INITIAL STUDY OF EDGE DETERIORATION – TTS ON LOCAL ROADS

Version 1.0

by PJ Watson, SG McRobbie and MA Wright (TRL Limited)

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Client: Edward Bunting, Traffic Management Division, Department for Transport

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Executive summary

Project Title: Initial study of edge deterioration – TTS on local roads
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Objectives of Project
One of the biggest limitations in applying TRACS Type Survey (TTS) techniques, which were developed for trunk roads, to local roads, is the inability to detect and measure edge deterioration. This is a widespread problem on local roads, particularly on rural roads without defined edge kerbs, and local authority engineers have highlighted it as one of the main causes of pavement maintenance expenditure.

There are two aspects to the problem:
- deterioration of the pavement edge due to inadequate foundations or lateral support.
- deterioration of the verge caused by vehicle overrun, leading eventually to dangerous conditions such as potholes forming adjacent to the carriageway.

The objectives of this project are to:
- Review recent developments in the detection and measurement of edge detection worldwide.
- Identify what information is available currently, or could be easily derived, from currently available automated road condition surveys to characterise the pavement edge condition.
- Identify an achievable interim method for inclusion in surveys in 2005/06 which will detect and/or measure edge deterioration.

This work will provide the basis for the initial specification for TTS surveys on non-principal roads, due to commence in 2005/06. It also provides a foundation for the longer term research and development programme to provide more a comprehensive measurement of edge deterioration.

Project Outputs
The research should cover:
- The types and causes of edge deterioration on different types and classes of local road
- How these different types of edge deterioration can be identified and classified from visual information and road surface condition measurements.
- What systems or techniques are currently available in the UK and overseas that are potentially capable of identifying, classifying and measuring edge deterioration.
- What measurements, currently obtained from automatic road condition survey vehicles, are potentially suitable for providing information about edge deterioration.
- How these techniques and measurements could be processed to give an indication of edge deterioration.
- How these techniques and measurements could be reported, presented and used within the UKPMS framework.

The technical development work should include a demonstration of the capabilities of the proposed system or method on a small but representative sample of local roads.

The final output of the project is this comprehensive report covering all aspects of the research, specifically covering: any edge deterioration detection systems, measurements and techniques which are sufficiently developed for inclusion in TTS surveys of local roads in 2005/06; which edge deterioration detection systems, measurements and techniques should be researched and developed further for possible inclusion in surveys from 2007/08; an assessment of the risks associated with including edge deterioration detection and/or measurement at each stage of the survey development; an outline technical specification and quality assurance procedure, which will be required for the inclusion of edge deterioration detection or measurement in the specification for surveys in 2005/06.
Summary

A review has found that edge deterioration is associated with several main defects, including cracking, fretting/potholes, longitudinal/transverse bumps and deformations, poor structural strength, erosion of the road edge and overriding. The key defect relating to edge deterioration is overriding and rutting of the verge. This reduces the support given to the edge of the road surface resulting in accelerated deterioration of the road edge. Edge deterioration is consequently one of the most important defects found on local roads. It was found in an earlier study (McRobbie and Wright, 2004) that local authority engineers would be reluctant to accept TTS if it was unable to at least detect, and quantify, edge deterioration. This earlier review also showed that there was no strong relationship between any existing TTS output and CVI reports of edge deterioration.

A literature review and consultation exercise found that there are no currently available methods for detecting and assessing edge deterioration which are either routinely used or sufficiently developed for routine use. Because of this, and because of the short timescale for the implementation of TTS on non principal roads (April 2005), it was decided that it would not be feasible to carry out any major hardware configuration changes. Therefore, any methods developed in this research should be capable of detecting edge deterioration using currently available vehicles, instruments and information.

The measurements available on current TTS systems were considered in order to assess any ways in which existing measurements could be interpreted to indicate the level of edge deterioration present. It was found that the transverse profile measurements would extend towards or over the edge of the road surface on narrower B and C class roads, and that transverse and longitudinal undulations in the road surface (which could be the result of deformations, potholes and fretting, or breaking up of the surface) could be indicated in this data. It was also found that, in cases where the profile measurement system measures beyond the road edge, the shape of the profile data may allow the identification of the boundary between measurements made over the verge and measurements made over the pavement.

Three methods for detecting and assessing the severity of edge deterioration have been developed. All three methods use transverse profile data, as currently recorded by existing TTS machines. They also make use of an edge location method developed in parallel research being carried out into the assessment of transverse profile (Nesnas et al., 2004). The three techniques provide measures of edge stepping, edge roughness (short wavelength longitudinal variance) and the difference between the roughness recorded in each half of the transverse profile. Measurements on test sites indicate that the three techniques may be capable of reliably reporting the presence of edge deterioration. It is therefore recommended that these methods be included in the TTS surveys of non-principal roads in 2005/06. Descriptions of the chosen methods are given in Appendix A of this report.

Because the existing fleet of TTS vehicles should be able to adopt the recommended methods without having to significantly change their hardware or data collection approaches, the risks to the successful implementation of the edge deterioration measures is reduced. Furthermore, the measurement and analysis of transverse and longitudinal profile has, over the years, been developed to a reliable level which is reasonably comparable between machines. Any novel developments built on these proven techniques, such as these edge deterioration measurement methods, will therefore be more easily implemented and more likely to be successful in the forthcoming survey year. Testing of the implementation by TTS contractors should also be straightforward as, for any given input data, the results of all systems should be identical.

As the new methods have undergone only limited testing it is not recommended that they be included in the calculation of BVPI values for 2005/06. However, it is suggested that the methods be included in the specification for 2005/06 surveys for testing and to establish their use as part of the assessment and research toolkit. Finally, UKPMS will require modification to accommodate the edge deterioration parameters.
1 Introduction

The DfT intends to introduce TRACS Type Surveys (TTS) on the Principal Road Network (PRN) and the non-Principal Road Network (non-PRN). The first stage of these surveys began with the introduction of TTS on the PRN in April 2004. This is to be followed by the expansion of the TTS to include the non-PRN in April 2005.

An initial review of the requirements of TTS on the non-principal road network, which included consultations with selected experts in the field of local road maintenance and automated condition monitoring surveys has been carried out by McRobbie and Wright (2004). The review stated that the measurement of edge deterioration is required in order to obtain best value from TTS surveys, and to ensure that they meet the needs of the maintenance engineer. However, as pointed out in the TRACS Type Surveys for Local Roads Scoping Study (Ekins and Hawker, 2003), the state of the art in the detection of edge deterioration is such that substantial further research is required before this deterioration can be reliably quantified by current automated systems. The Scoping Study therefore recommended that an initial research project to be carried out with the aim of providing an interim measure of the condition of the edge of the pavement for use in the 2005/06 survey.

The results of this initial research into the monitoring and characterisation of the condition of the pavement edge are presented in this report. The work has been carried out with the following objectives:

- To review recent developments in the detection and measurement of edge deterioration in the UK, Europe and elsewhere
- To identify the information available from current methods of automated road condition surveys, and how this may be related to the presence and severity of edge deterioration
- To identify an appropriate method for detecting edge deterioration such that this may be practically included in the requirements for surveys commencing in 2005.

2 Review

The results of the review are presented as five separate phases in the following sections:

- Phase 1 – Review of visual surveys
- Phase 2 – Literature review
- Phase 3 – Expert consultation
- Phase 4 – Local Authority questionnaire
- Phase 5 – Existing systems.

2.1 Phase 1 – Review of Visual Surveys

2.1.1 Defects

Phase 1 involved a study of current and recent UK visual survey manuals, including the CHART survey manual (Department of Transport, 1986), and the UKPMS guidelines (UKPMS Owners Forum, 2001) for performing Coarse Visual Inspections (CVI) and Detailed Visual Inspections (DVI). The review also called upon existing experience at TRL in the field of road edge deterioration. The following list of defects, measurable features and problems was compiled:

Deterioration in/on the road surface adjacent to the road edge:
- Cracking
- Fretting
- Fatting Up
- Potholes
- Poor Transverse Profile (including, but not limited to, rutting)
- Poor Longitudinal Profile (specifically short wavelength bumps)
- Poor Structural strength

At the road edge:
- Erosion of the road edge, resulting in the edge of the road surface moving into the carriageway

On the verge adjacent to the road edge:
- Overriding (causing rutting of the verge and ponding)

2.1.2 Assessing Edge Deterioration under CHART, CVI and DVI

The CHART survey combines the defects in order to assess edge deterioration over the three severity levels:

1. Severity 1: Cracking, fretting or potholing of the edge of the carriageway with a need for patching but with little or no overriding of the verge.
2. Severity 2: Severe overriding, with or without rutting or potholing of the verge, either alone or with carriageway edge deterioration as for severity 1.
3. Severity 3: Serious deformation or serious cracking of the carriageway in the vicinity of the edge, with or without overriding of the verge.

For CVI and DVI surveys the following definition is used to determine whether road surface defects are correctly located to be recorded as edge deterioration:

Defects are counted as edge deterioration when “…occurring WITHIN 0.5m of the road edge AND NOT extending further than 0.5m from the edge AND extending right to the edge.”

It is noted that there is no reference in the UKPMS manual to defects located on unpaved verges, and hence overriding is not covered by the CVI and DVI surveys, and does not come under the description of edge deterioration used by these surveys.

As for the CHART survey, the DVI survey assesses the deterioration in terms of severity. For DVI surveys, this is assessed as:

1. DVI Right/Left Recorded Edge Deterioration Severity 1
   - Major Cracking
   And/or
   - Fretting
   Confined to wearing course
2. DVI Right/Left Recorded Edge Deterioration Severity 2
   - Disintegration of the edge of the carriageway to a depth below the wearing course
   And/or
   - Deformation greater than 20mm.

As the CVI survey is carried out at higher speed than both the CHART and DVI surveys the level of detail in assessing severity is reduced. Therefore in the CVI survey the inspector records CVI Right/Left Recorded Edge Deterioration where there is:

- Major Cracking
- Fretting
- Deformation (visually assess)
To convert the CVI data to a severity the following rules are applied when generating the CVI Edge Deterioration data, reported over 20m lengths in the HMDIF file:

Level 1 – Length of Edge Deterioration is between 5% and 20% of the reporting length inclusive.
Level 2 – Length of Edge Deterioration is above 20% and up to 40% of the reporting length.
Level 3 – Length of Edge Deterioration is above 40% of the reporting length.
In CVI the defect is not reported at all if the length within the 20m section is less than 5%.

2.2 Phase 2 – Literature Review

Phase 2 took the form of a short literature study, focussing on research carried out into the assessment of road edge condition on local roads. There were no papers found describing methods relevant to the particular issue of the automatic detection of edge deterioration. However, there were two papers of note:

2.2.1 Guylas

In work carried out with the goal of international harmonisation of aspects of pavement management, Guylas (1999), provides a table of road surface defect types. Edge problems were listed separately from other defects and Guylas includes ‘Edge Damage’ – Cracking or breaking of the edge of the pavement, and ‘Lane-to-shoulder drop-off’ – Difference in elevation between the road surface and the outside shoulder as defects of interest.

2.2.2 Duffell

Duffell et al. (1999) report the results of a ten year study of the deterioration of a sample of minor roads. A large number of minor road sites, each 100m in length and which exhibited edge and whole-carrigeway deterioration, were monitored over the duration of the study. The study began with 74 sites in Hertfordshire, a second phase of the study added rural and urban sites from several participating counties. For each site periodic condition surveys were carried out. These surveys used a wide selection of available measurement methods including manual surveys, SCRM, FWD, Deflectograph and other machine survey vehicles. As well as studying the relationships between the different survey methods, the project established multiple variable equations for determining deterioration rates of edge defects from causal factor measurements (factors that affect the rate of wear such as road width, traffic load, drainage, edge support, construction). The work also established a relationship between the manual and machine surveys using the machine survey technology of the time. There was found to be a correlation between the ‘ride quality’ indicated by the longitudinal profile 3m variance (measured by the WDM Ltd MRM and TRL HSV vehicles) and the Structural Condition Index (SCI) that is calculated from a number of manual survey measurements of the same site. Attempts to calculate an equivalent structural condition index from machine survey measurements were less successful.

