard SMTD data from SCRIM and HARRIS to achieve the best match possible. Figure 4-7 shows the SMTD data after alignment and it can be seen that both devices produced nearly identical SMTD measurements, which gives confidence in the alignment of the two measurements and any resulting correlations.

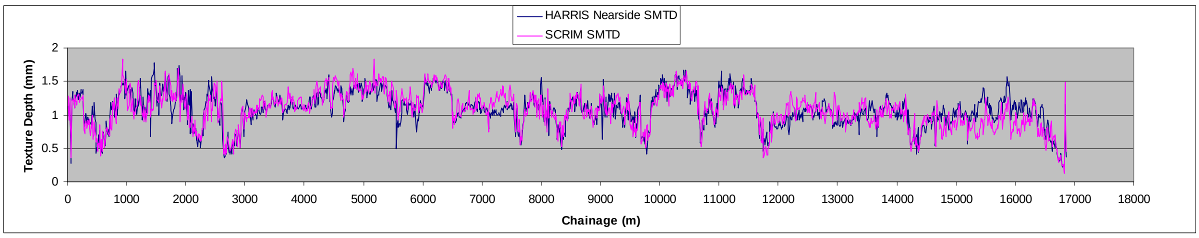


Figure 4-7 Alignment of SCRIM and HARRIS texture profile

The spacing of the raw data, 0.2mm, means that the minimum texture wavelength that can potentially be detected using the HARRIS system is 0.4mm. As noted above, the standard measures of SMTD and MPD include a range of wavelengths:

- Up to wavelengths of approximately 600mm for SMTD
- Up to wavelengths of 100mm for MPD

Features with long wavelengths tend to have larger amplitudes, and so both these measures of texture depth will tend to be dominated by the presence of longer wavelength features. To reduce this effect and produce a parameter that is more sensitive to finer scales of texture, an additional high-pass filter was applied to the texture profile to attenuate the amplitude of wavelengths longer than a specified length. The texture depth was then calculated from the filtered texture profile using methods similar to SMTD or MPD. Table 4-2shows the alternative filter frequencies used, along with the corresponding wavelength cut-off. Figure 4-8 and Figure 4-9 show the texture depth results calculated from the filtered profiles using the MPD- and SMTD-methods respectively.

Table 4-2 High Pass frequency filters applied to texture profile

Frequency (m^{-1}) (filter removes frequencies below value)	**Wavelength (mm) (filter removes wavelengths above value)**
100	10
200	5
300	3.3
400	2.5
500	2

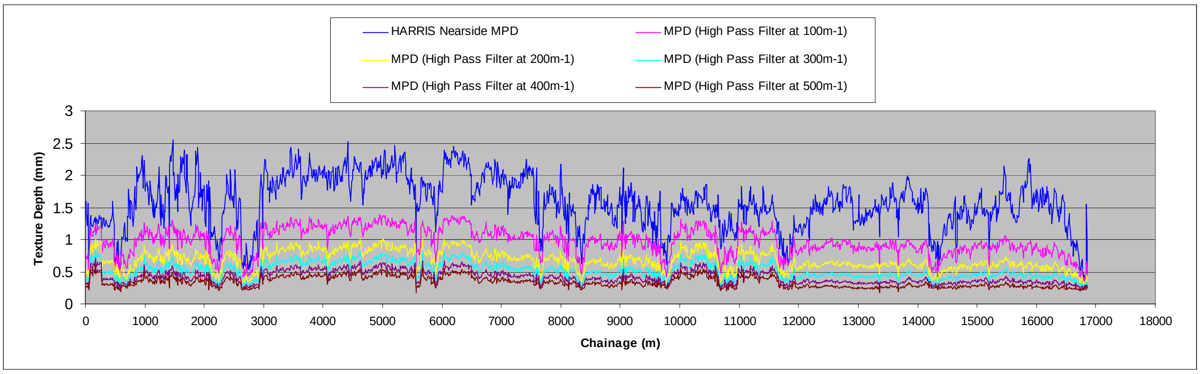


Figure 4-8 MPD texture profile with standard and additional wavelength filters

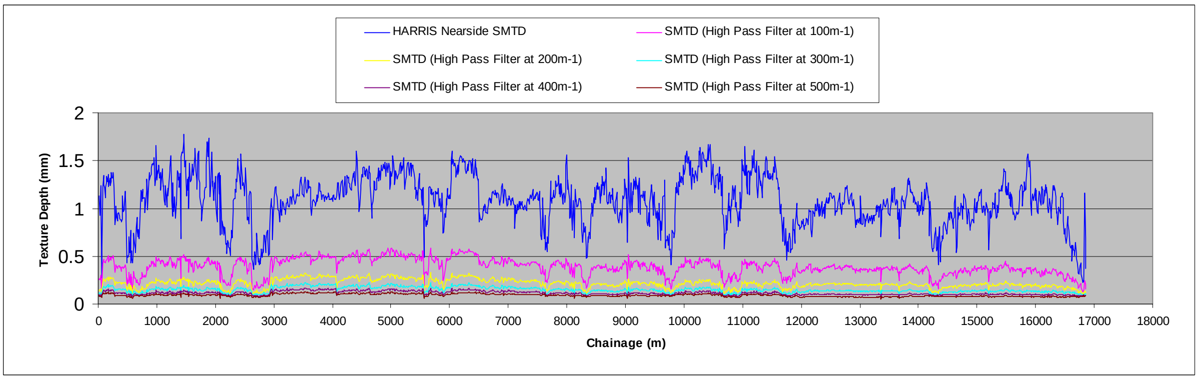


Figure 4-9 SMTD texture profile with standard and additional wavelength filters

It is apparent from Figure 4-8 and Figure 4-9 that the overall amplitude of the measured texture depth reduces as the longer wavelengths are progressively removed. The final stage of the investigation was to assess the correlation between skid resistance and these texture depth measurements. Figure 4-10 shows the relationship between texture depth and skid resistance for a selection of the filter frequencies. No evidence of any such trend was found. There is also a large amount of scatter, which is the reason for the low R^2 values. It was expected that this would be the case for the standard SMTD and MPD algorithms, however no improvement was seen in the alternative frequency filters. This suggests even at the highest resolution, the texture lasers cannot at present produce a good representation of microtexture levels.

As a result of the findings, the conclusion is that texture depth measured using conventional technology cannot be used as a surrogate measurement for skid resistance. Although texture depth has been proven to affect the levels of skid resistance at high speeds, it does not relate directly to the levels of low speed skid resistance provided by SCRIM surveys.

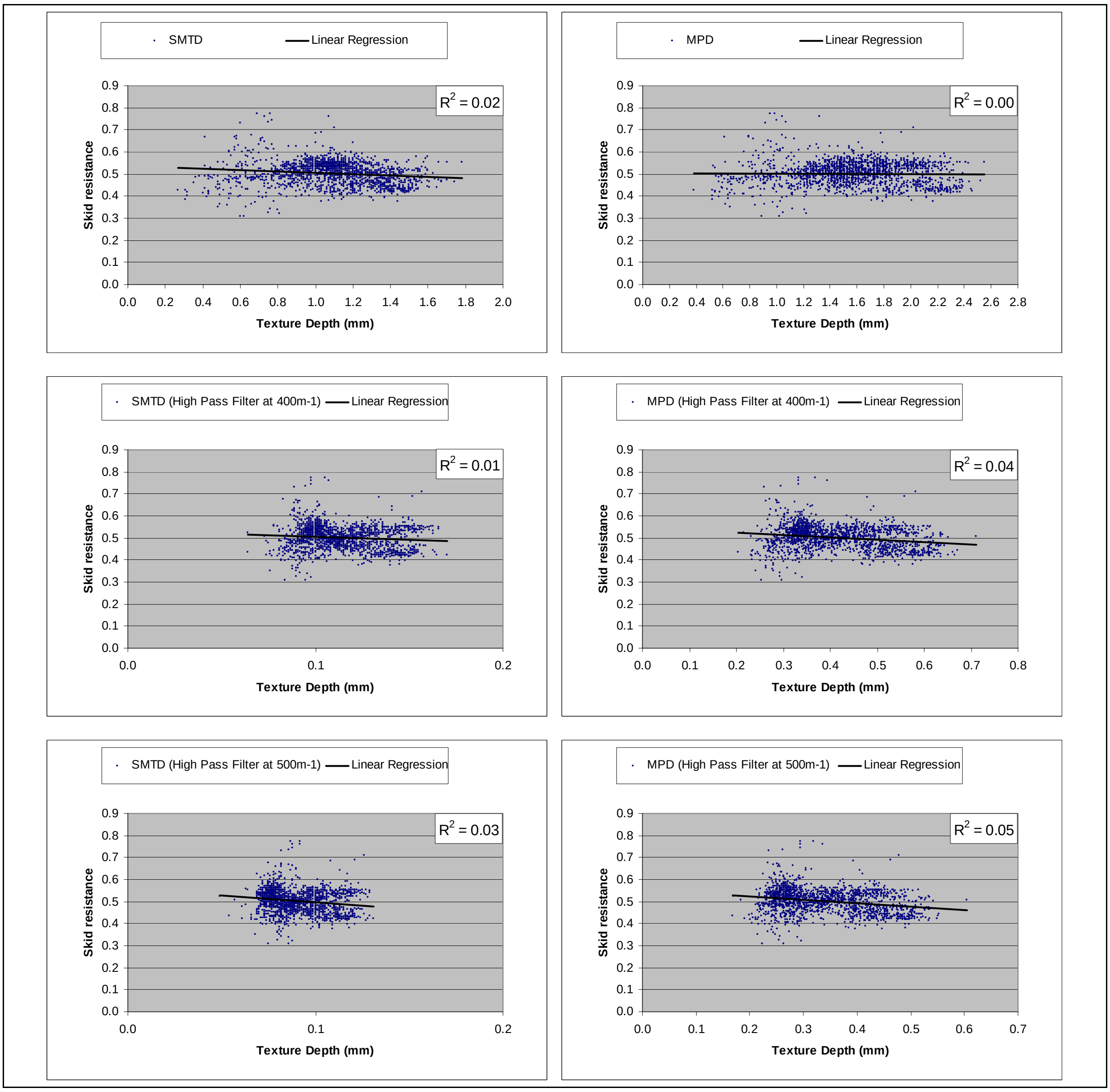


Figure 4-10 Relationship between texture depth and SCRIM coefficient at a standard speed of 50km/h

4.3.2 *Direct measurement of microtexture*

The previous section demonstrated that it was not possible to find a measure of texture depth based on conventional measurement technology that provided any correlation with low-speed skid resistance. It was therefore decided to investigate whether alternative measurement technology could offer a direct measurement of surface microtexture. WDM Ltd were commissioned as part of this project to carry out a review of technology that was already available or could readily be adapted to this purpose, given the constraints that a system needed to be capable of implementation in 2007.

The formal definition of surface microtexture (of features with wavelengths of less than 0.5mm) was generally considered impossible to meet, and WDM therefore considered a more relaxed definition for the purpose of this review. In relation to this relaxed definition they concluded:

- […] vehicle borne applications […] would necessitate the use of servo mechanisms to raise and lower the sensor.
- Using the desired specification the performance of spot based triangulation displacement sensors was compared. No sensors capable of meeting even the relaxed specification have been identified. All of the sensors investigated have laser spot sizes that are too big and scan rates that are too slow.
- Newer devices are becoming available using two dimensional triangulation techniques, achieved by using a laser line generator coupled with a two dimensional CCD array sensor. No products utilizing this principle are currently available that are capable of meeting even the relaxed specification. Future developments based on this principle may however produce a feasible solution, worthy of investigation.

The full WDM report is given in Appendix A, from which it is clear that technology for the traffic speed measurement of surface microtexture is not at a sufficiently advanced stage to be feasible for implementation within the timescale required.

4.4 Texture depth and accident risk

As noted above, texture depth is required to maintain skid resistance performance in wet conditions. As well as the known link between skid resistance and accident risk, a number of studies have also indicated a link between low texture depths and increased accident risk, which indicates that highway authorities need to develop appropriate strategies for maintaining both skid resistance and texture depth on their road networks. The findings of these studies are summarised briefly below. As part of this project WDM Ltd were commissioned to conduct a short investigation of whether accident risk appeared to be linked to surface texture on Scottish trunk roads. This is also summarised below, with the full report in Appendix B.

Following the introduction of high-speed techniques for the measurement of texture depth in the UK, the relation between texture depth and accidents was investigated on three networks comprising almost 2000km (Roe et al., 1991). These were mainly A-roads but included some motorways and B and unclassified roads. This work showed that, for each of the networks studied, more accidents occurred on lower textured roads than would be expected given their overall length. This was found to affect all accidents, whether or not skidding was reported and whether or not the road was wet. Overall, it was found that the risk of all types of accident was greater on roads where the texture depth was less than about 0.7mm SMTD, irrespective of the underlying level of skid resistance and the proximity to junctions.

In a study carried out by VicRoads (VicRoads, 2002) the distribution of texture depth levels on a selected rural network was compared with the distribution of texture depth levels on accident sites. This showed an excessive number of accidents occurring on roads with a texture depth of less than 1mm, compared with the occurrence of these roads on the network. As a result of this work, minimum performance limits were established for 7, 10 and 14mm surface dressings. A smaller study on the urban, mainly asphalt, network showed that there was not a significant relationship between texture depth and crashes in this case.

Other work in Australia has investigated the skid resistance at sites where fatting up had resulted in the presence of excess bitumen on the surface, and consequent reduction of the surface texture (Axup, 2003). At two sites where loss of control accidents had occurred, localised loss of friction was reported when tested with a drag sled, from values of 0.74 to 0.45 on one site and from 0.51 to 0.34 at a second site. SCRIM tests at a number of other sites gave SCRIM Readings as low as 9, and consistently under 40 (this corresponds to 0.07 and 0.31 units SFC, respectively).

Work in France on approximately 200 km of routes with different layouts showed that the accident rate (number of accidents per 100 million vehicle kilometres travelled) increased as either the skid resistance or the texture depth decreased (M Gothie, 2000 and 2002). A particularly rapid increase in accident rate was observed at very low values of either skid resistance or texture depth. In individual case studies it was found that the trend with skid resistance was reproduced, and that the severity, and hence the average cost of an accident, increased steadily as the skid resistance fell. On sections containing bends it was found that the accident rate increased sharply as the radius of curvature decreased.

TRL have recently investigated the link between skid resistance, texture depth and accident risk in a study that supported the 2004 revision to the skid resistance standard for UK trunk roads (Parry and Viner, 2005). It was found that texture depth was a significant variable in explaining accident risk for some SCRIM site categories although, notably, not for motorways. The accident model obtained for single carriageway non-event sections[4] is illustrated in Figure 4-11. This shows the combined effects of skid resistance and texture depth on the accident rate predicted for a specified traffic level. The highest accident rate arises from a combination of low skid resistance and low texture depth. The increase in accidents when comparing a site with a moderate texture depth of 0.8mm with a higher texture depth of 1.3mm is similar to the increase in accident risk predicted for reducing the skid resistance by 0.05 units SFC. A similar effect was observed for non-event lengths on dual carriageways.

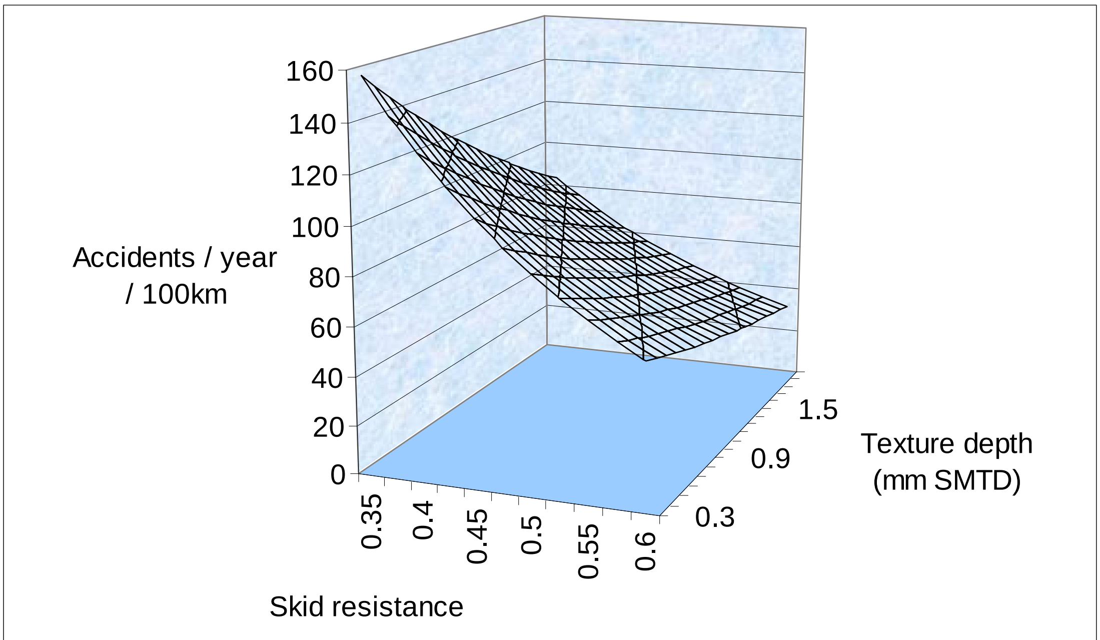


Figure 4-11 Predicted all-accident rate by skid resistance and texture depth for single carriageway trunk roads in England (reproduced from Parry and Viner, 2005)

[4] See DMRB 7.3.1 for definition of SCRIM site categories including "non-event"

The TRL work was carried out for the Highways Agency and used data from trunk roads in England. To support this work, WDM Limited were commissioned to explore the relationship between texture depth and accidents on the Scottish trunk road network, which has road geometries more similar to principal roads in England. The key conclusions from this work are summarised below; the full report is reproduced in Appendix B.

For most site categories, no correlation was observed between texture depth and the accident density (accidents per km) or accident rate (accidents per 100 million vehicle km). However, this may reflect the small length of the network with low texture depths. There did appear to be a correlation between accident density and texture depth for dual carriageway non-event sections, but this was not also reflected in the accident rate. For major junctions, both the accident density and accident rate appeared to correlate with the texture depth over the narrow range of texture depth for which there was sufficient data available.

For sites with gradient between 5% and 10%, a correlation was observed for sites with low skid resistance, at least 0.05 units SFC below the investigatory level. This was not observed for sites 0.05 units SFC above the IL. However, again there was only data available over a restricted range of texture depth. The difference between urban (i.e. low speed roads) and rural (i.e. high speed roads) was also considered, with a weak relationship observed between texture and accident density for rural dual carriageway non-event sites, and with accident rate for rural sites with a gradient between 5% and 10%. There was insufficient data on urban roads to carry out the analysis. In cases where trends were observed, it was frequently observed both for the accidents on wet and dry roads.

All the research above indicates that there are circumstances where low texture depths can be associated with greater incidence of accidents. This trend has consistently been reported to include accidents on dry roads, but it is not known whether this is because braking performance on dry roads is also better with higher surface texture, or because the distinction between wet and dry is not reported accurately. It is notable that the trends in accident density in the recent WDM work were not generally supported by a corresponding trend in accident rate, suggesting that while more accidents occur on low textured surfaces, this could be because there is more traffic on these parts of the network. A limitation of the early work by Roe and later work by VicRoads is that the traffic flows were not considered. However, the later TRL work included traffic flow in the accident models and the texture depth was found to be a significant factor in some cases.

The overall picture confirms the importance of maintaining good levels of texture depth, particularly on rural roads, and particularly where the skid resistance is also low.

5 Localised texture changes

5.1 Background

Section 3 showed that measuring texture depth in a single line in the nearside wheelpath is appropriate on A roads to identify lengths where the surface texture may not be adequately providing good skid resistance, but that this approach was unlikely to be effective on B or C roads, where the texture depth is lower and low texture, on its own, is not a good indication of the need for maintenance. On these roads, deterioration of the surface texture is more likely to result in localised changes in the surface texture, e.g. fatting up or fretting. Furthermore, on local roads, there may not be a defined, canalised, driving line followed by the majority of vehicles as on trunks roads, so deterioration of surface texture may not always occur in the wheelpaths, where texture is currently measured.

Detection of localised variability requires more detailed information than is provided under the current SCANNER specification. Current texture measurement systems could readily provide data at shorter intervals, e.g. 1m rather than 10m, although the implications for increased measurement uncertainty would need to be considered. However, detection of localised defects also requires more information about the variability of texture depth across the lane width, and this could potentially be achieved using existing equipment for measuring road profile (road shape).

The current SCANNER specification requires transverse and longitudinal profile to be measured and, at the outset of the project, all the accredited systems used a "profile beam" system consisting of multiple profile lasers to achieve this. These systems have the capability of detecting features with shorter wavelengths than the road profile information that is currently delivered, although they do not currently match the performance of the texture profile lasers in this respect. This section investigates whether data from a profile laser system can improve the detection of deteriorating surface condition related to the presence of localised texture defects.

5.2 HARRIS Profile laser system

The Highways Agency Road Research Information System (HARRIS1) collects video images and laser measured data relating to the texture, profile and geometry of the road and is used as the reference device for the accreditation of SCANNER and TRACS survey vehicles.

HARRIS1 has two texture lasers (nearside wheel path and centre) which operate at 64kHz and collect texture profile information at 1mm intervals. This is stored as texture profile and subsequently processed to give the sensor measured texture depth (SMTD) or mean profile depth (MPD). A profile beam is used to assess the overall shape of the road including the measurement of rut depth. This consists of 25 lasers spaced to measure the full width of the lane. Typically, these 25 lasers collect information at 100mm intervals which is then processed to give the shape and geometry of the road.

The HARRIS1 profile system lasers operate at 16kHz and so, at maximum resolution, can provide a measurement every 1/16,000th of a second. At a survey speed of 100km/h this corresponds to an achievable sampling interval of just below 2mm. It should be noted that the data collection system must also have sufficient bandwidth to be capable of recording with signals of this frequency. Although not meeting the specification to deliver MPD, this performance is as good, or better than, the high speed texture meters used on trunk roads prior to the TRACS contract in 2000.

5.3 Capability for measuring texture information

The first step to assessing the suitability of the profile lasers system for texture measurement was to carry out controlled measurement at TRL facilities. In one experiment, HARRIS was driven over a texture mat, consisting of an aluminium step followed by a set of ridges in a saw-tooth formation. Figure 5-1 shows the processed data from the profile laser system in blue, and the raw profile data in orange. The texture mat is clearly visible in both lines, between 4 and 6m. The profile lasers measure their height above the ground; this raw data is the orange line. In normal use, this raw data is processed using additional information from the inertial system that describes the movement of the profile beam through space. When the laser measured distances are processed in this way, the distances are inverted and adjusted to give the height of the road relative to a reference level and the slope in the road surface can be seen from the blue line. However, this processing also reduces the number of data points by a factor of 16, and so the raw, unprocessed data has been used for the purpose of the following work.

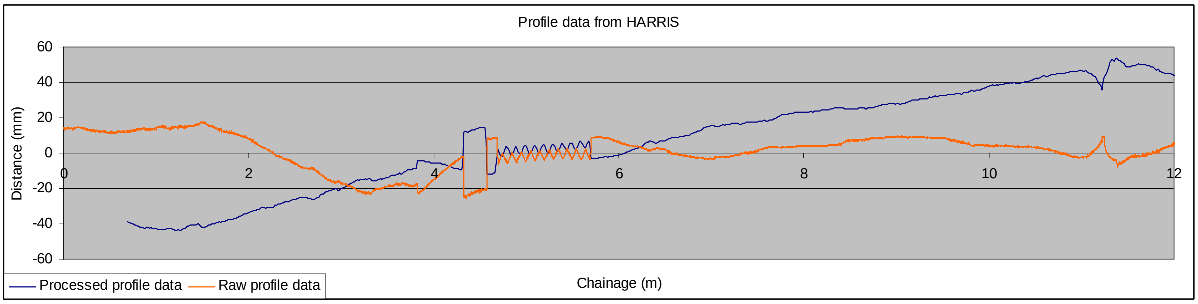


Figure 5-1 Graph showing profile data

Texture is generally reported as a measure of the variation in surface profile over relatively short distances. As texture measurements do not need to take account of larger changes in the road geometry, the raw data, uncorrected for inertial effects, should be useable for this purpose. To test this, additional software was written to handle the large raw data files (for every metre there can be more than 1100 individual measurements) and to create texture measurements from all 25 lasers.