2.3 Phase 3 – Expert Consultation

The third phase of the review was a detailed technical consultation with selected key experts in the UK who were considered to be well placed to comment and advise on the causes, monitoring and treatments of edge deterioration.

A number of local authority highway maintenance engineers and other industry experts identified during the Initial Review (McRobbie and Wright, 2004) were consulted to confirm industry requirements for reporting edge deterioration on the non-PRN. The purpose of this consultation was to ascertain the industry’s view of edge deterioration and to establish what forms of measurement and reporting of edge deterioration defects would be most useful for the purposes of highway maintenance and condition assessment. The answers were useful in defining the problems to be addressed when
automatically assessing edge condition, and deciding how to target the development of new methods to tackle the problem for implementation in 2005/06.

It was generally agreed that edge deterioration problems are caused, primarily, by overriding at the road edge. In the opinion of those consulted, the main defects associated with edge deterioration are:

- Cracking
- Major fretting/potholing
- Deformation
- Overriding.

The experts also generally agreed on the following key points:

- Deterioration rates at the road edge are much higher than in the carriageway
- Many minor roads have not been properly designed - they are made up of many surface layers
- Even a basic reporting yes/no for the presence of edge deterioration would be useful
- However, reporting defect type and severity would be more useful
- Survey information would be used to drive appropriate maintenance intervention
- Survey information also be used to prioritise further investigations
- A TTS report would target more detailed investigations before repairs are carried out.

The following additional points were made:

- Short lengths of the road edge (edge segments) often erode to create pothole-like defects
- It would be useful to have and use traffic flow information alongside TTS information and to link maintenance hierarchies to this rather than road class.

The consultation with the experts found that an ideal TTS edge deterioration system would accurately report the presence of road edge deterioration, would report the particular edge defects found and assign some sort of severity level suitable for determining the required maintenance intervention much like the CHART survey severity level definitions. However, it also found that a simple methodology which indicated nothing more than the presence of edge deterioration would be of some benefit, and would certainly be better than no information at all regarding the condition of the road edge.

2.4 Phase 4 – Local Authority Questionnaire

The fourth phase of the review took the form of a series of questions which were included on behalf of TRL in a questionnaire produced by Atkins Highways and Transportation as part of work being carried out to establish the base data for TTS (Atkins, 2004).

TRL contributed a number of questions to this questionnaire regarding the problem of monitoring the condition of the edge of the road. The questionnaire was distributed to over 75 local authorities.

The questions and summaries of the answers received are given below. There was not always agreement between the responses from different respondents but it was found that, overall, the responses supported the results of the above phases of the review.

**Question 1**

*From a maintenance perspective, do you consider road edge deterioration to be the occurrence of any defect type on or near the road edge, which might also exist in the rest of the carriageway, or to be only the defect types that are a result of road edge specific problems and only occur here?*

The responses varied with roughly two thirds of respondents of the opinion that edge deterioration covers any defect near to the road edge (e.g. defects such as cracking, which can occur anywhere on the carriageway) and the remainder stating that edge deterioration only
covers specific and unique defects (such as overriding) that result in the use of an edge-specific treatment.

**Question 2**

Would a TTS survey that reports “whole” carriageway defects but ignores the road edge and therefore does not distinguish defects detected on the carriageway from those detected near the road edge be a useful system to you?

About half of the respondents said that being able to report carriageway defects accurately but not report on the edge condition was of no use at all. In general the remainder stated that such a system would be of some use, but this would be more applicable on wider, higher class (A and B) local authority roads where edge defects are less of a problem.

**Question 3**

Would a survey that, in addition to “whole” carriageway defects, simply reports the likely presence of edge deterioration but with no specific detail, be of benefit?

Almost half of the responses answered negatively, the others stated that this would be some use, as a ‘coarse sieve’. One response indicated that reporting severity in line with the CHART defect definitions would be more useful and that in the past this was instrumental in triggering maintenance intervention.

### 2.5 Phase 5 - Existing systems

Consultation with researchers, developers and equipment manufacturers showed that there are three systems currently in development that attempt to measure edge defects to some degree. The first of these systems is developed by the VTI for use in Sweden, the second approach uses developments made by Roadware to their ARAN (Automatic Road ANalyzer) system and the third is currently being developed by TRL Ltd.

Complete details of the methods employed by the non-TRL systems have not been made available to TRL in the preparation of this report, however the following summarises the limited information that has been provided.

**Swedish System**

- The transverse profile is used in combination with the crossfall. The shape of the transverse profile is analysed in order to provide a measure of edge deformation.

**Roadware ARAN System**

- Edge deterioration process is an enhancement to their existing Crack Detection software.

**TRL System**

- This system, currently under development, utilises image processing combined with high resolution transverse profile measurements. The development work is using this data with an aim to measure the road edge, and hence identify and quantify overriding, potholes and cracking.
3 Development of methods to identify edge deterioration

The review, presented in section 2 above, has confirmed the desire for a measure of edge deterioration in the TTS surveys on the non-PRN. The review has also shown that there are few systems for the automatic detection of this deterioration. It was decided, for the systems identified, that it would not be appropriate to attempt to develop these methods in this work. However, discussions with VTI indicated that the Swedish measure utilises a basic assessment of the transverse profile to identify edge deterioration, and therefore their development experience was taken into account when developing algorithms in this project. The development work of TRL was also taken into account, but the use of the specific methods employed in the TRL work were not pursued because the data requirements may exceed the capabilities of some current TTS systems. The development of the Roadware system was not considered practical because of the lack of information provided regarding this equipment. Furthermore, it was deduced that the system relies on the use of the Roadware in-house image collection and processing systems, which, within the scope of this initial work, would not be practical to develop further. Furthermore there was concern that making developments on such a system would complicate the definition of a full specification that could be employed by all TTS contractors.

Work was therefore carried out to develop methods that would identify edge deterioration such that they may be implemented for TTS surveys in 2005. For practical purposes it was decided that such methods would provide edge measures which could be calculated quickly and easily using information already available from existing TTS survey vehicles. This approach would make the implementation of the method more straightforward for 2005 surveys.

3.1 Development Approach

The defects associated with edge deterioration and the measurement capabilities of TTS specification vehicles were considered in conjunction with TRL’s experience in the detailed analysis of laser measured profile, texture and video image data from machine surveys to produce a shortlist of methods. These methods were selected according to their likelihood of success when considered in theory, and whether they addressed the detection of the most important edge deterioration features identified in the review stages of the project.

3.2 Current TTS machine characteristics

Current TTS specification equipment typically contains transverse and longitudinal profile measurement equipment, an image collection system, texture profile measurement equipment and a location referencing system based on distance-travelled and GPS. Current systems for TTS surveys include the WDM RAV1, RAV2 and RAV3, the Babtie TTS system and Roadware’s ARAN. A further system that does not undertake routine surveys but is used for Quality Assurance and Accreditation purposes is the Highways Agency HARRIS vehicle.

A questionnaire was sent out to these TTS vehicle manufacturers to obtain data about vehicle sensors and dimensions. Only WDM Ltd. provided a response to this. The RAV1 and RAV2 have a front mounted laser ‘rut-bar’ of width 2.5m. On RAV3 this system is mounted between the axles. These rut-bar systems have a measurement width of 3.2m. For RAV1 and RAV2 the ground clearance is 200mm, but a sensible lateral running clearance is suggested to be 500mm. On RAV3, with the centrally mounted profile measurement system, the vehicle ground clearance is higher at 300mm, but the 500mm lateral clearance is still considered applicable. In general similar clearances apply for the HARRIS system, and it is assumed that other vehicles would have similar requirements. It is noted that these clearances may not be practical on many C class roads.

The WDM rut bar and HARRIS utilise a transverse array of distance measuring lasers that measure the distance between the laser and the road surface. The HARRIS vehicle measures the transverse profile at a transverse spacing of 150mm. This spacing is 168mm for WDM’s RAV1. Although a response was not received from Roadware, a known current alternative to the rut bar laser system is
used on the Roadware ARAN equipment, which uses two scanning lasers to provide measurements at a transverse spacing of approximately 3mm. The Roadware lasers differ in operation from conventional distance measurement lasers in that they use an image collection system to image the swept path of the laser and then process the image to obtain the transverse profile. This system provides more detailed transverse profile measurements, but may have lower accuracy than traditional methods. Furthermore, in its current form the rate at which the system can scan along the road is limited to 25Hz, which will only provide a transverse profile every 88cm at 80km/h. In contrast with this the traditional lasers can readily provide transverse profiles spaced at 0.05m at this speed.

In addition to the use of lasers to measure transverse profile, systems have in the past used ultrasonic transducers mounted on a ‘rut-bar’ to measure spot heights above the road surface and produce a transverse profile in a similar fashion to systems that make use of distance measuring lasers. TRL are not aware of any current TTS vehicles using ultrasonic transducers to measure transverse profile. Scanning laser technology based on distance measurement is also becoming available, which gives high accuracy, high resolution measurements at both transverse and longitudinal spacings of 10mm at traffic speed. However, this technology is not widely adopted and developed enough for use in 2005.

To collect images of the pavement the RAV systems have a 3.2m wide imaging system situated at the rear of the vehicle. This uses four cameras that capture frames to video via CCD transducers. The frames are intermittently lit by strobe lighting and immediately processed on board to produce images suitable for crack and feature detection, which is also carried out during the survey using automatic crack detection software. A similar image system is operated by Babtie’s TTS survey vehicle, but the automatic processing is carried out after the survey. The Roadware equipment also uses strobe lighting, digital image collection and automatic crack detection software which is run after the survey is complete. However, the Roadware software currently employs a degree of manual intervention to “fine-tune” the analysis to the survey. HARRIS uses a different image collection method based on line-scan cameras system, which build up a continuous image of the road surface line by line as the vehicle moves along the road. The images are stored as 1m long frames and analysed after the survey either manually or using automatic crack detection software.

Current TTS systems utilise lasers to record texture profile, typically in the nearside wheelpath. However, the RAV has three possible transverse locations for mounting texture profile laser systems, these are the wheel paths and to the left of the vehicle centre-line, between the front and rear axles. HARRIS has two texture lasers, which, for this study, were mounted at the front of the vehicle on the vehicle centre-line and in the nearside wheel track.

### 3.3 Assessment of defects and base data

Because of the requirement that automated methods of detecting edge deterioration will have to be implemented in a short timescale, it was decided that there was no possibility of making large-scale changes to the instruments carried on the TTS vehicles. Therefore any methods proposed would have to be able to operate using current equipment, or require only very slight hardware modifications. For this reason it was important to define what sensors were available on the TTS vehicles, and what information it would be possible to obtain from these. It was then possible to give some consideration to the issue of what use could be made of such information.

The data analysis carried out as part of the work by McRobbie and Wright (2004) into the implementation of TTS on local roads found no strong relationships between edge deterioration as recorded by CVI surveys and any of the parameters currently recorded by a TTS survey. Therefore any methods developed during this project which had to rely on information already gathered during TTS surveys had no obvious foundation on which to build. These new methods had to result in entirely new parameters, which could be calculated quickly and easily using information already available from existing TTS survey vehicles.