The two texture lasers, mounted in the nearside wheel path and in the middle of the vehicle, are approximately aligned with profile lasers 7 and 13, respectively. Short HARRIS surveys were carried out on the TRL research track to determine whether the texture measurements from these profile lasers bear good resemblance to the two texture lasers. Figure 5-2 shows extracts from a survey carried out with the profile system recording interval set to 14.8mm. By retaining raw data collected by the lasers, this interval is reduced by a factor of 16 to just less than 1mm, which is then comparable to the texture laser system. (This resolution can only be achieved when surveying at low speed.) The two blue lines show the texture readings produced from the nearside (top line) and middle (bottom line) texture lasers, and the two orange lines show the texture readings produced using raw data from laser 7 (top line) and laser 13 (bottom line) of the profile lasers system.

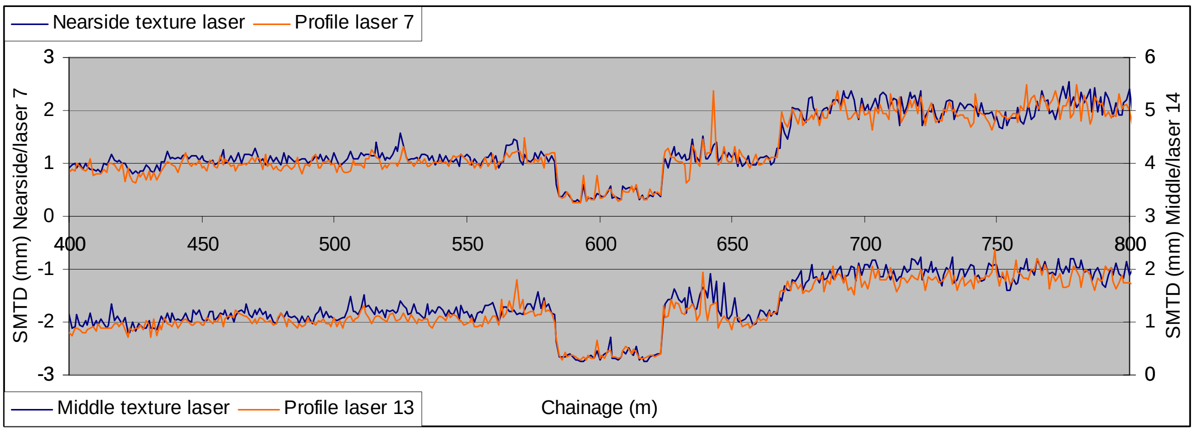


Figure 5-2 Comparison of measurements using texture lasers and profile lasers

While there are some differences, the texture measurements from the profile lasers are broadly similar to those from the texture lasers. Several repeat runs were made with different recording intervals, to determine the effect of vehicle speed. The shorter the interval, the slower the vehicle must go in order to record, with the shortest being 14.8mm at approximately 20km/h maximum speed. This is not practical for network surveys, so speeds up to 50km/h with its associated interval of 36.9mm (approximately 2.5mm in raw data mode) were tested. When texture from profile lasers is plotted against texture from texture lasers, a near 1:1 correlation is achieved for all speeds tested, and no significant advantage is shown by the shorter interval. Later road trials confirmed this to be generally the case, however some exceptions were noted. In some cases this seemed to relate to the presence of lighter or shinier road surfaces.

5.4 Detection of localised defects

The next stage of investigation was to survey local roads where visible texture deterioration was present. Longer surveys were made of roads local to TRL, selected to include locations where the surface texture was deteriorating. Surveys were carried out with recording intervals of 36.9mm (found earlier to be sufficiently accurate) and 100mm (the current standard operating interval, achievable at normal survey speeds). During this investigation, it was found that measurements taken using the 100mm recording interval, when processed as raw data at a separation of 6.25mm, gave texture results matching the texture lasers as closely as with shorter intervals tested. Using the longer interval reduces the amount of data collected, the size of data files, and the time in processing the results.

5.4.1 SMTD values from multiple measurement lines

When readings from all 25 lasers are considered simultaneously it is possible to create a texture map of the whole pavement width. The examples in Figure 5-3 show matrices of values for two short sections. Longitudinally, the values are averages over 1m lengths and transversely each cell is given a width according to the spacing of the 25 lasers. In each case, SMTD values below 0.4mm are shaded red, values between 0.4mm and 0.6mm are shaded orange and values above 0.6mm are shaded grey.

In the first example (the left hand matrix, and the top photograph) the end of the section of high friction surfacing and even the arrow further on can clearly be seen in the data. In the photograph a strip to the right of the lane is apparent, that appears smooth in comparison to the rest of the surface; this can also be detected in the data as lower texture. The low texture of the HFS and of the arrow is typical of these materials and is probably not a sign that the surface is deteriorating. Such false positive regions of low texture will have to be catered for. Notice also that in both cases, the far left of the matrix of data has very low readings which probably correspond to the concrete kerbing. In the second example, a region of almost complete aggregate loss to the right of centre in the lane can be seen in the photograph and is picked up in the data. Deterioration of this type would not necessarily be detected by measurements taken in the nearside wheelpath or middle of the lane.

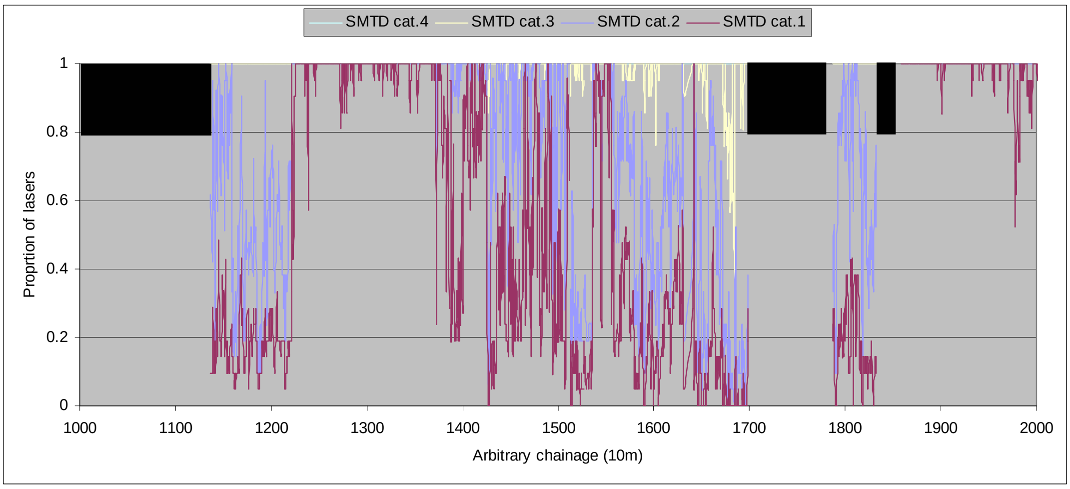
This type of texture map gives a visual representation of the surface of the road that could be studied by engineers before visiting a site. However, this type of presentation is more suited to site investigation than to network analysis, which would be rather time consuming and requires a large amount of data to be imported into a pavement management system. Therefore, there is a need for a way of flagging a particular stretch for closer inspection.

Figure 5-3 Example matrices of SMTD texture values and illustrative photographs

Using texture across the full width allows the proportion of the road width in poor condition to be assessed instead of relying on one single, narrow, laser path. Figure 5-4 shows the proportion of the road width falling into the different condition categories defined in Table 3-3. Figure 5-5 shows the corresponding incidence of surface deterioration noted in the CVI survey. Following the earlier comparison of CVI data against nearside texture depth measurements (section 3.4.7) it was noted that the limited correspondence between the location of CVI defects and areas of low texture depth might be improved if there were more lines of data. This appears to be bourne out by this example: there is a promising agreement between the two graphs:

- Between 1250-1400m and 1850-2000m, almost the whole road width in category 1 (high texture depth; shown below the dark red line) and is therefore likely to be in good condition, and there is no recorded surface deterioration in the CVI survey.
- Between 1150-1250m, a low but measurable proportion of the road width is in category 1, but a greater proportion is in category 2 (below the blue line) or category 3 (above the blue line). At this location severe surface deterioration was noted in several places on the CVI survey.

- At several locations between 1500-1700m most of the road width falls into category 2 (below the blue line) or 3 (above the blue line; below the yellow line) but some of the width is measured as category 1 (below the red line) and category 4 (above the yellow line). For some of these locations surface deterioration was noted in the CVI survey.



Shaded black blocks where there is no corresponding HARRIS data

Figure 5-4 Texture categories from HARRIS survey

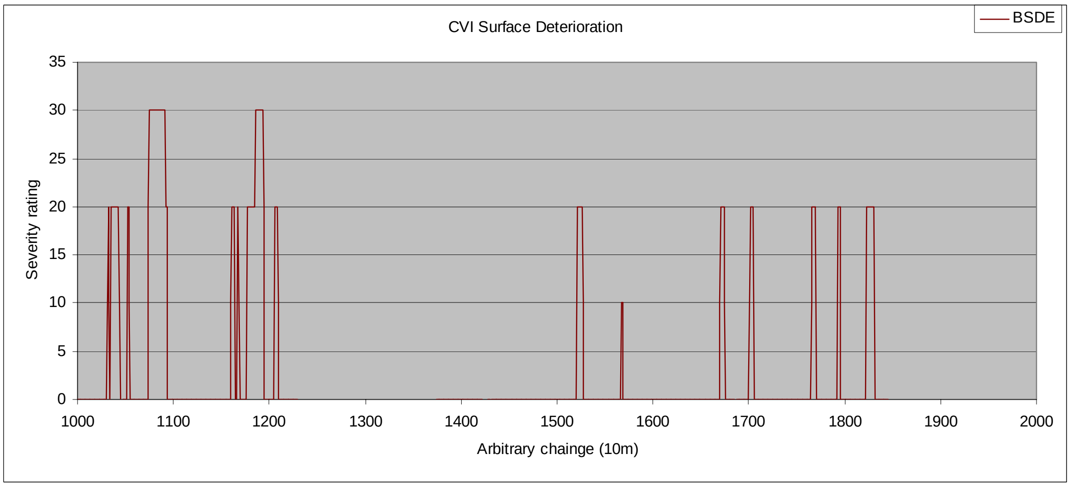


Figure 5-5 CVI surface deterioration

It is notable that the areas where no deterioration is noted are characterised by category 1 (high) texture depth across the whole road width, whereas areas that are deteriorating have a range of texture depth from category 1 to category 4 across the road width.

5.4.2 Variance of SMTD values

The previous section suggested that a measure of the transverse variability of the texture depth may improve the identification of sections with deteriorating surface texture compared with using a threshold based only on the average texture depth measured in one line. As noted earlier, even setting a very low threshold for average texture depth identifies an unrealistic proportion of road length for further investigation.

To characterise the level and the local variability of texture depth, the average and variance of the 1m SMTD readings within a five metre moving data set was calculated using the central 21 lasers. The outside two lasers on both sides were removed for this analysis because they were considered more prone to error due to measuring concrete kerbs or white lines. Each datum therefore consists of the average or the variance of 105 individual readings over a 5m length.

Figure 5-6 below shows the variability, measured as variance, plotted against the average SMTD. Points corresponding to lengths of road with areas of high friction surfacing, as noted by the survey operator, are highlighted in yellow. Points corresponding to lengths of road noted visually as being in "poor condition" by the operator are highlighted in light blue.

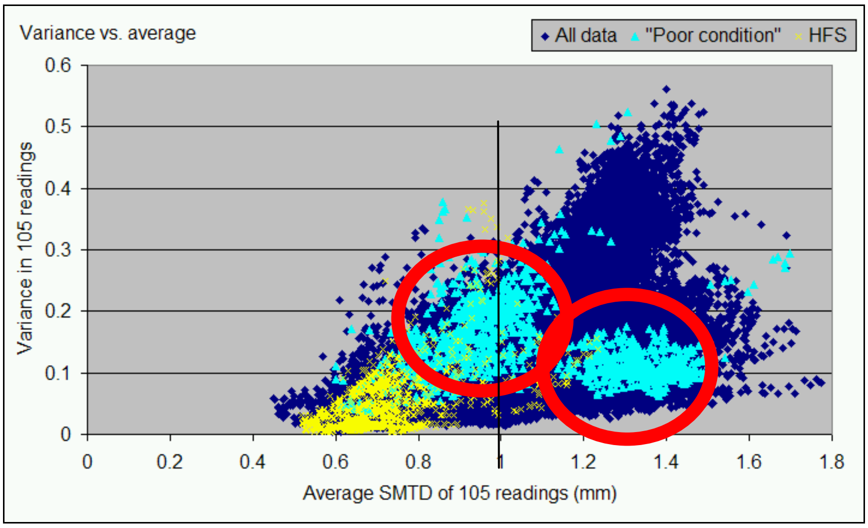


Figure 5-6 Variance vs average of laser readings

The majority of this particular survey was carried out on A-roads, which accounts for the relatively high texture depths that can be seen. High friction surfacing material has a low texture depth and, when new, is uniform across the width of the pavement so the variance is low. The majority of yellow points corresponding to high friction surfacing are therefore grouped between 0.6 and 0.8mm SMTD with a variance below 0.1mm^2.

There are two clusters of light blue points corresponding to lengths with poor surface condition, which are indicated on the plot. The first has category 2 texture (0.8-1.1mm), which is notable because this is unlikely to be flagged by a low texture threshold. Within this range of texture depth, the data in poor condition can be seen to have generally higher variance compared with the overall spread of the data. The second cluster of light blue points has high texture and low variance, and probably corresponds to lengths of good surface within the lengths identified as generally poor.

This analysis suggests that including an assessment of the transverse variability of the texture, measured as the variance of 1m SMTD values across the road width within a 5m length could improve the detection of locations with poor surface condition.

5.4.3 Characteristics of specific defects

A selection of sites local to TRL in Crowthorne were selected to determine the effect of specific texture defects such as fatting up, aggregate loss and fretting on the measured texture depth. These sites were surveyed using HARRIS and its profile measurement system as described above. A coarse visual inspection (CVI) was simulated using the colour forward and black and white downward facing video footage recorded by HARRIS. This CVI information was lined up with the texture measurements from the profile system for the full road width, and this in turn was analysed in short segments to see if there were any characteristics of specific defects, in terms of level of texture or variation in texture, that could be readily identified.

The graphs below show examples of the effects of different defects on the texture measurements. The first style of graph shows the distribution of texture values from 19 lasers (the outer three on each side having been discarded) in a 20m length (in which there are 20*19=380 readings). This graph also shows the mean, 10th and 90th percentile texture measurements (vertical blue lines), the variance in the readings (open blue circle on the left axis), the skew and kurtosis of the distribution (pink and yellow circles on the right hand axis). The second graph shows the average texture in the 20m section for each of the individual 19 lasers. These are shown in blue (nearside on the right), while averages for the middle three lasers, and the four lasers in the nearside and offside wheelpaths are shown in red behind.

Figure 5-7 and Figure 5-8 show the SMTD texture values, and statistics, for a section of road identified as having no defects. The distribution of values is narrow, and the variance is accordingly low. The mean of the section is approximately 0.9mm SMTD and the texture across the width of the road is consistent, with averages for the middle and wheelpaths being very similar.

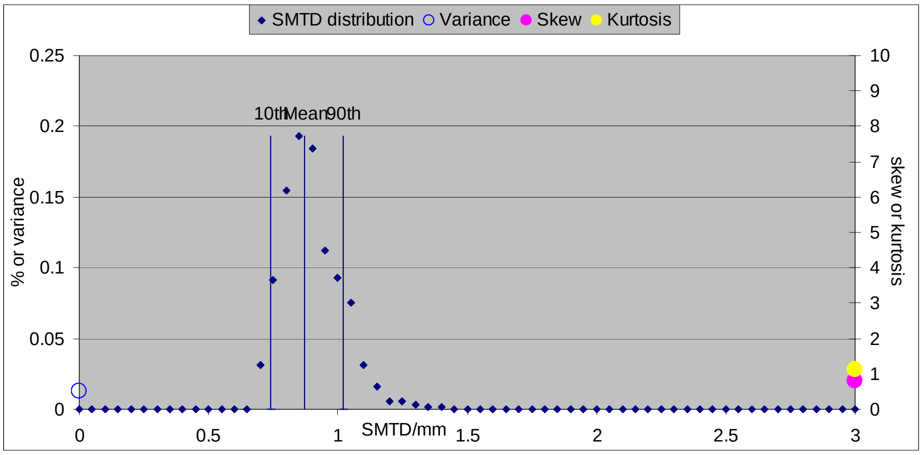


Figure 5-7 Distribution of texture depth measurements for a section with no defects

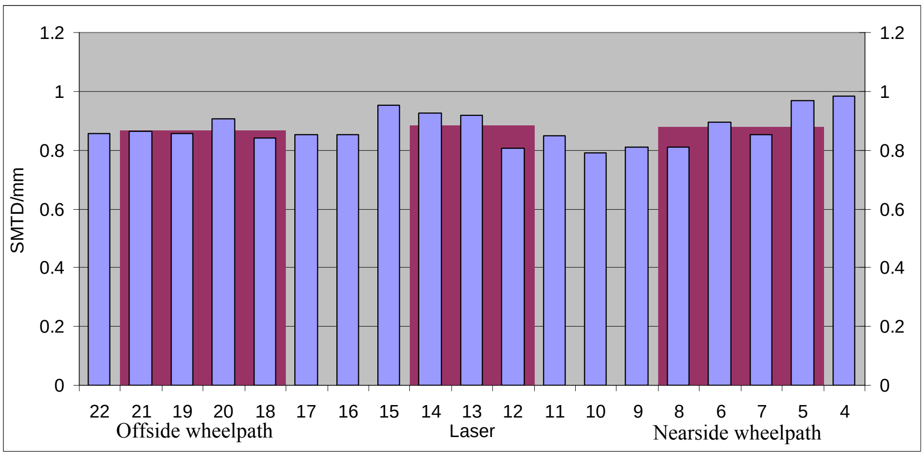


Figure 5-8 Average texture depth measured by each laser for a section with no defects

Figure 5-9 and Figure 5-10 represent a section of road that was identified as having fatting up in the wheel paths. In this case the distribution of texture is broader, with higher variance, and has a lower mean across the full road width. Inspection of the values for all the lasers shows that this lower mean is predominantly due to the low texture in the wheel paths, particularly on the offside.

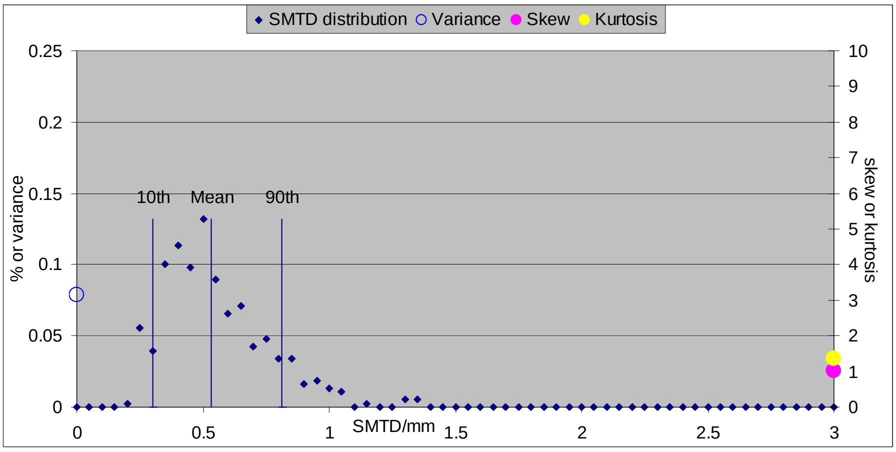


Figure 5-9 Distribution of depth measurements for a section with fatting up

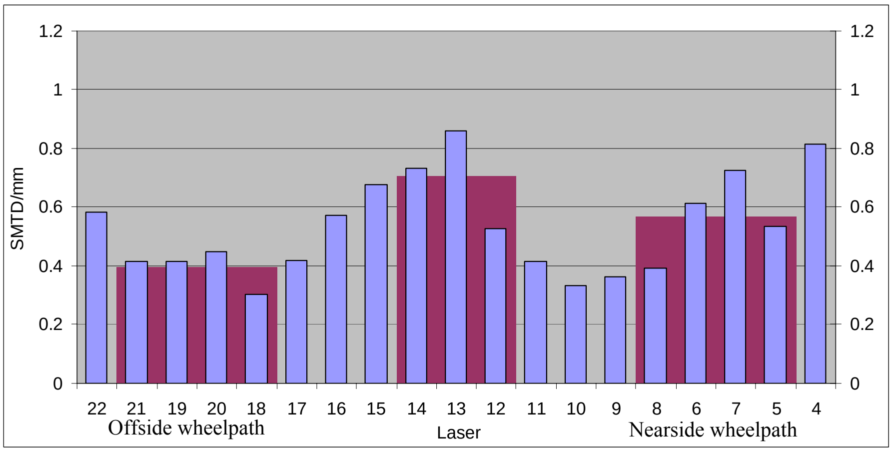


Figure 5-10 Average texture depth measured by each laser for a section with fatting up

Figure 5-11 and Figure 5-12 show that where there is aggregate loss, the texture of the road can be high, and certainly above SMTD threshold requirements. However, the distribution of texture across the road is very wide, and there is much greater variability. In this case, the middle of the road has fairly low texture whilst the nearside wheelpath measures very high texture.

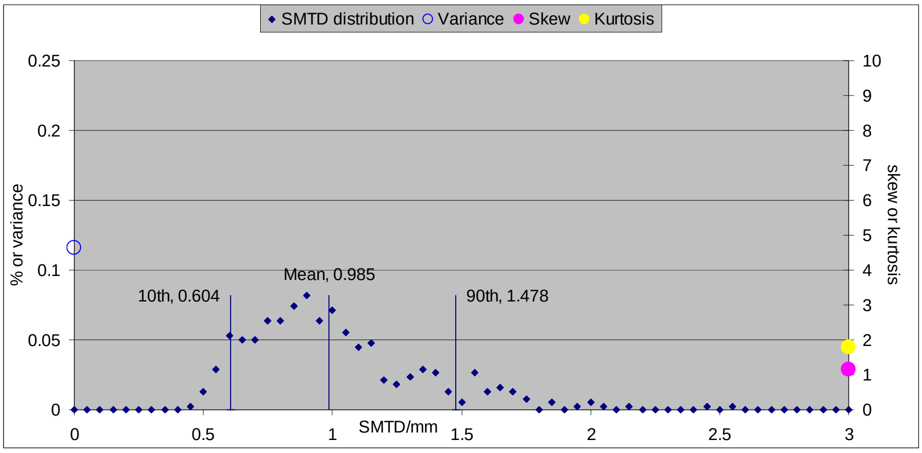


Figure 5-11 Distribution of depth measurements for a section with aggregate loss

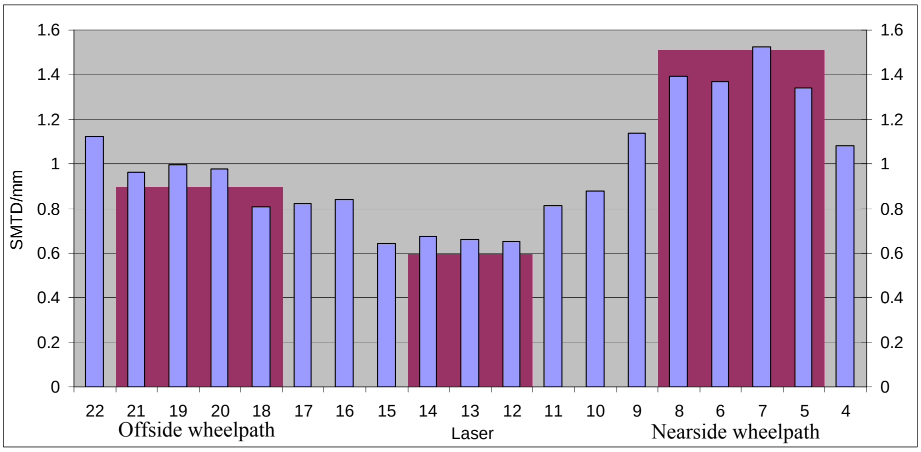


Figure 5-12 Average texture depth measured by each laser for a section with aggregate loss

In order to see how this information could be applied, Figure 5-13 shows the results of the video analysis compared with the various measurements derived from the 1m SMTD measurements each 20m for a 10km route known to have texture defects such as fatting up and aggregate loss. In the first graph, the severity of different defects is measured subjectively, with the lower values (ranging from 1.4 to 2.0) indicating more severe defects. Whilst there appears to be predominantly fatting up, the results may be skewed because fatting up is more obvious from video footage than other defect types. The other graphs show:

- The average SMTD from three middle lasers minus the average SMTD from the 8 wheelpath lasers, denoted "Mid-WP".
- The variance calculated from the same 11 lasers (middle, nearside and offside).
- The average of all readings calculated from the same 11 lasers.
- The value of a combined surface texture measure that is designed to give high values where either the average texture is low, the variance is high, or the difference in texture between the middle of the land and the wheelpaths is high. The value of this combined parameter is calculated by multiplying the square root of the variance by the value of "mid-wp" and dividing by the average texture.

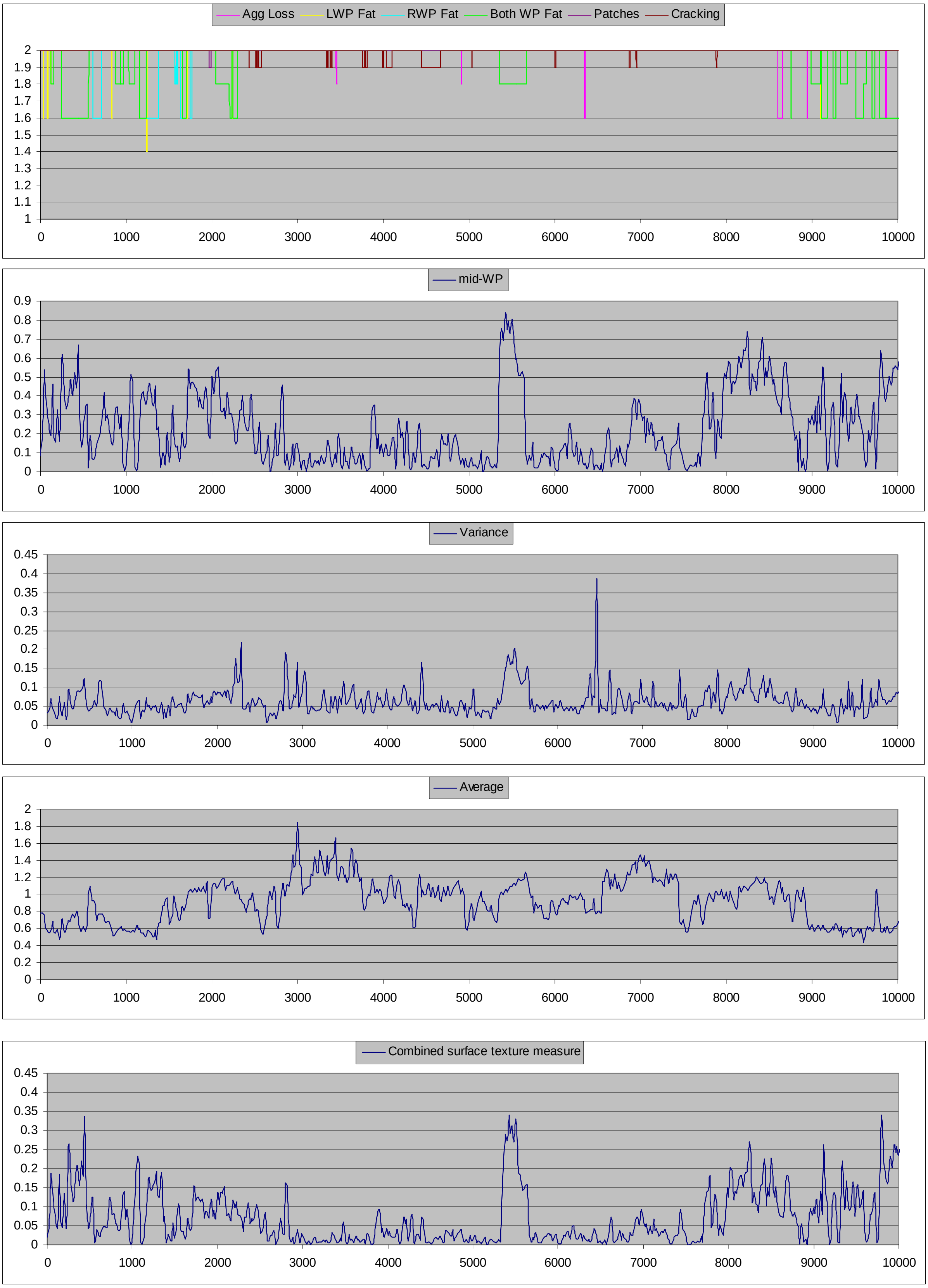


Figure 5-13 Video inspection and texture measurements

Where fatting up is present, the difference between the middle and wheelpaths is generally high. Fatting up also causes the variance in the readings to be high as well (lower SMTD in the wheelpaths causes greater deviation from the mean), but the variance is also increased coinciding with areas of aggregate loss (higher SMTD in the lossy areas causes greater deviation from the mean). The majority of the road has good (above 0.8mm) texture, but there are regions with lower texture (less than 0.6mm) coinciding with areas with noted defects.

To assess the relative performance for each of these measures of texture depth for identifying lengths with surface deterioration, thresholds were determined that identified a consistent proportion of the total dataset as needing investigation, either 17% (the proportion of the dataset where the worst condition had been observed in the video analysis) or 30% (the proportion of the dataset where anything more than the most minor deterioration had been observed). The extent of the agreement between the lengths identified from each of the texture depth parameters and the lengths identified from the video analysis is assessed in Table 5-1. Here, the true positive rate is the percentage of 20m sections with surface deterioration that were correctly identified by the texture parameter, and the false positive rate is the percentage of 20m sections where no defect was observed, that were wrongly identified as needing investigation.

Table 5-1 Performance of different texture depth parameter for identifying locations with surface deterioration

		Parameter			
		Average	**Variance**	**Mid-WP**	**Combined parameter***
Low threshold (17% of dataset)	Threshold (mm or mm^2)	0.616	0.088	0.430	0.0200
	True positive rate (%)	43.3	21.1	25.6	37.8
	False positive rate (%)	7.7	13.0	12.7	9.0
High threshold (30% of dataset)	Threshold (mm or mm^2)	0.720	0.072	0.335	0.095
	True positive rate (%)	61.8	38.2	57.2	61.8
	False positive rate (%)	15.3	25.5	17.5	15.3

Combined parameter = Sqrt(Variance)(Mid-WP)/Average

For this dataset, it is apparent that the performance of the average SMTD is the same or slightly better than that of the combined parameter. The performance of the other parameters, the variance and the difference between the centre and wheelpaths, was less good. Although it is surprising that the combined parameter does not appear to be an improvement on the average SMTD, Figure 5-13 indicates that the texture depths recorded in this dataset are generally high, and the most prevalent defect is fatting up, which will generally result in lower texture in the wheelpaths. For this particular combination, the nearside SMTD measure performs reasonably well. However, the performance of the combined parameter might reasonably be expected to outstrip that of the average SMTD on a more representative dataset that includes roads in good condition with lower texture depth. However, a wider scale, network level trial would be necessary to confirm this and to establish more representative threshold levels.

6 Noise

6.1 Introduction

Recent estimates indicate that more than 30% of EU citizens are exposed to road traffic noise levels above that viewed acceptable by the World Health Organisation (WHO) and that about 10% of the population report severe sleep disturbance because of transport noise at night (European Environment Agency, 2003). A major source of road traffic noise is generated by the interaction of the vehicle's tyres with the road surface (tyre/road noise) and from contact between the vehicle's chassis and the suspension (body noise), particularly in the case of commercial vehicles travelling on poorly maintained roads.

Noise is, by definition, sound that is undesired or unwanted by the recipient. Its measurement therefore involves an understanding of the physical attributes of the sound being emitted and the effects that it causes to individuals that are exposed to it. Consequently, the evaluation of road traffic noise involves relating physical measures of the sounds emitted by road traffic with results from attitude surveys designed to assess annoyance or the disturbance that it causes. The evaluation is complex requiring not only an understanding of how sound is generated and propagates but also on the physiology of the human ear, the environment of where and when the sound is perceived and on the activity of the recipient and their attitude towards road traffic and their neighbourhood.

To assist road engineers in understanding these complex issues, this report reviews some of the key issues. It begins by describing the basic noise sources on a vehicle and how their emission levels contribute to the overall traffic noise level depending on vehicle type and operation. This is followed by a brief overview of the mechanisms involved in the generation and propagation of tyre/road noise, highlighting the importance of surface texture, aggregate size and surface unevenness on noise emission levels, including some examples of the acoustic performance of road surfaces that have been assessed using the method adopted in the UK Highway Authorities Product Approval Scheme (HAPAS) system (British Board of Agrément, 1998). The next sections describe experiments that were carried out on the TRL test track and along the A325 near Farnham in Hampshire, including the methodology and results. The aim of these experiments was to examine the relationship between body noise emission levels and indicators that could be related to the surface profile.

In addition, two Appendices have been included. The first, Appendix C, provides the reader with background information on the noise indicators used for describing noise disturbance from road traffic noise and the impact of the recent EU Directive requiring the production of noise maps and action plans to reduce noise disturbance, particularly from road traffic (European Commission, 2002). The second, Appendix D, lists all the agglomerations that have been selected for noise mapping based on population size.

6.2 Noise sources relating to road traffic

Road traffic noise is the accumulation of noise emissions from all vehicles in the traffic stream. Each vehicle has a number of different noise sources, which when combined give the total vehicle noise emission. This section of the report provides the background information that describes the various noise sources associated with vehicle noise emissions.

The main noise sources on a vehicle are the power unit (engine, air inlet and exhaust), cooling fan, transmission (gearbox and rear axle), tyre/road surface interaction, aerodynamic, brakes, body rattles and payload. In general, sources associated with the power unit and transmission up to the layshaft are referred to as power train or propulsion noise. All other sources are referred to as rolling noise. Providing the vehicle and road pavement are well maintained and vehicles do not greatly exceed the legal speed limit, the dominant rolling noise source is from tyre/road noise.

The relative importance of propulsion noise and tyre/road noise depends on the type of vehicle, the vehicle's speed, the way the vehicle is driven and the acoustic performance of the road surface. This is relevant because using quieter surfacing materials will mainly influence the tyre/road noise component of the total noise emissions. The maximum benefit from quieter surfacings will therefore be obtained in locations where the tyre/road noise component is greatest.

Propulsion sources are primarily controlled by the vehicle's engine speed whilst tyre/road noise is controlled by the vehicle's road speed. Under constant road speed operation, Table 6-1 provides an indication of the relative contribution propulsion noise and tyre/road noise make to the overall pass-by noise level for three categories of vehicles. Vehicles types within each category are regarded as similar in noise emissions.

Table 6-1: Contribution to overall noise level from propulsion and tyre/road noise sources for different vehicle categories at constant speed

Vehicle speed (km/h)	Contribution from propulsion (P) and tyre/road (R) noise sources expressed as a percentage to overall noise emission for each vehicle category at constant speed (%)[1]					
	Category 1 Light		Category 2 Medium heavy (2-axle)		Category 3 Heavy (>2-axle)[2]	
	P	R	P	R	P	R
40	40	60	90	10	80	20
100	20	80	70	30	60	40

[1] Values based on source noise algorithms developed for the HARMONOISE model[5].
[2]Values calculated assuming a 4-axle vehicle

For category 1 vehicles, which include cars and car-based vans, propulsion noise contributes about 40% of the acoustic output at low speeds (40 km/h) compared with only about 20% at higher speeds (100 km/h). Clearly, at the higher speed, the tyre/road noise component for category 1 vehicles is the dominant noise source and provides a significant contribution at lower speeds. For category 2 vehicles, 2-axle medium heavy vehicles including buses, propulsion noise is the dominant source, particularly at lower speeds (40 km/h), contributing about 90% of the acoustic output. A slightly lower contribution, about 80% at low speeds, is shown for propulsion noise from category 3 vehicles, heavy vehicles with more than 2-axles. For both heavy vehicle categories, as vehicle speeds increase the distribution of acoustic energy shifts towards tyre/road noise but, at 100 km/h, the contribution from the propulsion noise, although reduced, is still the dominant noise source at about 60% to 70%. The slightly higher contribution from the tyre/road noise for category 3 vehicles compared with category 2 vehicles, illustrates the influence of the extra number of tyres on category 3 vehicles.

The above example is based on the HARMONOISE model for a particular reference surface (Jonasson et al, 2004). It should be noted that the relative contributions of propulsion and tyre road noise for other types of surface may be different. However, it is clear that, for a road where the traffic consists mainly of heavy vehicles and where traffic speeds are low, the acoustic performance of a surface designed to reduce tyre/road noise would provide little benefit in reducing overall traffic noise levels.

This example is also based on vehicles travelling at a constant speed. For situations where traffic is congested and where vehicles are not travelling at constant speed, the contribution from propulsion

[5] The HARMONOISE model is a traffic noise prediction model that has been developed for widespread use across the EU for the purposes of noise mapping.

noise sources will be more dominant than that illustrated above and therefore, for these conditions, the acoustic benefits from low-noise surfaces tend to be reduced.

6.3 Tyre/road noise

Tyre/road noise is the result of a complex interaction between the rolling tyre and the road surface. It is a major cause of noise from road traffic particularly for vehicles travelling at moderate to high road speeds as illustrated in the previous section. The main factors which influence tyre/road noise include the design of the tyre, the way the vehicle is driven and the road surface. Of these, the engineer can influence the the road surface and vehicle speed. This section considers how the design and construction of the road surface can affect both the generation and propagation involving several complex mechanisms, which will now be briefly described.

6.3.1 Mechanisms noise generation and amplification

Tyre/road noise is considered to result from a combination of physical processes that are categorised by convention into three distinct classes of mechanism. These are:

Impacts and shocks essentially consisting of the excitation of the tyre tread elements as they come into contact with the road surface, the vibrational response of the tyre carcass, and the subsequent radiation of sound by an area of the vibrating tyre.

Aerodynamic processes by which movement of air in the cavities of the tread pattern causes noise to be generated, principally at the contact area. Of these processes the most commonly cited is referred to as “air pumping”. This involves the sudden outflow of air trapped in the grooves of the tread pattern or road surface texture when the tyre comes into contact with the road surface, and the sudden in-flow of air when the tyre lifts away from the contact area.

Adhesion and micro-movement effects whereby tyre vibrations are induced by the frictional forces created in the contact patch between the tyre and road surface. When the tyre flattens in the contact patch, the continually changing radial deflection produces tangential forces between the tyre and road. These forces are resisted by friction and tyre stiffness, and any residual forces are dissipated by slip of the tread material over the road surface. Forces comprised of hysteresis and adhesion components control friction between the tread and the surface. The hysteresis component of tyre/road surface friction is largely controlled by the surface macrotexture, which comprises texture wavelengths corresponding to the size of the aggregate used in the surface material.

It is reckoned that for standard rolling conditions the tyre/road noise is mainly composed of "impacts and shocks" noise and "air pumping" noise, with the first mainly occurring below 1000 Hz and the second mainly occurring above 1000 Hz.

Amplification. Noise generated at or near the contact patch can be exaggerated due to the shape of the region between the tyre and road surface immediately to the rear (or front) of the contact patch. In this region multiple reflections between the tyre and road surface occur which focus the sound. This process is referred to as the “horn effect”

6.3.2 Propagation

In general, noise radiating from a sound source into a free space attenuates with distance from the source, with the rate of attenuation dependent upon the shape of the wavefront. For an idealised acoustic point source the sound waves propagate along a spherical wavefront and the sound pressure decreases according to the inverse square law. Road vehicles cannot be described as acoustically ideal point sources, but a similar attenuation function can be obtained at relatively long distances from a road for isolated vehicle noise although there are some important limitations.

When a source and a receiver are located above a flat surface, reflections from the ground plane occur. When the surface is perfectly reflective, the reflected acoustic rays appear to come from an image source located below the surface of the ground, as shown in Figure 6-1(a). When the surface layer is porous, additional factors may need to be taken into account. Figure 6-1(b) shows the principal acoustic ray paths governing wave propagation from a source to the receiver located above a porous surface layer.

To determine the acoustic field strength at the receptor for both these situations it is necessary to determine the phase and amplitude of the direct and reflected waves and then combine these components taking account of any phase interactions (i.e. interference) that occur. The important factors affecting this combination are the type of ground (which, if porous, can have a significant affect on the phase of the reflected waves), the source and receiver heights and the source-to-receiver distance.

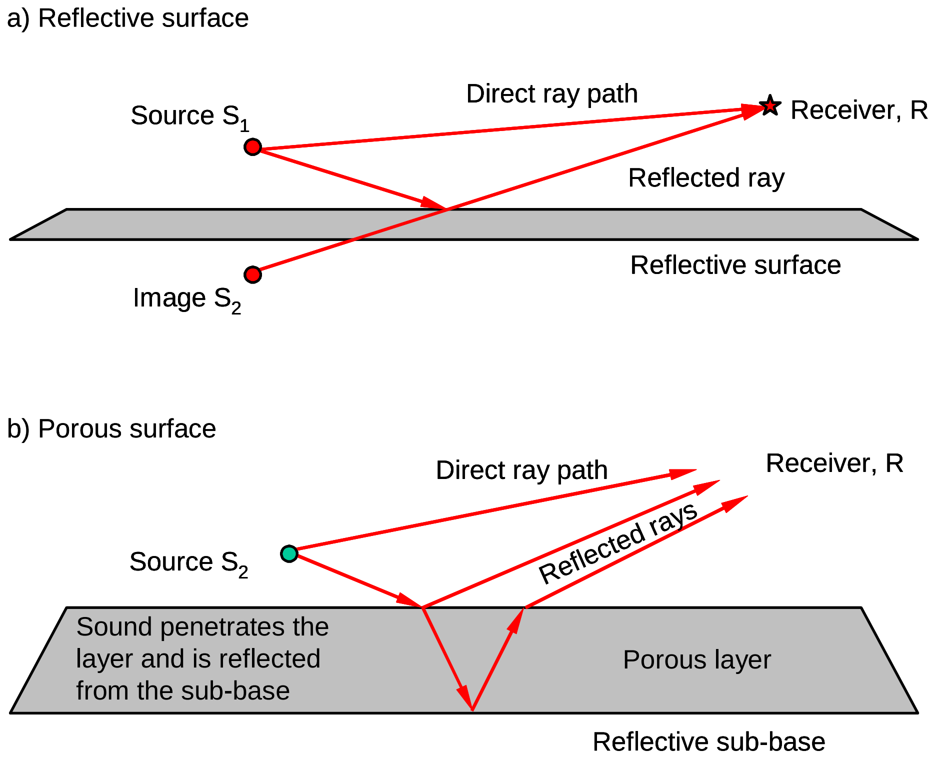


Figure 6-1 Geometry for a source and receiver in the vicinity of a ground plane

For a highly reflective surface (i.e. with low porosity) and when the path difference between the direct and reflected wave is small, then interference only occurs at relatively high frequencies and can be ignored for most practical applications. Under these conditions the sounds arriving from the two paths will add together to give a 6 dB(A) increase over the free field for point source radiation. When the surface layer is porous, or where the path length difference is large, then interference will occur at lower frequencies and typically, for vehicle noise source-to-receiver geometries, destructive interference will generally occur in the frequency range 250-1000 Hz. The frequencies and amplitudes of these important interference effects depend greatly upon the acoustical properties of the surface layer and the angle of incidence of the reflected wave.

6.3.3 Influence of surface texture

The road surface profile can be visualised as a continuous series of peaks and troughs which may typically be randomised or alternatively reasonably well defined as in the case of transverse textured surfacings. Nevertheless, any type of profile shape can be described as the summation of a number of sinusoidal variations differing in both amplitude and wavelength. This process of reducing a complex profile shape into its component cyclic waveforms is known as “Fourier Analysis”, each waveform has associated with it a texture amplitude (a mm) and texture wavelength (λ mm).

Work carried out by Sandberg and Descornet (1980) and later developed by PIARC (1987) identified certain ranges in texture wavelengths that are influential on the surface characteristics related to noise, tyre rolling resistance and skidding resistance (Figure 6-2).

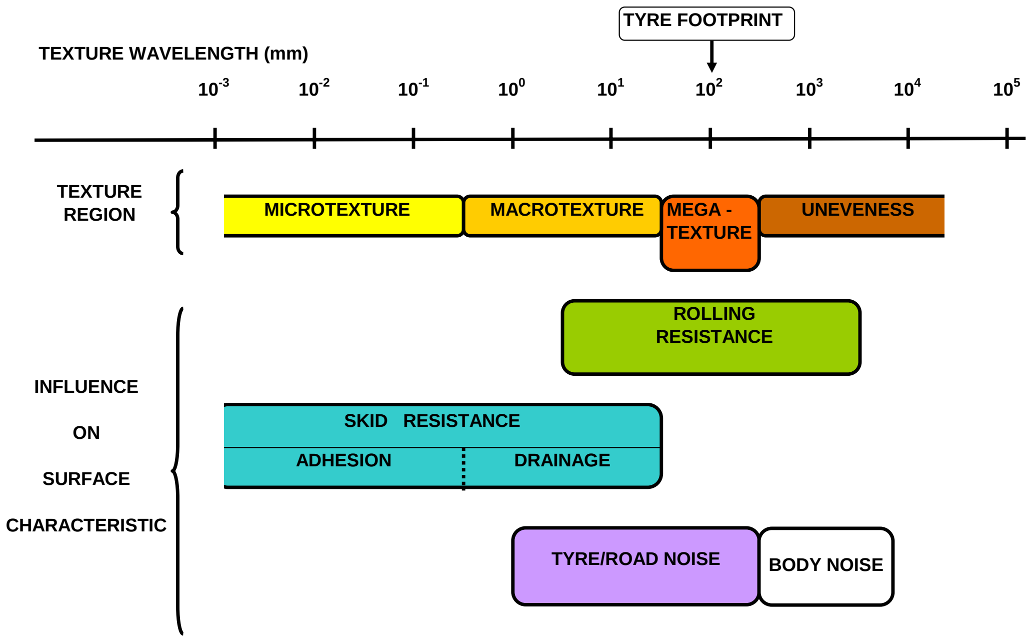


Figure 6-2 Influence of surface texture on the characterisation of road surfaces

It was found that it is convenient to divide the range of texture wavelengths into four regions, shown in the upper half of Figure 6-2. These texture regions have been defined by the texture wavelength (λ mm) of the surface irregularities as follows:

- Microtexture: λ < 0.5 mm;
- Macrotexture: 0.5 mm < λ < 50 mm;
- Megatexture: 50 mm < λ < 500 mm;
- Unevenness : λ > 500 mm.