The data available from HARRIS and TTS specification survey vehicles was considered with respect to defects associated with edge deterioration. This is summarised in Table 1 and this formed the basis for the development of ideas for methods to detect edge deterioration.
It can be seen, from Section 3.2 and Table 1, that insufficient information is recorded by current equipment to enable a full assessment of the condition of the verge and of overriding depth and width. This is indicated by the fact that none of the sensor systems are designed to collect data from far beyond the vehicle width on the nearside. For a full assessment of verge condition a combination of measurements such as image and profile data beyond the width of any overriding would be required. A full assessment of road edge and verge condition is also likely to require the use of more detailed profile data with a smaller transverse spacing between points. Current transverse profile measurement systems can only measure a small distance beyond the widths of the vehicles due to the fact that their original design is to measure lane condition only, however it is possible on B class roads, and likely on narrow rural C and U class roads, that the transverse profile system will measure past the nearside edge of the road surface and therefore has the potential to measure the edge step down from the road surface into a rutted verge. The height of this step could be taken as an indicator of possible overriding.

<table>
<thead>
<tr>
<th>DEFECT</th>
<th>Sensor Systems</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracking</td>
<td>Visible, detected by image processing.</td>
<td></td>
<td>Could possibly show up in texture profile.</td>
</tr>
<tr>
<td>Fretting</td>
<td>Visible, could possibly be detected by image processing.</td>
<td>Transverse/longitudinal variation in profile heights.</td>
<td>Texture profile method exists to detect this.</td>
</tr>
<tr>
<td>Fatting Up</td>
<td>Visible, could possibly be detected by image processing.</td>
<td></td>
<td>Possibly a low texture measurement.</td>
</tr>
<tr>
<td>Potholes</td>
<td>Visible, could possibly be detected by image processing.</td>
<td>Possible to detect transverse step, relate position to wheeltrack?</td>
<td>Profile could trace pothole shape longitudinally.</td>
</tr>
<tr>
<td>Poor Transverse Profile</td>
<td>Measured. Transverse profile shape could be analysed for deformations of any shape, not restricted to the standard ‘two-ruts’.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor Longitudinal Profile</td>
<td>Profile variance derived from transverse profile on HARRIS, separate sensor on other vehicles.</td>
<td></td>
<td>Short wavelength deformations would be evident in the texture profile over ride height oscillations.</td>
</tr>
<tr>
<td>Erosion of Road Edge</td>
<td>Detect step at road edge.</td>
<td></td>
<td>High mega-texture (0.1m+) for broken-up edge pieces.</td>
</tr>
<tr>
<td>Overriding, rutting of verge.</td>
<td>Visible where survey vehicle drives over edge.</td>
<td>Detect step at road edge.</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Consideration of how the available sensor systems could be used to detect various defect types.
3.4 Proposed Methods

It was immediately noticed that, for many of the possible methods suggested by Table 1, it would be important to know which data points have been measured on the road surface and which data points represent the verge. For example the image system may record images over the road edge, but a crack detection algorithm would need to know which part of the image to ignore (the verge) to eliminate the false positive detection of cracks from features seen on the verge. Therefore the edge of the road surface needs to be accurately located and this edge location must be used in combination with the various measurements to derive an indication of road edge condition.

It can be seen that the image data collected by TTS vehicles could provide a significant amount of useful information regarding the road edge condition through the development and application of image processing techniques. However, these techniques are more complex to develop and implement than the methods that can be applied to profile and texture data and there is greater scope for variability between the image data obtained by different systems, which were not available for the testing carried out within this study. It was decided that any quick-win methods that could be applied by April 2005 would most likely come from the use of profile and texture data.

A method for determining the location of the road edge in each transverse profile has been developed as part of the parallel research project into the assessment of transverse profile on local roads (Nesnas et al 2004). This method, which was developed for the purpose of removing data from transverse profiles that affect the measurement of rutting, uses a consecutive series of transverse profiles and assumes that the shape of the road surface does not change significantly over short distances. The edge location method was tested on profile data collected with HARRIS and with the WDM RAV 1 and was found to detect the road edge reliably.

After consideration of what data would be available, summarised in section 3.3 of this report, it was decided to implement and test the following methods. All the tested methods give information about aspects of the road edge condition and were realistic for implementation in time for the proposed 2005/06 implementation:

- **Road Edge Location**: Use transverse profile to find road edge location by the method described in Nesnas et al (2004). This method defines a road edge location for each profile that is used in each of the methods below.
- **Edge Roughness**: Use the transverse profile sensors to identify short wavelength bumps in the longitudinal direction, caused by deformation, severe crazing and fretting in the road edge region.
- **Edge Texture**: Use nearside texture laser profile to measure fretting and report SMTD (Sensor Measured Texture Depth) where within the road edge region.
- **Edge Cracking**: Segment crack-map to report area of cracking lying in the road edge region.
- **Edge Step**: Determine the height of the edge-to-verge step at the edge location of each profile.
- **Transverse Variance**: Calculate the difference in variance of the profile heights for the nearside and offside half of the transverse profile, utilising the method described in Nesnas et al (2004).

These proposed methods were implemented in software and then a testing and assessment programme was followed to compare the results generated by each method with reference data and hence determine their suitability for use in the identification of edge deterioration on the non-PRN. The methods above are outlined further in the following sections (3.4.1-3.4.6).
3.4.1 Road Edge Location

The method outlined in Nesnas et al, 2004 results in a value indicating the transverse position of the edge of the road surface for each transverse profile within the survey. The method works by analysing fixed lengths of closely spaced transverse profiles. For this project a length of one metre was used and the profiles were spaced 0.1m apart.

For each one metre length, the profile shape is analysed with the assumption that the shape of the road will change gradually along the road and will therefore not change greatly within the length. An averaged and smoothed transverse profile is produced from the profiles in the 1m section. A second derivative method is used to locate any step or slope in the averaged profile that marks the edge of the road surface. Each profile within the 1m section is then aligned with the part of the average profile on the road side of the located edge. The road edge is then calculated for each profile by applying the transverse shift value calculated when aligning to the average. The full description of this method can be found in Nesnas et al, 2004.

The road edge position is located for each profile, and a ‘road edge region’ is defined from the edge point to a point 0.5m further into the road, to the right of the profile. In this way, the road edge regions from consecutive profiles along the road define a ‘road edge strip’ which is used by several of the methods for calculating measures of edge deterioration suggested below.

It should be noted that where the profiles have not recorded over the road edge (and no defects within the road affect the shape), the averaged profiles should not produce an edge location when the second derivative method is applied. The implementation tested here will in this case return the edge position with the value 0, which is the nearside end of the profile measurements. In this circumstance outputs that result from the use of the 0.5m edge strip have in this report been calculated using the nearside 0.5m of the profile which may or may not be adjacent to the road edge. Different approaches can be taken to deal with where the edge is not located within the profile; these are discussed in Section 6.4.

3.4.2 Edge Roughness

A method for measuring the longitudinal roughness along the 0.5m edge strip of the road surface was proposed. The TTS specifications for Principal Roads (UK Roads Board, 2003) require that consecutive transverse profile height readings are located at an interval of 100mm along the road and form parallel longitudinal profiles, one for each transverse laser position. The method proposed applies a profile variance analysis to each of these longitudinal profiles using a short moving average filter of wavelength 0.6m. Potholes and rough edge surfaces due to severe cracking, deformation and erosion of the road edge should produce higher variance figures, as will locations where a laser is recording heights along the verge past the road edge.

At this stage, each individual profile measurement point has an associated variance value from the above calculations. Then, output statistics are calculated using only the filtered profile variances for points lying in the 0.5m road edge strip (Section 3.4.1). Two main calculations were tested, the mean variance value of all of the qualifying edge strip variance values, and the proportion of variance values that exceed a particular threshold value.

It is noted that TTS transverse profiles are not corrected for vehicle movement on its suspension. However it is thought that the 0.6m wavelength filter applied in this method will be suitable for application to transverse profiles that are not ride height corrected and will be able to filter out bumps from vehicle movement on its suspension whilst capturing the local surface unevenness. Severe or sharp bumps to the vehicle might contribute to the output of this filter but these bumps are likely to be caused by the surface unevenness, potholes and bumps that this method is attempting to measure.

The procedure for this method is described in more detail in Appendix A.2.
3.4.3  Edge Texture

Edge deterioration includes damage to the road surface adjacent to the road edge. This damage includes fretting (loss of material from the surface), that can eventually lead to potholes. Loss of material from the surface, fretting, will result in a rough surface texture and a high texture depth.

The nearside wheelpath texture laser fitted to many TTS vehicles measures a detailed single-line profile along the road which also contains components of the vehicle suspension movement as well as the detail of small bumps and mega/macro texture elements of the road surface height. This cannot practically be moved outboard of the nearside wheel path where it is located on most TTS vehicles but it is likely for many narrower minor roads, particularly of C and U class, that the line of the profile measured will lie within the 0.5m ‘edge strip’ of the road surface. The texture laser profile will report detailed information about the road surface from within the road edge region, but this will only be in one narrow line and will necessarily also be in the wheelpath.

To test whether the texture profile could provide relevant information relating to edge deterioration rather than carriageway surface deterioration, in spite of its lack of coverage transversely, the standard SMTD (Sensor Measured Texture Depth) output and a Highways Agency algorithm for detecting fretting from the texture profile (Wright, 2004) were compared to reference data indicating edge deterioration. This was assessed with consideration of the transverse distance between the nearside texture laser and the road edge location (Section 3.4.1), to establish where the laser is measuring within the 0.5m road edge strip.

3.4.4  Edge Cracking

For this method, the positions of the road edge points (Section 3.4.1) are used in conjunction with the crack-map generated from the crack detection system. The crack-map is generated over the full image width as normal by crack processing routines applied to the downward facing images collected by a survey vehicle.

The given edge points are mapped onto the crack-map according to the geometry of the two systems on the vehicle such that the edge points located from the profiles are correctly superimposed onto the image data. This may result in edge points located outside the nearside extent of the image data (as profile measurement systems may cover a wider width than the imaging system) but the relative location of the edge point relative to the crack map reference frame can be specified.

The interval between the edge point found and the point 0.5m further into the road is specified for each profile. When the series of profiles from a survey are put together an ‘Edge Strip’ is defined. The area of cracking that lies within this edge strip is then calculated for the chosen reporting length.

3.4.5  Edge Step

The height of any step-up or step-down in the transverse profile at the nearside edge of the road surface is measured where the road edge location (Section 3.4.1) has been located within the profile width. To the left of the located edge point, the laser readings are assumed to be from surfaces outside of the road edge (verge, kerbs). To the right of this point the profile heights are assumed to be measured from the road surface. A line is fitted (by linear regression) to the profile heights that lie between the road edge point and 1 metre to the right of the edge point (into the road). This is to approximate the transverse slope of the road surface next to the road edge and to prevent a severe crossfall exaggerating any edge step measurement.

The height difference between each profile reading outside of the road edge is compared to the extrapolated road slope line and the height is established of any step up (due to a banked verge or kerb) or down (due to overriding or raised road surface construction) adjacent to the road edge.

The procedure for this method is described in more detail in Appendix A.3.
3.4.6 Transverse Variance

A method was developed which, after removing any of the left part of the profile that has recorded past the road edge (defined by the detected road edge point described in Section 3.4.1), analyses the profile for deformations and profile defects of any shape. The variance of the profile height values is calculated for the left and right parts of the profile, either side of the vehicle centre line.

The variance of the left, nearside half of the profile is an indicator of transverse deformation of the road edge (which could be due to settlement and subsidence resulting from inadequate edge support) and severe loss of material from the surface (severe fretting and potholes, where profile heights have been recorded in holes in the road as well as on the surrounding surfaces). Subtracting the variance of the right, offside half of the profile will provide a measurement of these defects at the road edge in excess of the level that exists across the whole carriageway, represented by the right half variance, giving an indication of edge deterioration.
4 Development and Testing of methods

4.1 Test Sites

A number of surveys were carried out on local authority roads to obtain data for the development and testing of the methods. The surveys were carried out with the HARRIS survey vehicle. A summary of the survey sites is given in Table 2. The majority of the sites were of B and C class, but some lengths of local authority A class roads were also surveyed, as well as a small amount of unclassified roads. The sites were selected on the basis of where edge deterioration was known to exist, but also to ensure that a representative sample of roads were included that did not exhibit deterioration. The identification of the sites drew on local knowledge, and CVI data supplied by local authorities in the South East of England.

The HARRIS survey vehicle was driven along the selected routes at a typical survey speed. However, as the survey is carried out in “live” traffic there are inevitably variations in survey speeds according to the road conditions, traffic, road geometry etc. Reference events were marked manually, by the vehicle operator using a push button, at the start and finish of the site and at intermediate road junctions. The HARRIS transverse profile measurement system is capable of measuring at survey widths up to 3.6m, but for practical and safety considerations, the width was reduced for these surveys so that the system was operated in its narrowest configuration, with 21 laser readings spaced 150mm apart covering 3 metres width.

It was found that the operation of HARRIS on some C and U road sites was complicated by the size of the vehicle and the measurement equipment mounted on it. HARRIS is based on a 5.5 tonne van, it is 8m long and 2.1m wide. HARRIS has a profile measuring beam mounted onto its front bumper which has a physical width of 2.3m in its narrowest configuration. Operation on B class roads was generally satisfactory although any narrow sections of road, or those exhibiting tight and frequent bends, required greater care to be taken with the driving line. It was found that although surveys were possible on C and U class roads, they were not without problems, and hence it was concluded that the HARRIS is not ideal for surveying over these types of sites. The vehicle width means that very low survey speeds are required. Difficulties are encountered when meeting other vehicles which can result in the need to override the road edge during the survey, stop or reverse. As the size of HARRIS does is typical of several current TTS systems, it is therefore felt that, for TTS surveys on C and U roads, smaller vehicles with greater manoeuvrability will be required.

<table>
<thead>
<tr>
<th>County/Borough</th>
<th>Site</th>
<th>Date, route No.</th>
<th>Length</th>
<th>Roads</th>
<th>No. of Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bracknell Forest, Wokingham District, RBWM</td>
<td>Twyford, Shurlock Row, Binfield</td>
<td>26/4/2004, 1</td>
<td>18km</td>
<td>A321, B334, B3018, C.</td>
<td>3</td>
</tr>
<tr>
<td>Bracknell Forest, RBWM</td>
<td>White Waltham, Shurlock Row.</td>
<td>29/6/2004, 1</td>
<td>24km</td>
<td>B3024, C</td>
<td>3</td>
</tr>
<tr>
<td>Bracknell Forest</td>
<td>Cabbage Hill Minor Roads.</td>
<td>29/6/2004, 2</td>
<td>7km</td>
<td>B3034, C, U</td>
<td>1</td>
</tr>
<tr>
<td>Bracknell Forest, RBWM</td>
<td>Braziers Lane, Winkfield A330.</td>
<td>29/6/2004, 3</td>
<td>17Km</td>
<td>A330, C</td>
<td>2</td>
</tr>
<tr>
<td>Bracknell Forest</td>
<td>Maiden’s</td>
<td>29/6/2004, 4</td>
<td>17km</td>
<td>C</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 2: Summary of surveyed routes (RBWM: Royal Borough of Windsor and Maidenhead)

<table>
<thead>
<tr>
<th>County/Borough</th>
<th>Site</th>
<th>Date, route No.</th>
<th>Length</th>
<th>Roads</th>
<th>No. of Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBWM</td>
<td>Green – Drift Road</td>
<td>5/7/2004,1,2</td>
<td>80km</td>
<td>A26, A228, B2026, B269, B2176, B2017, B2160, B2162, B2016, C, U</td>
<td>2</td>
</tr>
<tr>
<td>Kent.</td>
<td>Oxted, Tonbridge, Brenchley, West Malling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2 Assessment of Survey Data

4.2.1 Reference Data

CVI data provided by the Local Authorities were used to construct a reference data set. Software was developed to read the CVI HMDIF files and to generate summary CVI defect reports for each 10m length, over each survey section. As a similar output was generated by the edge deterioration detection methods this reference data could be compared easily with the test survey data. It was deemed logical to use CVI data as a reference because the edge deterioration detection methods developed in this work are ultimately aimed at replacing such visual surveys. However, it is known that CVI surveys are somewhat subjective, and are limited in the defects they can record. Indeed one of the major reasons for the move away from CVI surveys towards TTS is the improved objectivity and repeatability of TTS survey results. Table 3 lists the CVI defect codes referred to in this report.

Table 3: CVI defect codes

<table>
<thead>
<tr>
<th>CVI Defect Code</th>
<th>Title</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLED</td>
<td>Left Edge Deterioration</td>
<td>Located on nearside edge relative to survey direction</td>
</tr>
<tr>
<td>BRED</td>
<td>Right Edge Deterioration</td>
<td>Located on the far edge of the opposite side of road relative to survey direction.</td>
</tr>
<tr>
<td>BCKJ</td>
<td>Carriageway Major Cracking</td>
<td></td>
</tr>
<tr>
<td>BFEJ</td>
<td>Carriageway Major Fretting</td>
<td></td>
</tr>
</tbody>
</table>

As noted in Section 2.1, CVI road surveys report only defects from the surface of the road, and do not have any facility for recording or reporting overriding of the verge, or any other defect which occurs off the road, but is indicative of current or future edge deterioration. It may well be the case that experienced inspectors are able to account for this when performing CVIs, or that engineers are able to interpret the available data to read between the lines, but this is a clear shortcoming of the CVI system. An alternative source of reference data was therefore utilised wherever possible to supplement the CVI results. This data was been obtained by the analysis of forward facing video images gathered during the HARRIS surveys. Experience showed that, by tilting the forward facing camera downwards from its standard operating position, a better view of the edge of the road and the verge could be obtained, which allowed a better assessment of the edge of the road to be made. Manual analysis of video data collected in this way was used to record locations where it was thought that each of the following two defect categories could be seen:

- Deteriorated road edge surface (bad patching, cracking, severe fretting/erosion/potholes)
• Damaged or rutted verge, downward step from the carriageway to the verge

This additional data has been particularly useful as CVI data gives no indication at all regarding many of the indicators used in the algorithms, such as the step height between the edge of the road and the verge.

4.2.2 Survey (HARRIS) Data

The HARRIS crack, transverse profile and texture profile data were processed using the proposed methods for the detection of edge deterioration to report a measure relating to each method over each 10m length of the survey. As for the reference data, the results were reported in relation to the section such that direct comparisons could be made with the reference data.

As noted in Section 3.4, there were five proposed edge deterioration detection methods. Each of these methods generated a number of output parameters that were compared with the reference data. For transverse profile based measurements, where the value reported is a length meeting some condition within the 10m aggregation section, this is calculated by taking the number of profiles meeting the condition and multiplying this by the spacing between profiles. The output parameters were:

• **Edge Roughness:**
  - The mean variance value of all of the profile height points falling within the 0.5m edge strip over the 10m summary length.
  - The proportion of the edge points with variance values above a threshold, using the threshold values 3mm$^2$ and 5mm$^2$ which were found to be appropriate after some initial processing with the survey data.

• **Texture:**
  - Average SMTD (Sensor Measured Texture Depth) over 10m length (UK Roads Board, 2003).
  - Length per 10m where the HA Stoneway fretting algorithm has indicated stone loss, this is calculated by summing lengths of individual stone shaped ‘dips’ (exceeding a certain size) in the texture profile and so very short lengths are accumulated (Wright, 2004).

• **Cracking:**
  - The absolute area of the crack map grid within the edge strip over the 10m length that is taken up by grid squares containing a positive response from the crack detection algorithms.

• **Edge Step:**
  - The length per 10m section where the step height measure fell within a number of ranges, stepping both up and down at the road edge.

• **Transverse Variance:**
  - The average transverse variance value over the 10m length for the left and right halves of the profile.

• **Edge Location:**
  - Length per 10m where the road edge position is at the extreme left end of the width measured (at profile sensor 0 by convention).

To view the performance of each method on the test survey data (assessed in section 5), the data was plotted as the 10m output statistics listed above, against the chainage location associated with each 10m length. This enabled the response of the methods to be assessed for the different sections, road types, widths and conditions known to exist over various lengths of the survey route. The plots
(Figure 1 to Figure 23) show in some detail how the methods work at different locations and give an indication of the road types and conditions that can be expected to produce higher responses.

The outputs generally appear noisy on plots showing results every ten metres, and the location referencing is unlikely to be accurate enough to ensure comparisons between particular 10m sections between reference and test data are made using the correct data. The high-frequency output also does not demonstrate how well the output works as a network level tool as it can be difficult to see the trends in the data for reporting indicators of defects on a particular site. Therefore, for the second and third survey sites where full CVI reference data was available, comparisons using 500m statistical summaries of the data were adopted. This worked by deciding upon an appropriate threshold for the parameter that would indicate a defective 10m section, then counting the number of 10m sections within each 500m length that exceed this threshold. A small number of parameters were reported as lengths defective per 10m and so the total length per 500m is calculated by summation of the 10m output statistic. The reference data was summarised by counting the number of particular CVI responses occurring within the 500m length in a similar way. The video data was summarised as lengths defective per 500m, this was then expressed as a multiple of 10m to allow plotting on a similar scale to the other data.

This analysis means that the performance of the methods can be compared to reference data at the appropriate level given the fact that one would not expect the CVI and test outputs to be equivalent. An example question is: does a particular 500m length have less “positive” recordings of edge deterioration than the surrounding 500m lengths, for both the test and the reference data?

### 4.2.3 Shape and intensity of reference and test data

The CVI edge deterioration measure covers a range of defects but does not distinguish between them. The assessment is subject to a degree of subjectivity such that the level of deterioration that may result in positive recording of a defect will also vary. This can lead to large differences between results on different sites that may actually exhibit similar levels of deterioration. This means that it is not always possible to plot sites together on the same graphs, and there is a problem with comparing the specific measurement of one aspect of edge deterioration from the methods tested to the CVI general assessment of edge condition.

To deal with the varying levels reported in the CVI Edge deterioration output, the CVI reference data is plotted with each measure to be assessed on different vertical scales. This allows the underlying shape of the output to be compared to assess agreement rather than the magnitude of the values. It was also found, when plotting three items on one plot, that some items had to be moved to a different scale than for the previous site in order to plot the data together.

The use of the forward video visual survey data as a second reference dataset allows consistency to be checked between surveys. Variations in the range of output values in the test and video visual survey data can be compared with the difference in the range of values reported by the CVI data. If the CVI data reports much larger values on one site, but the video reference and the test TTS output produce values over a similar range for both sites, and the underlying shapes are similar for all three datasets, then this might indicate that the CVI edge deterioration recording has been triggered differently between the sites.

The video visual survey reference data can be used to assist with the problems of comparison of a specific edge defect output with the general CVI assessment of edge deterioration. This reference is split into two sets of data, the presence of overridden or damaged verges with stepping at the road edge, and the deterioration of the actual road surface adjacent to the edge. In particular, this enables one to see where a test output has indicated deterioration due to eroded verge support or due to a deteriorated surface, and indicates where CVI edge deterioration may have been recorded due to overriding of the verge and stepping at the edge.
5 Testing and Further Development

This section will present, in detail, the results of the comparison between the edge deterioration detection methods and the reference data on three of the test sites, as follows:

- Section 5.1 Twyford - Shurlock Row – Binfield Run 1, 26/4/2004. The comparison between the limited amount of CVI reference data available for this site and the data provided by the edge deterioration detection method is discussed in terms of the use of the results to identify edge deterioration.