The lower half of Figure 6-2 illustrates the approximate range in texture wavelengths that influence surface parameters including rolling resistance, skid resistance, tyre/road noise and body noise. For example, texture wavelengths in the macro- and megatexture range i.e. 0.5 mm < λ < 500 mm, are important for controlling tyre/road noise and higher wavelengths are important for controlling body noise.

However, the relationship between surface texture and tyre/road noise is complex. Research has shown that increasing texture amplitudes at wavelengths in the range 0.5 to 10 mm may reduce noise generation particularly at high frequencies generally above 1 kHz (Sandberg and Descornet, 1980). Texture wavelengths in this range accord with dimensions associated with the small asperities in the surface which are thought to have an influence on the aerodynamic mechanism of tyre/road generation, particularly air pumping. Increasing texture amplitudes at wavelengths in the range 0.5 to 10 mm reduces the air resonating in the grooves of the tread pattern of the tyre and the surface of the road as the tyre passes through the contact patch. The increase in texture allows the air trapped between the tyre and the road surface to be released less suddenly and therefore generates less noise.

In addition to this high frequency noise effect there is a low frequency component which behaves differently. Increasing texture amplitudes at wavelengths in the range 10 to 500 mm causes noise levels to increase, particularly at frequencies generally below 1 kHz. The tyre mechanism affected by texture amplitudes in the 10 to 500 mm wavelength range is thought to be associated with tyre tread impacts with the road surface. As the texture increases, the vibration levels set up in the tyre carcass due to the tread impact increases causing higher levels of noise to be generated, particularly at frequencies below 1 kHz.

These findings are difficult to translate into practical advice, except to observe that different types of surface have different texture characteristics, which translates to different properties in relation to tyre noise generation. These are discussed in the following section.

6.3.4 Aggregate size

To illustrate the influence of the size of the aggregate used in road surfaces on overall traffic noise levels the results from several noise surveys carried out by TRL have been used. From these measurements, an estimate of the relative differences in traffic noise levels for different types of surfaces was made. The results of this analysis is shown in Figure 6-3 and indicate that, for high speed roads, the relationship between the relative change in traffic noise with maximum aggregate size of the surface chipping is logarithmic and reasonably well correlated: about 67% of the variation in the estimated change in traffic noise can be explained by variation in the maximum chipping size of the aggregate. The results show that replacing a surface with maximum chipping size of 20mm, typically used in hot rolled asphalt (HRA) with a 6mm sized aggregate, the estimated reduction in traffic noise levels for high speed roads would be about 5.8 dB(A).

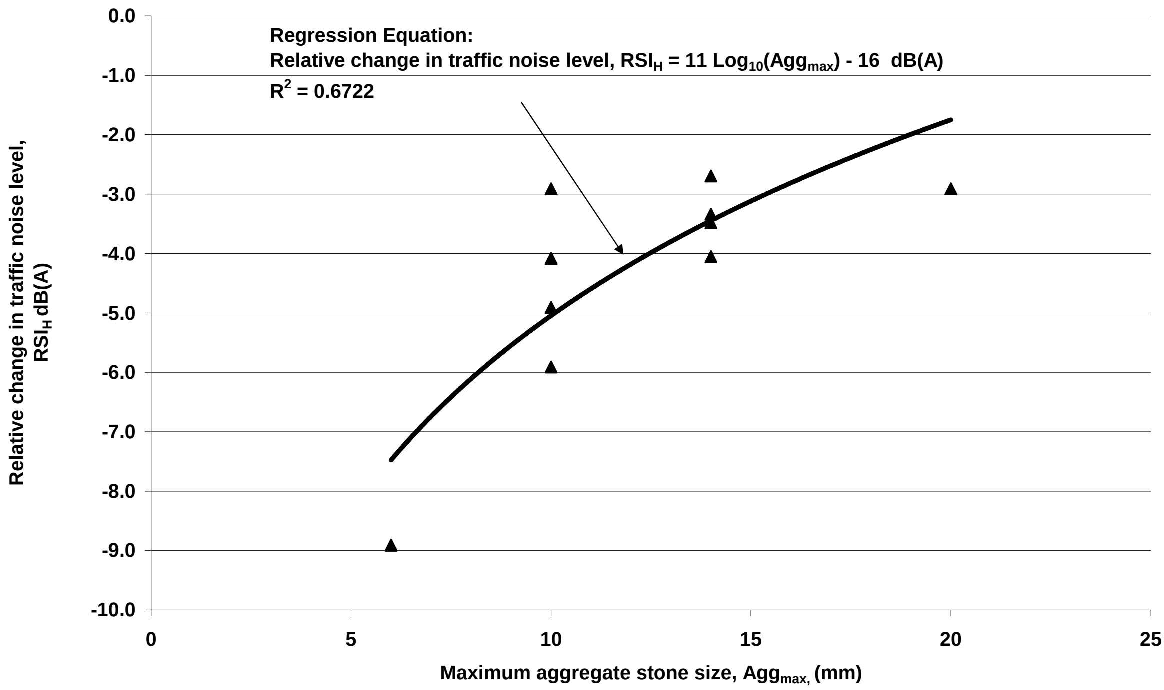


Figure 6-3 Relationship between the relative change in traffic noise and maximum aggregate stone size for high speed roads.

Results from modelling traffic noise levels using the HARMONOISE model allows the relationship between traffic noise and surface type to be examined for traffic conditions typical for lower speed roads. The results from this analysis is shown in Figure 6-4.

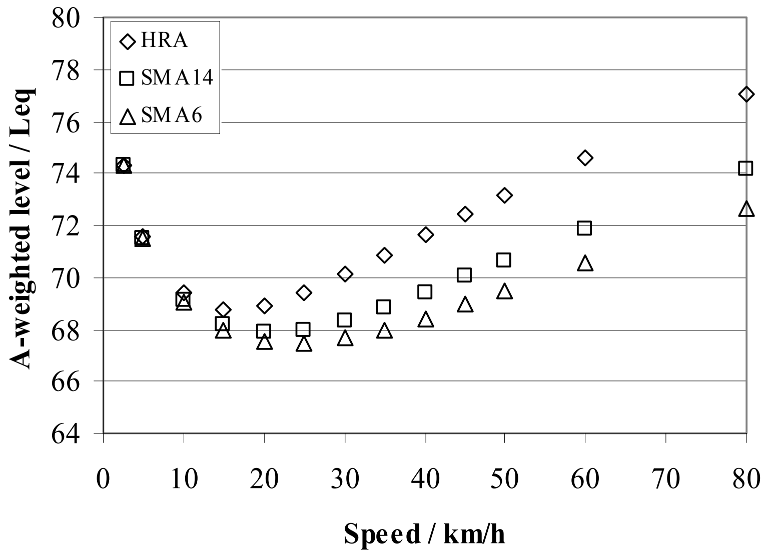


Figure 6-4 Traffic noise variation with average vehicle speed

Three road surfaces have been modelled i.e. hot rolled asphalt (HRA) with maximum stone size of 20mm, stone mastic asphalt with a maximum stone size of 14 mm (SMA14) and an SMA with a 6mm maximum stone size (SMA6). Figure 6-4 shows the trend in traffic noise levels predicted for these three surfaces. It can be seen that by replacing HRA with an SMA surface, this should deliver benefits above 15 km/h. There are advantages of approximately 3 dB(A) at speeds above 35 km/h. At 50 km/h the difference approaches 4 dB(A).

Clearly, as traffic speeds decrease the acoustic benefits achieved by resurfacing a road with an alternative surface with a lower maximum stone size reduces. The reason for this trend is due to the change in the noise contribution from the sources associated with tyre/road noise and those associated with propulsion noise discussed earlier.

6.3.5 Assessing the acoustic performance of road surfaces

Methods for assessing the acoustic performance of road surfaces were first developed in this country by TRL in the early 1970's and formed the basis of ISO Statistical Pass-by (SPB) method for assessing the influence of road surfaces on traffic noise levels (International Organisation for Standardisation, 1997). This roadside test includes the measurement of the maximum pass-by levels and speeds of a sample of light and heavy vehicles; sufficient measurements are taken to ensure the reliability of the measurements, which are normalised to standard pass-by speeds.

The Highways Authority Products Approval Scheme (HAPAS) was developed primarily with the aim of assessing the fitness for purpose of different products. New road surfaces now have to comply with the requirements of HAPAS in order to achieve certification for use in road constructions and maintenance programs. It was developed by a number of bodies involved in the management of roads that included the Highways Agency and the British Board of Agrément (BBA), which is responsible for the certification process (British Board of Agrément, 2004). In 1998 the scheme was extended to cover the type approval of proprietary thin surfacing materials, and it was decided at the time to include an optional noise test. The test procedure developed by TRL for this type approval largely follows the ISO (SPB) method.

For the purpose of classifying road surfaces in terms of their traffic noise levels it is useful to be able to compare their noise levels with corresponding levels for a given commonly used road surface type. In this way differences between the surface being tested and the reference surface readily identify whether the test surface is quieter or noisier than the reference and by how much. This approach has been used in the method employed in HAPAS by defining the noise indicator - Road Surface Influence (RSI), which is essentially the difference in noise level generated by traffic travelling on the surface being tested and the corresponding noise levels generated by the same traffic travelling on a new condition Hot Rolled Asphalt (HRA) surface. HRA was chosen as the reference surface as this surface is frequently used in the UK.

Table 6-2 provides a comprehensive list of RSI values for a range of thin surfacings that can be found on the BBA website (www.bbacerts.co.uk).

Table 6-2 Acoustic performance of a range of thin surfacings based on the HAPAS method of assessment

Surface Propriety Name	Road Surface Influence index (RSI)
Masterflex 10mm	-5.5
UL-M 20mm	-5.6
Hitex 14mm	-3.6
Hitex 10mm	-7.8
Masterphalt 10mm	-5.5
Masterphalt 14mm	-3.7
Viatex 14mm	-2.7
Masterpave 14mm	-3.7
Premierpave	-2.8
Tuffgrip 14mm	-3.3
Stratagem 10mm	-7.2
Safepave 14mm	-9.6[1]
Colrug 0/10mm	-5.1
Tuffpave 14mm	-3.3
Masterflex 10mm	-5.5

[1]The high RSI value was obtained from sites were Porous Asphalt had been overlayed with 14mm Safepave which may have influenced the results.

Clearly, from the RSI values shown in Table 6-2, thin wearing course surfaces can provide significant reductions in traffic noise levels compared with HRA e.g a reduction in traffic noise of 3 dB(A) is equivalent to halving the traffic volume and a reduction of 10 dB(A) is equivalent to halving of loudness.

6.4 Body noise

When a vehicle runs over a road surface, dynamic forces are generated as a result of the reaction between the tyre and longitudinal profile of the surface. These forces are translated into mainly vertical movements of the vehicle which are damped by deformation of the tyre and by the response of the vehicle suspension system. Body noise results primarily when these movements of the vehicle give rise to metal-to-metal impacts of parts of the vehicle.

6.4.1 Influence of surface uneveness

In the UK, newly laid roads are surfaced to a high standard of evenness and therefore would not normally cause dynamic forces to be generated in heavy vehicles that would result in significant levels of body noise. However, deterioration of the road profile, either as roads are trafficked or as a result of maintenance, can result in noticeable levels of body noise for vehicles running on uneven road surfaces. When the road surface is in poor condition i.e. when the surface contains obvious defects such as potholes, gullies, road repairs, or other surface discontinuities such as traffic calming tables and cushions, very high levels of body noise can be generated from some vehicles.

The factors of importance can be related to the amplitude and wavelength of the surface profile irregularities and the speed and characteristics of passing vehicles. Research carried out at TRL found that pass-by noise levels from vehicles travelling at steady speeds over surface irregularities designed to be representative of typical road surface features that might be encountered on public roads in poor condition were between 5 to 25 dB(A) higher than corresponding noise levels generated on a level reference surface[6] (DETR, 2000). In addition, it is known that certain surface irregularities can cause the vehicle's wheels to impact on the road surface and generate vibrations which may propagate inside nearby buildings. Although the levels of vibration are generally an order of magnitude below that which may cause building damage, nevertheless, they can be above the level of perception and when experienced can be extremely annoying.

Extending the capability of SCANNER, used for the measurement of the maintenance condition of the road network, to include a method which could assist the road engineer in identifying surface features likely to cause body noise and groundborne vibration nuisance would have significant benefits to those living alongside the road network.

The following sections describe an experiment that explores the possibility of using the longitudinal profile measurements available from SCANNER surveys to provide an indicator that would identify surface features that are typical in causing body noise in vehicles and therefore be used as a criteria for remedial treatment.

6.4.2 Experimental design

The aim of the experiment was to examine the relationship between road surface profile and vehicle noise emission levels generated by metal-to-metal impacts of parts of the body with the chassis.

The experiment used a skip truck, known to be a good generator of body noise when driven over discontinuities in the road surface. The vehicle was fitted with an accelerometer and two microphones. The accelerometer was fitted on the vehicle chassis underneath the skip, to measure vertical acceleration. The microphones needed to be placed at suitable positions on the vehicle such that the interference from both the vehicle engine and external sources were minimised. Both microphones were fitted with windshields and were placed facing the skip, one just behind the cab and the other at the back of the vehicle behind the skip. The output from both microphones and accelerometer were logged onto a PC. To provide a reference for the vehicle location, the IRIS GPS system used in the parallel road shape project (Benbow et al., 2006) was placed in the cab throughout the experiment. After the data was collected, it was aligned with longitudinal profile data from HARRIS, giving vehicle noise, chassis acceleration and road shape information at known locations.

[6] A noise level increase of 10 dB(A) is subjectively perceived as approximately a doubling in loudness

6.4.3 Track experiments

Prior to carrying out the survey on-site, a trial survey was carried out on the TRL test track to establish that the noise monitored by the microphones would be a good indicator of roadside noise levels adjacent to a surface feature that would cause body noise to be generated.

The trial on the test track was carried out in two phases. The first phase was to monitor the noise at a given reference distance from the skip truck as it was driven along a straight path at constant speed past a roadside microphone. The roadside microphone was positioned 7.5m from the centre of the wheeltrack of the skip truck as it passed the roadside microphone and at a height of 1.2m above the road surface, which is typical of the position used for assessing noise from road vehicles and used in type approval testing (ISO, 1981). The microphone was connected to a sound level meter set on FAST[7] response and configured to capture the maximum noise level dB(A). Simultaneous monitoring of the noise levels received at the two microphones together with vibration levels recorded by the accelerometer were carried out as the vehicle passed the roadside microphone. A vehicle speed radar system recorded the speed of the skip truck as it passed alongside the roadside microphone and the position of the skip truck was monitored using the IRIS GPS system. The skip truck was driven, in the appropriate gear for the designated speed, past the roadside microphone at steady speeds of 10, 20, 30, 35 and 40 mph. For each pass-by event the maximum noise level dB(A) captured on the sound level meter was recorded together with the vehicle speed. The noise and vibration levels captured on the vehicle mounted microphones and accelerometer when the vehicle was opposite the roadside microphone were recorded.

The second phase was carried out under identical conditions and procedures but with a plank, approximately 25mm thick and 150mm wide, firmly attached across the full width of the wheeltrack directly adjacent to the roadside microphone.

6.4.4 Site measurements

As part of the parallel Road Shape project (Benbow et al., 2006) sites in Hampshire had been identified and surveyed with HARRIS to monitor longitudinal profiles. After looking at various parts of the route it was decided that a route passing through Wrecclesham on the A325 near Farnham, Hampshire would be used to drive the skip truck and record noise, vibration and IRIS GPS data. The data were later aligned with the HARRIS data by matching the GPS data, to find links between road geometry and vehicle noise.

The vehicle was kept in the same gear and, as far as possible, at a constant speed. The speed of the vehicle was also calculated using the GPS position and time intervals from the IRIS. Any data where the vehicle speed was calculated to be outside $\pm$ 5mph from the target speed over continuous lengths greater than 20m was ignored. In most cases there were two runs over each section, and only data where the vehicle speed in both runs was within this tolerance was analysed. All the data was combined into one 9.2km data set on which the subsequent analysis is carried out.

Within the parallel Road Shape project, a measure was developed that predicted where the users would feel a bump-like sensation. This measure was based on the Central Difference Method (CDM) and was called the CDM Bump Measure. The CDM Bump Measure correlated reasonably well with perceived discomfort recorded during user perception studies (Benbow et al., 2006), and was therefore known to be sensitive to vertical acceleration caused in smaller vehicles. If it could be shown that this measure of surface profile was also well correlated with external measures of body noise then this would provide a convenient indicator for both internal perceived discomfort and external perception of body noise annoyance. For this study, a slightly simplified version of the CDM Bump Measure was used, namely the first derivative of the CDM (CDM_1) measured by the laser in the nearside wheelpath.

[7] The FAST response setting allows the meter to respond to sounds similar to human hearing see Appendix C.

6.4.5 Track results

The results from measurements carried out on the track are shown in Table 6-3.

Table 6-3 Roadside and on-board vehicle measures of noise and acceleration

Speed	With plank				Without plank			
	On vehicle			Roadside Mic	On vehicle			Roadside Mic
(mph)	Mic 1 (dB)	Mic 2 (dB)	Acceleration (ms^{-2})	(dB)	Mic 1 (dB)	Mic 2 (dB)	Acceleration (ms^{-2})	(dB)
10	90.8	87.5	4.8	86.9	81.4	75.8	8.2	75.5
20	93.3	90.0	5.5	87.9	85.8	79.8	20.5	75.4
30	100.2	98.7	150.1	89	88.6	81.2	27.8	79.8
35	99.2	98.1	89.1	90.1	89.3	84.6	41.4	80.4
40	100.7	100.5	286.6	93.7	90.3	86.8	59.6	82.8

The data from the two microphones on board the vehicle were found to be well correlated, independent of whether the plank is present or not. Figure 6-5 shows that both roadside and on-board measures of noise are influenced by vehicle speed, with and without the plank. It was found that, at speeds similar to the site measurements i.e. 30 to 40 mph, the differences in noise level with and without the plank measured at the roadside were in better agreement with the corresponding differences measured on-board the vehicle at position 1 than those measured at position 2. The average difference at the roadside position was 9.9 dB(A) compared with 10.6 dB(A) at position 1 and 14.9 dB(A) at position 2. This may be because the microphone at position 1 is better shielded from wind noise and other extraneous noise sources.

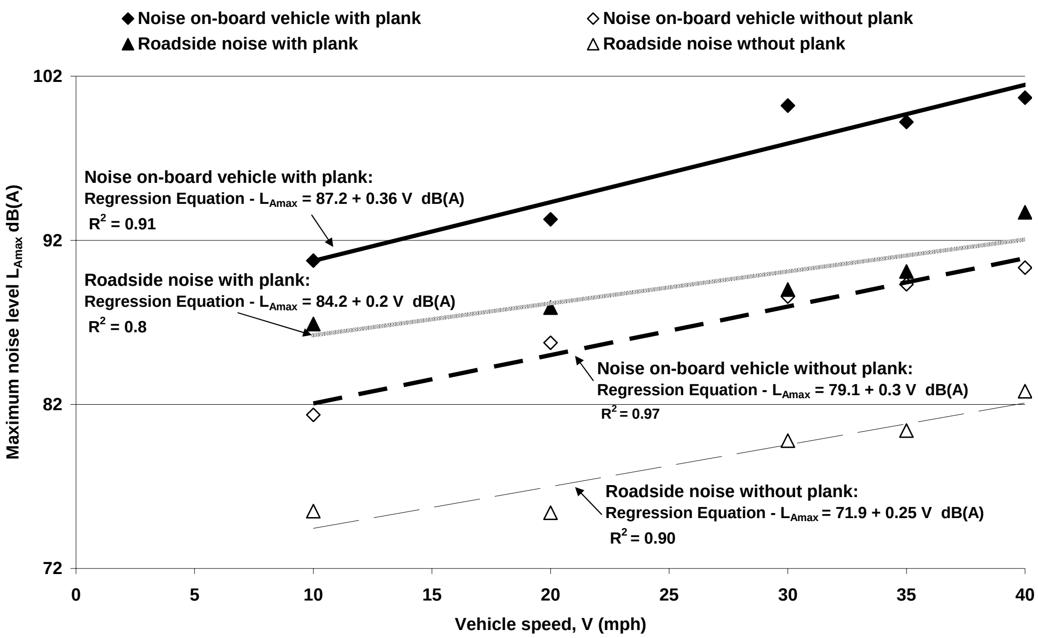


Figure 6-5 Relationship between roadside noise and on-board noise levels position 1 with speed with and without plank

Figure 6-6 shows that noise levels measured at position 1 on-board the vehicle are well correlated with those measured at the roadside.

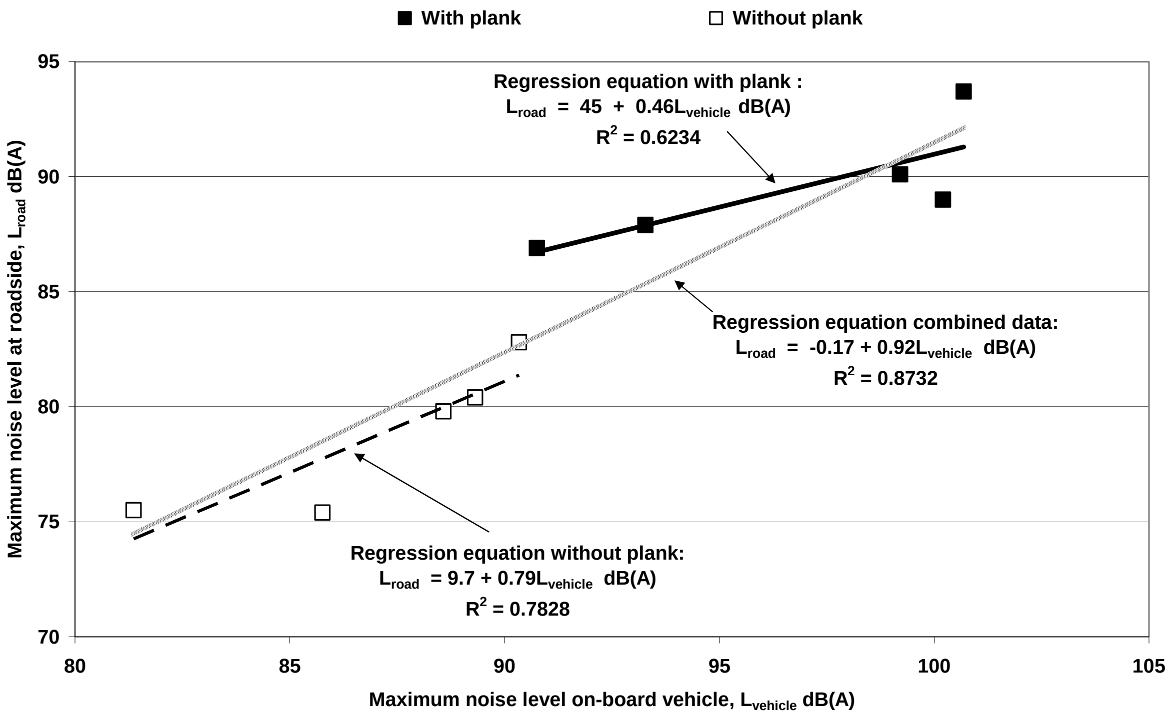


Figure 6-6 Relationship between roadside noise levels and on-board noise position1, with and without plank

The final stage of the analysis was to examine the relationship between the vibration levels measured in terms of acceleration (ms^{-2}) from the accelerometer mounted on the chassis and the noise levels recorded on-board the vehicle at position 1 for both with and without the plank. Figure 6-7 shows these relationships.