- Section 5.2, White Waltham – Shurlock Row Run 3, 29/6/2004 Route 1, and Section 5.3, Kent Run 1, 5/7/2004. This section compares the results of all five proposed edge deterioration detection methods with the CVI reference data available on these sites (which was reasonably comprehensive). Comparison is also made with the results of the manual assessment of the forward facing video footage.

- Section 5.3 also proposes a rating system to interpret and simplify the assessment of the edge deterioration detection methods. This is assessed over a range of road classifications on sites located in Kent.

5.1 Twyford - Shurlock Row – Binfield Run 1, 26/4/2004

For this initial test survey a circular route (shown in Figure 1) was chosen that covered a variety of roads covering three local authorities. The roads included an A road, two B roads which were known to exhibit surface and edge deterioration, and a C class road that had been previously used for other TRL research into edge deterioration.

![Figure 1: Route Followed for the Twyford-Binfield Loop Survey.](image)
5.1.1  Edge Roughness Method

Figure 2 shows the mean variance value output from the edge roughness method (described in section 3.4.2) for each 10m of the survey. Figure 3 shows the second output of this method – the proportion of points having a value greater than 5mm² over each 10m length. Note that the figures show the section boundaries representing relevant road junctions as vertical grey lines. The site spans several road classifications. Chainages 1500m to 7000m represents an A road, while chainages 9600m to 11600m represents a C class road known to exhibit edge deterioration. The defects seen on this length are edge cracking, a bumpy surface due to deteriorated edge patching and some small potholes. It can be seen that this length has produced a greater response in the output of the edge roughness method than the surrounding A and B roads.

**Figure 2: Edge Roughness: Mean, Binfield-Twyford Survey Route.**
Figure 3: Edge Roughness Proportion above 5mm$^2$, Binfield-Twyford survey route.

It can be seen that the mean variance appears to differentiate more between the known site of edge deterioration and the surrounding roads than the output of the proportion of points over 5mm$^2$. However, this was not the case for all sites, where it was often found that the proportion of points above a threshold (e.g. 5mm$^2$) gave better results. It is likely that the section of greater mean variance seen in Figure 2 reflects the change to a lower classification road more than it reflects serious deformation of the edge. The quantity of small deformations would increase on narrower minor roads, influencing the mean value, but these small deformations would not be included in the count of variance values above a certain threshold which should only count the greater variances caused by pot-holes, broken up surfaces and places of severe fretting.
As discussed above, the edge roughness measure relies on the output of the algorithms identifying the location of the road edge in the transverse profile. Figure 4 shows the length per 10m section of this site where the road edge location algorithm reported that the edge was at the extreme nearside of the transverse profile. This implies that the transverse profile system is either not extended to the road edge or that the verge is level (flush) with the road surface. As might be expected the proportion of zero edge points is higher for the A class road between 1.5 and 7km, but where the survey enters a narrow C road between 9.5km and 11.5km the edge point is placed at the end of the profile much less frequently, indicating that the profile system is measuring over the verge. For the other, mainly B class roads, the road edge is beyond the profile measurement width a variable amount averaging between two and six metres in every ten as indicated by the black moving average line between 0 and 1.5km and between 12 and 17km.

**Figure 4:** Length per 10m sub-section where a road edge location is not recorded, red line. Black line is a 250m Moving average.
5.1.2 Texture

As discussed in Section 3.4.3, SMTD and fretting values are calculated from the texture profile measured in the nearside wheelpath. The values of these parameters reported on this site are plotted in Figure 5. These values reflect the condition of the nearside wheelpath which should usually be located close to the road edge on narrower B and C class roads due to the driving line of the vehicle on such roads. It appears that on this site this output does not reliably reflect the edge condition. This may be because the laser cannot be guaranteed to follow a line that is always near to the edge and therefore may not capture much information about edge-specific defects.

![Binfield-Twyford Run 1, Texture Laser Output](image)

**Figure 5:** Texture laser and fretting output for Binfield–Twyford Survey Route.

5.1.3 Crack Detection

As a result of practical difficulties crack information was not available on this site.
5.1.4 Stepping at the Road Edge

The length per 10m sub-section containing each of five levels of stepping from the road edge to the verge was calculated. The levels were:

- steps greater than 50mm upwards (as with a kerb);
- between 20 and 50mm upwards;
- between 20mm upwards and 20mm downwards;
- between 20mm downwards and 50mm downwards;
- greater than 50mm downwards (as with rutting of the verge).

The calculated lengths over which each of these step heights occurred within each 10m sub-section are shown in Figure 6 as a stacked line graph. It was found that for parts of the survey containing continuous kerb at the road edge, the step-up output produced sporadic short readings of a step upwards. It was found by manual observation of the transverse profile data that the positive kerb step responses corresponded to where the survey vehicle has moved close enough to the kerb for it to show in the transverse profile. It was also found that on the A class part or wider B class parts of the survey, typically on entry or exit to built up areas, the width measured by the profile system only reached the kerbed edge intermittently. The two ‘step-down’ plots (orange and red) had the greatest response on the narrower C road section known to be a site containing edge deterioration. This site contains some overriding but it also contains a banked verge. It appears that the high step-down response on the known edge deterioration section may have positively identified the presence of overriding, an edge defect. There are intermittent responses on the B class road between 13 and 17km which includes some sharp bends and is also known to exhibit some deterioration.

Figure 6: Stepping Up and Down at the road edge, Binfield-Twyford route run 1.
5.1.5 Left/Right Transverse Variance

Figure 7 displays the output of the left and right variance calculations for this site. It appears that the left half variance values are generally higher than the right half values, with certain sections containing much greater left half values than the right half. The sections with significantly greater left half variance agree with the output of the variance and edge stepping methods as indicators of edge deterioration, though as with these other methods it may be that the narrower sections of road with close proximity of the verge produce higher variance values and make the methods sensitive to the accuracy of the road edge location in the transverse profile.

Figure 8 plots the difference between the two variance values, calculated as the left variance minus the right variance. This output is more appropriate than the use of the left transverse variance value in isolation as it would respond less to whole carriageway deterioration that may extend to the road edge, the subtraction removes the whole carriageway component of the deterioration. The plot indicates that an appropriate good/bad threshold for this measure to indicate edge deterioration would be in the region of 0.5mm² to 1mm².

Figure 7: Plot of transverse variance calculated from the left and right halves of the profile, averaged over 10m, Binfield-Twyford route run 1.
Figure 8: Plot of the difference between the left and right half profile transverse variance, averaged over 10m, Binfield-Twyford route run 1.

5.2 White Waltham – Shurlock Row Run 3, 29/6/2004 Route 1

This survey was carried out over a circuit of B and C roads where analysis of local authority CVI data had shown the presence of Edge Deterioration. The circuit (Figure 9) was surveyed in both directions in one run so both sides of the road are represented in the data. CVI data was available for the full survey length and this comparison data was processed such that left edge deterioration (BLED) data was used when the test survey went in the same direction as the CVI section definition, and right edge deterioration (BRED), with corrected and reversed chainage values, was used where the test survey was in the opposing direction to the CVI survey.
In Section 5.1 the results of the edge deterioration detection methods were plotted in terms of the values reported by each method, for the Twyford-Binfield survey site. It was found that this although this method is able to show where the method does and does not respond to the presence of edge deterioration, it is not the most appropriate way to assess the general level of performance, as the noise in the measure can hide the underlying trends in the data. Therefore in this section the outputs of the edge deterioration detection methods have been interpreted in terms of the number of 10m subsections within each 500m length for which the edge deterioration detection methods indicates there is edge deterioration present. This decision is made by applying an appropriate threshold to the 10m values provided by the edge deterioration detection method, as discussed in the following sections.
5.2.1 Edge Roughness Method

On this site the edge roughness algorithm reported the proportion of the profile measurement points within the 0.5m wide road-edge having a moving average variance value greater than 3mm² over each 10m length. This value was then interpreted to be reporting the presence of edge deterioration in any 10m length if the value for that 10m length was greater than 0.1 (more than 10% of points had a variance greater than 3mm²). The total number of 10m lengths for which this level was triggered over 500m sub-sections was then calculated and plotted against the reported level of CVI defects over the same 500m sub-sections, as shown in Figure 10.

![Figure 10: Edge Roughness Variance and CVI Edge Deterioration, aggregated over 500m sections.](image_url)

The results of the comparison with the manual analysis of the forward facing video obtained from the survey of this site are shown in Figure 11. Again this plot shows the number of defective 10m lengths per 500m sub-section. The plot shows some agreement between the edge roughness measure and the video analysis, and also agreement between the video analysis and the CVI data can be seen. However the ‘peaks’ are of differing magnitudes which makes it difficult to find an appropriate scaling to compare the CVI and video data.

- The subjective nature of the CVI survey (McRobbie and Wright 2004).
- The variance method measures the condition of the surface in the road edge region without making the further decision as to whether the condition reflects an edge defect or a carriageway defect extending near to the edge.
- This method may have some response to ride quality at the nearside edge and respond to more minor edge deformation/patching defects which may not be reflected in a CVI survey but are a concern to road users.
Figure 11: Edge Roughness Variance and CVI Edge Deterioration, aggregated over 500m sections with manual video analysis ‘deteriorated edges’ superimposed.
5.2.2 Texture

Examination of the SMTD and fretting algorithm values (described in Sections 3.4.3 and 4.2.2) obtained on this site indicated that the SMTD measurement is affected by changes in surface type and the associated texture, which may affect its use as a measure of edge condition. For further analysis involving aggregating the average SMTD for each 10m section over longer lengths, the Highways Agency Level 1 threshold of 1.1mm was used (Highways Agency, 2002). For comparison with the reference data the ‘total’ length’ within each 500m sub-section of fretting and of the number of 10m SMTD average values that exceed the level 1 threshold were calculated. The results of this analysis are shown in Figure 12, against CVI Edge Deterioration (BLED/BRED) and CVI Whole-Carriageway Fretting (BFEJ). There does appear to be some agreement between the texture outputs (SMTD and FRETTING) and the manual survey reporting of carriageway fretting (BFEJ), which indicates, as may be expected, that wheelpath texture laser methods are a better indicator of carriageway defects than they are of edge defects.

Figure 12: Texture laser SMTD and Fretting Outputs, CVI Edge Deterioration and Fretting, 500m Summary values
5.2.3 Crack Detection

The area of cracking within the region of the crack map occupied by the 0.5m edge strip – defined using the road edge calculated from the transverse profile – was calculated and reported for each 10m length of the survey. To compare the results the output of the proposed method for measuring ‘Edge Cracking’ (Sections 3.4.4 and 4.2.2) was again aggregated over 500m lengths and plotted (Figure 13) against the number of 10m lengths of CVI edge deterioration with severity level 1, 2 or 3. Also plotted was the 500m aggregation of CVI whole carriageway cracking (CVI code BCKJ). This comparison is to determine whether the automatic detection of cracking at the road edge is more closely related to the visual survey recording of edge deterioration (section 2.1.2) or to cracking of the surface in the carriageway (UKPMS Owners Forum, 2001).