Regression analysis on the data showed that the relationship between acceleration and noise followed an exponential relationship for both with and without the plank. Interestingly, at low road speeds, 20 mph and less, acceleration levels recorded without the plank were similar to those recorded at similar speed with the plank and yet noise levels increased by about 10 dB(A). A similar increase in noise with the plank is recorded at higher speeds, but there was a significant increase in acceleration levels in this case. These results indicate that output levels from the accelerometer mounted on the chassis may not provide a reliable indicator of the influence of surface profile on noise levels at low speed but, at speeds typically encountered during the site measurements, the output from the accelerometer may prove to be a useful indicator for locating surface features which may influence noise levels.

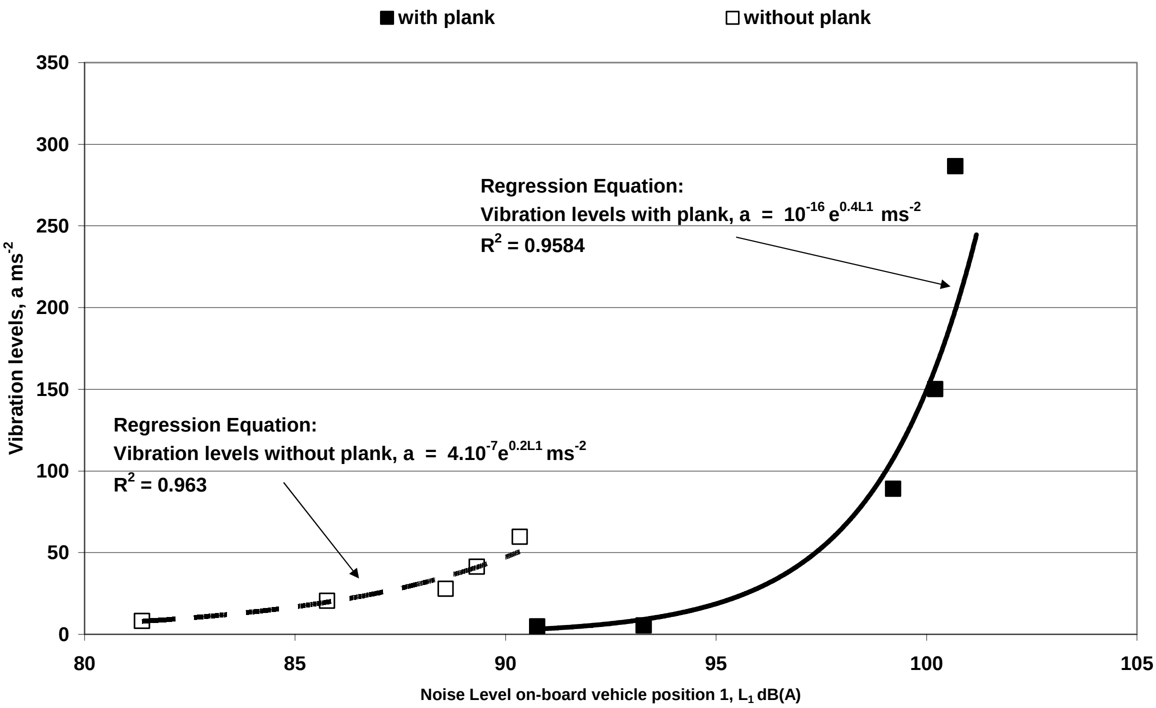


Figure 6-7 Relationship between chassis vibration levels and on-board noise levels with and without plank

6.4.6 Results of site measurements

After considering a number of road shape measurements, such as 3m variance, and texture it was verified that the first derivative component of the Central Difference Method (CDM_1) was the best measure to describe body rattle noise. Figure 6-8 shows the data recorded by microphone 1 on two runs over the same section of road and the corresponding CDM_1 data. The data is promising, showing matching peaks in both runs of noise data and in the CDM_1 data. A number of peaks have been highlighted to illustrate this. However, it can be seen that the peaks are not in identical positions, as a result of small errors aligning the data, and that there are differences in noise levels between run 1 and 2.

By visually inspecting the data set to match peaks and noting the extent of misalignment it was possible to assess the maximum error in the location referencing between the two runs of noise data, approximately 12m, and also between the noise and CDM_1 values, approximately 10m.

It was anticipated that the amplitude of the noise measured would be dependent on a large number of factors and may not be linearly related to the magnitude of the CDM_1 measure of road profile. Therefore, further analysis has concentrated on identifying the peaks in the noise data, which are likely to correspond to the greatest cause of annoyance relating to body rattle noise, and determining the extent to which these can be predicted by peaks in the CDM_1 data. Values of CDM_1 above a chosen threshold, determined as a specified percentile of the values in the whole CDM_1 dataset, were identified. The location of any CDM_1 values above the threshold was marked and the highest noise peak, from either of the two microphones, on either of the two runs, at this location was recorded. To allow for the difference in alignment of the data sets, a range of ± 5m from the CDM_1 location was allowed for finding noise peaks associated with each feature of the surface profile.

Figure 6-9 shows a short section where CDM_1 values above the 95th percentile of CDM_1 values are marked, together with the corresponding noise peaks. The average noise level for all the noise peaks identified by this process was determined, and calculated as a percentile of the total noise data set, to test how severe the noise levels were at these locations. Table 6-4 shows how the average noise level changes as the CDM_1 threshold increases from the 90 percentile value to the 99.9 percentile value.

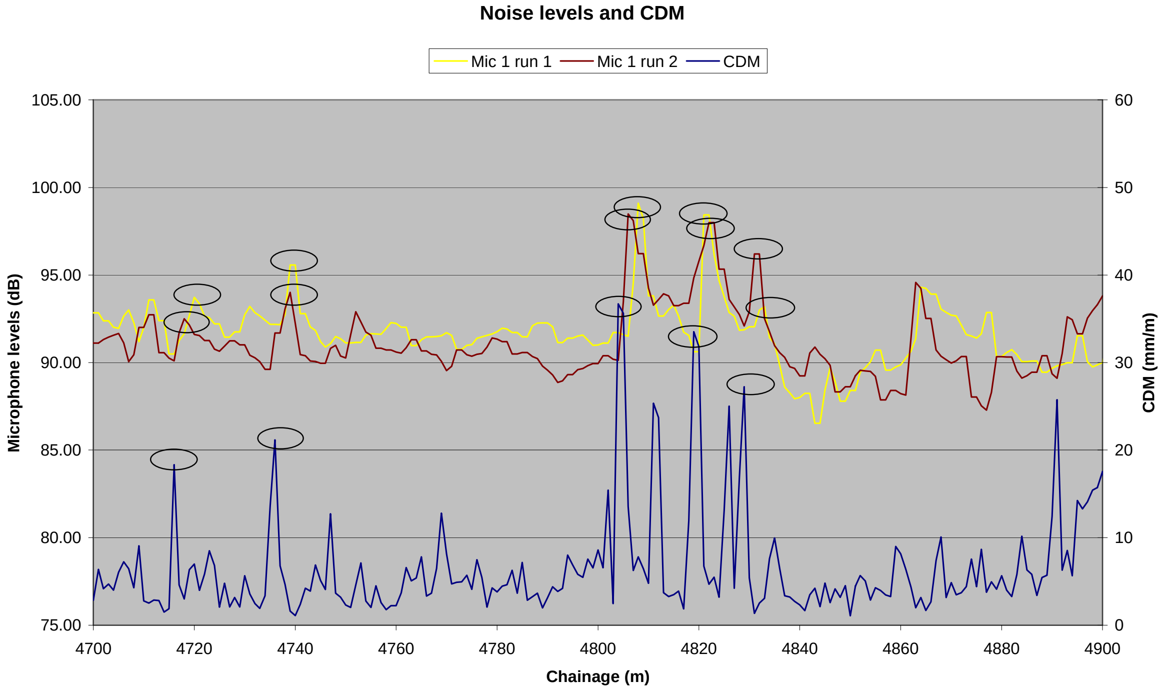


Figure 6-8 Comparison of 2 runs of noise data with the CDM_1 data over the same section of road

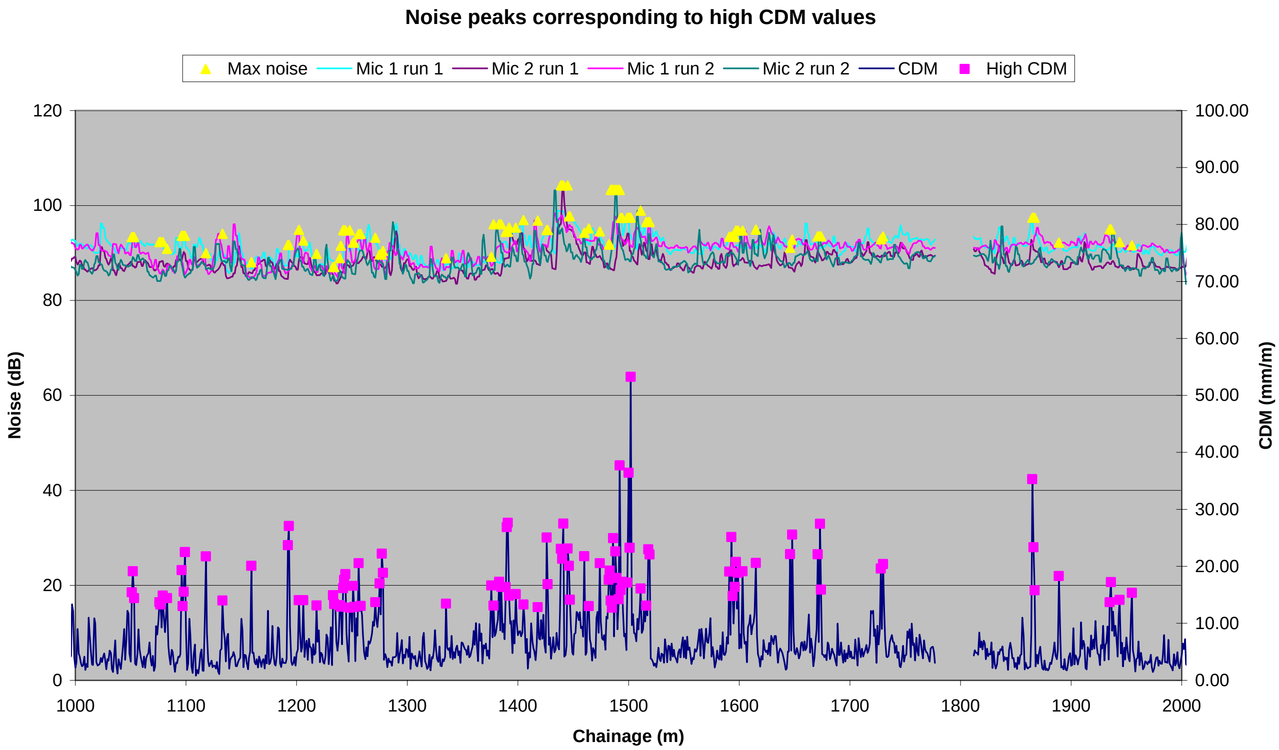


Figure 6-9 Location of CDM_1 values above the 95th percentile and the corresponding maximum noise peaks

Table 6-4 Average noise level for locations with CDM_1 values above the threshold indicated

CDM_1 threshold		Average noise level*	
Percentile of CDM_1 data set	**CDM_1 value (mm/m)**	**Average noise level (dB)**	**Percentile of noise data set**
90%	12.682	93.046	92.1%
92%	14.134	93.091	92.3%
94%	16.078	93.150	92.6%
95%	17.298	93.110	92.4%
96%	19.015	93.424	93.8%
98%	23.693	93.700	94.8%
99%	28.634	93.163	92.6%
99.5%	35.629	93.679	94.7%
99.9%	48.325	94.355	96.5%

*Average, for all locations with CDM_1 values above the threshold, of the highest noise level recorded within ± 5m of each of those locations

The CDM_1 percentile values in Table 6-4 were selected to be high, because it would be impractical to identify a large proportion of the road network potentially requiring maintenance to reduce body rattle noise. In each case, the average noise value at the locations with high CDM_1 values is within the top ten percent of the distribution of noise values. However, although locations with high CDM_1 values have, on average, high noise levels, not all locations with high noise levels were associated with high CDM_1 values. This may be because only one line of longitudinal profile data was considered in this analysis, the nearside wheel path. Applying similar CDM_1 criteria to both wheel paths may further improve the accuracy with which locations prone to generating high levels of body rattle noise can be identified.

As the CDM_1 threshold is increased, there is generally an increase in the average noise value, as shown in Table 6-4 and Figure 6-10. This strongly suggests a positive link between body rattle noise and surface unevenness, as indicated by the CDM_1. The figure shows that the top 5% of all CDM_1 values identify locations that have peak body rattle noise values with an average within the top 8% of noise measurements. For this dataset, this corresponds to a CDM_1 threshold value of approximately 17mm/m and this may be an appropriate threshold to use for identifying locations particularly prone to body rattle noise. However, this threshold would need to be verified by considering the distribution of CDM_1 values over a longer network and in more than measurement line.

The track experiments showed good agreement between the accelerometer and noise readings. Repeating the above analysis using the accelerometer readings instead of the CDM_1 values shows that the accelerometer provides a highly effective measure of body rattle noise. Figure 6-11 shows that the top 0.5% of all acceleration values identify locations within the top 0.4% of all noise readings.

This suggests that a direct measurement of vertical acceleration may provide a better indication of the potential for body rattle noise than the longitudinal profile. However, the amount of vertical acceleration produced on board the vehicle is affected strongly by the suspension characteristics of the vehicle, in this case a skip truck, and the vehicle speed, as identified above. Further work would be needed to determine whether the vertical acceleration of a SCANNER vehicle could be used as a measure of body rattle noise, particularly given the different types of SCANNER vehicle already present and the greater diversity that may be expected in future. In the meantime, the CDM_1 measure provides an acceptable measure of body rattle noise, which has the advantage of being independent of the suspension characteristics of the SCANNER vehicle.

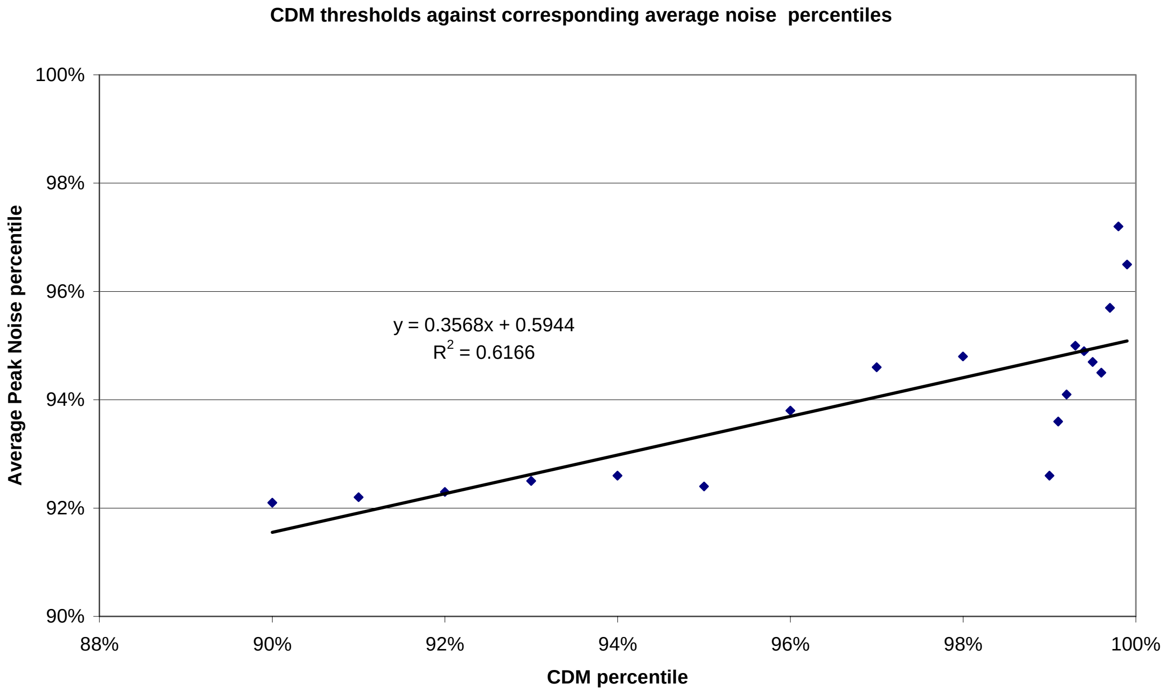


Figure 6-10 Average noise level*, as a percentile of all noise measurements, for locations with CDM_1 values above the indicated percentile of all CDM_1 measurements

*Average, for all locations with CDM_1 values above the threshold, of the maximum noise within ± 5m of those locations

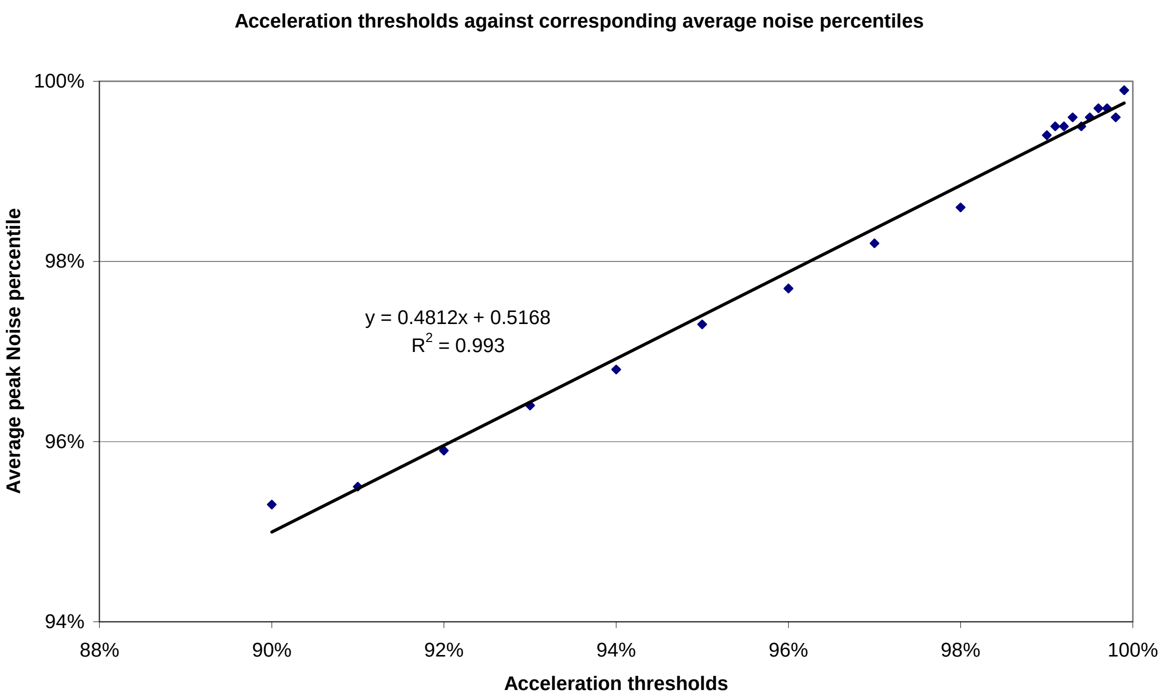


Figure 6-11 Acceleration percentiles and corresponding average noise percentiles

6.5 Summary and conclusions

This section provides background information on assessing noise from road traffic. It describes the various noise sources on a vehicle and how they contribute to overall traffic noise levels. The main conclusion relevant to local engineers using SCANNER surveys is that three sources of noise generation need to be considered:

- Propulsion noise can be a major component of the overall noise level where traffic speeds are low and/or heavy vehicles are a high proportion of the traffic. As propulsion noise is related to engine speed, it is exacerbated if the traffic is congested or the vehicle speed is otherwise not uniform, i.e. vehicles are accelerating or braking. As seen in section 6.4.6, propulsion noise is also increased where the gradient increases. Quieter surfacing materials are unlikely to be effective in reducing noise emissions where the dominant source of noise is propulsion noise. Although porous materials may help to reduce the reflected component of propulsion noise, these surfacing materials are unlikely to be suited to applications where the traffic speed is low with a high proportion of heavy vehicles.
- Tyre road noise is the dominant form of noise for light vehicles travelling at moderate and high speeds. Vehicle speed and the nature of the surface both have significant effects on the generation of tyre road noise as indicated in sections 6.3.3 and 6.3.4.
- Body rattle noise is low on roads where a high standard of evenness is achieved. On uneven roads, the vertical movements of the body produced when driving over poor profile cause significant levels of body noise. This can be identified by the first derivative of the Central Difference Method (CDM_1) parameter calculated from the longitudinal profile: in this study, locations with CDM_1 values within the top 5% were associated with an average noise level within the top 8% of noise measurements.
- The accelerometer used in the experiment give a very accurate representation of locations producing loud body rattle noise with vehicle speeds above 30mph. The top 0.5% of accelerometer values from the site experiment matched the top 0.4% of body-rattle-noise peak values. However, as well as being very sensitive to the vehicle suspension characteristics, the early tests indicated that the acceleration results were influenced by vehicle speed, and so this method is not sufficiently developed to provide a robust measure under practical conditions.

7 Conclusions and implications for SCANNER

This project has sought to establish the characteristics of surface texture and to identify how it can be measured and interpreted to assist in monitoring the condition of the local road network and identifying lengths in need of maintenance investigation. The conclusions and implications for SCANNER surveys from 2007 are as follows.

7.1 Texture characteristics of local roads

On rural A-roads, which carry high volumes of traffic at high speeds, it will generally be appropriate to use the texture depth thresholds established for use on trunk roads to maintain good skid resistance at high speeds. Ideally, these thresholds should also be applied to A-roads in urban areas, since the effect of lower texture depth begins to affect friction at speeds of 30mph on wet roads. However, this is less critical than for the rural, high-speed routes and there is less evidence that texture depth influences accident rates in urban locations. The relevant threshold levels are:

- Above 1.1mm Category 1 Sound
- 0.8 - 1.1mm Category 2 Some deterioration
- 0.4-0.8mm Category 3 Warning level of concern
- Below 0.4mm Category 4 Severe deterioration requiring urgent investigation and possible remedial action.

On the sample data analysed, just over 30% of A-roads trigger warning level of concern using these thresholds but less than 5% trigger urgent investigation. Therefore, applying these thresholds is realistic.

This approach is not satisfactory for B and C-roads because, even setting thresholds at an extremely low level identifies an unrealistic proportion of the network as requiring further investigation. The weak correspondence between the texture depth and engineers' assessment of condition and with CVI data also suggest that this will not be a sufficiently precise way of identifying areas suffering from deterioration of the surface texture.

Local roads are sufficiently variable across their width that measuring in more than a single transverse position is necessary to obtain a reliable view of the condition of the road.

For reporting at network level, it is recommended that texture data are averaged over 100m lengths to take advantage of better measurement precision. However, in many cases, the lowest 10m texture depth value is significantly below the 100m average value, and so this approach will fail to identify localised lengths with low texture. Therefore, the 10m data should be used as the basis for identifying sections for further investigation and possible treatment to improve high speed skid resistance.

7.2 Skid resistance

Texture depth is related to high speed skid resistance in wet conditions, but not to low speed measurements, such as those made by a SCRIM or Griptester. Current laser technology is not capable of measuring the fine scale surface microtexture, such as that on the surface of aggregate particles, as part of a SCANNER survey. Consequently, there is no evidence to justify texture depth measurements being used as a surrogate for skid resistance measurement at present. Accident studies strongly support the need for skid resistance data in addition to texture depth data.

7.3 Noise

This report provides background information on assessing noise from road traffic and describes the various noise sources on a vehicle and how they contribute to overall traffic noise levels. Three sources of noise generation need to be considered:

- Propulsion noise can be a major component of the overall noise level where traffic speeds are low and/or heavy vehicles are a high proportion of the traffic. As propulsion noise is related to engine speed, it is exacerbated if the traffic is congested or the vehicle speed is otherwise not uniform, i.e. vehicles are accelerating or braking. As seen in section 6.4.6, propulsion noise is also increased where the gradient increases. Quieter surfacing materials are unlikely to be effective in reducing noise emissions where the dominant source of noise is propulsion noise. It is possible that porous materials may help to reduce the reflected component of propulsion noise, but porous surfacing materials are unlikely to be suited to applications where the traffic speed is low with a high proportion of heavy vehicles.
- Tyre road noise is the dominant form of noise for light vehicles travelling at moderate and high speeds. Vehicle speed and the nature of the surface both have significant effects on the generation of tyre road noise as indicated in sections 6.3.3 to 6.3.5.
- Body rattle noise is low on roads where a high standard of evenness is achieved. On uneven roads, the vertical movements of the body produced when driving over poor profile cause significant levels of body noise. This can be identified by the first derivative of the Central Difference Method (CDM_1) parameter calculated from the longitudinal profile: in this study, locations with CDM_1 values within the top 5% were associated with an average noise level within the top 8% of noise measurements.
- A promising agreement was observed between the vertical acceleration produced and the body rattle noise measured, which suggest that it may be possible to develop the use of accelerometers to provide more accurate identification of locations producing loud body rattle noise. However, this would require further development to produce a method that would be independent of the vehicle suspension characteristics and speed.

7.4 Detection of localised surface texture defects

Conventional systems for the measurement of longitudinal and transverse road profile can provide, at traffic speed, information about localised changes to the surface texture that reflect defects such as fatting up or loss of aggregate. However, differences between texture depth measured in this way and with a dedicated texture laser have been observed in some circumstances and the specification of these systems is not adequate for MPD requirements. Therefore, it is recommended that this approach should enhance rather than replace existing systems for the measurement of texture depth.

For network level analysis, texture data collected using a road profiling system can be summarised according the level and variability of texture to identify lengths needing further investigation. A combined parameter was developed that uses measurements from 11 profile lasers to determine the average texture depth, the variance and the difference between the middle of the lane and the wheeltracks. The value of this combined parameter was shown to be equally effective as the nearside SMTD measurement for detecting surface deterioration in the test data set, with the potential for better performance on roads with lower overall texture depth. However, further investigation is needed to establish appropriate threshold levels for this parameter at the network level.

For more detailed analysis, at scheme level, the detailed information from multiple measurement lines can be displayed to give a visually detailed map to help engineers to assess the type and extent of the local areas of deterioration. However, this would require a substantial increase in the amount of data delivered by the survey contractor and stored by Pavement Management Systems and this may be a development which needs to be introduced over the longer term.

7.5 SCANNER specification for measurement of surface texture depth

As a result of this work it is recommended that the specification for texture depth measurement on local roads should include the following requirements:

7.5.1 Measurement of texture in nearside wheeltrack

Accurate measurement of surface texture depth should continue to be made through a single laser fitted to measure the nearside wheeltrack to the current specification. MPD should be reported for future compatibility with Europe. Therefore the specification should include:

- Texture profile data to be measured at intervals of no more than 0.5mm and delivered at intervals of no more than 1mm.
- Average SMTD and average MPD to be calculated and reported at 1m intervals in the RCD.
- The average SMTD and average MPD to be reported over 10m intervals in HMDIF.
- The accuracy requirement to be such that 95% of SMTD measurements are within ±0.25mm of the reference values recorded by HARRIS1. This accuracy to be demonstrated on each of a number of test sections selected to have homogeneous transverse texture and to include high, medium and low texture depths and a range of surface types.
- An additional requirement to determine that MPD is calculated correctly from the texture profile.

7.5.2 Measurement of transverse texture variability

Measurement of nearside texture depth should be supplemented by measuring the transverse variability of the surface texture. The best way of doing this will be to make use of the laser profiling systems used on the majority of current SCANNER accredited vehicles. Although less accurate than the dedicated texture systems, this approach has the advantage of obtaining substantial added benefits at low cost since no additional hardware is required. The systems would need to be modified to enable processing of the additional data, which would be a one-off cost, plus there would be a modest additional cost per kilometre surveyed due to the additional need to supply the extra derived data parameters.

One currently accredited system uses a transverse scanning system rather than a profile beam to measure road shape. Although, in principle, equivalent information could be obtained from this system, initial consultation with the contractor indicates that the system may not have the necessary technical capabilities. Therefore, while the long term goal should be to achieve an equivalent level of detail to that available from a profile beam, a short term option, to avoid placing this survey contractor at a disadvantage, would be to offer an option of deriving equivalent information by using additional dedicated texture lasers. It should be noted that using fewer measurement lines will reduce the accuracy with which the surface texture can be reported. Consequently, this option should be regarded as a short term option pending improving the capabilities of the equipment.

The specification should therefore require:

- Texture profile to be measured in a minimum of three and a maximum of 20 measurement lines, at intervals of no more than 5mm. The equipment and specification must be equivalent for each measurement line.
- Texture depth to be calculated as indicated below and the average texture depth reported for each measurement line at 1m intervals in the RCD.
- The average nearside, offside and middle texture depth to be calculated, as described below, and reported in the HMDIF at 10m intervals. Each parameter should be calculated including data from all measurement lines within ±0.3mm of the position indicated.

- The variance of the texture depth measurements used to calculate the above parameters should be calculated and reported in the HMDIF at 10m intervals.
- The accuracy requirement to be such that 95% of measurements are within ±0.25mm of the reference data. This accuracy to be demonstrated on each of a number of test sections selected to have homogeneous transverse texture and to include high, medium and low texture depths and a range of surface types. The reference data will be determined as the average texture depth calculated from the profile beam system of HARRIS1, using the 5 lasers at each of the positions required.

Although the texture depth from the transverse measurement system could be reported as SMTD, using an improved definition would reduce the scope for differences resulting from the different systems that could be used to meet this specification. For example, if a contractor chose to use additional texture profiling systems, as opposed to the profile beam, the sampling interval may be lower (1mm rather than 5mm) and the sensitivity could be different, either to short wavelength features (because of the sampling interval and bandwidth) or to long wavelength features (differences may include servo-controlled sensors or inertial measurement correction).

It is therefore recommended that to reduce the effect of differences between systems, a more robust bandpass filter should be used to attenuate wavelengths below 10mm and above 100mm. TRL will define the filter for this (it will be the same as the one for enhanced variance with different parameter values). The texture depth, for the purpose of the transverse variability, would be calculated as the root mean square deviation of the texture profile following the application of this filter.

7.5.3 Measurement of potential for body rattle noise generation

The Central Difference Method (CDM) parameter, and its first derivative component (CDM_1), should be measured and reported as described by Benbow et al. (2006).

7.5.4 UKPMS requirements

As a result of this recommended specification, UKPMS should be required to handle, at a minimum:

- Nearside SMTD
- Nearside MPD
- Nearside texture depth
- Middle texture depth
- Offside texture depth
- Texture depth variance
- Surface texture condition measure, equal to the square root of the variance, multiplied by the middle texture depth minus the average of the nearside and offside texture depth, and divided by the average of the nearside, middle and offside texture depth.
- Central difference of the longitudinal profile

8 Acknowledgements

This work was carried out in the Infrastructure and Environment Division of TRL. The authors are grateful to Emma Benbow who carried out the quality review and auditing of this report. Thanks are due to Birmingham City Council and Oxfordshire and Somerset County Councils for permission to use their data in this work. In addition, to WDM Limited for their contributions to the work on skid resistance and accident risk.

9 References

Abbott P and Watts G (2005). Correlating statistical pass-by (SPB) and close-proximity (CPX) noise levels. Proceedings of the Inter-Noise 2005, Rio de Janeiro, Brazil.

Axup D R (2003). *The implications of pavement flushing on skid resistance.* Impact, Spring 2003. Institute of Traffic Accident Investigators, Derby, UK.

Benbow E, Nesnas K and Wright A (2006). Shape (surface form) of local roads. TRL published project report, PPR131, in preparation, TRL Limited, Wokingham, Berkshire, UK.

British Board of Agrèment (1998). *Guidelines document for the assessment and certification of thin surfacing systems for highways*. British Board of Agrement, Garston, United Kingdom.

DETR (2000). *Control of Body Noise from Commercial Vehicles. Guide to Best Practice.* Department of the Environment, Transport and the Regions: London.

DMRB 7.3.1 *Skidding Resistance*. Design Manual for Roads and Bridges, Volume 7 Section 3 Part 1, HD28/04. The Stationery Office, London.

European Environment Agency (2003). *Europe's environment:The third assessment.* EEA Environment Assessment Report No. 10 EEA, Copenhagen, Denmark.

European Commission (2002). *Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise.* Official Journal of the European Commission, L 189/12.

Gothie M (2000). *The contribution to road safety of pavement surface characteristics.* Bulletin des Laboratoires des Ponts et Chaussees, Vol 224 pp 131 January 2000, Laboratoires des Ponts et Chaussees, Paris, France.

Gothie M (2002). *Could adherence of a road surface be used to identify the areas where maintenance is needed?* Bearing capacity of roads, railways and airfields, Lisbon 2002.

Highways Agency (2005). Traffic Speed Condition Surveys (TRACS): Revised Assessment Criteria. Interim Advice Note, IAN 42/05.

ISO (1981). *Acoustics - Measurement of noise emitted by accelerating road vehicles - engineering method.* International Standards Organisation, Geneva

Jonasson H, Sand berg U, van Blokland G, Ejsmont, Watts G and Luminari M (2004). *Source modelling of road vehicles*. Technical Report HAR11TR-041210-SP10, Deliverable 9 of the HARMONOISE project, SP, Boras, Sweden.

Parry A R and Viner H E (2005). *Accidents and the skidding resistance standard for strategic roads in England.* TRL report TRL622. TRL Limited, Wokingham, Berkshire, UK.

PIARC (1987). *Report of the Committee on Surface Characteristics.* XVIII World Road Congress, Brussels, Belgium, 1987.

Roe P G, Parry A R and Viner H E (1998). *High and low speed skidding resistance: the influence of texture depth.* TRL report TRL367. TRL Limited, Wokingham, Berkshire, UK.

Roe P G, Webster D C and West G (1991). *The relation between surface texture of roads and accidents.* TRRL Research Report RR296. TRL Limited, Wokingham, Berkshire, UK.

Sandberg U and Descornet G (1980). *Road surface influence on tyre/road noise - Parts I and II.* Proceedings of Inter-Noise 80, Miami, Florida, USA, 259-266; 267-272.

VicRoads (2002). *Performance levels for surface texture*. GeoPave Technical note 59, VicRoads, Australia.

Appendix A. Research Into Laser Displacement Sensor Capabilities

Report prepared by WDM Limited.

A.1 Objective

An assessment of commercially available Laser Displacement Sensors to determine if any would be capable of measuring road microtexture.

Microtexture is defined as:-

The deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of less than 0.5mm (corresponding to texture wavelengths with third-octave bands with up to 0.4mm of centre wavelengths). Peak to peak amplitudes normally vary in the range of 0.001mm to 0.5mm.

A.2 Desired Specification

For the purposes of this report it is necessary to determine a desired sensor specification for the proposed application. From initial research it is quite clear that there are no sensors available capable of measuring the specifications in full so a relaxed specification will be used to set a base line to compare the performance of currently available sensors. This will be called the desired specification.

Range: Ideally to be mounted on a vehicle the range needs to be about 200mm but this is totally unachievable and a relaxed target specification of 25mm will be assumed. This will inevitably mean that servo mechanisms would be required to move the sensor up and down.

Stand Off: To be mounted on a vehicle the stand off needs to be about 300mm but a relaxed target specification of 50mm will be assumed. Even using servo mechanisms great care would be needed to protect the unit from damage.

Height Resolution: The microtexture definition resolution is 1 micron but for a working range of 25mm it would be realistic to aim for a resolution of 0.025mm (25 microns) NB Many manufactures will quite happily quote resolutions in the order of 1 micron but on inspecting the repeatability and accuracy figures the resolution becomes meaningless.

Spot Size: To measure a texture wavelength of 0.05mm the waveform should be sampled twice per cycle. To measure the height the measured spot size should be of the order of ten times smaller than cycle length to acquire an accurate sample height of the feature. This gives a spot size in the order of 0.005mm (5 microns). This spot size needs to be achievable over the full measuring range of the sensor. Most sensors focus the laser spot using lenses so the size at the extremes of the measuring range will be much larger than the size in the centre. When the spot size is too big it is indeterminate which point within the spot will determine the measured height. This will depend on many things including the type of detector used and the change in height and reflectivity of the target over the area of the spot. The end result may or may not be a good indication of the height of the centre of the spot, but this will vary due to many factors and the only way to ensure accurate repeatable results would be to use a small spot.

Sample Rate: To sample the lowest wavelength at least twice assuming a maximum vehicle speed of 100kph would require a sampling frequency in excess of 1MHz.

A.3 General Requirements

Sensors for road use operate in a very challenging environment. Road surfaces vary greatly in their reflectivity and their ambient lighting conditions. Sensors for road use are normally optimised for this type of performance. In this application it is assumed that the sensor can be shrouded so that the illumination will stay reasonably constant, therefore the maximum ambient light characteristics of the sensor has not been included in the required specification. The two common types of detector used in laser displacement sensors are the PSD (Position Sensitive Detector) and the CCD (Charge Coupled Device) as used in line scan cameras. The PSD sensor measures the centre of the light distribution and the measured value will depend on the shape and variation in intensity of the received image. CCD's use data processing to determine the height from the light intensity of all of the illuminated pixels, and are better able to detect the correct value over a range of target conditions. The large physical area of a PSD also inherently generates a large amount of noise. For macro texture and profiling, where multiple samples over a specific distance interval can be taken, this is not a problem. For microtexture every discrete sample needs to be accurate. It is quite likely that the PSD accuracy will not be adequate for this type of application and a CCD would be required. Unfortunately the processing required for the CCD is more complex and scan rates are generally considerably lower than those available for PSD sensors.

A.4 Currently Available Road Profiling Sensors

A review of the sensors currently used for road profiling work was conducted to establish if any would be suitable for this application.

A.4.1 Selcom (LMI): www.lmint.com

Selcom produce a range of PSD based sensors that are widely used for measuring road profile and road macro texture. They are available in sampling speeds up to 78kHz which appears to be the fastest available from any manufacturer for this type of sensor and even this is well short of the desired sampling rate. The smallest spot size available is in the region of 100 microns in the middle of the working range, it will be considerably larger than this at the limits of the working range. None of Selcoms' current range of single spot triangulation displacement sensors would be capable of measuring micro texture successfully

A.4.2 Acuity Research: www.acuityresearch.com

Another major supplier of sensors for road applications is Acuity Research. The AR600/RP family uses CCD sensors and covers a range of measuring distances. The maximum spot sizes are not quoted but this is irrelevant as the sampling rate of only 1.25kHz makes this range totally unsuitable.

There are other manufactures such as Romdas : www.romdas.com who manufacture the RRL16, but as with Selcom and Acuity the sensors are designed for macro texture and profiling use. As such the designs strive to eliminate micro texture as unwanted noise. The current range of sensors targeted at road applications were all found to be unable to meet the desired specification.

A.5 Displacement Sensors For Factory Automation Application

The search was then broadened to see if devices targeted at factory automation applications would be suitable. Typical vendors of such devices are Micro-Epsilon and MTI Instruments Inc.

A.5.1 Micro Epsilon: www.micro-epsilon.com

The fastest range is the optoNCDT 2200, which utilizes a high speed CCD system.

Model number ILD 2200-20 most closely matches our desired specification with a measuring range of 20mm and a stand off of 50mm. The spot size is quoted as 60microns at mid range and 160 microns at the limits. The maximum sampling rate is 10kHz. The linearity is 12micron +/- 0.03% of Full Scale Output (FSO) and the resolution is 2 microns +/- 0.005% FSO. Note that the resolution is swamped by the linearity. The slow sampling rate and large spot size however renders the device totally unsuitable

A.5.2 MTI Instruments Inc: www.mtiinstruments.com

MTI produce a CCD based sensor called the MicroTrak 7000. Model MT-600-800 has a range of 20.3mm and a stand off of 152.4mm. The resolution is quoted as 1.27microns with a linearity and accuracy of 0.1% FSO. Note that once again the accuracy of 0.1%, which is 20.3 microns for a working range of 20.3mm, is 20 times greater than the resolution. The spot size is quoted as 150 * 250 microns but there are no figures for how this varies over the measuring range. The sampling frequency is 100kHz, but the bandwidth is 20kHz These figures are closer to the desired specification but the spot is too big and the device is still not fast enough to offer a viable solution.

A search of several other manufactures of industrial targeted systems, such as Freedom Technologies, Keyence, Lap, Omron and Sick, produced the same conclusions. The combination of desired parameters is simply not available in conventional spot triangulation based sensors.

The specifications are only achievable using these types of sensors by going to purpose made surface profiling equipment. In this case the position of the surface to be measured is closely controlled to stay within the very small working range of a high resolution sensor, and the spot can be focused to a very small size. The target is typically clamped to a workbed and the displacement sensor moves over the target in a very controlled and slow manner.

A.6 Laser Line Profiling Sensors

Having determined that there are no conventional laser spot based triangulation systems currently available able to meet the desired specification the search was widened to investigate any other non contacting optical systems that may be suitable. Systems utilizing a laser line rather than a spot were investigated. Micro-Epsilon produces such a system, as does Selcom. The Selcom version has a mirror scanning system and the Micro-Epsilon utilizes an optical line generator. They are designed for high speed profile measurement for industrial in line applications and make use of the triangulation principle for two dimensional acquisition of profiles.

The Micro-Epsilon device is the LLT 2800. It use's an optical system to project a laser line onto the surface of the object to be measured. The back scattered light from the laser line is detected by a CMOS array. Along with distance information (z-axis), the controller also computes the true position along the laser line (x-axis) from the CCD camera image, and outputs both values as a two dimensional coordinate.

The shutter can be controlled in real time via an external trigger input. The sampling limit is the acquisition of a maximum of 250,000 points per second. If it is set up to record 1024 points per profile it can record 250 profiles per second. In the microtexture application the sampling rate would limit the sampling coverage along the road but the microtexture would be computed from a snapshot across the road. In this case it would be the minimum exposure time required to produce a usable image that would be crucial. No figures are available for this and it is unlikely that a small enough exposure time could be chosen to allow the system to work at the desired speeds, however slow speed versions may well be possible.

For a 25mm working range the resolution in height measurements (z-axis) is quoted as 12.5 microns and for the x-axis, with a range from 15mm to 20mm, which if programmed for a 1024 points system would give a 5 micron resolution. The stand off for the sensor is 70mm and with a working range of 25mm it would still require a servo mechanism to keep the sensor in the required position on a moving vehicle.

No details are given about the width of the laser line so it is impossible to judge how this might effect the accuracy.

Selcom produce a similar device, the SPS2301 called a flying spot profiler. In this device a spot is scanned across the target at a 60Hz rate by a mirror. This device appears to use a single dimension sensor with the x-axis information being determined from the mirror positioning. The device has a maximum sample rate of 62.5KHz and a bandwidth of 20kHz. The 26mm measurement range version (z-axis) has a height resolution of 8 microns but a noise figure of 30 microns. The x axis is quoted as a range of 60mm with a resolution of 60 microns. Because this is a scanning device the light intensity of the spot would be a lot higher but obviously the x-axis figure quoted assumes that the target is stationary. If the target is moving then the spacing of each sample would increase. This makes this system unsuitable for a moving application. No information is given about the size of the flying spot.

Other manufactures such as Acuity produce mirror scanning systems as well, but they would all be unsuitable on the same grounds as the Selcom.

A.7 Conclusions

A relaxed desired specification was developed to enable sensor capabilities to be compared. For vehicle borne applications this relaxed specification would necessitate the use of servo mechanisms to raise and lower the sensor.

Using the desired specification the performance of spot based triangulation displacement sensors was compared. No sensors capable of meeting even the relaxed specification have been identified. All of the sensors investigated have laser spot sizes that are too big and scan rates that are too slow.

Newer devices are becoming available using two dimensional triangulation techniques, achieved by using a laser line generator coupled with a two dimensional CCD array sensor. No products utilizing this principle are currently available that are capable of meeting even the relaxed specification. Future developments based on this principal may however produce a feasible solution, worthy of investigation.

Appendix B. Correlation between Texture Depth and Accidents

Report prepared by WDM Limited.

B.1 Introduction

WDM were commissioned to perform a small study using an established database to assess if there appeared to be any relationship between texture depth and accidents.

B.2 Methodology

The database used was the Scottish Executive PMS. Accidents were collated over a three year period from 1999 to 2001 and these accidents were banded into different skid resistance site categories that were available in HD 28/94 and some additional site categories that have been proposed for Scotland previously. The additional site categories included bus stops, lay bys, and multiple sites.

To allow the accidents to be compared with the texture depth at particular site categories the accidents within each of the site categories were further collated into the texture bands shown in Table B1. The texture depth values are in millimetres as measured by Sensor Measured Texture Depth. Also shown in Figure B1 is the texture distribution for all sites used. All the data used in this analysis has been averaged over 100m.

Table B1 Texture Bands Used

Texture Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

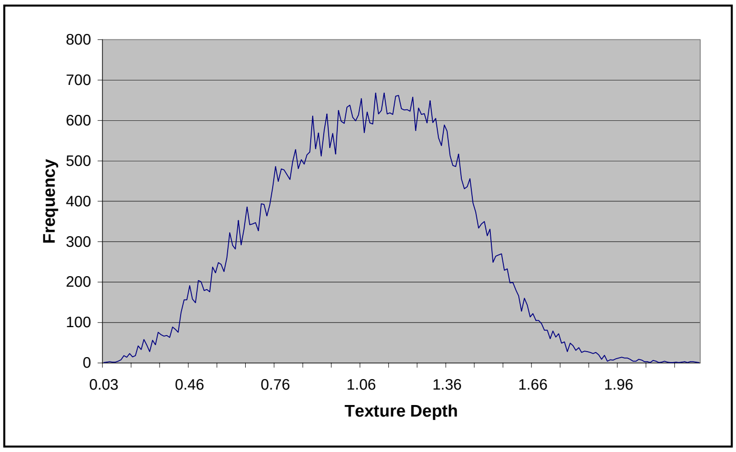


Figure B1 Texture Distribution

B.2.1 Additional Filtering

Additional filtering was carried out to try and identify, and possibly negate, the effect of the skid resistance on the accident rates. The accidents and textures were filtered into sites that were:

- 0.05 SC below the investigatory level, the data in this case is referred to as below IL
- 0.05 SC above the investigatory level the data in this case is referred to as above IL

Also, since texture is thought to maintain the skid resistance at higher speeds the data was also filtered into Urban and Rural sites. Urban sites representing slow speed traffic and the rural sites representing a mixture of speeds but with an emphasis on high speed traffic.

The data was also analysed without these additional filters and in this case, the data is referred to as combined.

B.3 Results

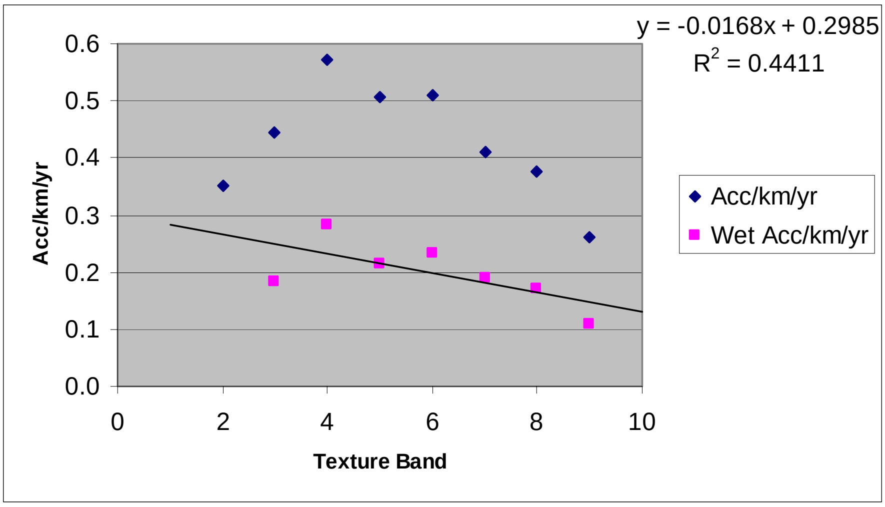
The filtered data was formed into charts of Accident densities (accidents per km) and Accident rates (accidents per 100 million vehicle kilometres). These were plotted against the Texture band for each of the site categories and for both skid resistance filters and the urban and rural and combined data. For each of the plots the dry accidents are shown by the blue diamonds and the wet accidents by the magenta squares. The list of texture bands shown in Table B1 has been placed against each plot to facilitate the interpretation.