It can be seen that the road edge crack detection measure matches either the CVI Edge Deterioration or the CVI Carriageway Major Cracking in places. However, there are also a number of large peaks in the crack output that do not match the reference data, or vary in magnitude from the reference data. It is not clear from the survey whether the area of cracking agrees most closely with the CVI Edge or Carriageway defect recordings. It is noted that there is a question over the level of edge cracking that would trigger the recording of edge deterioration in CVI surveys and whether this may vary between surveys. Also cracking that covers the full carriageway width and the edge should not be recorded as edge deterioration under the CVI guidance, this should be recorded as carriageway major cracking. The automatic detection of cracking in the edge region tested here does not differentiate between cracking at the edge that extends across the road and cracking confined to the edge. Hence the automatic edge cracking detection will agree more positively with the CVI edge deterioration in some places and with the CVI carriageway major cracking in other places.

![Figure 13: Count of the occurrence of each Severity Level for CVI Edge Deterioration and Area of Cracking output, 29062004 survey route 1 run 3.](image-url)
5.2.4 Stepping at the Road Edge

As discussed in Section 3.4, the step down from the pavement to the verge is measured in each transverse profile. Using the generated values as described in 4.2.2, for analysis of the data on this site the length within each 10m sub-section where this step size was between 20 and 50mm downwards (Step Level 1) were calculated, as were the length where the step was greater than 50mm downwards (Step Level 2). For each of the two step size bands, the number of 10m lengths within each 500m sub-section where the step was triggered over a length of greater than 1m (i.e. where a step was recorded for greater than 10% of the reporting length) were counted and are plotted on Figure 14 alongside the CVI edge deterioration reference data.

There is good visual agreement between the Step Level 1 (20-50mm) and the CVI recording of edge deterioration. The main peaks are in the same places. The second step level does not reflect the reference data so well for much of the survey, indicating that reporting one value of stepping, where greater than 20mm, is most suitable for this site. This measure does seem to reflect the reference at each end of the survey, 0-3km and 21-24km which correspond to both sides of the same section of one of the more heavily trafficked B roads on this site. However, it may be that this site generally features a low amount of edge stepping (and rutted verges) and so the higher step trigger level reports less deterioration on this site.

Figure 14: Edge step output for two levels of stepping and CVI Edge Deterioration severity levels, aggregated over 500m sections.

Figure 15 shows the results of the manual video analysis output ‘deteriorated edges’, aggregated by length over 500m sections, against the Stepping output and CVI reference data. The Video reference data consists of a measure of deterioration of the road surface at the edge (black line), and a measure of deteriorated/rutted verges (green line). Both of these measures are expressed as the length defective per 500m. There is some agreement between the two video assessment outputs and certain parts of the test data. However, the video edge step/verge damage data (green plot) has recorded little in the second half of the survey and so disagrees with both the large values in the CVI data and the edge step output from the algorithm. It is noted that edge stepping was hard to identify from the forward facing video and so this reference data may have missed some lengths of this deterioration.
Significantly, the video edge surface assessment supports the edge step output where agreement was not found in the CVI reference data of edge condition. This can be seen at 0-2km and 11-16km. It is possible that the condition of the road has changed between the recording of the CVI data and the test survey carried out for this project, either through deterioration or repairs, which may have resulted in this disagreement between the two reference datasets. Secondly, the video survey has recorded very little verge deterioration with edge stepping, this corresponds with the low level of output from the higher level 2 output of the edge stepping method. It seems that for this site the edge deterioration recorded by both CVI and the video survey is a result of poor edge surface condition occurring without a significant level of edge stepping.

Figure 15: Edge step output for two levels of stepping (aggregated over 500m lengths) compared with CVI Edge Deterioration and the results of the video analysis
5.2.5 Left/Right Transverse Variance

Figure 16 has plotted (red line) the difference between the left and right half transverse profile variance output, as the number of 10m lengths per 500m that have an average variance difference greater than 0.5mm². There is some agreement with the reference data (blue and black for CVI and manual assessment of the HARRIS video respectively) in places but not in others, e.g. at 12-13km. Some good agreement is seen between 4 and 7km, and 17-23km. It is likely that some of the differences can be attributed to the fact that the transverse profile variance methods only reports where the edge of the road surface is deforming as a probable result of edge deterioration. The method is not expected to report edge deterioration related to other defects, which will be included in the reference measurement but which don’t necessarily deform the surface, such as fine cracking, minor fretting and edge stepping occurring without settlement and subsidence. Conversely, due to the fact that the method uses data from the full road width and reports deterioration in the right half of the carriageway, the transverse profile variance will also record deterioration that might not be edge deterioration. This may explain the large response from the method at 8-10km and 14-17km in Figure 16.

Figure 16: Number of 10m sections per 500m with difference between left and right half transverse variance greater than 0.5mm², compared with the reference datasets.
5.3 Kent Run 1, 5/7/2004

The Kent survey route (Figure 17) contained primarily B class roads, but also incorporated a lower number of C and D class roads. A restricted junction encountered on the route also meant that some data was collected from an unclassified road. CVI data was supplied for the B and C roads making up most of the route. This enabled 56km of CVI and Test data from B and C class roads to be compared. As in Section 5.2, the test and reference data has been compared using 500m aggregation lengths.

![Figure 17: Route plan for the Kent survey run 1.](image)

5.3.1 Edge Roughness Method

There is some reasonable agreement between the CVI data and the number of 10m sections per 500m where more than 5% of the variance points were above 3mm, this is shown in Figure 18. However, for the chainages 33-40km and 46-50km the high level of CVI Edge deterioration has not been reflected in the edge roughness values. It is noted that Figure 20 and Figure 21 in Section 5.3.2, below, do show good agreement between these high values of CVI Edge Deterioration and the outputs of the Edge Stepping method, indicating that this Edge Deterioration may have been recorded in part due to overriding and rutting of the verge, rather than with an uneven surface that would be indicated by edge roughness.

Although the shape of the data from the edge roughness measure and the reference is consistent, it is important to consider the intensities recorded by the measure when assessing its suitability to report edge deterioration. It can be seen in Figure 18 that the scales used to plot both the reference CVI and edge roughness measure are the same. Examination of the data obtained on the White Waltham – Shurlock Row route in Figure 10 shows that, for comparison of the reference and edge roughness measure, the scales differed by over 3 times.

As for the White Waltham – Shurlock Row site an analysis was carried out of the forward facing video from the Kent survey run, as described in Section 4.2.1. For comparison with the edge roughness measure, the video assessment of deteriorated edge surfaces is appropriate as the edge roughness measure should in theory indicate where the road edge is severely fretted, potholed, is breaking up or has bad patching and longitudinal bump deformations. Figure 19 compares the total length per 500m of the survey length for which a defective surface at the road edge was recorded in
the video analysis with the results of both the CVI and edge roughness measure. It can be seen that the video analysis has provided broadly similar results to the CVI reference. The video survey has marked a large amount of deteriorated surface at the road edge between 30 and 50km. The edge step method output has also indicated a number of large sections of edge stepping and rutted verges in this length, plotted in Figure 22. It appears that this section shows CVI edge deterioration and stepping at the road edge but in this case this does not coincide with a significant response from the edge roughness variance analysis, this is a possibility in reality where edge stepping has not yet resulted in deformation of the road edge but may have resulted in cracking at the edge which is below the level that would be recorded in a CVI survey.

Figure 18: Edge roughness method compared with the CVI Edge Deterioration
Figure 19: Comparison of video analysis with the CVI and edge roughness measure.
5.3.2 Stepping at the Road Edge

The two Edge Stepping levels, assessed as proposed in section 5.2 (Level 1 20-50mm, Level 2 >50mm), are compared with the CVI recorded Edge Deterioration in Figure 20 and Figure 21. It can be seen that the Level 1 step height assessment (20-50mm) reports a number of peaks in the same locations as the reference data. However, it is noted, in particular, that between 10km and 30km the Level 1 step height assessment has reported a significant number of positive responses where the reference has recorded a low level of edge deterioration.

Figure 20: Edge Step Level 1 (20-50mm step) and CVI Edge Deterioration, Kent survey run 1.
Figure 21: Edge Step Level 2 (>50mm) and CVI Edge Deterioration, Kent Survey Run 1

It can be seen in Figure 21 that by applying the Level 2 limit to the assessment of the step heights (>50mm step) the count of step heights exceeding the limit is reduced and the false positive high level responses between 10 and 30km are suppressed, whilst still retaining the agreement with the higher values in the length extending from 33km to the end of the survey. On this site the higher limit therefore produces a better response for this method. However, this disagrees with the result obtained on the White Waltham – Shurlock Row site discussed in section 5.2, where the Level 1 limit was preferred as a result of the significant reduction in the reporting of any deterioration when the level 2 limit was applied. This is an indication that on this, Kent, site the stepping at the road edge is more significant than on the White Waltham – Shurlock Row site, and makes a significant contribution to the reported level of deterioration in the CVI survey, either by direct recording of overriding as edge deterioration, or because the reduced support of the road edge on this site has resulted in more defective edge surfaces.

In the interest of only having one level of output for edge stepping, a third level of assessment of the edge stepping was considered. For a third assessment the number of 10m lengths with more than 10% by length of stepping exceeding 20mm is calculated for each 500m length. This measure included the higher false positive responses and masked the smaller but more significant quantity of larger edge stepping present on this Kent site, and so was not found to be a useful output. It was found that it is more appropriate to either maintain the use of the two step thresholds or to use the single higher threshold such as the level 2 (>50mm) step that is seen to be more significant on this site. The use of two thresholds would make it possible to distinguish between significant levels of stepping that result in more severe edge deterioration, and lower levels of stepping that may be associated with deterioration of the edge. However, the use of only the higher threshold may be more desirable as it would only report significant edge stepping, and would therefore reduce false positives, at the expense of omitting some true positive responses.
As with the assessment of edge roughness, the comparison of the results of the video analysis can be used to provide a further insight into the breakdown of defects on the route that is not provided in the CVI results. For the assessment of edge stepping the Kent video survey data has been interpreted to record where stepping was apparent at the road edge (4.2.1) - this was often indicated by an overridden or defective verge. The data from the video survey was aggregated to give a length defective for each 500m of the Survey, as shown in Figure 22. The video analysis for the site is plotted in Figure 22 along with CVI edge deterioration and the higher level (>50mm) step output. It has been seen that the higher level step output is more significant on this site and this is reflected in the higher levels of verged damage and edge stepping recorded by the video survey compared to the previous site plotted in Figure 15. This indicates that the higher step level may be a more accurate indicator for significant levels of edge deterioration.

This plot shows sections between 15 and 30km of rutted and defective verges that are reflected more in the automatic step output than in the CVI Edge Deterioration reference data. This is in line with the fact that CVI edge deterioration is not meant to include damaged and rutted verges, although it has been unclear whether the presence of these defects will influence the CVI survey in some instances. Because we know that the video reference is specifically recording locations with both verge damage and stepping at the edge (where visible and determinable from the forward facing camera footage) we can see that for several places where the edge stepping is much higher than the CVI edge defect recording, the higher values are due to deteriorated verges not necessarily co-incident with deteriorated edge surfaces and so the higher values from the step method in this section are justified.
5.3.3 **Left/Right Transverse Variance**

The assessment of the difference between the left and right half of the transverse profile for variance in the profile heights as an indicator of transverse deformation of the surface at the road edge is plotted in Figure 23. It does not seem to match the two reference datasets particularly well, though there are points where the responses correspond (5km, 30-34km, 46-56km). The high values of the output between 17 and 27km do correspond to higher quantities of edge stepping at the 20mm+ level (Figure 20). It is a possibility that there is an amount of edge stepping and some associated surface transverse deformation that have not appeared significant during the CVI and video assessments, having not yet resulted in any serious defects (potholes, fretting, cracking).