B.3.1 Minimum Accident Requirement

Data for each texture band has been omitted if there are less than 10 accidents so that abnormal events cannot influence the outcome. This removed a number of sites from consideration these included: Approach to roundabout; Dual minor junctions; Garages; Gradients; Multiple events high risk. In addition, when the requirement for a minimum of 10 accidents was applied to the wet accident data, further sites were removed from consideration including Bends <100m radius; Bus stops; Gradients >10% and Approach to traffic signals.

B.3.2 Combined Data

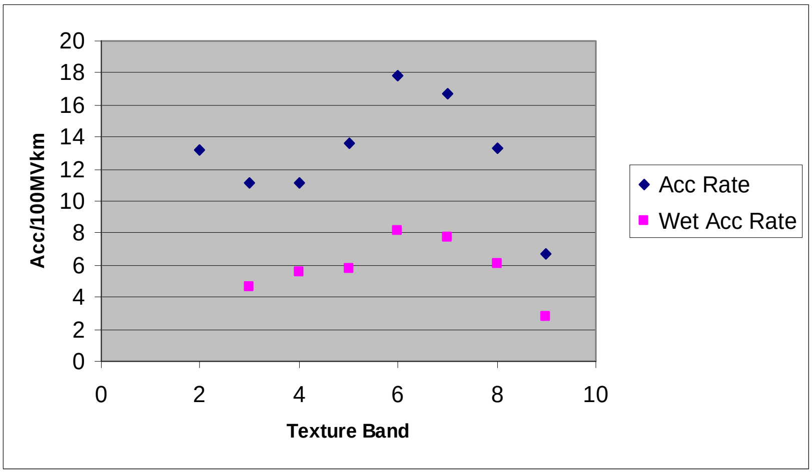
For the majority of the sites using the combined data, there appear to be no relationship between the texture and the accident density or the accident rate; however, there are a few exceptions. As seen in Figure B2 the Dual non-event sites produce a weak relationship for the both the wet accident density with a coefficient of determination (r2) of 0.44. If the data point at texture band 3 was removed, the relationship would be significantly improved but there are 30 wet accidents in texture band 3 so this cannot be justified by numbers of accidents. There is also relationship between accident density and texture in the dry until texture band 3.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B2 Density Versus Texture for Dual Non-Event Sites

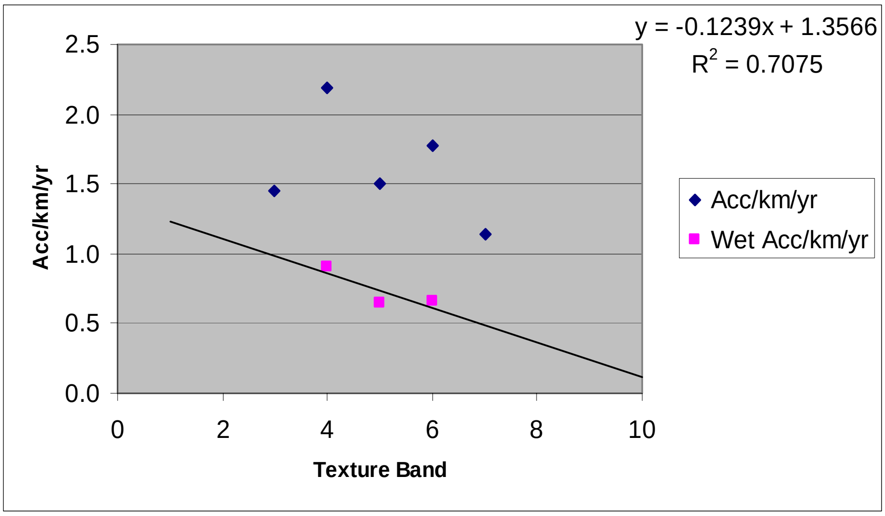
Accident rate versus texture is shown in Figure B3 for wet and for dry accidents and in this case there does not appear to be a relationship for either set of results. However, there is a shortage of sites that have very low texture. The accident rate is generally considered a more meaningful parameter than the accident density when determining if a relationship exists between accidents and texture because it incorporates a measure of traffic flow. The accident density, however, can be useful for estimating the total number of accidents occurring at particular texture bands for each site and in this way provides a method for assessing the benefit cost ratio for any changes that might be proposed in maintenance standards. It should also be noted that if the accident volumes are very high congestion can develop which slows the traffic and forms an atypical site that is not comparable to other sites. In these cases the accident rate would not be indicative of relationship between accidents and texture.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B3 Accident Rates versus Texture for Dual Non- Event Sites

There appears to be some relationship between the texture and accidents for the major junctions as seen in Figure B4 and B5 although excluding data when there are less than 10 accidents has removed most of the data points for the wet accidents.

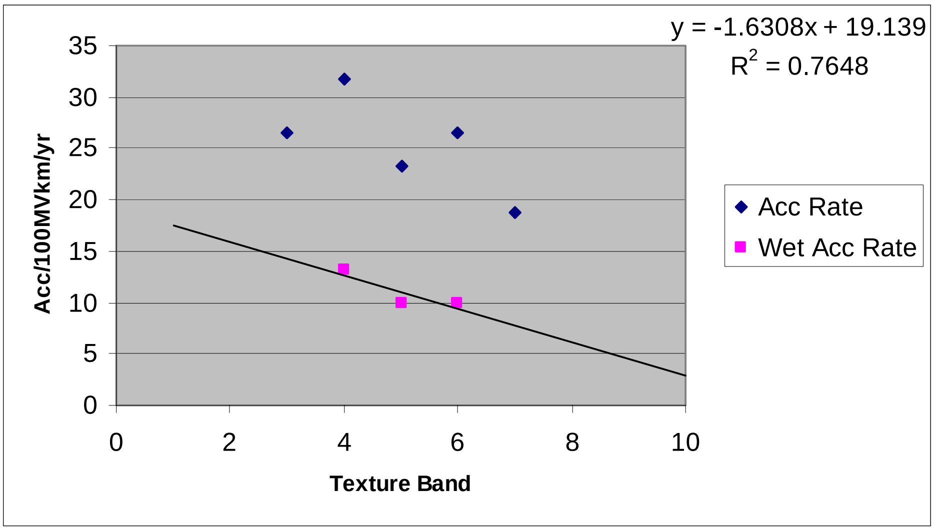


Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B4 Accident Density versus Texture for Major Junctions

The R^2 for the accident density is 0.7 but with only 3 data points, not a lot of confidence can be attributed to these figures.

The plot of accident rate versus the texture is shown in Figure B5, as seen there is a similar relationship as the accident density but with a slightly better R^2 but again there are only 3 data points. There is also a definite tendency for the accident rate to increase as the texture decreases for accidents in the dry.

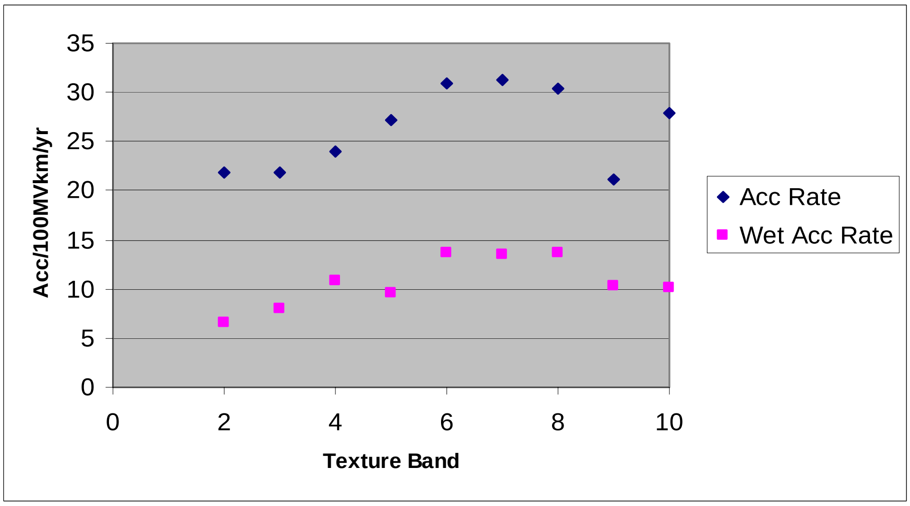


Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B5 Accident Rate versus Texture for Major Junctions

In a number of the plots such as those for major junctions, it appears that there is a relationship between the dry accidents and the texture. This has been noted in previous studies but is not completely understood since smoother textured surfaces provide a larger contact area and in the dry and should offer increased friction but a more textured surface will provide an increase in hysteresis. The overall skid resistance will be determined by a combination of factors.

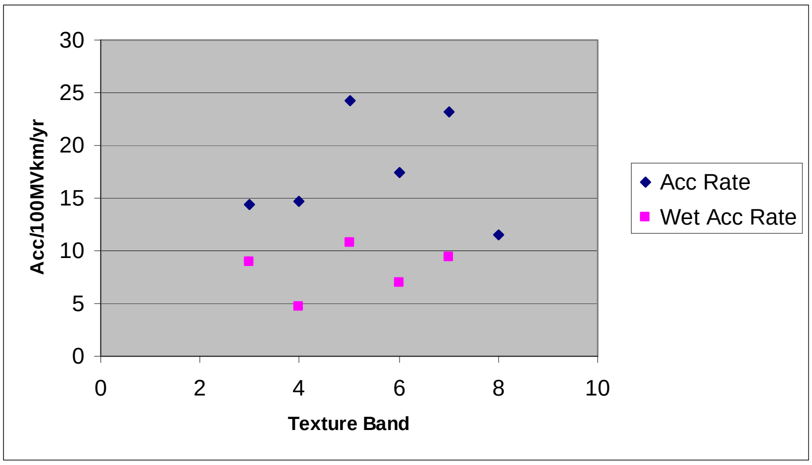
As stated previously for most sites either no relationship or no rational relationship exists between texture and accidents; two examples of this situation have been included in Figure B6 and B7 for the single non event sites and the single minor junctions to illustrate the lack of correlation.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B6 Accident Rate versus Texture for Single Non- Event sites

The data in Figure B6 shows the accident rate increase as the texture increases and the lowest accident rate is at texture band 2 which has textures between 0.20mm and 0.39mm.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B7 Accident Rate versus Texture for Single Minor Junctions

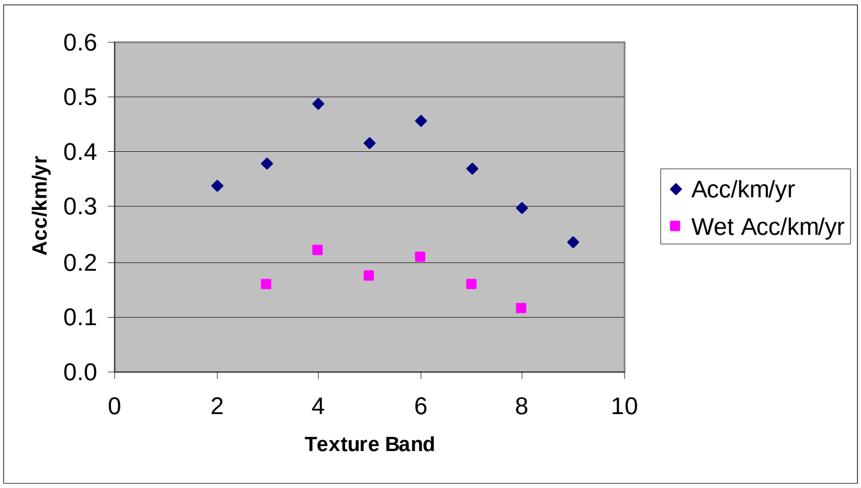
The plot for single minor junction does not indicate any relationship between accident rate and texture.

B.3.3 Sites Above and Below the IL

One of the major influences on the wet accident rate is the skid resistance of the surface. Ideally, it would be better to keep the skid resistance the same and vary the texture but there were insufficient accidents for this. As indicated in the introduction an attempt has been made to reduce the effect of the skid resistance by filtering into sites that were 0.05 SC above the IL and sites that were 0.05 SC below the IL.

B.3.3.1 Sites above the IL

Dual Non- Event sites were the only categories where the accident density had a correlation with the texture but as seen in Figure B8 the correlation is weak for the wet and dry accidents. There was no correlation for the accident rates.



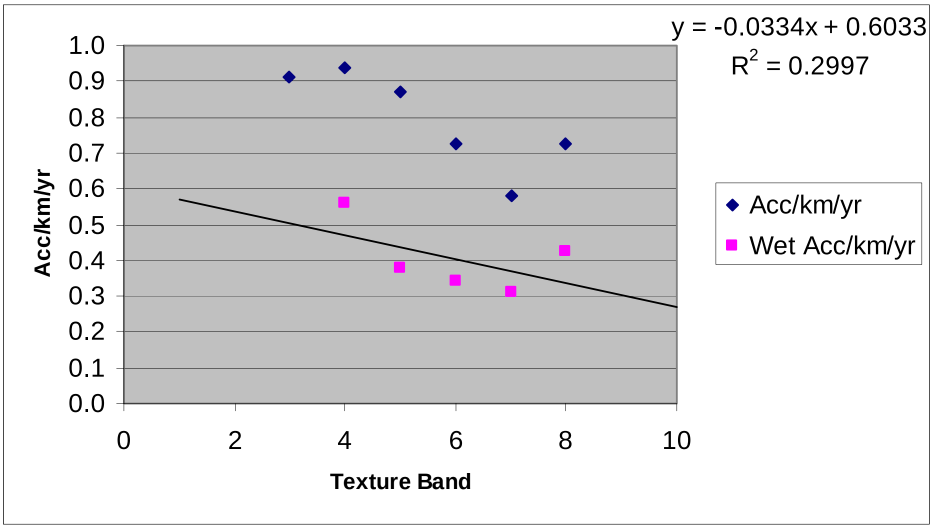
Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B8 Accident Density versus Texture for the Dual Non-Event Sites Above the IL

B.3.3.2 Sites below the IL

For sites below the IL, 2 categories gave a weak correlation between the accident and texture, the dual non-event sites for accident density and the Gradients between 5 and 10% for both accident density and accident rate.

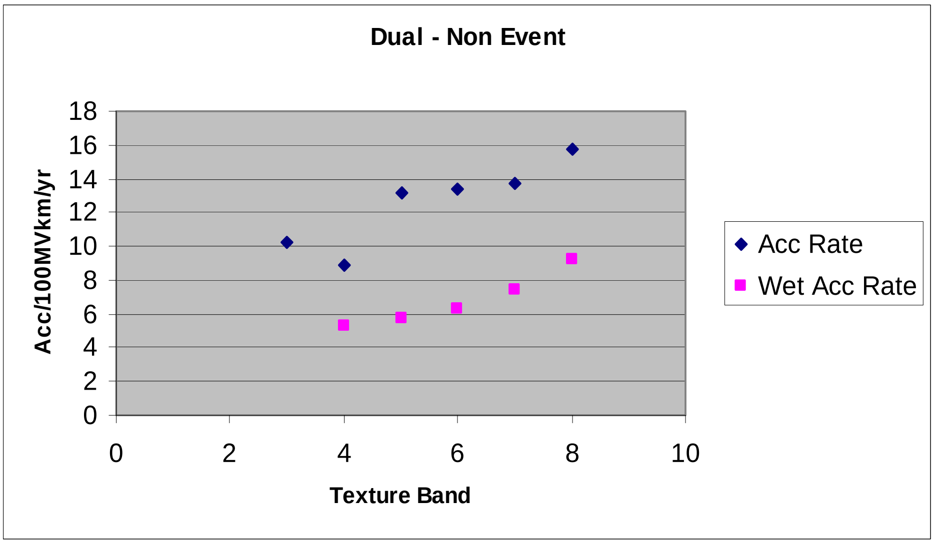
Figure B9 shows a weak correlation between wet accident density and texture for the dual non event sites. The correlation for the dry accidents is slightly stronger.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B9 Accident Density versus Texture for Dual non Event Site below the IL

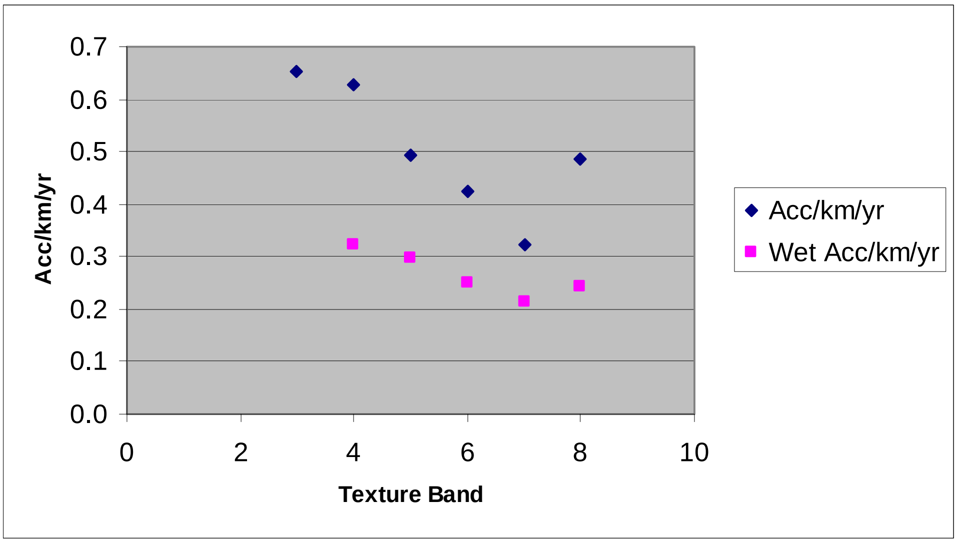
The accident rate on the other hand shows a negative correlation against the texture for both wet and dry accidents, Figure B10. This implies that texture depth is lowest on sites with high traffic flows and this might be something that should be investigated further to see how well current mixes continue to exceed the required texture depth with time.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

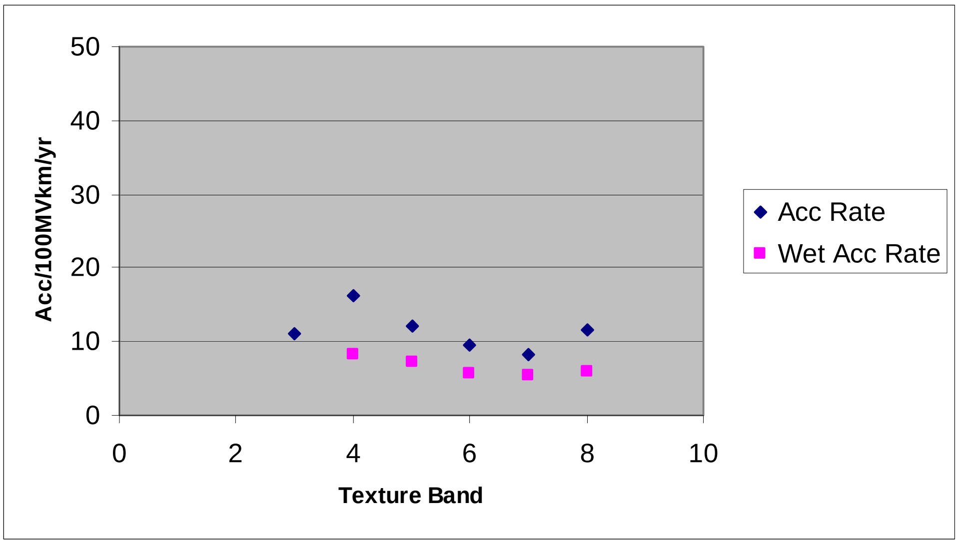
Figure B10 Accident Rate versus Texture for Dual non Event Site Below the IL

It can be seen from Figure B11 that there is a reasonable correlation with texture for both wet and dry accident densities on Gradients 5 to 10%. There is also a relationship between the accident rate and the texture for the Gradients 5 to 10%, Figure B12, but it is weaker than for accident densities.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B11 Accident Densities versus Texture for Gradients 5 to 10% Site below the IL



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B12 Accident Rate versus Texture for Gradients 5 to 10% Site below the IL

B.3.4 Sites in the Urban and Rural Environment

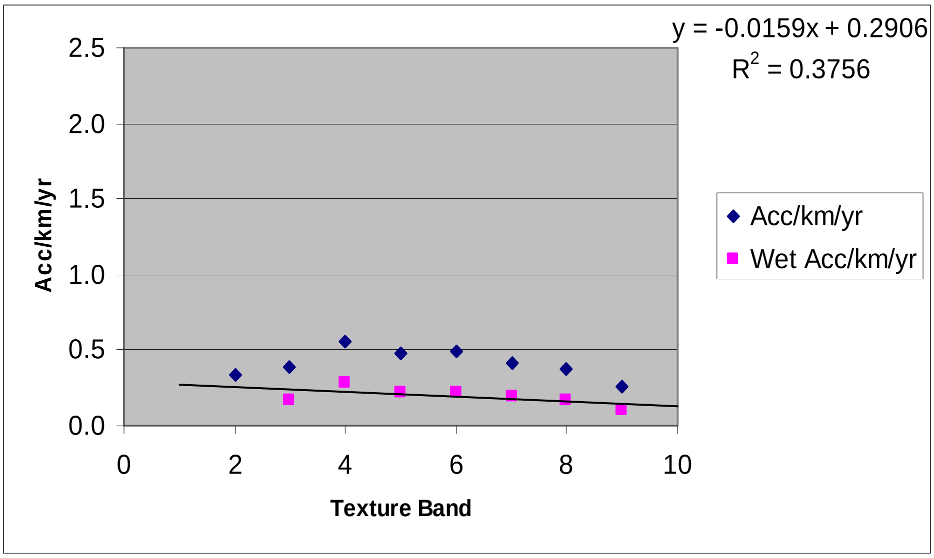
Texture is believed to be more important at higher speeds when it is wet since it provides drainage paths for the water. The effect texture on dry high speed accidents is unknown. In an attempt to determine the effect of speed on the results the sites were filtered into urban to represent low speed roads and rural that represented high speed roads.

B.3.4.1 Urban Sites

For the data base used there is a much smaller quantity of roads in the urban area than in the rural environment, 371km compared to 5025km. Consequently, there were significantly fewer accidents on the urban sites and most of the sites did not have sufficient accidents to meet the 10 accident rule. For the small number of sites where there were sufficient accidents there was no correlation between the accident density or accident rates and the texture.

B.3.4.2 Rural Sites

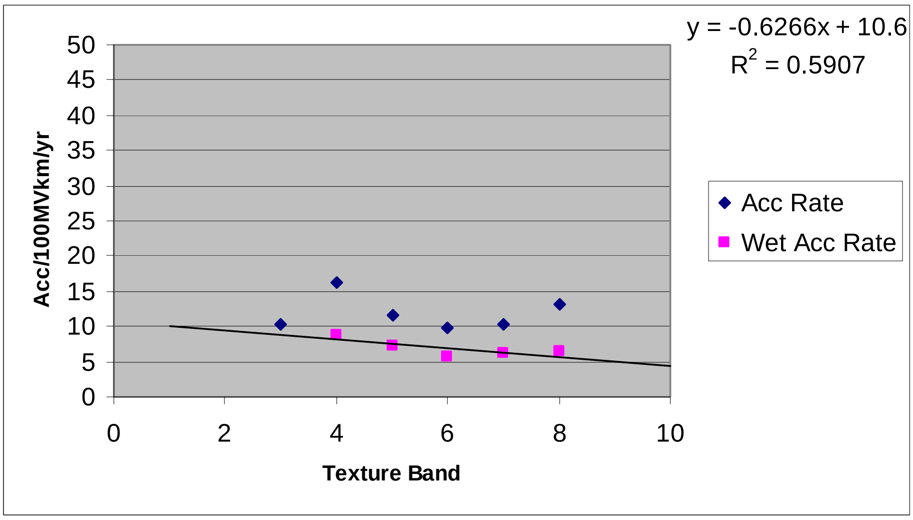
Once again there is a relationship, albeit weak, between the wet accident density and texture for the Dual non Event sites in the rural area but as for previous results there is no relationship between the accident rate and texture.



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B13 Accident Density versus Texture for Rural Dual non Event Sites

There was also a correlation between wet accident rate and the texture for the gradients between 5 to 10% in the rural environment as shown in Figure B14



Tex Band	Lower Texture	Upper Texture
1	0.00	0.19
2	0.20	0.39
3	0.40	0.59
4	0.60	0.79
5	0.80	0.99
6	1.00	1.19
7	1.20	1.39
8	1.40	1.59
9	1.60	1.79
10	1.80	>1.80

Figure B14 Accident Rate versus Texture for Rural Gradients 5 to 10%

B.4 Conclusions

The lack of any correlation between the texture depth and accident rate for most of the site categories is probably indicative of the fact that there is only a small length of eligible network where there are 10 or more accidents and very low texture.

For the combined data there appeared to be a correlation between the accident density and texture for the Dual non Event sites. However, the lack of a correlation for the texture and accident rate throws doubt on these findings. The accident density and the accident rate did appear to correlate with the texture for Major junctions but there were only 3 data points.

Filtering the sites by skid resistance did not produce better correlations.

A few sites appeared to give a correlation between accidents and texture in the dry. It is possible that an increase in hysteresis due to the greater deformation of the vehicle tyres over the larger textures will contribute to stopping distances in the dry although the larger texture will result in a reduction of dry contact area. The overall result is likely to be a complex combination of factors. It should be borne in mind that there may also be reporting errors for the road surface conditions possibly due to the road drying between the accidents occurring and the road conditions being reported.

When the data was filtered by skid resistance, the sites that were 0.05 SC below the SCRIM investigatory level produced a correlation for gradients 5 to 10% which was not established for the sites above the SCRIM investigatory level. However, there were only 3 data points for the gradients that were above the IL.

There were a number of cases where certain site categories appeared to give a correlation between the accident density and the texture but not for the texture and accident rate. This indicates that the texture depth is lowest on sites with high traffic flows and this might be something that should be investigated further to see how well current mixes continue to exceed the required texture depth with time.

There was insufficient data for the urban sites to determine if a correlation existed between texture and accidents. The rural sites showed weak relationships for the texture and accident density for the Dual non Event sites and for the accident rate on the Gradient 5 to 10%.

Overall, the results gave an impression that improving the texture may contribute to decreasing accidents but the relationship was not strong. Unfortunately, the results were restricted because the database had relatively small accident numbers and only a very small portion of the surfaces had low textures.

There would be merit in a more detailed study using a larger database that has a greater number of accidents and a larger quantity of low textured surfaces.

Appendix C. Noise indicators and control measures

C.1 Noise disturbance caused by road traffic

C.1.1 Physical measures

Sound is vibrations transmitted in the air and received by the human ear causing the sensation of hearing. The physical measures used to describe this phenomenon relate to the variations in atmospheric pressure caused by a vibrating body. The magnitude of these pressure variations is described as the sound pressure level, which forms the basis of a noise scale designed to assess the annoyance or disturbance associated with road traffic noise.

The sound pressure level (SPL) is the ratio of the mean amplitude of the measured sound pressure, p, relative to the mean amplitude of the sound pressure that can just be detectable to the human ear, p_0, normally referred to as the threshold of hearing and equal to 20 micro pascals (Pa). The pressure variation over the audible range is large, over 106 Pa at the threshold of pain. To conveniently express sound pressure levels the decibel scale is used and defined as:

$$\text{Sound Pressure Level, } SPL = 10\,\log_{10}\left(\frac{p}{p_0}\right)^2 dB$$

The audible range of sounds expressed in terms of sound pressure levels (dB) can now be conveniently covered within the range 0 dB (the threshold of hearing) to 120 dB (the threshold of pain).

For the purposes of assessing the noise from road traffic it is important that the rules for combining noise levels from different traffic sources are understood. If two sources of traffic noise, of levels L_1 and L_2, where L_1 is greater than L_2, occur together, the resultant noise level can be calculated by adding a correction, ΔL, to the higher of the two noise levels, L_1. The correction is dependent on the difference in level between the two noises, $D = L_1 – L_2$. Figure C1 shows the relationship between ΔL and D. Where the difference between the two noise levels is zero, i.e. the two levels are identical (D = 0), 3 dB(A) is added to either noise level to obtain the combined value. Where there is a 6 dB(A) difference, the combined level is obtained by adding only 1 dB(A) to the higher of the two noise levels, L_1.

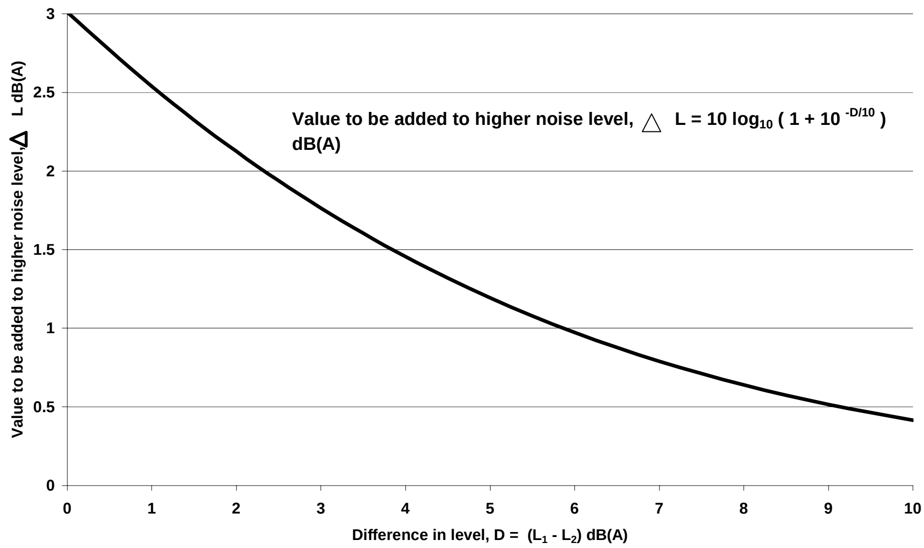


Figure C1 Combining two noise levels, L_1 and L_2: value to be added to the higher level, ΔL, as a function of the difference in level, $D = L_1 – L_2$

C.1.2 Perception

The perception of sound is dependent on the complex physiology of the human ear and its response to variations in sound pressure and to the processing of this information by the brain. The response of the ear to sound depends on the pitch or frequency of the sound wave (Hz), the time taken for the hearing process to respond and to the strength or loudness of the stimuli.

The frequency response of the ear covers a wide range of frequencies from about 20 Hz to about 20 kHz. However, an individual's range of hearing may be much less and dependent on health, occupation and age. The sensitivity of the ear to different frequencies across the audible range is not uniform. Within this range of frequency the sensitivity of the ear changes. For example, hearing sensitivity decreases markedly as frequency falls below about 250 Hz and likewise as frequency increases above about 10 kHz. Unfortunately, the human ear is most sensitive in the frequency range at which tyre/road noise occurs i.e. from about 1 kHz to 5 kHz. It is therefore important that instruments used for assessing noise impacts have a frequency response related to that of the human ear in order for the physical measures of noise to correlate with subjective response. This will be discussed later when loudness is discussed.

To respond to variations in sound pressure the hearing system requires a certain time period during which the information is assimilated. The brain acts like an integrator where the perceived incoming stimuli are dependent on previously received information. This process occurs over a very short period of the order of 30 to 300 ms and is dependent on the frequency of the noise. For assessing variations in traffic noise levels typical of where tyre/road noise is the dominant noise source an exponential averaging time period of 250 ms is used in the signal processing of sound level meters to simulate the response time of the human hearing system. This averaging process is often referred to as FAST response and typically used for environmental noise assessments where the source noise is not impulsive i.e. or tonal.

The loudness of a sound is measured on a scale of units called phons and is dependent on both frequency and pressure. For comparison purposes a pure tone at a frequency of 1 kHz and at a pressure of 0 dB i.e. just audible to the human ear, is by definition set at a loudness level of 0 phons. At 1 kHz the loudness level in phons is numerically equal to the decibel level e.g. a sound pressure of 120 dB at 1 kHz will have a loudness level of 120 phons. As explained earlier, because the frequency response of the human ear is not linear with pressure, pure tones at other frequencies and rated as having equal loudness, will have different sound pressure levels. For example, a 100 Hz tone at a pressure of 66 dB is found to have a loudness level of 60 phons i.e. rated as equally as loud as a 1 kHz tone at 60 dB.

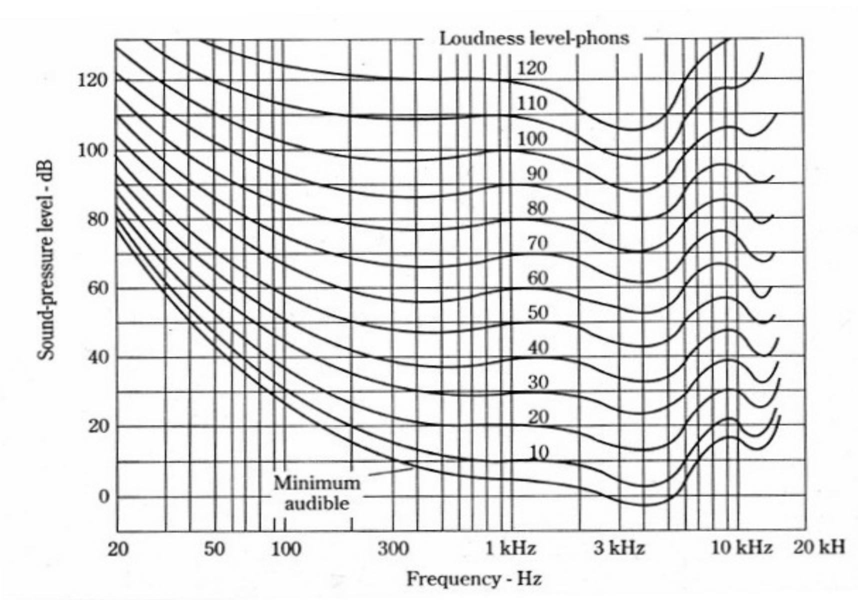


Figure C2 Equal loudness contours

The map of equal loudness contours is shown in Figure C2, and has been derived from many laboratory experiments on the subjective ratings of loudness. These contours have been used to assist in the development of a frequency response relationship between the rating of loudness and sound pressure levels for types of noises where the sound energy is spread over a wide range of frequencies such as traffic noise. Results from attitude surveys have show that the frequency response described by the 40 phon contour shown in Figure C2 is reasonably good at rating the subjective loudness of traffic noise and describes the A-weighting filter response used in sound level meters for assessing the environmental impact of road traffic noise. Noise levels measured on this scale are expressed in units of dB(A).

C.1.3 Annoyance

The previous sections have described the relationship between the physical measures used to describe noise with how sound is perceived. This understanding has led to the development of instruments for measuring noise such as sound level meters to respond to the variation in noise levels similar to that of the human hearing system. The next stage in the process is to understand the general long-term adverse reaction to the exposure of road traffic noise on communities normally referred to as annoyance and the various methods that have been developed to express it on a simple numeric scale i.e. a noise scale.

C.1.3.1 Noise scale ($L_{Aeq,T}$)

The most commonly used noise scale used in Europe for assessing the noise impact from road traffic is the equivalent continuous sound level, $L_{Aeq,T}$, which is an energy based measure represented by a steady sound level which, over a defined period of time, T, has the same A-weighted acoustic energy as the time varying noise level that is typically associated with traffic noise.

An advantage of adopting the $L_{Aeq,T}$, scale is that it can be described in terms of the time varying A-weighted sound pressure level, $L_A(t)$ dB(A), using the following formula:

$$L_{Aeq,T} = 10\log_{10}\left[\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} 10^{L_A(t)/10}\,dt\right] \quad \text{dB}$$

which, providing the time period T = ($T_2 - T_1$) is large compared to the averaging time associated with $L_A(t)$ i.e. 250ms, is a good approximation and generally satisfied for most practical measurements of traffic noise.

To illustrate the concept of $L_{Aeq,T}$, Figure C3 shows a typical variation in noise level measured close to a busy road.

Over the six minute period of recording, the fluctuations in noise levels are shown as vehicles travel past the microphone. The constant level at 78.1 dB depicted in the figure represents the equivalent noise level, $L_{Aeq,T}$ which over the 6 minute period, T, has the same acoustical energy as that received from the fluctuating noise from the traffic over the same period.

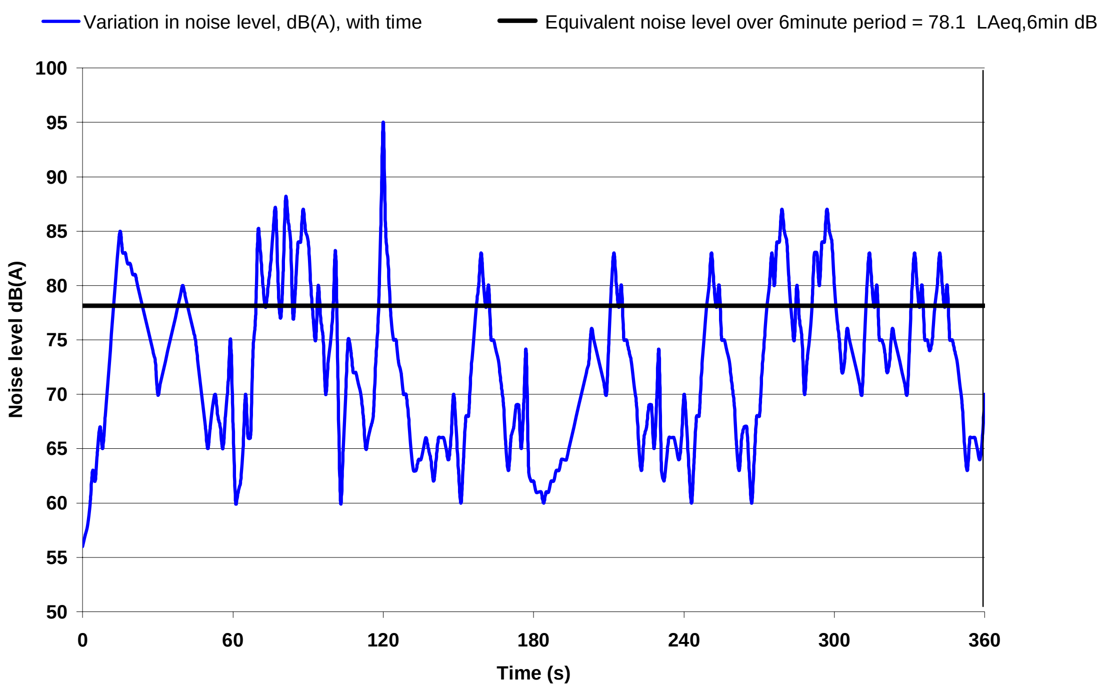


Figure C3: Variation in traffic noise level and the equivalent noise level, $L_{Aeq,T}$ dB

The factors which contribute to a noise scale, however, are not in general the only factors that may determine annoyance from road traffic noise. Composite measures of noise referred to as noise indices or indicators have been developed, which although based on noise scales include additional attributes important for assessing the noise impact on communities. These additional attributes may be related to a particular noise source or characteristic or to certain situations when the noise intrudes. The following provides relevant information on the noise indicators for road traffic noise.

C.1.3.2 Noise indicators (L_{den} and L_{night})

Over the past forty years there have been a proliferation of noise indicators that have been shown to correlate reasonably well with community response to annoyance caused by road traffic noise. In November 1996, the European Commission published a Green Paper on 'Future Noise Policy'. This paper was to be the first step in the development of an overall noise policy with the aim of providing a common basis for tackling the noise problem across the EU (Commission of the European Communities, 1996).

For the purposes of assessing the impact of environmental noise on communities including that from road traffic, the EU has recommended two indicators, L_{den} and L_{night}, to be used throughout Europe. Both noise indicators use the noise scale $L_{Aeq,T}$ as a basic metric but include additional factors concerning the time of day and length of exposure. These indicators are defined as follows:

L_{den} is the primary noise indicator of annoyance from long-term exposure to noise. It is calculated from

$$L_{den} = 10 \times \log_{10}\left(\frac{1}{24}\right)\left(12 \times 10^{L_{day}/10} + 4 \times 10^{(5+L_{evening})/10} + 8 \times 10^{(10+L_{night})/10}\right) \quad \text{dB}$$

where

L_{day} is the A-weighted equivalent sound level for the 12-hour daytime period from 07:00 to 19:00 hours, determined over all of the day periods of a year;

$L_{evening}$ is the A-weighted equivalent sound level for the 4-hour evening period from 19:00 to 23:00 hours, determined over all of the evening periods of a year;

L_{night} is the A-weighted equivalent sound level for the 8 hour evening period from 23:00 to 07:00 hours, determined over all of the night periods of a year.

In equation (2.3) $L_{evening}$ and L_{night} have a 5 and 10 dB weighting applied respectively to take account of the difference in annoyance due to the time of day.

L_{night} is used for the assessment of sleep disturbance but does not include the 10 dB weighting that is applied when determining L_{den}.

It should be noted that the start of the daytime period (and subsequently the start of the evening and night-time periods) are set by individual Member States and that there is the flexibility to shorten the evening period by one or two hours and lengthen the day and/or night period accordingly.

These recommendations form the basis of the EU Directive for assessing the environmental impact of road traffic noise on communities (Commission of the European Communities, 2002). The importance of this Directive is that it sets out the procedures to adopt in the production of noise maps and the drawing up of action plans to reduce noise exposure. It is anticipated therefore that the utilisation of low noise surfaces will play an important role in the implementation of action plans by Member States as a means to reduce exposure from road traffic noise.

The noise indicators described above show the importance of the time of day when the noise occurs on disturbance. At night there is a 10 dB weighting applied to the overall traffic noise level to take account of the sensitivity of people to noise particularly when they are trying to get to sleep and prior to wakening. Although traffic flows during the night are lower and less congested, vehicle speeds are generally higher and the dominant noise is generated by tyre/road noise, particularly on high speed roads. It is therefore important when evaluating the benefits of low-noise surfaces that the impact takes into account the changes in the sensitivity of people to noise particularly with respect to the time of day when the noise occurs.

C.1.3.3 The Noise index, $L_{A10,18h}$, used in the UK to control road traffic noise

Partly due to historic reasons, the noise index, $L_{A10,18h}$ is predominantly used in the UK for controlling the environmental impact of road traffic noise for both legislative and planning purposes. This index is described in terms of a statistical description of the time varying noise level typical of road traffic noise and defined as the arithmetic average of the noise level exceeded for 10% of the time in each hour over the period from 06:00 to midnight.

Until recently, the argument for adopting an alternative index based on the noise scale, $L_{Aeq,T}$, has not been sufficiently convincing to off-set the financial burden associated with the necessary changes in legislation that would need to be incurred. However, over the past few years, there has been a concerted effort both in the UK and in other European countries to rationalise the various different noise indices used in assessing the noise impact from all transportation sources, as described earlier which led to the introduction of the EU Directive and will be transposed into English law over the next few months.

The next section describes the impact of these changes and the implication on local authorities' noise policy, particularly in controlling the noise from road traffic.

C.2 Impact of recent EU Directive on local noise policy

The timetable set out in the EU Directive for the completion of the strategic noise maps and associated action plans is detailed in Table C1.

Table C1 Timetable of strategic noise maps and actions plans outlined in EU Directive

Actions	Date of completion
Strategic Noise Maps:	
1st Round	30th June 2007
Agglomerations (population > 250,000)[1]	
Major Roads (> 6 million vehicles per year)	
2nd Round[2]	30th June 2012
Agglomerations (population > 100,000)[1]	
Major Roads (> 3 million vehicles per year)	
Setting criteria or limit value:	18th July 2007
Action Plans:	
1st Round	18th July 2008
2nd Round[2]	18th July 2013

[1] Includes all roads with 18-hour flows (06:00 to 24:00) > 1000 vehicles
[2] Repeated at 5 year intervals

The timetable includes only those sources associated with road traffic, a similar schedule is planned for other environmental noise sources from rail, air and industry.

The first round of strategic noise mapping will include all agglomerations with populations greater than 250,000 and all major roads with traffic flows which exceed 6 million vehicles per year. However, the Directive requires that within each agglomeration, noise sources which contribute a noise level of L_{den} ≥ 55 dB or L_{night} ≥ 50 dB at the most exposed façade of properties are to be included in the mapping process. It is therefore required that roads within each agglomeration with 18-hour traffic flows (06:00 to 24:00) exceeding 1000 vehicles will need to be included. The agglomerations that have been identified in the first round are listed in Table D.1 of Appendix D and are to be completed by 2007. In addition to publishing the noise maps, an estimate of the number of people exposed where the L_{den} level is within the noise bands 55-59, 60-64, 65-69, 70-74 and >75 dB and L_{night} level is within the noise bands 50-54, 55-59, 60-64, 65-69 and >70 dB are to evaluated. By 2008, action plans designed to manage noise issues and their effects including noise reduction are to be in place. The measures within the plans are at the discretion of the competent authorities, but should notably address priorities which may be identified from the strategic maps taking into account any criteria or limit value set by Member States to be announced one month after the noise maps have been published.

This process will then be repeated at 5 year intervals and will include all agglomerations with populations with greater than 100,000 and all major roads with traffic flows which exceed 3 million vehicles per year. The agglomerations that have been identified in the second round are listed in Table D2 of Appendix D.

The responsibility for producing the noise maps, the setting of criteria or limit values and the development of action plans will primarily be with the Secretary of State. The action plans will identify the local authorities responsible for a particular action. Although there are concerns about the extent to which local authorities will be involved in the decisions making process when the action plans are developed, it is clear that local authorities will be charged with the responsibility of achieving reductions in noise exposure if identified in the action plans.

Appendix D. List of major agglomerations in England to be mapped under Directive 2002/49/EC

D.1 Agglomerations with a population of >250,000 (to be mapped in 2007 onwards)

Birkenhead
Blackpool
Bournemouth
Brighton
Bristol
Coventry
Greater London
Kingston-upon-Hull
Leicester
Liverpool
Manchester
Nottingham
Portsmouth
Preston
Reading
Sheffield
Southampton
Southend on Sea
Teesside
The Potteries
Tyneside
West Midlands
West Yorkshire

D.2 Agglomerations with a population of >100,000 (to be mapped in 2012 onwards)

All the agglomerations listed above plus:

Barnsley
Basildon
Blackburn
Burnley
Cambridge
Cheltenham
Chesterfield
Crawley
Derby
Doncaster
Farnborough
Gillingham
Gloucester
Grimsby
Hastings
High Wycombe
Ipswich
Luton
Mansfield
Margate
Milton Keynes
Northampton
Norwich
Oxford
Peterborough
Plymouth
Slough
Southport
St. Albans
Sunderland