Though the results do not show strong agreement with the reference data, it appears that this method does produce some useful output that can be cross referenced with the outputs of the other new methods.

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**Figure 23:** Number of 10m sections per 500m with difference between Left and right half transverse Variance greater than 0.5mm², plotted against reference datasets for Kent route 1.
6 Using the proposed methods to identify and report the severity of edge deterioration

Several methods for identifying road edge deterioration using the measurements currently collected by TTS machines have been proposed and tested in the preceding sections of this report. Here the methods are summarised and their performance and suitability for indicating edge deterioration is discussed, along with the risks involved with each proposed method.

The overall level of edge deterioration can potentially be indicated by a single measure generated from combining the measurements from a number of the methods. An approach to this combination is set out in Section 6.3 as an example of the methodology that could be taken.

6.1 Performance of proposed methods

Tests were included in this work to investigate the use of crack detection to identify edge deterioration by segmenting the output of HARRIS to only count cracking reported in the detected road edge strip. Although it is felt that this method has potential for the detection of edge deterioration, we were not able to successfully apply this method in this work. This can be attributed partly to the fact that it was not straightforward to obtain images on the narrow C roads using the HARRIS system, which had an inevitable effect on the resultant crack outputs. However the method is simple to apply to existing crack detection methods as it involves calculating the area of cracking falling into the 0.5m edge strip defined relative to the detected road edge. Furthermore, there are many more features that could be detected by image processing in this region (Table 1) in parallel with crack detection and hence this method would be of interest for future developments.

The output of the nearside wheeltrack texture laser was considered because it was thought that the SMTD and further analysis of the texture profile could provide an indication of the edge condition on narrow roads where the nearside wheelpath falls within the 0.5m edge strip. The SMTD and a prototype algorithm developed by TRL to detect fretting gave a good indication of the road condition in the wheelpath but it was felt that this did not necessarily reflect the edge condition and the particular defects associated with it.

The edge roughness measure, obtained by a short wavelength variance analysis of the profile laser heights from consecutive profiles and the selection of laser points lying in the located 0.5m edge strip, provides an indication of the condition of the road edge surface. This measure can indicate where the road surface at the road edge is of poor condition, but on its own cannot tell you which particular surface defects are involved.

The edge stepping measurement combined with the located road edge position accurately reports the step at the edge, either up or down. The step down output seems to provide a good indicator of overriding for rural roads and the two levels of stepping tested appear to successfully differentiate between a level that may be associated with some deterioration and a more severe level that strongly indicates the presence of edge deterioration.

The ‘Transverse Variance’ measure seems to have a good fundamental basis and the results (Section 5.1.5) from the first section tested are encouraging. The outputs for the other two sites show some agreement with the Edge Roughness and Edge Step outputs and there are some similarities with the reference data. However, the results seem more inconclusive for this measure and it is considered that testing this method on the full network will provide a better indication of its usefulness.

6.2 Methods recommended for implementation in 2005

The methods proposed for implementation in the 2005/2006 survey year are the Edge Step, Edge Roughness and Transverse Variance method, all using the edge location method described in Section 3.4.1 and by Nesnas et al, 2004.
The ‘Edge Stepping’ measurement can provide a good indication of the level of edge support, and an implied indication of the condition of the verge. The agreement seen with CVI edge deterioration demonstrates the use of this measure as an indirect indicator of the road edge condition, and reflects the fact that the rate of deterioration is considered to be related to the level of support at the road edge.

The ‘Edge Roughness’ measurement provides a direct measure of the quality of the edge of the road surface, indicating short wavelength bumps and depressions or holes in the surface. This indicates severe irregularities in the edge surface but should not, for example, respond to a smooth surface containing deterioration in the form of fine cracking.

The transverse variance method did not reflect the reference data quite so well but it did show some agreement in places and correlated with the outputs from the variance and edge stepping methods. It is felt that this method would benefit from further testing on the network.

6.3 Severity

For ease of assessment it may be desirable to produce a single measure of the level of edge deterioration calculated from the values of the proposed methods ‘edge roughness’, ‘edge step’ and ‘transverse variance’. In parallel, it is also desirable for information from the individual measures to be available which will indicate the different types of defect, and will differentiate between verge and pavement edge surface damage. A severity rating system for edge deterioration is suggested here that could be used within UKPMS and makes use of the different measures to determine the level reported.

Because it is recommended that the three methods are subject to further testing within the survey year (see below), it is also recommended that a framework be developed within UKPMS that will allow different ways of assessing an overall edge deterioration severity level to be assessed. This should allow the suggested measures to be combined in different proportions and using different rules once further data has been looked at. Therefore each measure adopted should be separately reported within UKPMS, these can then be queried in different ways in order to generate a single severity rating for edge deterioration. This flexibility will allow the methods to be better interpreted when more thoroughly tested, and can allow measurements to be discarded or new measurements to be added.

The following ‘severity levels’ combine the three methods. There are four levels, but it is noted that a three severity level system could easily be created by using three of the suggested levels or by combining the defects in different ways. The severity is calculated for each 10m (or 20m) reporting length using the relevant outputs of the different methods:

1. Severity 1: A positive response to ‘edge roughness’ and ‘transverse variance’.
2. Severity 2: The occurrence of ‘edge stepping’ only.
3. Severity 3: The occurrence of ‘edge stepping’ and either ‘edge roughness’ or ‘transverse variance’ but not both.
4. Severity 4: The occurrence of ‘edge stepping’ and ‘edge roughness’ and ‘transverse variance’.

Note that the occurrence of edge stepping refers to the Level 2 stepping from the assessment of the survey data (Section 5), which is where more than 10% of the reporting length has stepping greater than 50mm.

It is noted that ‘edge roughness’ and ‘transverse variance’ are measures of a similar aspect of the transverse profile data (how bumpy it is) where one is measured longitudinally and the other transversely, hence they have been considered together in the severity levels suggested here. Figure 24 plots the four severity levels along with the CVI edge deterioration and video edge surface and verge/step reference datasets. It can be seen that, on this site, severity level one, which essentially indicates surface roughness in two directions, has some significance when compared to the reference dataset. Severity level two, based entirely on the edge step measurement, gives a good indication of the deterioration recorded by the reference surveys. Severity level three, which combines stepping and the two edge surface measures, has produced a smaller number of positive sections per 500m but...
these do appear to coincide with places of greater deterioration as indicated by the reference data. The fourth level, which is triggered by a section containing positive responses from all three methods, has only indicated two 500m sections with one positive 10m length. These are indicated by the light blue peaks at 9km and 40.5km, which are both areas where higher peak values of CVI edge deterioration is reported.

Figure 24: Edge Deterioration Severity Levels against CVI Edge Deterioration, Kent Survey Run 1.

6.4 Areas of further consideration for the proposed methods

There are a number of risks to consider in relation to the short-listed methods, these are factors that could affect the performance of the measure as an indicator of edge deterioration and factors related to their implementation with different TTS machines:

Edge Roughness

1. The response of the output to survey vehicle movement over bumps, particularly at low speed needs to be considered as part of the output that is recorded. The method is designed to indicate values related to the shape of the road surface but the actual influence of vehicle suspension movement has not been established within the timescale of this project. The risk is greatest with slow, crawling speed operation encountered in towns or on narrower rural roads, this could lead to reduced comparability between survey vehicles. Possible solutions are to implement the system with enhanced filtering as adopted by the Highways Agency, rather than the moving average filter tested here, and to keep the output simple enough that detailed correlation between different vehicles of individual measurement values resulting from particular points on the road is not necessary.

2. The driving line taken by the survey vehicle is important for this output. The edge of the road needs to fall within the width measured by the profile system. This is likely to be unavoidable for many B and most C roads. It is recommended that some form of driver training and accreditation is put in place to ensure these surveys are correctly carried out on the different non-principal road types. An additional step would be to include an output from the automatic processing that reports where the road edge cannot be identified in the profile (as in Section 5.1.1, Figure 4), as currently when this occurs the edge is placed at the nearside end of the
profile in the method proposed in Nesnas and McRobbie (2004). This output could indicate the level of certainty that the 0.5m wide strip assessed is indeed at the road edge, or is just using the nearside 0.5m of the profile. Alternatively the variance values used in the edge roughness calculation could be set to 0 within each transverse profile that has the road edge point set to 0, therefore these profile points will not contribute to the edge roughness assessment.

3. Alternative sensor spacing on different survey vehicles could result in a lower number of profile measurement points falling within the moving 0.5m road edge strip. With the HARRIS system tested here, the number of profile measurements within the edge strip would vary between 3 and 4 dependent on the road edge position on each profile. It is recommended that a minimum of two points should fall within the 0.5m to adequately reflect the general state of the surface, but that three points falling within this width on all machines would give a better sample size. A minimum of two points would be assured by a sensor spacing closer than 250 mm, three points by a sensor spacing closer than 166.6mm. It should be considered that two systems with different laser spacing may therefore be making use of dramatically different sample size over the ten metre averaging length. If a system cannot be easily modified to achieve an appropriate laser spacing, than it may be appropriate to define an edge strip a little wider than 0.5m.

4. It is a possibility that some survey vehicles cannot record transverse profile data at a longitudinal spacing of 100mm or less, although it is a current TTS requirement that rutting should be reported at an interval no greater than this (UK Roads Board, 2003). It is less likely that the method will perform to a satisfactory level if applied to transverse profile data recorded at a greater longitudinal spacing than 100mm because the number of points used would be reduced and the longitudinal undulations resulting in the ‘roughness’ of the road surface will be less adequately sampled.

**Edge Step**

1. Risk with this method is again associated with whether the driving line places the edge of the road within the measured profile. Driver training can address this, and the output that reflects how much of the reporting length contains profiles where the road edge is on or past the end of the profile measurement width can be used in conjunction with the step data. As tested here, the system should be set to report a step height of zero or within the lowest size bound, or to have the output ‘unknown’ where the edge has been located at the end of the profile.

2. Where there is a large road to verge step down that is not a result of overriding; perhaps due to the road construction, then the presence of a large step does not necessarily indicate overriding or edge deterioration. The extent of this should be assessed during the first year’s implementation.

**Transverse Variance**

1. The transverse variance method compares data from the two parts of the profile, it reflects the condition of the road surface from the vehicle centre line to the road edge. This means that it uses data from potentially the edge-half of the carriageway rather than the 0.5m wide edge strip. It remains to be seen whether this reduces the ability of the method to reflect edge deterioration rather than whole carriageway deterioration.

**Use of the Road Edge Location**

As discussed above, where the profile does not contain a clear edge, the road edge algorithm records the edge position as being at the nearside end of the profile measurement system, conventionally defined as transverse position 0. Therefore for the ‘edge step’ measure no step height can be measured and hence a step height value of zero is reported. For the assessment of the ‘transverse variance’ tested here, the full left half of the profile is used and a value is given, similarly for the ‘edge roughness’ measure the left hand 0.5m of the profile is assessed.
It may be more desirable to not assess edge deterioration where the proximity of the vehicle to the road edge cannot be determined confidently. An alternative approach would be (within the calculation of the parameters) to set to zero any measurements for a transverse profile that does not have the edge located within its width. The 10m or 20m average difference between the left and right half profile variances can be calculated with such profiles excluded. The short-wavelength variance heights used in the edge roughness calculation can be either set to 0 to reduce the proportion of points that may exceed the threshold, or these points can be excluded from the calculation so that the proportion of ‘qualifying’ points exceeding the threshold is calculated.

In summary, the implementation could take the approach of omitting measurements for which the road edge could not be identified within the profile width, this would lead to reduced coverage from the collected data if the driving line is not close to the road edge – an issue that may effect A roads and B roads more than C roads. An alternative would be to include data from the first 0.5m of the profile where the road edge cannot be seen, this would be based on the assumption that on narrow roads if the profile is not recording over the road edge, it will be near to it. This would maintain coverage, but may mean that the data does not accurately reflect the edge condition.
7 Implications of this Work for TTS

This summarises the key findings of this report and its implications for the assessment of edge deterioration on local roads. This Section also discusses scope for further research in the area of measuring edge deterioration.

Types of edge deterioration

The main defects identified that are associated with edge deterioration are:

- Cracking
- Fretting/Potholes
- Longitudinal/Transverse bumps and deformations
- Poor Structural strength
- Erosion of the road edge
- Overriding

It was found that the key defect related to edge deterioration is overriding and rutting of the verge. This defect reduces the support given to the edge of the road surface resulting in accelerated deterioration of the road edge.

Systems already available to measure edge deterioration

It was found that although three developments towards measuring edge deterioration could be identified there are no systems developed outside of TRL for which significant performance or implementation details could be obtained. Some details that could be obtained were taken into account in the development of the algorithms in this project. It was noted that for certain systems, the development of proprietary software could complicate the definition of a full specification that can be employed by all TTS contractors in 2005.

Measurements that can be used to detect edge deterioration

The measurement capability of current TTS systems was considered with respect to how the measurements could be interpreted to indicate the level of edge deterioration present. It was determined that the transverse profile measurements made by these systems would typically extend towards or over the edge of the road surface on narrower B and C class roads, and that transverse and longitudinal undulations in the road surface (that could be the result of deformations, potholes and fretting or breaking up of the surface) would be contained in this data. It was also considered that where the profile measures past the road edge, the boundary between profile measurements on the road and on the verge surfaces could potentially be established from the shape of the profile data.

Imaging systems used in conjunction with crack detection software could be segmented to determine the level of cracking in the area where the road edge surface is visible in the image. The location of the road edge could potentially be determined from the image data if it is within the width captured, or could be obtained from the transverse profile analysis.

Near-side wheel-path mounted texture profile measurements can provide a single-line of detailed information relating to surface condition, longitudinal shape and ride, which is likely to be within the road edge region on narrower roads. However it is not certain whether the measurement from within the wheelpath near the road edge better relates to edge or carriageway condition.

Summary of proposed methods to measure edge deterioration

The above measurement capabilities were considered and, from this, algorithms developed for the identification of edge deterioration. Three methods showed the most potential. These are the edge stepping, edge roughness and transverse variance measurements. All three techniques use the edge location method (Nesnas et al., 2004) developed as part of the parallel project on transverse profile assessment, and are based entirely on the interpretation of transverse profile information. It is felt that
these techniques should be considered for inclusion in the TTS surveys of non-principal roads in 2005/06.

**Technical specification and quality assurance**

An outline description of the suggested methods is given in Appendix A. Quality assurance will primarily need to ensure comparability between the implementations of the new methods from different TTS survey systems. The new methods produce derived parameters so it is necessary to test the calculation of the parameters from base data. This can be a case of comparing the output from the contractor’s implementation of the algorithms with a ‘reference’ implementation that can be applied to the same set of collected data.

**Risks associated with the new methods to measure edge deterioration**

Because the existing fleet of TTS vehicles will not have to significantly change their hardware or data collection approaches the risk of this preventing the successful adoption of the edge deterioration measures is greatly reduced. Furthermore, as the measurement and analysis of transverse and longitudinal profile has developed to a reliable level that is reasonably comparable between machines, developments built on these proven methods will be more easily implemented and more likely to be successful in the forthcoming survey year.

However, the following risks can be foreseen relating to the calculation and use of the edge measures:

- The driving line of the TTS vehicle during a survey is important. Essentially the transverse profile should be recording just past the edge of the road surface and a method (discussed in section 6.4) should be established to cater for where no road edge is detected within the profile width.
- There are some risks regarding the performance of the methods which have received limited testing within the timescale of this report, also discussed in section 6.4.
- The differences in measurement width and sensor spacing of the transverse profile system for different TTS machines which may affect the performance of the methods and coverage achieved.
- The longitudinal spacing between consecutive transverse profiles will effect the performance of the ‘edge roughness’ method. It may be the case that not all survey vehicles can achieve an adequate sampling rate.
- Differences in the processing employed for each system (i.e. whether real-time or post-processing is used) which may complicate the implementation of the new methods.
- The possibility of the methods not being implemented by April 2005.

**Integration with UKPMS**

The three methods recommended for implementation in 2005/06 lend themselves to being reported as three separate defects for the use of maintenance engineers. The edge roughness measure is an indicator of the road surface condition at the road edge, the edge stepping can be taken as an indicator of overriding but may, for example, be given less significance on roads where there is known to be a non-defect step at the edge due to the construction.

It is recommended that the values of the three edge measures be provided in the UKPMS HMDIF data files delivered by TTS systems over 10m lengths. In UKPMS each value should be stored separately in addition to a derived edge severity value. A system of severity levels is suggested in this report and the results of this applied to the Kent survey data have been presented. However this severity measurement could be developed further once more data has been obtained, and different definitions for edge deterioration severity levels tested.

Due to the limited scope for testing a significant and representative sample of the non-principal road network within the timescale of this research, it is not recommended that the methods be included in the calculation of BVPI values for 2005/06. The methods included in the specification for 2005/06
surveys should be implemented for maintenance engineers to establish how useful the outputs really are on their roads, and a full run through of the years data will enable the performance of the methods to be more readily assessed. The assessment of the data collected during this period may lead to the refinement of the methods, or may confirm that they are suitable for BVPI purposes.

**Possibilities for Further Development**

There are several avenues recommended for further research.

- Image processing to assess cracking at the road edge, potholes, and poor edge patching. There is also the possibility of assessing overriding, erosion of the edge and fatting up.

- New enhanced profile measurement systems can give many more profile height readings at a much closer spacing and can cover a wider width. This gives a more detailed profile which enables more features to be identified, potentially including kerb stones and the full width of overriding. It should also enable the road edge to be more accurately identified.

- Further analysis of texture profile, both in the current wheel-path position and potentially with a number of nearside texture lasers. Several detailed texture profiles could enable the measurement of potholes and fretting across the road surface at the edge more accurately than using the transverse profile height readings that have a greater longitudinal spacing.
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Appendix A. Algorithm Definitions

A.1 Edge location method

The suggested edge deterioration methods outlined in A.2-A.4 make use of a method for locating the road edge from transverse profile data where the profile has been measured past the edge of the road surface resulting in a noticeable change in the shape of the end of the profile. This method is summarised in some detail in Section 3.4.1, and is described in full in Nesnas et al, 2004.

For the assessment carried out in this project, where the edge of the road surface cannot be detected within the profile, the edge has been assumed to be at 0, the nearside end of the profile measurement system. This means that an edge step is not reported by the edge stepping measure (Section 3.4.5), but the other methods will report defects having assumed the road edge region lies within 0.5m of the nearside end of the profile measurement system. These methods therefore have the potential to measure a level of deterioration from within the carriageway as edge deterioration. Methods that could be employed to deal with this are discussed in Section 6.4.

A.2 Edge roughness

![Diagram of edge roughness calculation]

The edge roughness measure is calculated as follows:

1. Obtain transverse profile data reported every 100mm.
2. Split the transverse profile data into 10m length segments which should include 100 profiles spaced at the specified distance.
3. For each 10m segment, consider the 10m long series of profile heights from each laser position as if it was a longitudinal profile.
4. Carry out a 0.6m moving average filtered longitudinal profile variance calculation for each laser line from position 0 (the leftmost laser) to at least the first laser to the right of the vehicle centre line:
   I. For each laser line, for each profile position between 0.3m and 9.7m along the 10m length, find the mean height value of the readings from the same laser from preceding and following profiles measured up to 0.3m before or after.
   II. Subtract this average height from the laser height.
   III. Square the value obtained – this is the variance.
5. Take the output of the edge location method to define the left side of a road edge strip with a point 500mm to the right of this road edge position defining the right side. For each transverse profile, there will be a number of profile height readings that lie within this interval, see figure A.1 above.
6. Count up all of the laser positions that lie within the road edge strip for the whole 10m length, defined as A.
7. Count up the number of laser profile variance values that lie within the road edge strip and are greater than 3mm². This number is defined as B.
8. Calculate the proportion of edge points above this variance threshold = \( \frac{B}{A} \).
9. To mark a 10m length defective, apply a threshold for the proportion of edge points with high variance calculated in step 8. A threshold of 0.05 (or 5% of points above 3mm²) was tested in this report and is recommended.
10. To be used in the reporting of Edge Deterioration for UKPMS in HMDIF format, it may be desirable to implement this algorithm to use a segment length of 20m as opposed to 10m described here. The filtering stages will need to be carried out over the interval 0.3 to 19.7m or could use data from proceeding and following segments to calculate variance values for the full 20m.

A.3 Road edge step
The edge stepping measure is calculated as follows:
1. This method requires measurement positions to be defined along the profile measurement width. \( R_0 \) is the leftmost (nearside) transverse profile sensor position, \( R_L \) is the sensor nearest to the left of (and not equal to) the edge position located by the method in A.1, \( R_R \) is the sensor nearest to the right of the road edge position. \( R_{R+1m} \) is a position in the profile 1m further to the right of position \( R_R \).
2. Obtain the least-squared best fit line for the measurements from position \( R_R \) to position \( R_{R+1m} \). This procedure uses the height measurement and transverse position of each sensor. This line is defined as \( Y=MX+C \). Where \( Y \) is the line height value at transverse position \( X \), \( M \) is the gradient of the line and \( C \) is the value of \( Y \) at \( X=0 \).
3. For each sensor \( i \) from position \( R_0 \) to \( R_i \), find the height \( S_i \) measured above the datum line \( Y \) defined above. This is calculated at each position by subtracting the value of the line at that sensor position \( i \) from the recorded height.
4. Record the largest step up (max \( S_i \)) and the largest step down (min \( S_i \)) found in step 3 above.
5. The edge step that is reported is either the largest step up or the largest step down (the largest negative step). Of these two maximum steps, the reported value is that which was calculated nearest to the road edge location.
6. If the road edge position is located at 0 which indicates that no edge was found within the profile and that there are no lasers recording to the left of the road edge, the edge step value 0 is reported.

7. Over a 10m (or 20m) length, count the number of edge steps less than -50mm and the number less than -20mm and greater than or equal to -50mm (corresponding to edge stepping levels 2 and 1 respectively in this report). Multiplying each count by the profile spacing to give the length within the reporting length that are within these defined step height intervals.

8. Where the reported length is greater than 10% of the reporting length for the chosen step level, the reporting length has an edge stepping defect at that level. If the reporting length has an edge stepping defect at more than one level, the higher level is reported.

A.4 Transverse Variance Method

The transverse variance method is based on the derivation of statistical parameters from individual transverse profiles. The calculation of these statistical parameters from the processed profile data, including the variance value referred to below, is described further in Nesnas et al, 2004.

1. Utilising the located road edge position to remove the part of the profile recording past the edge of the road, the remaining profile of the road is split into two equal halves.

2. The variances of the profile heights within each half are calculated, and reported as the left and right half variance values TL and TR.

3. Within each (10m or 20m) reporting length the average values (T_{Lave} and T_{Rave}) are then calculated as the means of TL and TR from the transverse profiles within the reporting length. This should sum the returned valid values of TL and TR and then divide each by the number of valid values used in the sum calculation.

4. The average difference between the two halves of the profile for the reporting length can then be calculated as T_{DIFFave} = T_{Lave} - T_{Rave}.

5. A reporting length is deemed defective if T_{DIFFave} > 0.5mm².